Commercially available wearable health monitor in dogs is unreliable for tracking energy intake and expenditure

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OBJECTIVE
Assess the accuracy of predicted daily energy requirement (pDER) reported by a triaxial accelerometer and activity monitor for dogs (FitBark 2; FitBark Inc) and determine whether the activity monitor accurately estimates the observed daily energy requirement (oDER). We hypothesized that the activity monitor would accurately estimate oDER in dogs and meet standards established for human devices.

ANIMALS
23 dogs between the ages of 1 and 10 years and variable sex, breed, and body weight were enrolled from May 5, 2021, through July 23, 2021.

METHODS
Dogs were weighed before and after the study period to ensure stable body weights. Owners recorded their dogs’ daily caloric intake for the entire 28-day study period while the device monitored physical activity and calculated pDER. oDER was defined as the reported caloric intake required to maintain a stable body weight over a 28-day period. pDER and oDER were compared using Bland-Altman graphs, Passing-Bablok analysis, and Lin’s Concordance correlation analysis. P ≤ .05 was considered significant.

RESULTS
23 apparently healthy dogs completed the study. There was no significant difference between starting body weights and ending body weights (P= .5). The activity monitor overpredicted 28-day pDER compared to 28-day oDER in the majority (18/23, 78.3%) of dogs. Based on Bland-Altman analysis, Passing-Bablok regression, and Lin’s concordance correlation analysis, there was poor agreement between the pDER and oDER.

CLINICAL RELEVANCE
The activity monitors consistently reported inaccurate pDER compared to oDER. Its usability for estimating pDER is of limited clinical and research utility based on the results of this study.

Keywords: accelerometry, activity monitoring, caloric requirement, obesity, nutrition

Activity tracking devices, or accelerometers, have become increasingly popular for activity monitoring in humans, and many of these devices advertise calorimetry, or the ability to accurately calculate estimated energy expenditure, as a function.1–11 Several studies5–11 have evaluated the ability of commercial accelerometers in humans to accurately calculate estimated energy expenditure and requirements. These studies5–10 have reported varying levels of accuracy for different accelerometers when estimating energy requirements. A commonly utilized standard for determining accuracy between accelerometer predicted daily energy requirement (pDER) and observed daily energy requirement (oDER) in human devices is achieving a less than or equal to 5% difference between measurements.4,5 Similarly, accelerometers have become increasingly popular with pet owners in the veterinary market. Conventional accelerometers used in veterinary research are expensive, have clearly defined

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The ability to evaluate the daily calories expended by an animal in addition to activity level could be helpful in diagnosing and monitoring various conditions for both pet owners and veterinarians.\textsuperscript{17-22} The DER is defined as the amount of energy required per day for an animal to maintain a stable weight.\textsuperscript{22,23} \pDER from the activity monitor is an estimate of the DER based on recorded activity levels coupled with a proprietary algorithmic calculation of energy expenditure from the manufacturer based on the pet’s phenotype. This is in contrast to an oDER, which is the actual nutritional caloric intake recorded while maintaining body weight.

Historically, standard DER calculations are based on the requirements of healthy laboratory dogs that are adjusted based on various life stages and lifestyles.\textsuperscript{22,23} Detailed diet histories are used as the standard to calculate oDER for individual patients, but this can be laborious for owners, and there is no way to measure DER in real time.\textsuperscript{23} This is increasingly important as nutritional intake is important in monitoring health and managing disease in veterinary species.\textsuperscript{22} The activity monitor in this study is reported by the company to provide an accurate calculation of \pDER.\textsuperscript{24} However, the device’s calculated \pDER has not been independently validated for accuracy. The primary aim of this pilot study was to assess the accuracy of the activity monitor’s \pDER compared to oDER. A secondary objective was to determine whether the activity monitor meets the agreement standards of less than or equal to 5% established for similar human devices in a medical setting. We hypothesized that the activity monitor would accurately estimate DER in dogs and meet standards established for human devices.

**Methods**

This prospective cohort study was approved by The Ohio State University’s Institutional Animal Care and Use Committee (IACUC 2019A00000130). Informed owner consent was required before enrollment. Inclusion criteria included dogs of any sex, breed, and body weight, between the ages of 1 to 10 years old, with no known disease or health concerns. Dogs were deemed apparently healthy based on a complete clinical history and physical exam by one of the primary investigator veterinarians. Body weight and body condition scores were assessed at the beginning and end of the study.\textsuperscript{24} Owners were required to accurately track and log daily food intake for 28 consecutive days. They were also required to download and use the manufacturer’s application (FitBark app; FitBark Inc) on a smartphone with supervision and training from the research team. The investigators could monitor data via the app throughout the study. The activity monitor was then kept on the dog’s collar for the study period without removal at any time. While active, the activity monitor continually supplied data as it collected readings multiple times per second. The data collected by the activity monitor were sent to the investigators directly through the application for monitoring and data management.

To set up the activity monitor, owners had to download the application on a smartphone and connect it to the activity monitor under the guidance and supervision of the investigators. They were then instructed to enter their dog’s signalment and location. Owners were asked to classify their dog’s activity level based on the categorical classifications provided to users (eg, average, active, Olympian, custom) in instructions by the manufacturer. The activity level selected was determined by the owner’s opinion of their dog’s activity under normal circumstances, alongside guidance from the FitBark app and website, which provides examples of typical activities for each activity level category and activity percentiles when compared to all dogs. These data, in addition to collected accelerometry data, were then used to guide the activity monitor’s proprietary \pDER calculation.

During the 28-day study, each owner tracked their dog’s daily caloric intake including all meals, treats, and medications/supplements in a provided diet diary (Supplementary File S1). At study enrollment, the diet diary was reviewed with each participant, and example entries were provided. During the study, an investigator contacted study participants weekly to verify continued completion of the diary. In the diet diary, owners were asked to list the brands and product names and amounts of all foods, treats, snacks, and any other foods that their pets consumed during each study day. This description for each food consumed included amount and frequency fed to provide enough detail that it is possible to go to the store and purchase the exact same food or serve the exact same amount. Based on the information provided in the diary entry, data from individual diet entries were converted to specific caloric intake amounts by utilizing product nutritional information or the USDA nutrient database using the food description, amount, and frequency supervised by a board-certified veterinary nutritionist.

At the end of the study, diet data were used to calculate daily and 28-day \oDER. \oDER was used as the gold standard for DER measurement in this
study. Since all dogs maintained stable body weights over the study period, indicating that no dogs were in a caloric deficit or excess, the daily and 28-day calories recorded in the diet logs could be used as a proxy for oDER. Daily pDER was defined as the sum of the daily oDER over the entire 28-day study period. Daily pDER was defined as the daily number of calories expended calculated by the proprietary algorithm from the manufacturer. Twenty-eight-day pDER was defined as the sum of the daily pDER for each dog over the 28-day study period. At 18 months following study completion, owners were contacted again to assess whether their pet had experienced any medical concerns or been diagnosed with any new conditions.

Statistical analysis was carried out using GraphPad Prism (GraphPad Prism for Mac, version 7.0.0; GraphPad Software), MedCalc (Statistical Software, version 22.014; MedCalc Software), and SPSS (SPSS Statistics for Mac, version 23.3; IBM Corp). Data were tested for normality using the Shapiro-Wilk test. Normally distributed data were reported as mean and SD, whereas nonnormally distributed data were reported as median and range. Descriptive statistics are reported for the entire data set. A paired t test was used to compare prestudy and poststudy weights. The ratio of poststudy body weight-to-prestudy body weight versus oDER:pDER was graphed for the predictive ability of caloric estimates in conjunction with weight changes. Data from individual pDER and oDER were plotted against each other in comparison to a line of equality to visually assess the degree of agreement among methods. Test-retest reliability was assessed using intraclass correlation coefficient (ICC) estimates and their 95% CIs based on 28-day pDER and oDER. Passing-Bablok regression was performed for statistical comparison between 28-day pDER and 28-day oDER calculation. Lin's concordance correlation was performed to assess agreement, precision, and accuracy between methods. Bland-Altman plots were constructed, and limits of agreement analysis were performed to further assess the relationships between pDER and oDER. Before beginning the study, it was established that differences between oDER and pDER of 5% or less would be considered acceptable based on established human medical standards. Differences between oDER and pDER greater than 5% were considered clinically unacceptable. Contingency analysis using Fisher's exact test was used to determine the differences in categorial variables (eg, sex and meeting < 5% variability). For all analyses, P ≤ 0.05 was considered significant.

Results

Twenty-five client-owned dogs of varying breeds were enrolled in the study with written owner consent. All medical histories and physical examinations obtained on enrolled dogs were clinically insignificant and revealed no overt signs of illness. No dogs developed abnormal clinical signs or new medical diagnoses in the 18 months following study completion. Two dogs were excluded after data collection due to incorrectly recorded weights at the end of the study. One of these dogs failed to have a weight recorded in the medical record, and the other had a body weight recorded as 20.2 kg less than the original body weight. The body condition score of both dogs remained the same throughout the study. They were excluded due to missing data or presumed inaccurate measurement recording. The remaining data are from the 23 dogs with complete data collection. The ages ranged from 1 to 10 years old with a mean age of 4.6 years. Ten dogs were male (43.4%) and 13 (56.5%) were female. Breeds included mixed breed dogs (n = 8), Border Collie (2), Borzoi (2), Belgian Malinois (2), Jack Russell Terrier (2), and 1 each of the following breeds: German Shepherd Dog, Redbone Coonhound, Siberian Husky, American Pitbull Terrier, Australian Cattle Dog, Golden Retriever, and American Water Spaniel. Body weights at the time of enrollment (mean, 21.5 kg [SD ± 8.14]) were not statistically different from body weights at the conclusion of the study (mean, 21.8 kg [SD ± 7.85]; P = 0.5). Purina body condition scores were unchanged throughout the study (median, 5; range, 4 to 7).

The activity monitor was programmed at the average level for 7 dogs (30.4%), active level for 12 (52.1%), and Olympian level for 1 (4.3%). Three dogs were programmed at a unique custom activity level: below average, between average and active, and above average. Four households enrolled more than 1 dog, 3 households enrolled 2 dogs each (dogs 1 and 2; dogs 12 and 13; dogs 22 and 23), and 2 households enrolled 3 dogs each (dogs 3, 4, and 5; dogs 7, 8, and 9). Daily diary entries and activity monitor usage were fully completed in all enrolled dogs and confirmed by investigators before, weekly during the study, and at the conclusion of the study. Median daily oDER was 973 calories/day and ranged from 252 to 1,500 calories/day. Median 28-day oDER was 27,244 calories/28-day and ranged from 7,051 to 40,493 calories/28-day. Descriptive statistics for daily and 28-day oDER and pDER are presented (Supplementary Table S1). Twenty-eight-day pDER from the activity monitor was a median of 32,626 calories/28-day and ranged from 11,197 to 63,563 calories/28-day. Line of equality graphs for 28-day pDER and oDER are shown (Figure 1). The activity monitor overpredicted 28-day pDER compared to oDER in the majority (18/23, 78.3%) of dogs. Individual dog line of equality graphs are available (Supplementary Figure S1). During the study period, 12 dogs had their caloric intake overestimated by the activity monitor every day, 3 dogs had their caloric intake underestimated every day, and 8 dogs were variable in their distribution of days underestimated or overestimated. Two households with multiple dogs enrolled consistently reported the 28-day pDER greater than oDER. The third household enrolled consistently reported the 28-day pDER less than oDER. There was no consistent pattern of over- or underprediction in the fourth household.
ICC analysis through a 2-way mixed-effects model identified poor to good reliability between pDER and oDER when using both pDER and oDER to assess total 28-day DER. The average measure ICC was 0.740 with a 95% CI of 0.376 to 0.888 (P < .001). Even though the ICC is consistent with moderate reliability, the CI is wide spanning the range from poor to good, which indicates less confidence in the results. Passing-Bablok analysis results are reported (Table 1). CUSUM test for linearity confirmed the applicability of the Passing-Bablok method of assessment. The regression equation is presented. Systematic differences are indicated by intercept A and proportional differences by slope B. The large residual SD implies the methods of daily energy requirement (DER) are not in agreement.

<table>
<thead>
<tr>
<th>DER method comparison</th>
<th>pDER vs oDER (28-day)</th>
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<tr>
<td>Regression equation</td>
<td>y = -1.920.068054 + 0.876288 x</td>
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<tr>
<td>Systematic differences</td>
<td></td>
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<tr>
<td>Intercept A</td>
<td>-1.920.06</td>
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<tr>
<td>95% CI</td>
<td>-13,429.53 to 8,882.70</td>
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<td>Proportional differences</td>
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<tr>
<td>Slope B</td>
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<tr>
<td>95% CI</td>
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<td>Random differences</td>
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<tr>
<td>Residual SD</td>
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<tr>
<td>95% CI</td>
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<tr>
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<tr>
<td>CUSUM test for linearity</td>
<td></td>
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<td>P</td>
<td>.42</td>
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pDER and oDER (Pearson ρ [precision], 0.6751; bias correction factor Cb [accuracy], 0.885).

Bland-Altman plots were produced to further evaluate agreement between pDER and oDER from the activity monitor. Individual dog Bland-Altman plots are available (Supplemental Figure S1). Differences in 28-day oDER versus pDER results were largely within 2 SD of the mean difference except for 1 dog (Figure 1). The average mean of differences in observed versus calculated results was below zero consistent with the general trend for the FitBark to overpredict DER in the majority of dogs. In individual dog analysis, 19 dogs had a mean below zero while 4 dogs had a mean above zero. Over the 28-day trial, the activity monitor predicted caloric intake was between 51.9% and 216.6% of observed intake. The activity monitor calculated pDER was within 5% of oDER, meeting the accepted standard set forth by human activity monitoring standards in 2 (8.6%) dogs (Supplementary Table S2). Examples of percent difference between pDER and oDER for the first 5 dogs are shown (Figure 2).

Despite the lack of statistical significance, the majority of dogs in this study experienced mild variation in their prestudy and poststudy body weights (60.8% of dogs gained weight, 34.7% lost weight, and 4.3% of dogs stayed the same). The average percent change in body weight during the study was 1.6%. The ratio of postbody weight/prebody weight was graphed against oDER/pDER for each individual dog (Figure 3). This was performed to evaluate whether there was a relationship between change in body weight and pDER.

In dogs classified as having an average activity level, the activity monitor predicted daily caloric intake between 51.9% and 140.4% of observed intake with an average of 99.2% with a SD of 35%. None of these dogs had a calculated DER within 5% of the observed DER. In dogs classified as active, the activity

![Figure 1](image1.png)  
**Figure 1**—A—Line of equality graph comparing predicted daily energy requirement (pDER) for the 28-day study period from the FitBark 2 device to the observed daily energy requirement (oDER) for the 28-day study period from the diet diary logs. The solid line (line of equality) on the graph represents the location of data points if the oDER and pDER were in complete agreement. Data points above the line of equality represent overprediction of the pDER compared to the oDER. Data points below the line of equality represent overprediction of the oDER compared to the pDER. B—Bland-Altman plot comparing pDER and oDER for combined monthly totals. The central dotted line represents the mean difference between the 2 measurements. The upper and lower dotted lines encompass the entire shaded area represent ± 1.96 SD from the mean difference.
monitor predicted caloric intake between 103.7% and 214.4% of observed intake with an average of 138.7% and a SD of 34%. In female dogs, the activity monitor predicted daily caloric intake between 51.9% and 214.4% of observed intake with an average of 122.9% and a SD of 46%. In female dogs, 2 (15.4%) had an activity monitor pDER within 5% of the oDER. In male dogs, the activity monitor predicted caloric intake between 110.5% and 216.6% of observed intake with an average of 137.0% and a SD of 34%. There was no difference in the proportion of male and female dogs that achieved a pDER within 5% of the oDER (P = 0.5). These results are summarized (Supplementary Table S2).

Discussion

This study showed poor agreement between oDER and pDER. The inconsistency between the 2 methods violated the preset acceptable range of disagreement (≤ 5%) used in similar studies in human healthcare. As such, the clinical utility of this activity monitor for making accurate DER-based medical recommendations about caloric expenditure cannot be recommended. This is opposed to the previous study on the same activity monitor that demonstrated it was a reliable method of tracking off-leash activity. As such, practitioners should be aware of both the strengths and limitations of using activity and calorimetry data provided by this activity monitor.

Figure 2—Daily percent variance in sample of study dogs between pDER and oDER. Body weight was graphed for reference.

Figure 3—To evaluate minor fluctuations in body weight during the study and FitBark 2 pDER over the 28-day study period, the ratio of postbody weight/prebody weight was graphed against oDER/pDER for each individual dog. This enables a visual assessment of whether the error in pDER was due to unstable body weights. The dogs above the dotted line at 1.0 on the y-axis had a higher postbody weight compared to prebody weight. The dogs below the dotted line at 1.0 on the y-axis had a lower postbody weight compared to prebody weight. The dogs to the right of the dotted line at 1.0 on the x-axis had a higher oDER compared to pDER. The dogs to the left of the dotted line at 1.0 on the x-axis had a lower oDER compared to pDER. Evaluating these ratios together, it is expected that animals with body weights trending in the correct direction as their pDER error would be in the upper right or lower left quadrants. Conversely, it is expected that animals with body weights trending in the opposite direction as their pDER error would be in the lower right or upper left quadrants.
monitor and be aware of how this may affect clients’ animal husbandry practices when in use.

On average, the data from this study show the activity monitor pDER is greater than the oDER, but there was no consistent pattern seen on a daily basis between dogs and no consistent pattern seen in regard to activity level, household, or day-to-day diet variability. Prior studies5–7,11 have found varying degrees of accuracy in reported energy expenditure for different activity levels and subjects with prior medical history. For example, one device (Apple Watch, Apple Inc) consistently overestimated energy expenditure in humans with known cardiac disease, while other devices (Fitbit Charge 2 [Fitbit Inc]; Garmin [Garmin International]) had better accuracy when estimating energy expenditure during light to moderate activity than short intense exercise.5,6 Another study11 found a different device (Fitbit Charge; Fitbit Inc) had the greatest error when used during light to moderate physical activity. Our study allowed owners to program these types of settings to emulate real-life scenarios for data collection. However, future studies should evaluate the reliability of this activity monitor’s pDER estimates with lifestyle variables controlled, which may result in improved performance in calculating pDER. Further studies would also allow for larger and more variable populations of healthy dogs in terms of lifestyle, activity level, and other variables, as well as introduction of disease states.

Many studies5–7,11,14,17,24 have validated commercial-grade accelerometers in people and found acceptable accuracy in measuring heart rate and step count. However, almost all studies5–7,11,14,17,24 on human devices have reported poor accuracy in measuring energy expenditure, and significant variability has been reported between studies. For example, one study10,11 found that one device (Apple Watch; Apple Inc) underestimated calorie expenditure by over 100 calories, while another study found that the same device overestimated calories. Several studies5,9,11 also reported a significant increase in accuracy when the device contains a heart rate monitor to calculate energy expenditure, which is not a current capability of the activity monitor used in this study. Previous studies5,9 have shown that older models of human commercial wearable accelerometers that used algorithms to estimate energy expenditure without a heart rate tended to underestimate calories burned. This is the opposite of the trend seen in this data, where the activity monitor overestimated calories while calculating without incorporating the heart rate. Recent literature31,32 has been published on smart technology assessment of heart rate and oximetry and may be incorporated into activity monitoring for veterinary species in the future. The calorimetry error rate of 5% was utilized for this study based on evaluation of the literature43 regarding previous human-grade commercial accelerometer studies’ cut-off value for clinical accuracy. Once again, these findings in human devices mirror the findings of this study exhibiting poor pDER outcomes when compared to other assessment methods.

Validation studies performed for human products compare predicted energy expenditure to energy expenditure recorded by clinical gold standards. In most cases, this includes the use of either a validated research-grade accelerometer or calorimeter, as opposed to the method used in this study in relation to DER.5–11 This was done due to the intensiveness and availability of calorimetry usage in veterinary medicine. As a surrogate, this study evaluated the pDER from the activity monitor using an observed gold standard (ie, oDER) during a period of stable body weight. This is similar to the previous study16 examining this device’s accuracy for activity monitoring utilizing an observed gold standard of video analysis for activity monitoring to correlate with the device’s reported activity. Ideally, the evaluation and validation of these products should be done by integrating observed data and traditional gold standard methodologies to strengthen the veterinary medical literature and claims regarding the accuracy of these devices. Comparison studies16,17,14,15 like this have been performed with other commercial pet activity trackers. In comparison to a validated accelerometer most commonly used in canine research, one activity monitor (PetPace; PetPace LLC) was reported to have a moderate correlation with accelerometer readings from the validated accelerometer and another activity monitor (Whistle; Whistle Inc) was reported to have a strong correlation with the validated accelerometer readings.14,15 Future comparison of the activity monitor in this study to the validated accelerometer will enable a more accurate comparison between these products; this is currently being evaluated at our institution.

Finally, the majority of our outcome variables were analyzed over the course of an entire month (28-day study period). This was done to reduce day-to-day variability in caloric expenditure and activity levels seen under normal circumstances. Analyzing the data over longer periods of time like this should enable more consistent and repeatable results by reducing variability in the lifestyle of each animal. Reliability was also supported by one of the primary investigators being involved in the set-up of the activity monitor and training of enrolled clients.

Limitations of this study include variability in owner measurement and/or reporting of calories fed. A study validating human devices found that people tended to underestimate calories consumed and overestimate calories expended.8 In this study, there was an attempt to reduce this impact through regular touch bases and monitoring between the study team and owners of participating dogs. In addition, the owners were instructed and reported specific amounts of all foodstuff (eg, 8 Cheerios, one time, General Mill’s Original Cheerios). This process was developed and monitored by a board-certified veterinary nutritionist. Regardless, this variability may have affected the accuracy of the oDER in this study. This study was also aiming to test the activity monitor in a healthy population for validation. Health screening was done without extensive testing and relied heavily on clinical history and physical
Examining, but no lab work was done to evaluate systemic health. To compensate for this, we monitored dogs enrolled for a period of 18 months following the study to see if preclinical disease developed after study conclusion. This did not occur in any of the animals and supports the absence of clinically significant disease in this population at the time of study participation. However, even with these precautions, it is impossible to exclude the possibility of subclinical illness in this population. As such, concurrent illness may make the activity monitor pDER more or less accurate and represents another area of future study in other disease states.

This study was designed to assess 25 total dogs in a pilot study. During the study, 2 dogs were lost due to medical record errors in body weight recording. This reduced the total number of dogs in the study and resulted in data from 2 dogs being thrown out. Based on the design of the study, additional animals or a larger study may impact the results presented here. However, the effect size as evidenced by the large number of dogs unable to meet the criteria for human devices is convincing in this population and supports the conclusions of this manuscript. Further study in large patient populations with additional variables should continue to be explored.

Another source of error may arise from the owner’s estimation of their pet’s energy level used in the proprietary calculations made by the activity monitor. As discussed previously, this can have an impact on the results of activity monitors and may have influenced the results here. That being said, the approach of allowing owners to submit information used in this study accurately emulates a real-life scenario utilizing this equipment. In addition, within the manufacturer framework, it is possible that the error seen in the estimation of pDER is from the proprietary algorithm specifically utilized to calculate caloric expenditure from activity level. This is a possibility given that the data on the accuracy of activity monitoring for off-leash activity yielded more favorable results than the calorimetry data while using the same device. Due to these limitations, more research is needed to fully evaluate the utility of this activity monitor’s pDER in a clinical and research setting as this study was unable to determine the definitive source of the variability.

In conclusion, the activity monitor is a cost-effective real-time monitoring device for pet owners and their care teams. It has been used in published studies with success in tracking off-leash activity, but there has been no validation of pDER before this study. The data presented here found poor agreement between oDER and pDER. This finding raises concern for the accuracy of caloric data reported from this equipment in healthy animals with stable body weights. Therefore, its use in clinical and research settings to predict DER should be cautioned at this time.

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This research study was approved by the Institutional Animal Care and Use Committee (IACUC 2019A00000130).

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References


**Supplementary Materials**

Supplementary materials are posted online at the journal website: avmajournals.avma.org