Use of reduced-energy content maintenance diets for modest weight reduction in overweight cats and dogs

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Short title: reduced-energy maintenance diets and weight loss in pets

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Abstract

One option for controlled weight loss for dogs and cats in overweight condition could be to modestly restrict caloric intake using a reduced-energy ('light') maintenance diet, but there is no prior research on the safety and efficacy of such an approach. A prospective observational cohort study was performed in 67 overweight dogs and 17 overweight cats undergoing weight loss using reduced-energy maintenance diets from one manufacturer. Diets were fed at approximately 80% of maintenance energy requirements for ideal bodyweight for a period of 8 weeks. Essential nutrient intake was estimated for each dog and cat and compared with minimum requirement (MR) or adequate intake (AI, when no MR had been demonstrated) as set by the National Research Council in 2006. Weight loss was seen in 56/67 dogs (84%), losing a median of 4.7% (range 15.2% loss to 10.0% gain) of their starting body weight (SBW). Weight loss was also seen in all 17 cats, losing a median of 6.4% (range 2.0 loss to 15.2% loss) of SBW. Of the essential nutrients examined, only selenium, choline, potassium, and riboflavin were less than NRC recommendations in a minority of animals. However, no signs of any nutrient deficiency were observed in any of the dogs or cats during the study. In summary, modestly energy restricting overweight dogs and cats when feeding a low-energy maintenance diet can induce weight loss and might be a useful initial step for weight management. Although no adverse effects were seen, borderline intake of some micronutrients warrants further consideration.

Keywords

Canine; feline; weight management; obesity

1. Introduction

Obesity and overweight are associated with many adverse effects on the health of dogs and cats including increased risk of various diseases (Lund et al., 2005 & 2006; German et al., 2010) impairment of normal organ system function (German et al., 2009a, Tvarijonaviciute et al., 2012 & 2013; Mosing et al., 2013; Tropf et al., 2017; Marshall et al., 2010), a poorer quality of life (German et al., 2012a) and a shortened lifespan (Salt et al., 2018). Given the fact that prevalence is increasing in the pet population (Banfield Pet Hospital, 2019), overweight is an increasing welfare concern for the veterinary profession. Recently, therefore, many national and international veterinary associations have formally recognised obesity as a disease (Ward et al. 2019).

Weight reduction in overweight cats and dogs most commonly involves dietary caloric restriction using a purpose-formulated diet. Such diets are formulated such that all essential nutrients are met even when fed at less than maintenance energy requirements (Linder et al. 2012). One potential barrier to starting a weight management programme is cost, given that such therapeutic diets are more expensive than regular maintenance diets. As a result, owners might often be reluctant to feed them (German et al., 2015a). Arguably, this barrier might affect pets in overweight body condition (body condition score, BCS 6/9 or 7/9) more than those with obesity (BCS 8/9 or 9/9), because owners might be less convinced about adverse effects on health, despite the available evidence (Lund et al., 2005 & 2006; German et al., 2010; Salt et al., 2018) and less convinced about possible benefits of switching to a therapeutic diet. For such cases, being able to offer an alternative strategy would be advantageous, for example, modestly

77 restricting energy intake using a standard maintenance diet. The main concern with such an
78 approach is that such diets are designed to meet essential nutrient requirements when fed at
79 maintenance, but not at intakes usually required for weight reduction (Linder et al., 2012;
80 Gaylord et al., 2018). So, a possible approach for dogs and cats in overweight condition, might
81 be to use a maintenance diet designed for pets with reduced-energy requirements, often called
82 'light' diets. We hypothesised that it would be possible to restrict such a diet modestly enough to
83 induce weight reduction, whilst avoiding essential nutrient deficiency. Therefore, the first aim of
84 the current study was to test the efficacy of a range of reduced-energy maintenance diets, from
85 one manufacturer, for short-term weight reduction in dogs and cats in overweight body
86 condition. A second aim was to determine whether weight reduction could be successfully
87 achieved whilst ensuring that essential nutrient intakes are met.
88

2. Materials and methods

2.1 Study design and study sites

This was a prospective, observational cohort study of overweight dogs and cats undergoing weight loss. The study was organised by Royal Canin and administered by CEN Nutriment (Dijon, France). Prior to commencement, the protocol was first approved by the Royal Canin Ethics Committee (Permit Number: 120418-4), and owners of all participating animals gave informed consent in writing. As reasonable compensation for participating, owners were not charged for the study visits, and received all of the weight loss diet free of charge.

2.2 Eligibility criteria, recruitment, enrolment and exclusion

CEN Nutriment contacted cat and dog owners (by phone, mail and local advertising) from Bourgogne and the Dijon areas of France and invited them to participate in the study. A qualified veterinary nurse (I Mazzaro), who was an employee of CEN Nutriment, was responsible for all recruitment and enrolment. The advertisement and pre-recruitment process occurred between April and May 2018, where suitable cases were selected from the responses to the advertisements. Recruitment occurred during May and June 2018, with the weight loss programmes themselves running between June 2018 and August 2018. To be eligible, animals

had to be adult (>12 months age of cats and small-breed dogs; >18 months of age in large-breed dogs), in overweight condition (BCS 6/9 or 7/9; Laflamme 1997a and 1997b), healthy (i.e. without medical diseases that would make controlled weight loss clinically inappropriate, e.g. significant systemic disease such as chronic kidney disease, cardiac disease, liver disease, metastatic neoplasia etc.), and neither pregnant nor lactating. Further, animals needed to be consuming a standard maintenance diet, have no current or past history of an adverse reaction to food, nor have previously been diagnosed with any endocrinopathy that might influence weight loss or gain (including but not limited to diabetes mellitus, hypothyroidism [dogs], hyperthyroidism [cats]), or have clinical signs consistent with any such endocrinopathy. Finally, dogs and cats were ineligible if they were either currently on, or had previously undertaken, a weight reduction programme.

2.3 Patient welfare, adverse events, and study suspension

Efforts were made to safeguard the welfare of the dogs and cats enrolled throughout the course of the study. Owners monitored the wellbeing of their pet, and alerted investigators about any concerns that they had. Further, the weight reduction programmes for all animals were overseen by a veterinary nurse. Welfare issues, protocol deviations, and suspected adverse events were also recorded as part of the trial protocol. Moreover, the participation of animals in the study could be suspended (temporarily or permanently) for any of the following reasons: two or more days of eating less than half their assigned food allocation, signs of a possible adverse reaction to food (e.g. vomiting, diarrhoea, dermatological signs), or the development of a new disease

incompatible with continuing on the study protocol. In such cases, animals were assessed by a veterinary nurse who decided whether the trial should be suspended, with decisions being based upon the nature and severity of the illness, the treatment required, welfare of the patient and wishes of the owner. Other possible reasons for suspension included failure of owners to return for appointments or to comply with the protocol. Finally, owners could also choose to withdraw their pet at any stage if they wished to, without needing to give a reason.

2.4 Dietary intervention

The foods used for controlled weight reduction were wet or dry proprietary products for dogs and cats from one manufacturer (Royal Canin, Aimargues, France), formulated to be complete and balanced for all essential nutrients (with the exception of selenium, given the limit on the amount of supplementation allowed; FEDIAF, 2019). They were all intended to be fed to animals with reduced daily energy needs (e.g. neutered animals and those prone to weight gain). Dogs were fed one of four dry kibbled diets (Table 1), with the choice depending upon the typical adult size of the breed: dogs assigned to the 'extra-small' size group (e.g. adult breed size typically <5kg) were fed canine diet 1 (Canine Care Nutrition [CCN] Extra Small Light Care), dogs assigned to the 'small' size group (adult breed size typically 5-10 kg) were fed canine diet 2 (CCN Small Light Care); dogs assigned to the 'medium' size group (adult breed size typically 10-25 kg were fed canine diet 3 (CCN Medium Light Care), and dogs assigned to the 'large' size group (adult breed size typically >25 kg) were fed canine diet 4 (CCN Maxi Light Care). The cut-points for these size categories determined by the food manufacturer, but were not absolute

and some flexibility was allowed in group assignment. Cats were either fed dry food exclusively (feline diet 1; Feline Care Nutrition [FCN] Light Weight Care dry, Table 2) or a combination of wet (feline diet 2; FCN Light Weight Care wet; Table 2) and dry food (feline diet 1), with the choice dependent upon the preferences of owner and cat. Cats that received both wet and dry food were fed 1 pouch (85g) of feline diet 2, with feline diet 1 comprising the balance of the daily ration. The diets were provided in their normal packaging, and no attempt was made to blind owners to their identity.

2.5 Weight reduction protocol

All clinical assessments were performed at the CRO facility (Dijon, France) and overseen by a qualified veterinary nurse. During the enrolment visit, dogs and cats were assessed clinically using history and physical examination, and their eligibility for the trial was checked (see above). Animals were weighed using the same electronic scales each time (Scale Szaerfa LCD numeric scale; Dijon, France), their BCS assessed using a 9-unit system (Laflamme 1997a and 1997b), and subjective assessments made about their activity, quality of life (QOL), and food-seeking behaviour (see below). A two-stage method was then used to calculate the initial food allocation for the study. First, an estimate of ideal body weight (IBW) was calculated by dividing the current body weight by a factor that took into account the estimated percentage of excess weight (assumed to be 10% per unit of BCS between 5 and 9; German et al., 2009b, Flanagan et al., 2017 and 2018). Therefore, the estimated IBW for animals with BCS 6 and 7 were calculated by dividing the current body weight by 1.1 and 1.2, respectively. Dogs were fed an average initial

179 food allocation of about 335 kJ per $kg^{0.75}$ (80 kcal per $kg^{0.75}$, approximately 80% of MER) of
180 ideal body weight (IBW) per day, which was more modest than used in both short-term (276 kJ
181 [66 kcal] per kg $IBW^{0.75}$; Flanagan et al. 2017) and long-term (261 kJ [62 kcal] per kg $IBW^{0.75}$;
182 German et al., 2015b) weight reduction using therapeutic diets. Similarly, cats were fed an
183 average initial food allocation of about 286 kJ (68 kcal) per kg $IBW^{0.67}$ per day (approximately
184 70% MER), which was again a modest restriction than used for both short-term (~58 kcal per kg
185 $IBW^{0.67}$; Flanagan et al., 2018) and long-term (~56 kcal per kg $IBW^{0.67}$ per day; O'Connell et al.,
186 2018) weight reduction using therapeutic diets. Owners also received advice about lifestyle (e.g.
187 avoiding the feeding of table scraps and treats) and activity alterations (increasing physical
188 activity through walking and/or play) aimed at assisting in weight loss. However, exact details
189 of the advice given to each owner, and compliance with this advice, was not formally recorded.
190
191 Animals returned for an interim visit at approximately 4 weeks (optimal: day 28) and a final visit
192 at approximately 8 weeks (optimal: day 56), although flexibility was allowed depending upon
193 owner commitments. At the interim visit, a health check was performed to ensure that the
194 animal was clinically well, and problems that the owner might have encountered during the
195 weight loss programme were discussed (including compliance issues, food measuring, and
196 whether their pet had obtained additional food such as treats or table scraps fed by the owner or
197 food stolen by the pet). Animals were weighed and their BCS rechecked. If weight loss was
198 <0.5% per week, caloric intake was decreased by 10%, if weight loss was >2.0% per week,
199 caloric intake was increased by 10%, whilst if weight loss was between 0.5% and 2.0% per
200 week, caloric intake was not altered. Further, if the animal reached their IBW before the end of
201 the trial, food allocation was increased so as to maintain their weight. Owner perceptions about

their pet's behaviour were also recorded (see below). At the final visit, a further health check was performed, bodyweight and BCS were rechecked and owner perceptions about their pet's behaviour recorded again.

2.6 Estimation of essential nutrient intake

Essential nutrient intake during the period of weight loss was estimated for each dog and cat as previously described (German et al., 2015c). Briefly, for each dog and cat, the average daily intake of each essential nutrient was calculated from the daily food allocation of each animal and the average nutrient content for the diet (or diets) that the animal consumed (Tables 1 and 2). For cats that received both wet and dry food, nutrient intake from each food was calculated separately and the two added together to determine the overall daily intake. The number (and percentage) of dogs and cats with daily intake of essential nutrients less than minimum requirement (MR) or adequate intake (AI, when no MR had been demonstrated), as defined by NRC (2006), were then determined. Comparisons were made per kg of ideal body weight$^{0.75}$ for dogs and per kg of ideal body weight$^{0.67}$ for cats (NRC, 2006).

2.7 Owner-perceived changes in behaviour

223 Owners subjectively assessed food-seeking behaviour and quality of life (QOL) at all visits,
224 whilst changes in mobility were assessed at the interim and final visits only. Owners judged the
225 presence of food-seeking behaviour (including any of the following in relation to food:
226 vocalising, stealing or attempting to steal food, turning bowl over, following owner around,
227 waking owner up, irritable or aggressive behaviour) in relation to the timing of their last meal (0,
228 none; 1, just before meals; 2, two or more hours before meals; 3, just after meals), and judged
229 quality of life, using a 5-unit scale (from 1 [poor] to 5 [normal]). The criteria used in deciding
230 food-seeking behaviour and QOL were adapted from those of previous weight loss studies
231 (Flanagan et al., 2017 and 2018), but were not formally validated prior to use. To determine
232 possible changes in mobility, owners were both asked whether there had been any change
233 compared with before the enrolment visit (1, yes; 0, no), and also whether their pets ability to get
234 into the car (dog) or climb stairs (cat and dog) had changed (1, yes; 0, no).

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237 *2.8 Data handling and statistical analysis*

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239 Data were entered into an electronic spreadsheet (Microsoft Excel® for Mac version 16.19) and
240 checked for errors. Datasets containing the study data are available in the supporting
241 information (S1 and S2 Datasets). Continuous data are reported as median and range as
242 indicated, whilst categorical data are reported as absolute numbers and percentages. The only
243 missing data were 4 behaviour scores from cat owners (food seeking: 2 from visit 2; QOL: 1
244 from visit 2; mobility: 1 from visit 2) and 3 from dog owners (food seeking: 1 extra small dog at

visit 0; 2 medium dogs at visit 2). Given the small numbers of missing data, no adjustments were made.

Data were analysed with two computer software packages (Stats Direct version 3.1.22, Stats Direct Ltd., Altrincham, UK; JMP version 14.3.0, SAS Institute Inc., Cary, NC, USA), and the level of statistical significance was set at $P<0.05$, for two-sided analyses. Standard descriptive statistics were used to report continuous (age, bodyweight, and percentage change in weight) and ordinal (BCS) data as median and range given the small study numbers, whilst categorical variables were expressed as proportions (number with percentage in brackets). Non-parametric tests were used throughout, again because of the small numbers in each size group.

The primary outcome measure of interest was percentage change in bodyweight, during the 8-week study, expressed as a percentage of the starting (i.e. pre-intervention) weight (i.e. [pre-study measurement – post-study measurement] / [pre-study measurement] x 100). Secondary outcome measures included rate of weight loss, number losing at least 6% bodyweight, and also changes in food-seeking behaviour, QOL, and mobility. Changes in continuous outcome measures over time were assessed with the Friedman tests, whilst changes in categorical variables were assessed with Chi squared tests for trend. Differences amongst dog size groups for percentage weight loss, rate of weight loss and average energy intake were assessed with the Kruskal Wallis test, whilst differences in outcomes of weight loss amongst size groups were compared with r-by-c Chi-squared tests. Changes in subjective owner scores for food-seeking behaviour and QOL were assessed with Chi-squared tests for trend, whilst changes in mobility

were compared with 2-by-2 Chi-squared tests. Given small numbers, scores for all dogs were compared, rather than assessing dog size groups individually.

3. Results

3.1 Study animals

Sixty-nine dogs were recruited, but 1 dog was ineligible because its BCS was 8/9 and 1 dog suspended/was withdrawn before the start of the study because the dog would not eat the food. Ultimately, 67 started the weight loss programme, with 13, 16, 20 and 18 dogs, respectively assigned to the extra small, small, medium, and large categories. A range of ages, sexes and breeds were included (Table 3). Nineteen cats were recruited but 1 was ineligible because its bodyweight was already optimal (BCS 5/9) and 1 was ineligible because its BCS was 8/9. Ultimately, 17 cats were included, mostly of the European shorthair breed and comprising a range of ages, with 9 being neutered male and 8 being neutered female (Table 3). No adverse effects were reported in any of the cats or dogs, and there were no suspensions or withdrawals during the study.

3.2 Weight loss outcomes in dogs

Median (range) energy allocation throughout the study was 325 (277 to 384) kJ per $kg^{0.75}$ IBW per day (78 [66 to 92] kcal per $kg^{0.75}$ IBW per day), with no differences in food intake amongst dogs in different size groups (Table 4, P=0.729). Weight loss was seen in 56/67 dogs (84%), whilst 5 (7%) maintained a stable weight (i.e. weight remained ±1% of starting body weight), and 6 (9%) gained >1% weight. Again, there were no differences in outcomes of the different

size groups (Table 4, P=0.081). Twenty-six dogs (39%) lost more than 6% of their starting body weight, whilst 6 dogs (9%) had reached their ideal body weight by the end of the study. Once again, there were no differences in either of these outcomes amongst size groups (P=0.245 and P=0.641).

Median bodyweight was significantly less than SBW both at visits 1 and 2 (Table 4, P<0.001 for both), whilst bodyweight at visit 2 was also less than visit 1 (P<0.001). Median (range) percentage weight loss for all dogs was 3.0% SBW (15.4% loss to 6.3% gain) and 4.7% SBW (15.2% loss to 10.0% gain) at visits 1 and 2, respectively (Fig 1), corresponding to an overall rate of weight loss of 0.6% SBW per week (2.1% loss to 1.4% gain of SBW per week; Table 4). There were no differences amongst dog size groups for weight loss outcomes including energy intake (P=0.729), percentage weight loss (P=0.099), rate of weight loss (P=0.127), the proportion losing weight (P=0.245), the proportion losing at least 6% bodyweight (P=0.641), and the proportion reaching target weight (P=0.556).

3.3. Weight loss outcomes in cats

Of the 17 cats, 9 were fed dry food exclusively and 8 were fed both wet and dry food. Median (range) energy intake for cats was 278 (240 to 297) KJ per $kg^{0.67}$ IBW per day (66 [57 to 71] kcal per $kg^{0.67}$ IBW per day). Weight loss was seen in all 17 cats, with 9 (53%) and 2 (12%) losing more than 6% of SBW and reaching target weight, respectively. Median bodyweight was significantly less than SBW both at visits 1 and 2 (Table 4, P<0.001 for both), whilst bodyweight

316 at visit 2 was also less than visit 1 (P<0.001). Median (range) percentage weight loss for cats
317 was 4.5% SBW (-2.0 to 18.8%) and 6.4% SBW (2.0 to 19.2%) at visits 1 and 2, respectively
318 (Fig. 2), corresponding to an overall rate of weight loss of 0.7% (0.3% to 2.7%) SBW per week
319 (Table 4). There were no differences between cats fed dry food exclusively and cats fed both
320 wet and dry food for any weight loss outcome including energy intake (P=0.481), percentage
321 weight loss (P=0.796), rate of weight loss (P=0.673), number losing weight (P>0.999), number
322 losing at least 6% bodyweight (P=0.347), and number losing at least 9% bodyweight (P>0.999).
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324
325 *3.4 Determining the adequacy of essential nutrient intake during the study*
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327 The average daily intake of essential nutrients during the study was determined and compared
328 with NRC 2006 recommendations (Tables 5 and 6). In dogs, the average intake of all nutrients
329 was greater than either MR or AI, except for choline, potassium, riboflavin, and selenium. For
330 selenium, the minimum daily intake was less than AI in all dogs (100%) irrespective of diet
331 (median 8.9 µg per $kg^{0.75}$ IBW per day [range 6.3-10.2], NRC 2006 AI: 11.8 µg per $kg^{0.75}$ IBW
332 per day). Average daily intake of choline was marginally less than AI in 3 dogs (4%) on diet 1
333 (41, 44 and 44 mg per $kg^{0.75}$ IBW per day; NRC AI: 45 mg per $kg^{0.75}$ IBW per day), whilst daily
334 intake of potassium was marginally less than AI in 2 dogs (3%), one each on diets 1 and 2 (both
335 0.13 g per $kg^{0.75}$ IBW per day; NRC AI: 0.14 g per $kg^{0.75}$ IBW per day). Average daily intake of
336 riboflavin was less than MR in 10 dogs (15%) all of which were fed diet 1 (0.126 [0.107-0.148]
337 mg per $kg^{0.75}$ IBW per day; NRC 2006 AI: 0.138 mg per $kg^{0.75}$ IBW per day). In cats, the
338 average daily intake of all nutrients was greater than either MR or AI, except for selenium which

was marginally less than AI in 4 cats (24%; 7.39 [6.25-7.80] µg per $kg^{0.67}$ IBW per day; NRC 2006 AI: 6.95 µg per $kg^{0.67}$ IBW per day).

3.5 Owner determined changes in behaviour

Owner-reported subjective food-seeking behaviour and quality of life scores are reported in Table 7. During the course of the study, dog owners reported less food-seeking behaviour (P=0.003), improved QOL (P<0.001), and improved mobility (P=0.007). Cat owners also reported improved QOL over the course of the study (P=0.002), but there were no differences in food-seeking behaviour (P=0.304) or mobility (P=0.373).

4. Discussion

In this study, we have investigated the ability of reduced-energy maintenance foods from one manufacturer to induce modest weight reduction in overweight dogs and cats. Although it was only a short study, most dogs and cats lost weight successfully in a manner equivalent to other short-term weight reduction studies (Bissot et al., 2009; Flanagan et al., 2017 and 2018). Further, weight reduction occurred with more modest energy restriction than is usually used in weight reduction studies (e.g. 70-80% of MER at ideal weight, compared with 55-60% (German et al., 2015b; Flanagan et al., 2017 and 2018; O'Connell et al., 2018). Moreover, all animals remained healthy and the intake of most essential nutrients was greater than minimum requirements. To the authors' knowledge, this is the first time that the efficacy of any reduced-energy maintenance diet has been tested for this purpose. Given the study outcomes, using a reduced-energy maintenance diet could be an effective initial option for overweight dogs and cats, being easier for a client to accept, compared with switching to a purpose-formulated weight management diet. One limitation of the study was the fact that only a single range of diets from one manufacturer were tested. It is unclear as to whether the same results would be achieved with different reduced-energy diets from different manufacturers, given that there might be differences in the way they have been formulated, in terms of the amounts of essential nutrients incorporated. Therefore, further studies are required using a wider range of diets before this strategy can be more widely recommended.

Excessive dietary selenium intake can also have adverse effects (NRC 2006), both AAFCO (2014) and especially FEDIAF (2019) place limits for selenium supplementation, making it

374 difficult to meet NRC requirements (German et al. 2015c). The FEDIAF limit is particularly
375 strict, given their additional aim of reducing environmental pollution with trace elements. This
376 might explain why selenium intake was less than NRC AI in all dogs and some cats.
377 Nonetheless, the significance of this finding is unclear, not least because an MR has not been
378 reported. The NRC report the AI of an essential nutrient when its MR has not been determined,
379 which is a daily intake which is known to be sufficient (NRC 2006). Selenium is involved in
380 antioxidant pathways, thyroid function and immune system function, whilst signs of deficiency
381 include anorexia, depression, dyspnoea, and coma (NRC 2006). None of the dogs or cats in this
382 study showed any such signs although, given that this was a short-term study, it would there
383 might arguably have been insufficient time for such signs to develop. That said, selenium intake
384 on a purpose-formulated weight management diet was also frequently less than NRC AI in a
385 longer-term (>6 months) weight loss study, and again no signs of selenium deficiency were
386 evident (German et al. 2015b). Furthermore, in a related *in vivo* study using the same diet, no
387 decrease in selenium status during weight loss was seen. Instead, urinary selenium excretion was
388 greater after weight loss, compared with before, perhaps suggesting that requirements for this
389 essential nutrient might actually decline during weight loss (Linder et al., 2013). A further
390 complication with determining actual selenium requirements is the fact that vitamin E and
391 selenium have synergistic effects (NRC 2006). Daily intake of vitamin E was considerably
392 greater that AI in all dogs and cats in the study, and this might have compensated for the lesser
393 intake of selenium.
394
395 Besides selenium, average intake during weight loss was marginally less than MR for choline in
396 3 dogs (all from the extra small size group), whilst average intakes were marginally less than AI

for potassium and riboflavin in 2 (both extra-small) and 26 (10 extra-small, 16 small) dogs, respectively. Choline is a vitamin-like substance that is involved in neurotransmission, hepatic lipid metabolism, and coagulation (NRC 2006), with reported signs of deficiency including vomiting, fatty liver disease, and death (Fascetti et al., 2012). It is of note that choline was previously identified as a nutrient at risk of possible deficiency during controlled weight reduction in one *in silico* study (Linder et al., 2012), and daily intake was less than AI in 2 of 27 dogs in a previous study examining nutrient intakes in dogs (German et al 2015c). In that study, dogs were fed a purpose-formulated weight management diet, their period of weight reduction was over 6 months and, despite the fact that they had lost at least 15% bodyweight, no signs of deficiency were noted. Further, there is limited research into the actual choline requirements of dogs especially on its MR (NRC 2006). Although the AI recommended by NRC (2006) is 340 mg per 1,000 kcal ME for all physiological life stages, one study previous suggested that a choline-deficient diet could be rendered adequate by supplementing with DL-methionine, because methionine consumed in excess of requirements can be used to synthesise choline (McKibbin et al., 1944). In the current study, daily methionine intake in all dogs was greater than MR, and the excess might have been sufficient to compensate for the marginal choline deficiency in some dogs.

The significance of potassium intake being marginally less than AI in 2 dogs is also not known, not least since there are again no data regarding MR for this micronutrient (NRC 2006). The AI for potassium is based on previous studies where dogs were fed at this level for up to 6 weeks without any clinical signs of deficiency developing (Abbrecht, 1969 and 1972; Patterson et al 1983). Further, although hypokalaemia was noted when dogs were fed 0.06g per $kg^{0.75}$ per day,

420 no clinical signs were evident. It should be noted that the average intakes of the two dogs who
421 did not meet the AI for potassium were only marginally low, being 0.13g per $kg^{0.75}$ per day in
422 both cases. Neither dog had signs of potassium deficiency during or after the trial. Therefore,
423 these intakes are unlikely to be of clinical significance. In contrast to potassium, riboflavin
424 intake was less than MR in 10 dogs, all of which were in the extra small size groups. Chronic
425 deficiency of this micronutrient has been associated with weight loss, anorexia, weakness, as
426 well as skin and ocular lesions (NRC 2006). None of these signs were evident in any of these
427 dogs. The NRC 2006 reported the MR requirement of riboflavin to be 0.138 mg per $kg^{0.75}$ per
428 day, although this was an extrapolation from a study in beagle dogs where a diet with 1.05 mg of
429 riboflavin per 1000 kcal was sufficient (Cline et al., 1996). It is not known whether requirements
430 in this breed are similar to other breeds of dog, including extra small dogs. Further, studies from
431 many years ago have suggested intakes of under half that amount might be sufficient (Street and
432 Cowgill 1939, Street et al 1941). Therefore, once again the exact requirement for this
433 micronutrient is unknown, and further studies are required.
434
435 A second limitation was the fact that assessments of behaviour were made subjectively, most
436 notably the changes in food-seeking behaviour and QOL, where scales were used that had not
437 previously been validated. Ideally, we should have included negative controls (e.g. overweight
438 dogs and cats whose diet was changed but who were fed at maintenance energy requirements
439 rather than for weight reduction) to ensure that changes were due to weight loss rather than
440 simply due to dietary change. It would also have been advantageous to include 'positive'
441 controls (e.g. overweight animals where a therapeutic weight loss diet was used), since this
442 would have enabled us to determine efficacy relative to the conventional approach for weight

443 reduction. Third, feeding of extra food (e.g. table scraps and treats) and exercise was not
444 formally recorded in the study. This might have explained the variable response amongst
445 different study animals. It might also be the reason why some of 6 dogs gained weight during
446 the study, which mainly occurred between visits 1 and 2. Issues with poor compliance (such as
447 feeding extra food and maintaining increased activity) are more common later on in the weight
448 loss process, which is when more owners choose to stop (German, 2016). Fourth, the length of
449 the study was short, lasting only 8 weeks. Although weight loss occurred during this time, we
450 cannot be certain that this would have continued over a longer period, and nor can we be sure
451 that essential nutrient deficiencies would be avoided. Therefore, such a strategy can only be
452 advised for a short-term weight loss.
453
454 A fifth limitation was the fact that post weight reduction maintenance was not tested. Many
455 weight reduction programmes are successful in the short term, but long-term compliance is a
456 challenge (German et al., 2012b; Deagle et al., 2014). Weight regain after dieting is common in
457 human weight loss studies with most regaining weight and some regaining more weight than was
458 originally lost (Mann et al., 2007). Weight regain has also been shown in controlled weight-
459 reduction studies in dogs and cats (German et al., 2012b; Deagle et al., 2014). Continuing to
460 feed the same diet (e.g. one designed for weight reduction), is associated with decreased odds of
461 regain (German et al., 2012b). However, it is unclear how successful the diets used in this study
462 would be for post-weight-loss maintenance. A final limitation was the fact that we only used the
463 NRC 2006 report to judge nutritional adequacy, rather than also comparing against other
464 guidelines such as FEDIAF or AAFCO, which were updated more recently. Different
465 conclusions might well have been reached had different guidelines been used. The reason for not

doing including FEDIAF and AAFCO was that it would have made it difficult to report results succinctly, and any discussion would then have become overly complicated. For example, we might well have encountered inconsistencies amongst the guidelines as to whether a particular nutrient was adequate in the diet. Not only would it be necessary to discuss the implications of a potential deficiency, but also the reasons for differences amongst the guidelines themselves. Such an academic discussion might be of interest to nutritionists and pet food formulators but, arguably, would be of less interest to practising veterinarians meaning that the key study findings were lost.

In summary, the current study has shown that 8 weeks of modest energy restriction when feeding low-energy maintenance diets (albeit only from one manufacturer) can induce weight loss in dogs and cats. Overall compliance with this strategy was good and no adverse effects were seen, although the borderline intake of some micronutrients of the smallest dogs on diet 1 warrants further consideration. Such an approach might be a simpler initial weight management approach for dogs and cats in overweight, rather than obese, body condition. Of course, if such dogs and cats fail to lose weight with such a protocol, switching to a purpose-formulated weight management diet would then be recommended. The latter remains the preferred options for dogs and cats in obese rather than overweight body condition, since more marked energy restriction for a far longer period is often necessary.

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Competing interests

The diets used in this study were produced by Royal Canin. Although AG is an employee of the University of Liverpool, his post is financially supported by Royal Canin. AG has also received financial remuneration for providing educational material, speaking at conferences, and consultancy work from this company; all such remuneration has been for projects unrelated to the work reported in this manuscript.

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Figure legends

Figure 1. Percentage weight loss at visit 1 (days 24-32) and visit 2 (days 48-64) in the 67 overweight dogs participating in the 8-week weight reduction study using a reduced-energy maintenance diet. Percentage weight loss for individual dogs are represented by the points, with dogs losing weight (visit weight less than start weight by at least 1%) shown in green, dogs gaining weight (visit weight greater than start weight by at least 1%) shown in red, and dogs with a stable weight (visit weight ±1% of their starting weight) shown in blue. The green column and error bars represent the median and interquartile range of percentage weight loss for the size group. (a) Extra small dogs fed canine diet 1; (b) small dog fed canine diet 2; (c) medium dogs fed canine diet 3; and (d) large dogs fed canine diet 4.

Figure 2. Percentage weight loss at visit 1 (days 24-32) and visit 2 (days 48-64) in the 17 cats participating in the 8-week weight reduction study overweight cats of weight loss using a reduced-energy maintenance diet. Percentage weight loss for individual cats are represented by the points, with cats losing weight (visit weight less than start weight by at least 1%) shown in green, cats gaining weight (visit weight greater than start weight by at least 1%) shown in red, and cats with a stable weight (visit weight ±1% of their starting weight) shown in blue. The green column and error bars represent the median and interquartile range of percentage weight loss for the size group.

Supplementary material

S1 dataset. Complete study dataset for dogs. Electronic spreadsheet containing study data for all dogs in the study.

S2 dataset. Complete study dataset for cats. Electronic spreadsheet containing study data for all cats in the study.