Original article

An open-label randomised clinical trial to compare the efficacy of dietary caloric restriction and physical activity for weight loss in overweight pet dogs

M. Chapman[a], G.R.T. Woods[a], C. Ladha[b], C. Westgarth[a,c], A.J. German[a,d,*]

[a] Institute of Veterinary Science, Faculty of Health and Life Sciences, University of Liverpool, Leahurst Campus, Chester High Road, Neston, Cheshire, CH64 7TE
[b] VetSens, 53 Wellburn Park, Jesmond, Newcastle-upon-Tyne, NE2 2JY
[c] Department of Epidemiology and Population Health, Institute of Infection and Global Health, Faculty of Health and Life Sciences, University of Liverpool, Leahurst Campus, Chester High Road, Neston, Cheshire, CH64 7TE
[d] Institute of Ageing and Chronic Disease, Faculty of Health and Life Sciences, University of Liverpool, Leahurst Campus, Chester High Road, Neston, Cheshire, CH64 7TE

* Corresponding author. Tel.: +44 151 795 6100
E-mail address: ajgerman@liverpool.ac.uk (A.J. German)

Abstract

Canine obesity is usually managed with a combination of dietary caloric restriction and increasing physical activity, but no previous study has compared both of these strategies in a prospective randomised controlled trial.

Thirteen overweight dogs (body condition score 6-9/9) were randomised to one of two interventions: dietary caloric restriction or physical activity. The dietary caloric restriction intervention comprised feeding a therapeutic weight loss diet, whilst the physical activity intervention comprised increasing the dog's current physical activity pattern by at least a third. The primary outcome measure was change in body weight, whilst secondary outcome measures included change in neck, thorax and abdominal circumference and change in physical activity measured by triaxial accelerometer.

Bodyweight decreased significantly with the dietary caloric restriction (median -10% of starting body weight [SBW], 5 to -12%; *P*=0.028) but not with the physical activity intervention (-2% SBW, +3% to -6%; *P*=0.107). Abdominal circumference (dietary caloric restriction: median -12.0%; physical activity: median -7.8%, *P*=0.016) and thoracic circumference (dietary caloric restriction: median -7.5%, *P*=0.031; physical activity: median -3.6%, *P*=0.031) changed significantly in both groups. There was no change in activity levels within the dietary caloric restriction group, but vigorous activity increased significantly in the physical activity group (*P*=0.016).

Dietary caloric restriction is more effective than physical activity for controlled weight loss in overweight pet dogs. Although advising owners to increase their dog's activity by a third leads to a modest increase in measured vigorous physical activity, this is insufficient to promote weight loss on its own.

Keywords: Accelerometer; Canine; Diet; Exercise; Obesity

Introduction

Obesity is one of the most common medical disorders of domestic dogs (German et al., 2010) and is a significant health and welfare concern by predisposing to other diseases (Lund et al., 2006; Courcier et al., 2010; German et al., 2010), shortening lifespan (Kealy et al., 2002), causing metabolic derangements (German et al., 2009, Tvarijonaviciute et al., 2012 & 2013) and functional impairment (Mosing et al., 2013; Tropf et al., 2017), and adversely affecting quality of life (German et al., 2012). Recent studies have indicated that this is a problem of global significance (McGreevy et al., 2005; Colliard et al., 2006; Lund et al., 2006; Courcier et al., 2010; Mao et al., 2013). Most concerningly, prevalence has increased dramatically in recent years[1],with many dogs now affected during their growth phase (German et al., 2018).

Obesity is managed with a combination of dietary caloric restriction, using a therapeutic diet, and increasing energy expenditure. Whilst there have been many studies reporting outcomes of such programmes, most studies have focused on the effect of caloric restriction (Blanchard et al., 2004; German et al., 2007a, 2007b, 2010b, 2012 & 2015; Flanagan et al., 2017), with few studies examining the effect of activity of the development and management of obesity in dogs. In one study, obese dogs were less physically active than healthy weight dogs and did not appear to increase their activity levels spontaneously with weight loss (Morrison et al., 2013). One study incorporated physical activity into a conventional canine weight loss programme using a treadmill, and rate of weight loss was reportedly increased as a result (Chauvet et al., 2011). In a more recent study that also used a treadmill, rate of weight loss was unchanged but there was better preservation of lean tissue mass (Vitger et al., 2016). In addition, compliance was challenging due to the need for 3-times-weekly treadmill sessions and the fact that many dogs appeared to be physically incapable of markedly increasing their physical activity level. To the

[1] See: https://www.banfield.com/state-of-pet-health/obesity. (accessed 17 July 2018).

authors' knowledge, the impact on weight loss of more practical methods of increasing physical activity have never been assessed, for example asking owners to increase the amount of their dog's usual activity (e.g. walking and play behaviour). Therefore, the primary aim of this study was to compare the efficacy of either dietary caloric restriction (using a therapeutic weight loss diet) or increased physical activity (e.g. increasing current activity by at least a third) for weight loss in overweight dogs.

Materials and methods

Trial design, site, dates, objectives, and ethical considerations

The study was an open-label randomised controlled trial, using a two-group parallel design, and the main objective was to compare the efficacy of dietary caloric restriction and increased physical activity for weight loss in dogs. The Consolidated Standards of Reporting Trials (CONSORT) statement guidelines[2] (S1 Checklist) were followed to ensure open and honest reporting of the study. The trial was conducted at the University of Liverpool, Small Animal Teaching Hospital (SATH). The recruitment phase for the study was between September 2016 and December 2016, and the study itself was conducted between January 2017 and March 2017.

The trial complied with the University of Liverpool Guidelines on Animal Welfare and Experimentation, and was approved by the University of Liverpool Research Ethics Committee (VREC474). Prior to enrolment, the nature of the study was explained to both owners and their primary care veterinarians (see below), and both gave their informed consent in writing to enable the dog to participate. At the end of the trial, all owners were asked to complete a trial feedback form to ensure that they were happy with trial conduct. As far as possible (for a trial in a

[2] See: http://www.consort-statement.org/media/default/downloads/consort%202010%20checklist.pdf. (accessed 17 July 2018).

veterinary species), the studied complied with the principles of Good Clinical Practice[3]. No financial incentive (e.g. monetary payment) was given to any of the owners for participating in the study. However, as a reasonable reimbursement for their time and expense of participating (e.g. travel costs to and from the SATH), the costs of all clinical assessments, weight management support and interventions themselves (e.g. therapeutic weight loss diet, modified feeding bowl, toys) were waived.

Roles and responsibilities

Two investigators (GW and AG) were responsible for liaising with the owners, performing all clinical examinations and weight assessments, implementing the interventions, and follow up. The respective primary care veterinarian was informed of case progress by letter. Two further investigators (MC, CW) were responsible for the activity measurements, and also monitoring the wellbeing of all participants during the study visits. The final investigator (CL) was responsible for technical support and data analysis for the activity monitors.

Eligibility criteria

Dogs were eligible for the study if both the owner and primary care veterinarian consented to their involvement, they were overweight (i.e. body condition score [BCS] 6-9/9), and if they had a good temperament (i.e. easy to handle, not nervous or fearful, and not aggressive to other dogs or people). Further, dogs could not have any pre-existing medical problem that would make it clinically inappropriate to undergo controlled weight loss (e.g. significant systemic disease such as chronic kidney disease, cardiac disease, liver disease, metastatic neoplasia etc), inappropriate to change their food (e.g. on a therapeutic diet for a pre-existing medical disease or

[3] See: http://www.ich.org/products/guidelines/efficacy/efficacy-single/article/integrated-addendum-good-clinical-practice.html. (accessed 17 July 2018).

have known dietary intolerances), or alter their level of physical activity (e.g. pre-existing cardiac or severe orthopaedic disease). Finally, dogs were not eligible if they were already on a weight loss regimen or had undertaken a weight loss regimen in the last 6-months prior to the study.

Recruitment process and veterinary pre-screening

The study was featured on a British Broadcasting Corporation (BBC) television documentary series entitled "Trust Me, I'm a Vet", and was advertised with a combination of social media, radio advertisements and leaflets sent to local veterinary practices. Before deciding to participate, interested owners were sent an information sheet and discussed the study with their primary care veterinarian. The veterinarian then conducted a pre-trial assessment to confirm eligibility, by reviewing clinical history and performing a physical examination. In addition, the veterinarian measured bodyweight, assessed body condition using a 9-point system BCS system comprising a set of five size-specific BCS charts, for small, medium, large, and giant breeds, respectively (Flanagan et al., 2017). The system was adapted from the system originally described (Laflamme, 1997) and validated against body fat mass measured by dual-energy X-ray absorptiometry (Flanagan et al., 2017). In addition, the temperament of each dog was assessed to ensure that it would be suitable for participation (e.g. neither aggressive nor nervous meaning that participation would be stressful). If the dog was deemed to be eligible, the dog was formally referred to the SATH for inclusion in the study.

When the official referral request was received, one investigator (GW) reviewed the paperwork to confirm study eligibility and contacted the owners by telephone. Details of the study were again discussed in detail, and, provided that owners confirmed that they were happy to participate, a study pack was sent to them by post. This pack contained a second copy of the information sheet, a consent form, a questionnaire to obtain information about diet and activity, a 3-day food diary, and an activity monitor along with collar and written instructions on its use (see below). Owners completed the questionnaire and sent it back to the study researcher before the enrolment visit, and also ensured that their dog wore the accelerometer for at least 7 days.

Enrolment visit

All owners and dogs attended an enrolment visit at the SATH during the same 2-day period in January 2017. During this visit, each dog had a 30-minute individual consultation with two of the study investigators, one of whom was an EBVS® European Veterinary Specialist in Small Internal Medicine (AG), and the other (GW) was a Royal College of Veterinary Surgeons Registered Veterinary Nurse (RVN). After checking the paperwork and confirming that the owners had read the information leaflet, owners signed the consent form. The medical history and pre-study questionnaire were reviewed, and a full physical examination was performed. Measurements taken included body weight, BCS, circumferential measurements, and physical activity using activity monitors (see below). Once these screening procedures had been performed the treatment arm was revealed to the owner and their individualised plan was described in detail (see below).

Interventions

Dogs received one of two interventions, dietary caloric restriction or physical activity. The dietary caloric restriction intervention comprised feeding a high protein high fibre purpose-formulated weight loss diet (Satiety Support, Royal Canin; Table 1), for the duration of the study period. The initial food allocation for weight loss was based upon an estimate of maintenance energy requirement (MER = 440 [kJ] × body weight $[kg]^{0.75}$/day) using the ideal weight of the dog, as determined by current body condition score (German et al., 2015). The degree of restriction for each dog was then individualised based upon sex, neuter status and, if necessary, other factors that might influence MER (i.e. presence of associated diseases such as orthopaedic disease). The starting energy allocation was typically between 50-60% of MER at ideal weight. Owners were instructed to measure out food portions using electronic weigh scales, and to feed this in divided meals, using a provided modified feeding bowl (Slow Down Dog Bowl, Royal Canin). They were also asked to avoid feeding any additional foodstuffs (e.g. table scraps or treats) and not to change the dog's current physical activity plan.

The physical activity intervention comprised increasing the dog's current physical activity pattern and was tailored to the capabilities of both the dog and the owner, with the intention that the total weekly amount of physical be increased by at least a third. During the enrolment visit, detailed information on the current physical activity undertaken by the dog was collected, and tailored suggestions were given on increasing this activity through discussion with the owner. This could involve increasing the frequency or duration (or both) of physical activity sessions that the dog was currently undertaking. For example, an owner who was walking their dog once daily for 30 min could be asked to walk their dog for 40 min, whilst an owner who exercised their dogs three times a week could be asked to exercise them for four times per week. These suggestions provided a guide to the minimum desired increase in activity for each dog, but owners could increase activity levels beyond this if time allowed and if their dog could cope. In addition, owners were provided with a toy (Kong® Squeezz stick, Kong Company Ltd.) and encouraged to implement regular play sessions, with the number and frequency again determined by what the owner and dog could manage. Besides the changes to physical activity, owners were instructed not to alter any other aspect of their dog's lifestyle most notably their food and meal pattern.

Measurements

Measurements taken at both the enrolment and final visits included bodyweight, BCS, and circumferential measurements. For bodyweight measurements, dogs were weighed on a single set of electronic scales (Veterinary Scale, Soehnle Professional), which were regularly calibrated to verify precision and accuracy using certified test weights (Blake and Boughton Ltd). The 9-point BCS system was used for body condition by two experienced investigators (AG, GW). Initially, after each investigator had first independently assessed the dog, a final score was agreed by discussion and consensus. One investigator (GW) took three circumferential measurements at the enrolment and final visits using a fabric tape measure with measurements recorded in cm. The measurements taken were mid-neck (mid-point of the neck, approximately half way between occiput and cranial edge of the scapula), thorax (immediately caudal to the thoracic limb) and abdomen (immediately cranial to the pelvic limb). Other measurements, for example muscle condition scoring or measurement of thigh circumference, were not performed due to time constraints.

Physical activity was monitored for a period of seven consecutive days before the study commenced and for 7 days during the final two weeks of the study using a triaxial accelerometer and ActivityScope analysis software (VetSens®) which had previously been validated in dogs (Westgarth and Ladha, 2017). Before the enrolment visit, owners were sent the accelerometer by post, along with a fabric collar[4], modified with an elastic and Velcro pouch to secure the accelerometer snugly, and instructions on its use. Owners fitted the collar around the dog's neck,

[4] See: https://www.dog-games-shop.co.uk/20mm-top-piece.html. (accessed 17 July 2018)

and then left it in place for the 7-day period. Owners were instructed to keep the collar on except for bathing or swimming activities. They also completed a diary where particular events and times could be recorded, for instance if the collar had been removed.

After each 7-day period, data were downloaded from the accelerometers, and ActivityScope software was used to translate the raw actigraphy into VM3 (vector magnitude) counts, in order to filter out movement originating from mechanical sources such as vehicles (Westgarth and Ladha, 2017). The time spent in states of light, moderate and vigorous activity was calculated using a threshold approach (Table 2) as previously reported (Yam et al., 2011, Morrison et al., 2013), and percentages were derived from the time spent in each state for the whole 7-day period. The VetSens system automatically calculates non-wear periods, enabling these to be excluded from calculations. Percentage rather than absolute values were compared both within and between groups on account of the fact that the wear time for each 7-day period varied between dogs.

Owner support and study monitoring

Owners maintained a diary in which they recorded feeding of the purpose-formulated diet (amount offered and consumed), and any additional food that had been consumed (either given as treats or stolen). These records were used subjectively to determine compliance with the allocated intervention (see below). One study investigator (GW) contacted all owners every 2 weeks to monitor progress but, in addition, owners could contact the study investigators directly by telephone at any stage if they needed urgent guidance. For dogs on the physical activity intervention, compliance was discussed and encouragement was provided as required. As far as possible, further encouragement was given to attempt to increase activity further, again dependent on the capabilities of the individual dog. For the dietary caloric restriction intervention, counselling was provided regarding maintaining compliance with the food allocation, measuring food out, avoiding the feeding of additional foodstuffs, and strategies to mitigate any food-seeking behaviour that manifested during the trial.

Final visit and support after the trial

Dogs and their owners returned to the SATH 8 weeks later for a follow-up visit, with assessments for all dogs conducted over two consecutive days in March 2017. Each was re-examined by the same two study investigators (AG, GW). The diary record was reviewed, and the same measurements taken as for the enrolment visit (bodyweight, BCS, circumferential measurements).

After the trial was completed, all owners were given either a complimentary toy (Kong® Squeezz stick, caloric restriction intervention) or modified feeding bowl (Slow Down Dog Bowl, Royal Canin; physical activity intervention), and given further guidance on its use. In addition, all owners offered follow-up weight management support for their dog at SATH, and the opportunity to implement a long-term weight loss plan involving both dietary caloric restriction and increased activity. In total, the owners of six dogs chose to pursue this, comprising two dogs originally on the dietary caloric restriction intervention and four dogs originally on the physical activity intervention.

Compliance with intervention

The diary records of owners were reviewed to determine compliance with the allocated intervention. Given that only limited handwritten text notes were available, only a subjective assessment was possible. For the dietary caloric restriction group, compliance with the therapeutic diet (amount and meal frequency), the recommendation to maintain the same physical activity level, and the consumption of additional food (either offered or stolen) were considered. For the physical activity group, compliance with the recommended increase in physical activity, and with the recommendation to maintain the same feeding pattern were considered.

Patient welfare, adverse events and early trial discontinuation

Throughout the study, all efforts were made to safeguard the welfare of the dogs enrolled. For both the enrolment and final visits, two RCVS-registered veterinary nurses, one animal behaviourist, and one veterinary student were on hand to supervise and monitor all dogs. During the 8-week intervention period, owners observed the wellbeing of their dogs and alerted the investigators if they were concerned. One study investigator (GW) was responsible for recording the details of any welfare issues, protocol deviations, suspected adverse events, and development of concurrent medical problems. If any adverse event was thought to be related to either intervention, participation in the study was to be suspended immediately. If it was thought to be unlikely that an adverse event was related to the intervention, the dog was allowed to continue with the trial, provided that the owners agreed. Participation could also be suspended if an enrolled dog developed an unrelated condition whilst enrolled in the trial. Finally, owners were free to withdraw their dog at any stage, without needing to give a reason.

Randomisation procedure and allocation concealment

The *a priori* power calculation (see below) suggested that six dogs per group would be sufficient to demonstrate a clinical difference between interventions and, as a result, we aimed to recruit at least 12 and up to 24 dogs during the recruitment phase. Prior to recruitment, one investigator (AG) used the random number generator of a computer statistics programme (Stats Direct version 2.6.2, Stats Direct Ltd.) to create a random sequence of 24 treatments, with 12 labelled A and 12 labelled B. Given that it was unclear how many eligible dogs would ultimately be available, a block size of 2 was used (i.e. each sequential block of two treatments contained either an A or a B in random order). Therefore, the number of dogs assigned to each treatment arm always remain closely balanced throughout the list. Once created, the list was placed in a sealed envelope and not examined again until after recruitment was completed. A second study investigator without knowledge of the treatment allocation (GW) assigned the study numbers to the dogs as recruitment proceeded. Study numbers were assigned in strict chronological order according to the date that their referral request was received. After all referral requests for any eligible dogs had been received and the recruitment phase was closed, but before the treatment allocation list was revealed, the second study investigator decided at random which treatment (diet or physical activity) would be assigned to which treatment label (A or B). Only then, did the first study investigator open the sealed envelope to reveal the final treatment allocation for each dog. Once the treatment (diet or physical activity) was known, no attempt was made to blind the study investigators because the treatments were distinct and needed to be tailored to the individual.

Outcome measures

The primary outcome measure was change in body weight 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 change in neck, thorax and abdominal circumference and change in physical activity, all of which were again expressed as a percentage of the starting measurement. All of these outcome measures were decided prior to commencement of the trial.

Sample size

During the design phase of the study, one investigator (AG) performed a sample size calculation using a statistical software package (Stats Direct version 2.6.2). The primary outcome measure (percentage change in body weight) was used. The expected effect size (mean ± standard deviation) for the dietary caloric restriction was 8.7 ±4.85%, which was based upon the percentage weight lost over 8 weeks in a recent study using the same therapeutic diet (Flanagan et al., 2017). Given that a recent study incorporating physical activity using a treadmill did not reveal a significant additional effect over dietary caloric restriction (Vitger et al., 2016), the expected effect size was assumed to be equivalent to that of placebo as seen in previous experimental weight loss studies, e.g. 2.6% body weight over an 8-week period (Gossellin et al., 2007). A 1:1 test:control recruitment rate was used and calculations assumed that a power of 80% was required to identify this difference with a two-sided P of <0.05. Based upon these criteria, it was determined that six animals per group would be needed. In order to take account of possible study drop-outs, the investigators attempted to recruit at least 12 and up to 24 dogs within the short recruitment window.

Data handling and statistical analysis

Data were entered into an electronic spreadsheet (Microsoft Excel® for Mac version 16.19) and checked for errors, and this dataset is available as supporting information (S1 dataset). Two computer statistical packages were used for data analysis: StatsDirect version 2.6.2 and SPSS version 23.0 (IBM Corporation). The level of statistical significance was set at $P<0.05$

for 2-sided analyses. Standard descriptive statistics were used to report continuous (age, bodyweight, circumferential measurements, percentage change in weight and circumference) 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). Given the small group sizes, non-parametric tests were used throughout. Data comparisons were made with Fisher's exact test (for proportions), and either the Wilcoxon signed rans test or the Mann-Whitney test (for continuous and ordinal variables). The Mann-Whitney test was used to compare absolute continuous data at baseline between groups (e.g. age, starting bodyweight, duration of physical activity before weight loss; Table 3), whilst Fisher's exact test was used to compare differences in sex and the Cochrane-Armitage trend test used for BCS. The Mann-Whitney test was used to compare percentage changes in weight loss outcomes (e.g. body weight, bodyweight, circumference and physical activity) between groups, and the Cochrane-Armitage trend test was used for changes in BCS again between groups. For within-group comparisons (pre- vs. post-weight loss), a Chi square test for trend was used to assess changes in BCS, whilst Wilcoxon signed ranks tests were used to compare changes (pre- and post-weight-loss) in bodyweight, circumferential measurements, and physical activity. Outcome data were analysed on an intention to treat basis. Full datasets were available for all dogs, with the exception one dog where pre- and post-weight-loss zoometric data were missing (due to time pressures) and post-weight-loss physical activity data were not available (because the owner did not return the accelerometer after the second period of activity monitoring). In order to account for missing data in the intention to treat analysis, imputation was performed using the method of multivariate normal imputation (Lee and Carlin, 2010).

Protocol changes

Two protocol changes were made to study protocol during the enrolment visit due to unexpected findings at this stage. During the enrolment visit, it was discovered that one dog assigned to physical activity intervention was already on a weight loss regimen using a therapeutic weight loss diet, and one dog in the dietary caloric restriction group was fed a dry hydrolysed diet (Hypoallergenic Diet dry, Royal Canin), implying the presence of an adverse reaction to food. These details had not been reported by the referring veterinarians or owners before during the recruitment phase. These dogs had already been allocated to an intervention arm and, therefore, were allowed to remain within the trial (according to the intention-to-treat principle). In addition, the owner of dog already on the therapeutic weight loss diet was instructed to continue feeding the current daily food allocation.

A second dog in the physical activity arm had significant osteoarthritis, which again had not been reported by the primary care veterinarian or owner during the recruitment phase. Although the dog was physically active and receiving regular daily walks, increasing this further was not thought to be clinically appropriate. Instead, this dog received weekly 60-minute hydrotherapy sessions using an underwater treadmill, supervised by a trained veterinary physiotherapist. This dog also continued in the study and data was included in analyses.

Results

Dogs

Owners of 14 dogs expressed an interest in participating, 13 of which met the eligibility criteria and proceeded to the enrolment phase. These 13 dogs were then randomly allocated to the two treatment arms, with six dogs assigned to the dietary caloric restriction group and seven assigned to the physical activity intervention (Table 3). Before the trial, all dogs were fed adult maintenance diets, except for one dog in the dietary caloric restriction group that was fed a dry hydrolysed diet (Hypoallergenic Diet dry, Royal Canin), and one dog in the physical activity group that was fed a was fed a dry therapeutic weight loss diet (Satiety Diet dry, Royal Canin). Owners also reported feeding a range of dog treats and table scraps on a regular basis. There were no significant differences between groups for any of the baseline variables (Table 3). All dogs finished the trial and complete datasets were available for all parameters, with the exception of activity data post-intervention for one dog as discussed below.

Adverse effects and withdrawals

No significant adverse effects were reported, and no withdrawals occurred in any dogs during the study. However, one dog in the diet group sustained a leg injury and which required rest for 6 weeks. Despite this, it was possible to continue with the intervention as planned, and the physical activity recorded post-intervention was included in the analysis.

Compliance with intervention

Diary records were available for ten of the dogs, comprising five of six and five of seven from the dietary caloric restriction and physical activity groups, respectively. In the dietary caloric restriction group, records indicated that all owners had fed the correct amount of the therapeutic diet, whilst a review of activity suggested a similar amount to what had been undertaken previously. However, against recommendations, all dogs received additional food, usually given as treats but occasionally stolen. Items fed included additional therapeutic diet, other dog food, meat (e.g. chicken, pate), yogurt, fruit (e.g. watermelon, orange, strawberry, pear), vegetables (e.g. courgette, carrot), rawhide chews and chocolate. Given the limited information written, it was not possible to estimate the energy intake from this food. In the physical activity group, the written notes suggested good compliance with the recommendations in all dogs, consistent with an activity increase of at least a third compared with baseline, and no change in food intake.

Bodyweight and body condition

Bodyweight and BCS data from before and after weight loss are shown in Table 4. The bodyweight of dogs in the dietary caloric restriction group changed by a median of -10% from starting baseline (range -5 to -12%, P=0.031), but bodyweight in the physical activity group did not (median change -2% SBW, range +3% to -6%; P=0.109). Therefore, weight loss was significantly greater with dietary caloric restriction than with physical activity (P=0.014). There was a significant decrease in BCS in the dietary caloric restriction group (P=0.043), with the BCS decreasing by one category in four of the dogs and by two categories in the remaining two dogs. In contrast, BCS did not change in 6 dogs in the physical activity group, and decreased by one category in the remaining dog, with no significant change in the group as a whole (P=0.798). As a result, the decrease in body condition was significantly greater with dietary caloric restriction than with physical activity (P=0.003).

Neck, thoracic and abdominal circumference

Zoometric measurements taken from dogs from before and after weight loss are shown in Table 4. Abdominal circumference (dietary caloric restriction: median -12.0%, range -5.0 to -17.4, P=0.031; physical activity: median -7.8%, range -6.2 to -13.0, P=0.016) and thoracic circumference (dietary caloric restriction: median -7.5%, range -5.5 to -18.2, P=0.031; physical activity: median -3.6%, range 0.0 to -12.0, P=0.031) changed significantly in both groups. For thoracic circumference, the magnitude of change was greater for the diet intervention group than for the physical activity group (P=0.027), but there was no difference between interventions for the change in abdominal circumference (P=0.430). Further, there was no change in neck circumference in either group (dietary caloric restriction: median -4.5%, range 4.0 to -6.9, P=0.125; physical activity: median -4.1%, range 0.0 to -13.3, P=0.062), and no difference in the magnitude of change between groups (P=1.000).

Physical activity

Physical activity was monitored during the trial using triaxial accelerometer (Table 5), and an example of the activity data for the trial for one dog in the physical activity group is shown in Figure 1. There was some difference amongst dogs in the time the accelerometers were worn, although there were no differences between groups or time periods (Table 5). There was no difference in the percentage time spent in sedentary (P=0.943), light-moderate (P=1.000), and vigorous (P=0.720) physical activity between groups before weight loss. There was no change in activity levels within the dietary caloric restriction group, pre- and post-trial (sedentary: P=1.000; light-moderate: P=0.562; vigorous: P=0.312). There was also no change in sedentary (P=0.469) or light-moderate (P=1.000) activity in the physical activity group, but vigorous activity increased significantly (P=0.016). However, there were no differences between groups for the change in activity within each category (sedentary P=0.617; light-moderate, P=0.721; vigorous P=0.054).

Discussion

This is the first randomised controlled trial to compare dietary caloric restriction and physical activity as interventions for controlled weight loss in dogs. Although the study size was small, a difference between interventions was evident. All dogs in the dietary caloric restriction group lost weight, with the median percentage weight loss over being consistent with rates of weight loss seen in previous studies (German et al., 2007 & 2010; Vitger et al., 2016; Flanagan et al., 2017). In contrast, although six of seven dogs in the physical activity group did lose some weight, the amount lost was relatively modest (i.e. up to 6%) and not statistically significant. These results are consistent with human studies where clinically significant weight loss is unlikely unless there is a high level of aerobic exercise training (reviewed by Swift et al., 2014). For example, in the Studies of a Targeted Risk Reduction Intervention through Defined Exercise (STRRIDE) study, average weight loss was only minimal when exercising at low-amount / moderate-intensity (~0.6 kg weight loss with ~176 min activity per week) or at low-amount / high-intensity (~0.2 kg weight loss with ~117 min activity per week), whilst even high-amount / high intensity activity (171 min per week) only led to modest (~1.5 kg) weight loss (Kraus et al 2002). They are also consistent with other weight loss studies in dogs whereby exercise did not increase rate of weight loss (Vitger et al., 2016). Of course, whilst physical activity might not be suitable as a sole weight loss strategy, it arguably conveys other benefits that are desirable as part of a weight loss regimen (Vitger et al. 2016). In a recent 12-week study, adding physical activity to a canine weight loss regimen helped to minimise loss of lean tissue mass (Vitger et al., 2016). It could be argued that the reason there was no significant change in bodyweight in the current study was that loss of adipose tissue in the physical activity group was offset by an increase in muscle mass. Although plausible, it is unclear as to whether the strategy for increasing physical activity we used (which relied on owners increasing their dog's activity by at least a third) is equivalent to the 3-times-weekly treadmill activity that the dogs of the previous study received. For example, although an underwater treadmill was used in one dog in the physical activity group, it was only used once weekly. Measurements of body composition, for instance using dual-energy X-ray absorptiometry (German et al., 2007, Vitger et al., 2016), would have been required to determine whether lean tissue mass was maintained but, unfortunately, this was not performed.

Thoracic and abdominal circumferential measurements decreased in dogs on both interventions. These zoometric changes are likely to be the result of loss of adipose tissue, suggesting that body shape changed significantly even despite the short study duration. The reason why thoracic and abdominal girth decreased, but neck circumference did not, is not known, but might be due to differences in the relative change of visceral versus subcutaneous fat. Most visceral fat is present within the abdomen whilst subcutaneous fat is distributed more widely (Merlotti et al., 2017), and human weight loss studies have shown that the percentage decrease in visceral fat is greater than the percentage decrease in subcutaneous fat (Merlotti et al., 2017). Nonetheless, given that the study was short, it is unclear what might have happened in the longer term, and whether or not other changes would have been seen. Alternatively, the differences might have been caused by the known variability in zoometric measurements, since this technique lacks precision even when conducted by the same person (German, 2016). Whilst such variability would again not necessarily be expected to affect such measurements systematically, we must accept that the study was unblinded and we cannot discount the effect of unconscious bias.

Changes in physical activity were measured as another secondary outcome variable. Given the logistic challenges involved in posting out and receiving accelerometers, it was only possible to compare two 7-day periods of activity, one before and one at the end of the weight loss period. There was no significant change in physical activity in dogs on the dietary caloric restriction intervention but vigorous physical activity increased significantly in the physical activity group. Although this suggests that owners in both groups were compliant with the instructions given over physical activity (e.g. increasing exercise in the physical activity group, but not in the diet group), the magnitude of increase seen in the physical activity group was less than would be expected from the recommendation made (e.g. to increase activity by at least a third). In this respect, the typical time that the devices were worn over the course of the week was 9998 min, and a 0.6% increase equates to ~8 min additional vigorous activity per day, or 56 min per week. It is unclear as to the amount of vigorous physical activity necessary for health benefits in dogs (Wakshlag et al., 2012), but World Health Organization guidelines recommend that adult people should have at least 75 min of vigorous physical activity per week[5]. Irrespective of whether the increase was sufficient for a health benefit, it may well have been that maximum increase that was feasible for the dogs and their owners. Indeed, previous work has suggested that it can be challenging for both owner and dog to introduce meaningful amounts of physical activity into the daily routine of an obese dog. In a previous weight loss study involving 3-times-weekly treadmill sessions, dogs were often reluctant or unable to work energetically and, therefore, activity rarely exceeded a light-to-moderate intensity (Vitger et al., 2016). Additional work is required to explore the best forms of physical activity for obese dogs in order to maximise the benefits during a weight loss regimen.

On a related note, a limitation of the study was that the recommendation to owners regarding increasing physical activity was not based on previous scientific publications, for example, those confirming that such a change in activity would be enough to lead to significant weight loss. To the authors' knowledge, studies examining this have not been conducted in dogs. It is possible that significant weight loss could have been achieved had owners been advised to increase physical activity even more and, therefore, it could be argued that the current study actually compared dietary caloric restriction with placebo, rather than physical activity. The

[5] See: http://www.who.int/dietphysicalactivity/factsheet_adults/en/. (accessed July 2018)

recommendation made (i.e. increasing physical activity by at least a third) was based upon what we believed would be feasible for the majority of owners, having made similar recommendations on weight management to clients in the past. A review of diary records suggested that most owners complied with this recommendation, although the increase in physical activity measured by accelerometer was less marked. This suggests that it can be difficult for owners to increase the physical activity of their dog even modestly, implying this is unlikely to be a suitable strategy for managing overweight client-owned dogs.

There are a number of other limitations for this study that should be considered when interpreting findings. First, sample size was small and the group of dogs studied was heterogeneous. Therefore, although designed to be adequately-powered for the primary outcome measure (percentage weight loss), we cannot be certain that it was adequately-powered for secondary outcome measures such as zoometric measurements and physical activity. This was compounded by the fact that we analysed data on an intention-to-treat basis, not least given that the original study protocol was modified twice on account of unexpected findings at enrolment. For example, eligibility criteria were not met for three dogs, one in the dietary caloric restriction group that was fed a hydrolysed diet before the study, and two in the physical activity group, one of which was already on a therapeutic weight loss diet, and the other that had pre-existing osteoarthritis. These might feasibly have affected the response to each intervention although, to an extent the effects might have counteracted one another. In this regard, greater weight loss might be expected in the dog in the physical activity group that was already being fed a weight loss diet; in contrast, it is possible that the efficacy of this intervention might be less for the dog with pre-existing osteoarthritis. An alternative approach would have been to consider analysing data on a ‘per protocol’ basis, whereby only dogs that complied with the intervention were included. However, this approach is not recommended because it can introduce bias and invalidate the randomisation process (Moher et al., 2010). These protocol deviations, whilst unfortunate, are commonly-encountered when conducting trials in a clinical setting. Nonetheless, the authors recommend further studies to explore physical activity effects during weight loss, and the results of the current study could be used as a basis for a sample size estimation.

Second, unintended bias could have resulted from differences in owner compliance between interventions. As discussed above, owners might have struggled to increase physical activity by the expected amount whilst, conversely, owners used to feeding treats to their dog might have struggled to comply with dietary recommendations. Although not all owners completed the diary, the available records indicated relatively good compliance with both interventions, with the main exception being feeding extra food in the dietary caloric restriction intervention. Nonetheless, since these were based on self-reporting, these results should be interpreted with caution, not least since under-reporting is known to be a problem in human nutrition studies (Heitmann et al., 2000). In the current study, inaccurate self-reporting is suggested by the fact that the magnitude of increase in physical activity was less than expected based on the accelerometer data. Therefore, the extent to which poor compliance influenced the current results is not known. Third, the study was only 8 weeks in duration, which is shorter than most previous weight loss studies in dogs. Thus, the true effect of the interventions might have been under-estimated. As a result, it would be sensible to consider repeating the study in a larger population of dogs and following them for a longer period. Finally, the study was open-label with no attempt made to mask the treatments from either owners or study investigators. The decision not to mask the treatments was partly because they were completely different from each other, and also that each required a degree of tailoring to the individual unique to that intervention. With the dietary caloric restriction intervention, daily food portion recommended for weight loss was calculated based upon patient factors such as sex, neuter status and estimated ideal weight; for the physical activity intervention, the recommended increase was based on the existing exercise pattern, any concurrent medical diseases, and the lifestyle of owner to ensure the changes were feasible. For similar reasons, it was also not possible to mask the owner from these interventions. Nonetheless, this is a study limitation and, as a consequence, we can be certain that the results were affected by bias, for example if either study investigators or owners had pre-conceived ideas as to which intervention would be more effective.

In conclusion, the results of the current study confirm that dietary caloric restriction is more effective than physical activity for controlled weight loss in overweight pet dogs. A recommendation to owners to increase the activity of their dog by a third resulted in a modest increase in vigorous physical activity, but this was insufficient to promote weight loss. Further studies should consider health benefits of physical activity in overweight dogs beyond weight loss in overweight dogs.

Acknowledgements

The trial was televised by the BBC and broadcast in May 2017 on BBC2 as part of the "Trust Me I'm A Vet" series. The authors would like to acknowledge the staff of Small Animal Teaching Hospital, University of Liverpool for support provided during the study. AG's academic post at the University of Liverpool is financially supported by Royal Canin.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. However, the food used for the dietary caloric restriction group, as well as all modified feeding bowls and toys were provided by Royal Canin.

Competing interests

The diets used in this study was produced by Royal Canin. AG and GW are employees of the University of Liverpool, but their posts are 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. CL is an employee of VetSens, who supplied the triaxial accelerometers for measuring physical activity during the trial. Neither Royal Canin nor VetSens were involved in study design, data analysis, interpretation of results, drafting of the manuscript or the decision to submit the work for publication.

References

Blanchard, G., Nguyen, P., Gayet, C., Leriche, I., Siliart, B., Paragon, B.M., 2004. Rapid weight loss with a high-protein low energy diet allows the recovery of ideal body composition and insulin sensitivity in obese dogs. Journal of Nutrition 134, 2148S-2150S

Chauvet, A., Laclair, J., Elliott, D.A., German, A.J., 2011. Exercise and Active Client Motivation Improve Rate of Weight Loss in Obese Dogs. Canadian Veterinary Journal, 52, 491-496.

Colliard, L., Ancel, J., Benet, J.J., Paragon, B.M., Blanchard, G., 2006. Risk factors for obesity in dogs in France. Journal of Nutrition 36, 1951S-1954S.

Courcier, E.C., Thompson, R.M., Mellor, D.J., Yam, P.S., 2010. An epidemiological study of environmental factors associated with canine obesity. Journal of Small Animal Practice 51, 362-367.

Flanagan, J., Bissot, T., Hours, M.A., Moreno, B., Feugier, A., German, A.J., 2017. Success of a weight loss plan for overweight dogs: the results of an international weight loss study. PLOS ONE, 12(9). Doi:10.1371/journal.pone.0184199

German, A.J., Holden, S.L., Bissot, T., Hackett, R.M., Biourge V., 2007. Dietary Energy Restriction and Successful Weight Loss in Obese Client-Owned Dogs. Journal of Veterinary Internal Medicine 21, 1174-1180.

German, A.J., Hervera, M., Hunter, L., Holden, S.L., Morris, P.J., Biourge, V., Trayhurn, P., 2009. Insulin resistance and reduction in plasma inflammatory adipokines after weight loss in obese dogs. Domestic Animal Endocrinology 37, 214-226.

German, A.J., Ryan. V.H., German, A.C., Wood, I.S., Trayhurn, P., 2010. Obesity, its associated disorders and the role of inflammatory adipokines in companion animals. The Veterinary Journal 185, 4-9.

German, A. J., Holden, S. L., Bissot, T., Morris, P. J., Biourge, V., 2010. A high protein high fibre diet improves weight loss in obese dogs. Veterinary journal 183, 294-297.

German, A.J., Holden, S.L., Wiseman-Orr, M.L., Reid, J., Nolan, A.M., Biourge, V., Morris, P.J., Scott, E.M., 2012. Quality of life is reduced in obese dogs but improves after successful weight loss. The Veterinary Journal 192, 428-434.

German, A.J., Holden, S.L., Morris, P.J., Biourge, V., 2012. Long-term follow-up after weight management in obese dogs: The role of diet in preventing regain. The Veterinary Journal 192, 65-70.

German, A.J., Titcomb, J.M., Holden, S.L., Queau, Y., Morris, P.J., Biourge, V., 2015. Cohort study of the success of controlled weight loss programs for obese dogs. Journal of Veterinary Internal Medicine 29, 1547-1555

German, A.J., 2016. Inaccuracy when using tape measures for zoometry in dogs. Journal of Veterinary Internal Medicine 30, 394.

German, A.J., Woods, G.R.T., Holden, S.L., Brennan, L., Burke, C., 2018. Dangerous trends in pet obesity. Veterinary Record 182, 25.

Gossellin, J., McKelvie, J., Sherington, J., Wren, J.A., Eagleson, J.S., Rowan, T.G., Sunderland, S.J., 2007. An evaluation of dirlotapide to reduce body weight of client-owned dogs in two placebo-controlled clinical studies in Europe. Journal of Veterinary Pharmacology and Therapeutics 30, 73-80.

Heitmann, B.L., Lissner, L., Osler, M., 2000. Do we eat less fat, or just report so? International Journal of Obesity 24, 435-442.

Kealy, R.D., Lawler, D.F., Ballam, J.M., Mantz, S.L., Biery, D.N., Greeley, E.H., Lust, G., Segre, M., Smith, G.K., Stowe, H.D., 2002. Effects of diet restriction on life span and age-related changes in dogs. Journal of the American Veterinary Medical Association 220, 1315-1320.

Kienzle, E., Opitz, B., Earle, K.E., Smith, P.M., Maskell, I.E., 1998. The influence of dietary fibre components on the apparent digestibility of organic matter and energy in prepared dog and cat foods. Journal of Animal Physiology and Animal Nutrition 79, 46-56.

Kraus, W.E., Houmard, J.A., Duscha, B.D., Knetzger, K.J., Wharton, M.B., McCartney, J.S., Bales, C.W., Sarah Henes, R.D., Samsa, G.P., Otvos, J.D., et al. 2002. Effects of the amount and intensity of exercise on plasma lipoproteins. N England Journal of Medicine 347, 1483-1492.

Laflamme D., 1997. Development and validation of a body condition score system for dogs. Canine Practice 22, 10-15.

Lund, E.M., Armstrong, P.J., Kirk, C.A., Klausner, J.S., 2006. Prevalence and risk factors for obesity in adult dogs from private US veterinary practices. International Journal of Applied Research in Veterinary Medicine 4, 177-186.

Mao, J., Xia, J., Chen, J., Yu, J., 2013. Prevalence and risk factors for canine obesity surveyed in veterinary practices in Beijing, China. Preventive Veterinary Medicine 112, 438-442.

McGreevy, P.D., Thomson, P.C., Pride, C., Fawcett, A., Grassi, T., Jones, B., 2005. Prevalence of obesity in dogs examined by Australian veterinary practices and the risk factors involved. The Veterinary Record, 156, 695-702.

Merlotti, C., Ceriani, V., Morabito, A., Pontiroli, A.E., 2017. Subcutaneous fat loss is greater than visceral fat loss with diet and exercise, weight-loss promoting drugs and bariatric surgery: a critical review and meta-analysis (abstract). International Journal of Obesity 41, 672-682.

Moher D, Hopewell S, Schulz KF, Montori V, Gøtzsche PC, Devereaux PJ, Elbourne D, Egger M, Altman DG, 2010. CONSORT 2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials. British Medical Journal; 340: 1-28.

Morrison, R., Penpraze, V., Beber, A., Reilly, J.J., Yam, P.S., 2013. Associations between obesity and physical activity in dogs: A preliminary investigation. Journal of Small Animal Practice 54, 570–574.

Mosing, M., German, A.J., Holden, S.L., MacFarlane, P., Biourge, V., Morris, P.J., Iff, I., 2013. Oxygenation and ventilation characteristics in obese sedated dogs before and after weight loss: A clinical trial. The Veterinary Journal 198, 367-371.

Swift, D.L., Johannsen, N.M., Lavie, C.J., Earnest, C.P., Church, T.S., 2014. The role of exercise and activity in weight loss and maintenance. Progress in Cardiovascular Disease 56, 441-447.

Tropf, M., Nelson, O.L., Lee, P.M., Weng, H.Y., 2017. Cardiac and metabolic variables in obese dogs. Journal of Veterinary Internal Medicine 31, 1000-1007.

Tvarijonaviciute, A., Ceron, J.J., Holden, S.L., Cuthbertson, D.J., Biourge, V., Morris, P.J., German, A.J., 2012. Obesity-related metabolic dysfunction in dogs: a comparison with human metabolic syndrome. BMC Veterinary Research 8, 147.

Tvarijonaviciute, A., Ceron, J.J., Holden, S.L., Biourge, V., Morris, P.J., German, A.J., 2013. Effect of weight loss in obese dogs on indicators of Renal function or disease. Journal of Veterinary Internal Medicine 27, 31-38.

Vitger, A.D., Stallknecht, B.M., Nielsen, D.H., Bjornvad, C.R., 2016. Integration of a physical training program in a weight loss plan for overweight pet dogs. Journal of the American Veterinary Medical Association 248, 174-182.

Wakshlag, J.J., Struble, A.M., Warren, B.S., Maley, M., Panasevich, M.R., Cummings, K.J., Long, G.M., Laflamme, D.E., 2012. Evaluation of dietary energy intake and physical activity in dogs undergoing a controlled weight-loss program. Journal of the American Veterinary Medical Association 240, 413–419.

Westgarth. C., Ladha, C., 2017. Evaluation of an open source method for calculating physical activity in dogs from harness and collar based sensors. BMC Veterinary Research 13, 322.

Yam, P.S., Penpraze, V., Young, D., Todd, M.S., Cloney, A.D., Houston-Callaghan, K.A., Reilly, J.J., 2011. Validity, practical utility and reliability of Actigraph accelerometry for the measurement of habitual physical activity in dogs. Journal of Small Animal Practice 52, 86-91.

Table 1. Average composition of the therapeutic diets used for weight loss in dogs on the dietary energy restriction intervention.

Criterion	**Dry food 1** [a]		**Dry food 2** [b]		**Wet food** [c]	
ME content	2595 kcal/kg		2670 kcal/kg		600 kcal/kg	
	g per 100g DM	g per1000 kcal (ME)	g per 100g DM	g per 1000 kcal (ME)	g per 100g DM	g per 1000 kcal (ME)
Crude protein	33.1	116	33.1	112	49.7	141
Crude fat	10.5	37	10.5	36	11.7	33
Starch	19.3	67	18.2	62	10.5	30
NFE	31.8	111	31.8	108	17.5	50
Crude fibre	18.2	64	17.1	58	11.7	33
TDF	30.7	107	30.7	104	18.7	53
Ash	6.3	22	7.4	25	8.8	25
Fibre sources	Cellulose, beet pulp, FOS, psyllium husk, diet cereals		Cellulose, chicory pulp, FOS, psyllium husk, diet cereals		Cellulose, beet pulp, carrageenan, xanthan, diet cereals	

[a] High protein high fibre dry food (Satiety Weight Management, Royal Canin); [b] high protein high fibre dry food (Satiety Small Dog, Royal Canin); [c] high protein high fibre wet food (Satiety Wet, Royal Canin); ME = metabolisable energy content, calculated using a predictive equation based on total dietary fibre (TDF) (Kienzle et al., 1998); AF = as fed; DM = dry matter; FOS = fructo-oligo-saccharides; NFE = nitrogen-free extract.

Table 2. Cut points used to determine time spent in different states of physical activity in dogs, measured by accelomertry (Yam et al, 2011).

Cut Point (VM3[a] counts per minute)	Cut point recorded as	Interpreting the cut point	Example of behaviour eliciting this level of activity
<1352	Sedentary	Little movement of the trunk	Resting, sleeping
1352-5695	Light-Moderate	Slow movement of the trunk	Slow walk on lead or around the house
>5695	Vigorous	Rapid movement of the trunk	Running outdoors or vigorous play indoors

[a] VM3 count: triaxial vector magnitude count derived from the accelerometer.

Table 3. Baseline details of the dogs on the dietary caloric restriction and physical activity interventions.

Variable	**Dietary caloric restriction**	**Physical activity**	***P*-value**
Sex	3 male neuter 3 female neuter	3 male neuter 4 female neuter	1.000
Age (mo)	92 (20 to 96)	90 (25 to 117)	0.617
Breed	Border collie (1) Chihuahua (1) Golden retriever (1) Jack Russell terrier (1) Mixed breed (1) Shih Tzu (1)	Bichon Frise (1) Golden retriever (1) Mixed breed (4) Rottweiler (1)	---
Body Condition Score	8 (6 to 9)	8 (6 to 9)	0.823
Bodyweight (kg)	13.4 (7.4 to 35.0)	28.0 (11.0 to 60.0)	0.134
Diet before study	Therapeutic hydrolysed diet[a], dry (1) Adult maintenance, wet (1) Adult maintenance, dry (1) Adult maintenance, wet & dry (3)	Therapeutic weight loss diet[b], dry (1) Adult maintenance, wet (2) Adult maintenance, dry (4)	---
Physical activity before (min) [c]	40 (20 to 60)	35 (20 to 90)	0.497

[a] Hypoallergenic Diet, Royal Canin; [b] Satiety diet, Royal Canin; [c] Amount of physical activity undertaken each day before study enrolment, as estimated by the owner.

Table 4. Changes in bodyweight and zoometric measurements in the dogs on the dietary caloric restriction and physical activity interventions.

Measurement	Dietary caloric restriction	Physical activity	Intervention comparison
Weight (kg)			
Before	13.4 (7.4 to 35.0)	28.0 (11.0 to 60.0)	
After	12.4 (7.0 to 31.3)	28.8 (10.6 to 59.0)	
Change	-9.6 (-4.6 to -11.7)	-1.9 (2.9 to -6.4)	
P-value	0.031	0.109	0.014
Body condition score			
Before	8 (6 to 9)	8 (6 to 9)	
After	7 (5 to 8)	7 (6 to 9)	
Change	---	---	
P-value	0.043	0.798	0.003
Neck circumference (cm)			
Before	30 (25 to 67)	37 (29 to 53)	
After	30 (26 to 64)	36 (26 to 53)	
Change	-4.5 (4.0 to -6.9)	-4.1 (0.0 to -13.3)	
P-value	0.125	0.062	1.000
Abdominal circumference (cm)			
Before	48 (40 to 69)	60 (44 to 90)	
After	42 (38 to 60)	56 (40 to 83)	
Change	-12.0 (-5.0 to -17.4)	-7.8 (-6.2 to -13.0)	
P-value	0.031	0.016	0.430
Thoracic circumference (cm)			
Before	60 (49 to 73)	70 (50 to 96)	
After	52 (46 to 69)	67 (44 to 91)	
Change	-7.5 (-5.5 to -18.2)	-3.6 (0.0 to -12.0)	

P-value	0.031	0.031	0.027

Before and after values represent median with range shown in brackets. The change values represent the percentage change from baseline within each group. The *P*-values shown below each intervention (dietary caloric restriction and physical activity) are within-group comparisons for the respective measurement, whilst the *P*-value the ‘intervention comparison’ column are comparisons between treatment groups.

Table 5. Percentage of time spent in different intensities of physical activity at the start and end of the study, as determined by triaxial accelerometry.

Type of activity	Dietary caloric restriction	Physical activity	Intervention comparison
Wear time (min)			
Before	9916 (9246 to 10080)	9571 (9421 to 10080)	
After	9725 (8640 to 10080)	9991 (9480 to 10080)	
Change	-0.1 (-14.3 to 3.1)	0.0 (-0.9 to 7.0)	
P-value	1.000	0.562	0.391
Sedentary activity			
Before	77.4 (64.7 to 83.0)	79.5 (69.2 to 84.3)	
After	79.1 (66.8 to 82.4)	76.3 (71.2 to 83.1)	
Change	0.0 (-6.0 to 6.1)	-0.7(-5.6 to 5.0)	
P-value	1.000	0.469	0.617
Light-moderate activity			
Before	18.8 (15.4 to 31.4)	18.2 (14.7 to 24.6)	
After	19.1 (16.6 to 30.2)	20.0 (16.4 to 23.1)	
Change	6.7 (-14.7 to 16.4)	4.0 (-18.8 to 20.5)	
P-value	0.562	1.000	0.721
Vigorous activity			
Before	3.0 (1.6 to 4.2)	2.4 (0.4 to 6.2)	
After	2.8 (0.3 to 3.8)	3.4 (0.5 to 7.4)	
Change	-14.1 (-83.8 to 40.8)	16.7 (1.8 to 42.6)	
P-value	0.312	0.016	0.054

Wear time refers to the median (range) time in min that the accelerometers were worn during each monitoring period. The change values represent the percentage change from baseline within each group. All other data represent median percentage daily average with the range shown in brackets. The *P*-values shown below each intervention (dietary caloric restriction and physical activity) are within-group comparisons for the respective measurement, whilst the *P*-value the 'intervention comparison' column are comparisons between treatment groups.

Figure legend

Figure 1. Example of physical activity monitoring using triaxial accelerometry in a dog in the physical activity group. The figures show the VetSens® heat map before (a) and at the end of (b) the trial. Non-wear is shown in grey, sedentary activity is shown in green, light-moderate activity is shown in yellow and vigorous activity is shown in red. Subjectively, the time spent in vigorous activity appears to be greater at the end of the trial compared with before the trial.

Supplementary material

S1 checklist. Checklist for the CONSORT statement. The table lists the items of the respective checklist, and the location within the manuscript where they can be found.

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