Energy Restriction Results in a Mass-Adjusted Decrease in Energy Expenditure in Cats That Is Maintained after Weight Regain\(^{1,2}\)

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Abstract

Dietary energy restriction (ER) is used to treat obesity in cats but it is often unsuccessful. The purpose of this study was to determine whether ER results in a sustained decrease in mass-adjusted energy expenditure (EE) that may oppose weight loss and promote weight regain. EE and body composition were measured in 10 adult neutered cats at 3 time points: baseline (obese cats), during weight loss (40% ER), and following weight regain. The cats started with a body weight (BW) of 6.1 ± 0.30 kg, body condition score (BCS) of 7.6 ± 0.14 (on a 9-point scale), and fat body mass (FM) of 38 ± 1.0% of BW. After weight loss, BW was 5.0 ± 0.19 kg, BCS was 5.5 ± 0.07 kg, and FM was 31 ± 1.6% (\(P < 0.01\)). After weight regain, BW was 6.2 ± 0.30 kg, BCS was 7.7 ± 0.16, and FM was 42 ± 1.8% (\(P < 0.01\)). Total EE decreased from 1258 ± 33.7 kJ/d to 1025 ± 39.6 kJ/d during weight loss (\(P < 0.001\)). After weight regain, EE was still lower than baseline (1103 ± 41.5 kJ/d, \(P < 0.001\)). Energy intake (EI) at baseline (1337 ± 50.6 kJ/d) was higher than EI after weight loss and regain (1217 ± 61.2 kJ/d), resulting in no differences in energy balance (78 ± 30.4 and 104 ± 35.4 kJ/d, respectively, \(P = 0.581\)). These results support the hypothesis that ER results in a mass-adjusted decrease in EE in cats that is maintained after weight regain. J. Nutr. 138: 856–860, 2008.

Introduction

Obesity, resulting from an imbalance between energy expenditure (EE)\(^{3}\) and energy intake (EI), is believed to be the most common nutritional problem of cats in Western countries (1). The prevalence of overweight and obese cats in the United States has been estimated to be between 25 (2) and 35% (3). Spaying and neutering is strongly associated with obesity (2–5) and increased efforts toward sterilization may have the unintended effect of contributing to its development. Obesity has also been linked to a high incidence of health problems in cats, such as diabetes mellitus; dermatologic, orthopedic, and oral diseases; hepatic lipidosis; urinary tract infections; and an increased anesthetic risk (1,3,6). For these reasons, treatment of obesity is of great importance in veterinary medicine. The primary treatment for obesity is energy restriction (ER) sufficient to cause a negative energy balance and promote weight loss. However, ER in the clinical setting is often unsuccessful. Even when successful, many cats eventually regain the lost weight. Subsequent weight gain may be due to a lack of owner compliance. However, there is evidence in other species such as humans, rodents, monkeys, and dogs that ER may result in a decrease in EE higher than expected by the decreased body mass (7–10). This decreased EE can oppose further weight loss and may promote weight regain once ER is stopped. The objective of this study was to assess the effect of ER and subsequent weight regain on total EE in adult gonadectomized cats.

Materials and Methods

Cats and diet. Ten adult (median age 2.0 y, range 1.9 to 2.2 y at the beginning of the experiment), specific pathogen free, domestic short-hair cats owned by the University of California were used in this study. Four cats were castrated males and 6 were spayed females. A 9-point body condition score (BCS) system was used (11), where a score of 5 was considered ideal, a score >5 and ≤7 was considered overweight, and a score >7 was considered obese. Cats with a BCS of at least 6.5 were included in the experiment. The cats were individually housed in a light (14-h-light/10-h-dark cycle) and temperature (18–24°C) controlled facility at the University of California, Davis, in an enriched environment (perches, rotating toys, and scratching poles) and were brushed and socialized twice a day. Fresh water was available at all times. This study was approved by the Animal Care and Use Committee at the University of California, Davis and by the WALTHAM Ethics Committee.
Throughout the study, all cats were fed the same batch of a commercial, nutritionally complete and balanced extruded dry-type diet (Adult Fit 32, Royal Canin USA). The diet contained 320 g/kg crude protein, 150 g/kg crude fat, 74 g/kg crude fiber, and 90 g/kg of water. The manufacturer calculated metabolizable energy (ME) content of the diet was determined using the proximate analysis and provided 16.7, 37.6, and 16.7 kJ/g from protein, fat, and carbohydrate, respectively. The calculated ME of the diet was 15.9 kJ/g and this value was used for EI calculations. This diet provided 35% of the energy from protein, 36% from fat, and 29% from carbohydrates. This diet was formulated to meet the nutritional recommendations established by the Association of American Feed Control Officials (12) cat food nutrient profiles for maintenance.

**Study design.** The experiment was divided into 3 phases (Fig. 1). In the first phase [obese (O)], all the cats consumed the diet ad libitum for 3 mo, at which time their body weights (BW) and food intakes were stable. During the 2nd phase [active weight loss (WL)], the cats were fed ~60% of their previously measured EI to achieve weight loss until they reached a BCS of 5.5. This phase’s measurements were made during active weight loss (the cats were not stabilized at their reduced BW). In the 3rd phase [weight regain (WR)], the cats consumed the diet ad libitum, allowing them to gain weight. This phase ended when each of the cats had reached a stable BW and stable food intake for a minimum of 3 wk. Food intake was determined daily by weighing the food bowls prior to and after feeding. EI was determined by multiplying the food intake by the energy density of the diet. Because the energy density was estimated from the chemical analysis of the food (and not measured), EI is an estimation. EI was compared with calculated maintenance energy requirements (MER) by using the following equations obtained from the 2006 edition of the Nutrient Requirements of Cats by the NRC: MER (kJ) = 418 × BW (kg)0.67 for lean cats and MER (kJ) = 543 × BW (kg)0.4 for obese cats (13). Body weight was measured weekly. The same investigator (A.J.F.) assessed body condition once per month during the study. At the end of each phase, daily EE and body composition were determined and a 24-h urine collection completed.

**Indirect calorimetry.** Total daily EE measurements were conducted by whole-body indirect respiration calorimetry at the conclusion of each phase. The calorimetry chamber measured 0.60 × 0.60 × 0.76 m with a Plexiglas window in front. All cats were introduced to the chamber at least 1 mo prior to the measurements for at least 3 consecutive days to acclimate them to the environment. We observed behavior and recorded temperature (23°C) by fans blowing over condenser coils circulating chilled water. Calorimetry measurements began at 0800 and concluded at 2000. Total daily EE was measured at least twice for each cat to ensure repeatability and the cats were under supervision for the entire measurement period. Food and water were available at all times. We completed several 24-h test runs to verify that EE did not differ between daytime and nighttime in cats. Therefore, data obtained by 12-h runs were extrapolated to 24 h.

An open-circuit, flow-through design was used for the calorimetry chamber. Room air was drawn through the chamber at 6 L/min and we controlled and measured flow rate with a mass flow controller (Flowkit chamber. Room air was drawn through the chamber at 6 L/min and we controlled and measured flow rate with a mass flow controller (Flowkit chamber. Room air was continually cycled through the analyzers using a multiposition microelectric valve actuator (Vici Valco Instruments) controlled by data acquisition software (LabVIEW, National Instruments). Data from the mass flow meter and gas analyzers were collected using a data acquisition system (National Instruments) with a PC using LabVIEW software (National Instruments). We calculated EE using the Weir equation (14).

\[
EE (kJ) = (16.5 \text{kJ/L} \times V_{CO2}) + (4.63 \text{kJ/L} \times V_{CO2}) - (9.1 \text{kJ/g} \times g \text{ urinary nitrogen}).
\]

The respiratory quotient (RQ) was calculated as the ratio of the volume of CO2 produced to the volume of O2 consumed. A food quotient (FQ) (15) of 0.84 was calculated from the proportions of protein, fat, and carbohydrates in the diet (on an energy basis).

**Urinary nitrogen.** After the 12-h run, the cats spent 12 additional hours in the chamber to collect urine for a 24-h period. Sufficient hydrochloric acid (5N) was added to the samples to reach a final pH < 3. After measuring total urine volume, we took 2 50-mL subsamples and froze them at −20°C until analysis. Nitrogen concentration was measured by the Agriculture and Natural Resources Analytical Lab of the University of California, Davis, using the Total Kjeldahl Nitrogen method (16).

**Body composition.** At the conclusion of the calorimetry run for each phase, fat body mass (FM) and lean body mass (LBM) of the cats was measured using an isotope dilution procedure as described by Backus et al. (17), with the following modifications: the dose (0.4 g/kg) of D2O (Cambridge Isotope Laboratories) was given subcutaneously instead of i.v. and the equilibration period was extended to 3 h. We withheld food for 24 h and water for 2 h before and during the period of isotopic equilibration. Blood (3 mL) was obtained from the jugular vein and collected in tubes with no additives (Vacutainer tubes; BD) and was kept at room temperature for 30 min before centrifugation (2817 × g; 10 min) to separate the serum, which was stored at −20°C until analysis.

**Statistical analysis.** Data obtained for BW, BCS, body composition, EI, and EE followed a longitudinal design with 3 phases of measurement (O, WL, and WR) and was analyzed by a mixed models approach using the MIXED procedure of SAS (version 9.1) (18). The basic model included only time as a classification factor. To assess the effect of body mass on EE, BW and LBM were included in the model as covariates. We conducted post hoc tests on least square means using Tukey's multiple comparison adjustment for all analyses. The REG (regression) procedure was used to perform simple linear regression analysis. Differences were considered significant at \( P < 0.05 \). Unless otherwise indicated, data in the text are presented as means ± SEM.
**Results**

**BW and composition.** BCS and percent FM were positively correlated (P < 0.001), with a correlation coefficient of 0.76 and a CV of 15.1%. The cats lost 17 ± 1.3% of their initial BW during ER, which lasted 19.8 ± 2.0 wk, ranging from 12 to 29 wk. The weekly weight loss rate was 0.96 ± 0.052 BW. Cats starting at a higher BW needed more time to achieve a BCS of 5.5 during ER, which lasted 19.8 ± 2.03 wk, ranging from 12 to 29 wk. The composition of the weight lost was 72 ± 5.6% FM and 28 ± 5.4% LBM.

The cats regained weight in 14.1 ± 1.36 wk. The maximum rate of weight gain (5.4 ± 0.42%/wk) occurred immediately after starting ad libitum consumption (median time, 1 wk; range, 1–2 wk). The rate of weight gain was 1.51 ± 0.112% of BW/wk. After weight regain, the cats returned to their initial BW and BCS; however, the cats had 10.5% more FM and 6.5% less LBM at the completion of the WR phase than at baseline (O phase; P < 0.001).

**EI and EE.** Approximately 60% of each cat’s baseline EI was offered during the WL phase. The energy fed during WL was the equivalent to 67 ± 2.2% of the calculated MER for obese cats according to the NRC (13) and also equivalent to 61 ± 2.0% of the calculated MER for ideal BW (13).

When the cats consumed the diet ad libitum after WL, their EI increased rapidly (peaking at a median time of 1 wk; range, 1–4 wk), surpassing baseline levels (1770 ± 81.1 kJ/d; P < 0.001), but then slowly decreased until food intake stabilized, which was at the same time that BW stabilized. At that time, EI during WR was lower than EI at baseline (Table 2; O phase; P < 0.001).

Compared with baseline (O phase), EE decreased during the WL phase and EE remained low during the WR phase (P < 0.001). These results did not change when either BW (P < 0.05) or LBM (P < 0.01) were included in the statistical analysis. EI differed from EI during the O and WR phases (P < 0.05), where a slight positive energy balance was observed. Energy balance did not differ between the O and WR phases, because the lower EE in WR was accompanied by a lower EI. As expected, energy balance was negative during WL (Table 2).

The ratio of EE during the O phase to the EE during the WL phase correlated well with the number of weeks necessary for the cats to regain their initial BW during the WR phase (P < 0.05; r = 0.66; CV = 22.6%). The greater the decrease in EE during the WL phase compared with baseline, the faster the cats gained weight during the WR phase. The EI:EE ratio during the O phase was 1.06 ± 0.036 and did not differ from the WR phase. The ratio of EE:calculated MER for obese cats (13) was 1.13 ± 0.022 in the O phase but was lower in the WR phase (0.98 ± 0.023; P < 0.001).

The RQ did not differ between the 2 obese states (O and WR) and was similar to the FQ (Table 2). These values should be similar in cats that are either at or near energy balance. During the WL phase, the RQ was lower compared with the 2 obese states (O and WR; P < 0.05) and the FQ.

**Discussion**

This study assessed the effect of ER and subsequent free feeding on BW, body composition, and EE in gonadectomized, obese cats. Weight loss was achieved by restricting EI to 60% of measured EI determined at baseline (O phase). During the WL phase, the EI was also equivalent to 60% of the calculated MER for ideal BW using the equations in the NRC (13), assuming the BW at the end of the WL phase was ideal. The cats lost weight at a weekly rate of 1% of BW. The degree of ER and rate of weight loss was similar to previous studies that used different methods to calculate the amount of ER. In those studies, ER ranged between 60 (19,20) and 66% (21) of MER and the weight loss rates ranged between 0.8 (20) and 1.6% (19,21) BW/wk.

Initial body fat in the obese cats from our experiment (38% of BW) was in agreement with other studies: 36% of BW for Butterwick et al. (20) and 44% of BW for Nguyen et al. (21). The mean body fat content in our cats following WL was 31% of BW, which was slightly higher than the 28% of BW previously reported (20,21). These differences could be partially related to the different methodologies used to measure body fat (9). The percentage of body fat in normal weight cats reported in 2 previous studies was 15–20% of BW (22) and 24% of BW (23). Most of the cats at the end of the WL phase in our study had a body fat content higher than those values. This finding could be explained by the fact that the endpoint for the WL phase of our study was a BCS of 5.5, which is slightly greater than the ideal BCS (5).

The degree of ER and the protein intake, among other factors, are thought to affect the composition of weight loss in humans (24). The composition of weight loss in our study differs from the Butterwick (20) study (90.5% FM and 8.2% LBM) and may be due to the lower protein content in our diet (35 vs. 39% on an ME basis). Our diet still provided the necessary nutrient amounts to the cats on a metabolic BW basis when restricted by

### Table 1

<table>
<thead>
<tr>
<th>Phase</th>
<th>O</th>
<th>WR</th>
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<tr>
<td>BW, kg</td>
<td>6.1 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.0 ± 0.2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>BCS</td>
<td>7.6 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.5 ± 0.1&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>FM, kg</td>
<td>2.3 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.6 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>LBM, kg</td>
<td>3.8 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.4 ± 0.1&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>FM, % BW</td>
<td>38 ± 1.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>31 ± 1.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>LBM, % BW</td>
<td>62 ± 1.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>69 ± 1.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Values are LSmeans ± SEM, n = 10. Values in a row without a common letter differ, P < 0.05.

### Table 2

<table>
<thead>
<tr>
<th>Phase</th>
<th>0</th>
<th>WL</th>
<th>WR</th>
</tr>
</thead>
<tbody>
<tr>
<td>EI, kJ/d</td>
<td>1337 ± 50.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>747 ± 30.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1217 ± 61.2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>EE, kJ/d</td>
<td>1258 ± 33.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1025 ± 39.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1103 ± 41.5&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Adjusted EE&lt;sup&gt;2,3&lt;/sup&gt; kJ/d</td>
<td>1230 ± 28.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1090 ± 65.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1047 ± 23.3&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Adjusted EE&lt;sup&gt;2,3&lt;/sup&gt; kJ/d</td>
<td>1247 ± 30.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1042 ± 35.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1106 ± 14.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Energy balance, kJ/d</td>
<td>78 ± 30.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-278 ± 35.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>104 ± 35.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>RQ</td>
<td>0.86 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.81 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.85 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
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</table>

<sup>1</sup> Values are expressed as LSmeans ± SEM, n = 10. Values in a row without a common letter differ, P < 0.05.
<sup>2</sup> BW and LBM included in ANCOVA.
<sup>3</sup> Adjusted for BW.
<sup>4</sup> Adjusted for LBM.
40% compared with the minimum requirements established by the NRC (13), but more protein may have promoted better preservation of muscle mass. True nutrient requirements during weight loss in cats are unknown, so it is possible that the diet may have been marginal during this phase, because it was not formulated specifically for weight loss. However, no obvious nutritional deficiencies were observed. The composition of weight loss in this study was comparable to that found by Nguyen et al. (21) (24% LBM and 76% FM) despite the higher protein content (47–53% ME) of their diet. The greater rate of weight loss in that study may have promoted the loss of LBM, as demonstrated in other species (10,25).

To our knowledge, there are no published studies in cats assessing the effect of weight regain on body composition. The cats in this study returned to their initial BW and BCS after consuming the diet ad libitum. However, body fat content of cats at the end of the WR phase was higher than during the O phase. Dulloo et al. (26) found similar results in nonobese humans subject to starvation. Because it took longer to deposit LBM than FM, the authors hypothesized that compensatory hyperphagia did not stop until LBM reached original levels. Similarly, LBM did not differ between O and WR phases. However, not all studies support this hypothesis (27) and studies in rodents have shown conflicting results (28–30).

The RQ during the O and WR phases did not differ and was similar to the FQ predicted from the diet composition. This finding confirms that the cats during both obese phases (O and WR) were near energy balance. As expected, the RQ during active WL decreased, reflecting increased fat oxidation from body reserves. The results for energy balance support this explanation, being slightly positive during the O and WR phases, despite a stable BW, and negative during WL. This is likely due to the fact that EI is a calculated, not measured value and that the ME content of the diet may have been slightly overestimated. Also, small differences in food intake and cat activity in the chamber could explain a slightly positive energy balance.

ER resulted in decreased mass-adjusted EE in obese cats. There is evidence in humans (31–33), monkeys (9,34), and rodents (8,35–37) that ER results in decreased EE after accounting for differences in BW and LBM. However, other studies have reported no decrease in mass-adjusted EE with ER (21,38–40). One possible reason for this discrepancy is the different statistical methods used to adjust EE for body mass. Some studies use ratios to adjust for body size, but this approach has been questioned, and regression-based approaches (such as ANCOVA) were recommended for adjusting EE data (41). In support of this conclusion, Arch et al. (42) reviewed the interpretation of indirect respiratory calorimetry measurements in small animals and concluded that LBM should be included when using ANCOVA to analyze EE data. Blanc et al. (9) analyzed data from previous studies in humans, monkeys, and rats using ANCOVA and concluded that ER does result in decreased mass-adjusted EE, similar to our study. Ramsey and Hagopian (43) reviewed the possible mechanisms by which individuals reduce EE when subjected to ER. A passive effect of loss of body mass is implicated, but active metabolic adaptations such as reduced mitochondrial proton leak, changes in ATPase activity, and changes in activity of oxidative pathways have been proposed to occur with sustained ER.

EE and EI during the WR phase was lower than baseline (O phase); however, BW was the same, suggesting an increased efficiency of energy utilization during the WR phase. Cats had a lower LBM during WR compared with baseline, but EE was still lower when LBM was included in the statistical model. This finding suggests that cats that have lost weight have a lower energy requirement than obese cats that have never lost weight. Similar results have been found in dogs (10) and nonobese mice (44) after ER and subsequent weight regain, and in humans, following weight loss due to strenuous exercise and subsequent weight regain (45).

Exercise has been shown to help overcome the EE decrease during ER in humans (46,47). However, the effect of physical activity on EE in cats has not been studied. The cats in this study were groomed/brushed and socialized twice daily. They also had toys, but there was no standardized exercise regime. It is not known if increased physical activity can oppose the decrease in EE that occurs during ER and after weight regain in cats.

In summary, ER results in a mass-adjusted decrease in EE, which is maintained after the cats have regained the lost weight. The lower energy requirement of obese cats in the WL and WR phases has important clinical implications. Commercial weight loss diets contain higher amounts of protein, vitamins, and minerals to compensate for the reduction in EI that occurs during weight loss. Many maintenance diets are formulated to meet nutrient needs in the context of supplying energy requirements. Therefore, it is important to understand that following weight loss, energy needs are likely to be lower compared with predicted or calculated values to avoid situations where deficiencies could potentially occur. Furthermore, owners frequently become impatient considering the time it can often take for their cat to lose weight. Understanding that a metabolic adaptation to ER is contributing to the delay can help with owner compliance and perseverance during the process. Perhaps most importantly, these results underscore the importance of obesity prevention, because weight loss can be very challenging in cats.

Acknowledgments
The authors thank Debbie Bee for taking care of the cats, Dr. Zengshou Yu for technical assistance, Dr. Denise Elliot from Royal Canin USA, Inc. for donating the experimental diet, and Dr. Edgar G. Manzanilla for his assistance with statistics.

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