

1 *Association between lifespan and body condition in neutered client-*
2 *owned dogs*

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10

11 **Running head:** Lifespan and body condition in dogs

12 **Keywords:** Obesity, canine, nutrition, survival, longevity

13

14 **Abbreviations**

15 ANOVA Analysis of variance

16 BCS Body condition score

17 BMI Body mass index

18 CEM Coarsened exact matching

19 FS Female spayed

20	k	Thousand(s)
21	MN	Male neutered
22	m	Million(s)
23	mo	Month(s)
24	PH	Proportional hazards
25	USA	United States of America
26	y	Years(s)

27

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32

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39

40 **Conflict of Interest Declaration**

41 CS, PJM, and DW are employees of WALTHAM, whilst EML was an employee of
42 BANFIELD® Pet Hospitals at the time the study was conducted. Both companies both are
43 owned by Mars Inc. AJG is an employee of the University of Liverpool, but his post is
44 financially supported by Royal Canin, which is also owned by Mars Petcare. AJG has also
45 received financial remuneration for providing educational material, speaking at conferences, and
46 consultancy work for Mars Petcare; all such remuneration has been for projects unrelated to the
47 work reported in this manuscript.

48

49 **Off-label Antimicrobial Declaration:** Authors declare no off-label use of antimicrobials.

50 **Institutional animal care and use committee (IACUC) or other approval**

51 The study protocol was approved by the WALTHAM ethical review committee, and owners of
52 all participating dogs gave consent for data to be used.

53

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58 BANFIELD® Pet Hospitals.

59

60 **Abstract**

61 **Background.** There is an association between overweight status and life span in kenneled dogs,
62 but a similar association has not been reported for pet dogs.

63

64 **Objectives.** To examine the effects of being overweight in middle age on the lifespan of
65 neutered client-owned dogs.

66

67 **Animals.** 50,787 middle-aged neutered client-owned dogs attending a network of over 900
68 veterinary hospitals across North America.

69

70 **Methods.** Retrospective case-control study. For each of 12 breeds, groups of dogs aged
71 between 6.5y and 8.5y were identified as being in 'overweight' or 'normal' body condition.
72 Within each breed and sex, differences in lifespan between dogs in normal body condition and
73 overweight body condition in the two groups were then analyzed using Cox proportional hazards
74 models.

75

76 **Results.** For all breeds, instantaneous risk of death for dogs in overweight body condition was
77 greater than those in normal body condition throughout the age range studied, with hazard ratios
78 ranging from 1.35 (99.79% confidence interval [CI]: 1.05-1.73) for German shepherd dog to 2.86
79 (2.14-3.83) for Yorkshire terrier. In all breeds, median lifespan was shorter in overweight
80 compared with normal weight dogs, with the difference being greatest in Yorkshire terriers
81 (overweight: 13.7y, 99.79% CI 13.3-14.2; normal: 16.2y 15.7-16.5) and least in German
82 shepherd dogs (overweight: 12.1y, 11.8-12.4; normal: 12.5y 12.2-12.9).

83

84 **Conclusions and clinical importance.** Veterinary professionals should consider promoting
85 healthy body condition for dogs, particularly from mid-life onwards.

86

87 **Introduction**

88 Obesity is characterized by an expansion of white adipose tissue (WAT),¹ and is now a major
89 health concern in pet dogs,¹ with recent evidence suggesting a rapidly increasing prevalence.²
90 Dogs that are overweight or have obesity are at increased risk of developing a range of chronic
91 diseases including orthopedic diseases, diabetes mellitus, and certain types of neoplasia.^{1,3}
92 Metabolic derangements,^{4,5} functional impairment (most notably respiratory, cardiovascular and
93 renal function),⁶⁻⁸ and adverse effects on quality of life also occur.⁹ Parallels exist between
94 canine and human obesity because both are outbred species that share a similar environment,¹
95 and similar disease associations are seen including diabetes mellitus, cardiovascular disease, and
96 hypertension.¹⁰ As such, both the international medical and veterinary communities have
97 advised formally classifying obesity as a disease.¹¹ WAT expansion causes secondary disease in
98 two ways: through the ‘mechanical’ impact of increased tissue mass or volume on function, and
99 through the effects of perturbed endocrine function.¹ Both pro-inflammatory cytokines and acute
100 phase proteins (APPs) are produced by WAT, and both their tissue expression and circulating
101 concentration are altered by obesity in humans and dogs.^{12,13} The chronic, low-grade systemic
102 inflammation that results is thought to provide the link between obesity, insulin resistance and
103 the metabolic syndrome.¹²
104
105 In addition to increasing disease risk and causing functional impairment, having an overweight
106 body condition increases mortality risk in humans worldwide.¹⁴ All-cause mortality is least in
107 adults with a body mass index of 20.0-25.0, and increases significantly and incrementally
108 throughout the overweight range.¹⁴ In veterinary studies, there are negative associations between
109 lifespan and both underweight and obese body condition in cats from a single veterinary practice
110 in Sydney Australia,¹⁵ and evidence for overweight condition having an adverse effect on

111 lifespan effects in a lifelong feeding study involving a colony of Labrador retriever dogs.¹⁶⁻¹⁹ In
112 this latter study, dogs were paired, with one dog in each pair being fed *ad libitum*, while the other
113 dog was fed 25% less food than its pair-mate from 8 weeks of age until death. *Ad-libitum*-fed
114 dogs had a greater body condition and a shorter median lifespan than dogs of the restricted-
115 feeding group.¹⁷ Although this suggests a possible association between overweight condition
116 and shortened lifespan in dogs maintained in a controlled colony environment, to date, similar
117 effects have not been studied in client-owned domesticated dogs. Therefore, the aim of the
118 current study was to explore possible associations between body condition and lifespan using a
119 large database of veterinary health records from pet dogs in North America.

120

121 **Methods**

122 **Study design**

123 This was a retrospective case-control study to investigate longevity in dogs, utilizing
124 demographic, geographic and clinical data from dogs registered with a North American
125 veterinary hospital network (BANFIELD® Pet Hospitals).

126

127 **Data extraction and study population**

128 The network comprised 900 veterinary hospitals located predominantly in the USA
129 (BANFIELD® Pet Hospitals), which have electronic records dating back to 1994. All medical
130 notes from these records were anonymized by removing client-identifying details, and then
131 stored in an object-related database management system (Oracle 11g release 2, Oracle
132 Corporation, Redwood Shores, CA, USA), hereafter referred to as the ‘records database’.
133 Available records included those from April 1994 to September 2015. Data were extracted for
134 purebred individuals from 12 of the most popular breeds representing the five size classes
135 defined by similarities in patterns of growth.²⁰ The breeds studied were American cocker
136 spaniel, Beagle, Boxer, Chihuahua, Dachshund, German shepherd dog, Golden retriever,
137 Labrador retriever, Pit bull terrier type, Pomeranian, Shih tzu, and Yorkshire terrier. The data
138 extracted included demographic (breed, sex, neuter status and date of birth) and geographic
139 (latitude and longitude of the owner’s zip code) variables, plus data collected during in-clinic
140 visits (date of visit, bodyweight and if available body condition), and date of death. Pedigree
141 status and date of birth are both owner-reported parameters and were not verified by the
142 veterinary staff.

143

144 **Eligibility criteria**

145 Dogs were eligible for inclusion when they had at least one ‘in-clinic’ visit (defined as an
146 appointment when both the owner and dog were in attendance), were between 6.5y and 8.5y, and
147 whose veterinary care had not ceased (e.g. due to death or moving to a different veterinary
148 practice) before 9.5y. In this respect, there had to be some contact with the owner after this time,
149 for example, an in-clinic visit or a phone consultation about the dog. This was necessary so as to
150 minimize any possible influence of life-threatening disease on the body condition assessment, as
151 is customary in similar human studies comparing the association between overweight status and
152 mortality.¹⁴ In addition, dogs had to be neutered and from one of the 12 most common breeds in
153 the database (see above). Since most dogs were neutered before 2y, only data from visits after
154 this age were used in modelling studies to ensure that neuter status would not change during
155 follow-up. Further, for the group matching process (see below), a single in-clinic visit was
156 chosen for each dog as the representative visit, and this was the one that was the closest to 7.5y.
157 This ensured that each dog was only included once during matching.

158

159 **Age, date of birth, and date of death**

160 The age of the dog at each visit was calculated from the visit date and the date of birth of the
161 dog. Date of birth is a field within the computer electronic records and must be recorded for all
162 dogs; the field is completed at the time the dog is registered with the practice, based upon
163 information provided by the owner. Date of death is also a field within the computer electronic
164 records, and was completed when dogs died or were euthanized, along with the reason for death.
165 If the euthanasia is conducted by a veterinarian at the practice, the field is manually completed.
166 Neither the date of birth nor date of death fields are verified for accuracy. For dogs with a
167 recorded death date, lifespan was calculated from date of birth to date of death; where no date of

168 death was not recorded, survival data were censored at the date of the last contact (clinic visit or
169 phone consultation).

170

171 **Body condition assessment**

172 Before 2010, body condition was assessed using a subjective 3-category classification ('thin',
173 'normal' or 'heavy'). After 2010, a 5-category body condition score (BCS) was used, based on
174 visual characteristics and palpation as previously described.³ To ensure consistency between the
175 pre-2010 body condition categories and post-2010 BCS data, the five category BCS was mapped
176 to the 3-category classification with the same approach as that used in a previous study.²⁰

177 Briefly, the 'very thin' and 'thin' categories were mapped to the pre-2010 'thin' category, while
178 the 'overweight' and 'markedly obese' categories were mapped to the pre-2010 'heavy'
179 category. Additionally, the records database contains weight-related diagnoses, which
180 veterinarians can use when classifying the nature of any consultation. The use of these diagnoses
181 was also examined and, if it did not agree with the body condition assessment (e.g. dog assigned
182 a normal body condition, but given a diagnosis of 'thin'), the body condition assessment was
183 altered to bring it in line with the stated diagnosis.

184

185 One further issue for pre-2013 data was that the body condition field defaulted to 'normal' if a
186 body condition category was not entered. An extrapolation process was used to correct errors
187 arising from this issue: where a non-default body condition assessment either preceded or
188 followed a default body condition assessment, the default assessment was changed to the value
189 of the non-default assessment provided that the bodyweight of the dog had remained within $\pm 5\%$
190 between visits. The $\pm 5\%$ rule was used because changes in bodyweight of $>5\%$ are typically
191 required for changes in BCS to be seen.²¹

192
193 Body condition data were used to produce two groups of dogs, ‘normal body condition’ and
194 ‘overweight body condition’, that were matched on sex, visit age, visit year, latitude and
195 longitude (see below). The ‘overweight body condition’ group comprised dogs with a body
196 condition category of ‘heavy’ at every visit between 5.5y and 9.5y. The ‘normal body condition’
197 group comprised dogs whose body condition was never classified as “thin” or “heavy”, and
198 whose body condition was classified as “normal” between 5.5y and 9.5y.

199

200 **Data handling and statistical analysis**

201 Six substantial data cleaning steps were used to ensure both that eligibility criteria were met and
202 data were accurate and reliable (Fig 1). First, dogs younger than 5.5y or older than 9.5y at their
203 visit were excluded to ensure the selection of middle-aged dogs and to maintain a balance
204 between numbers of dogs and knowing with certainty that dogs were still alive at a specific age.
205 Second, outlying visits with extreme ages (which might have been keyed in by mistake) were
206 removed using a method based on box and whisker statistics for skewed data.²² Third, groups of
207 dogs in overweight and normal body condition were selected (as described above) to create a
208 single dataset for matching purposes. Fourth, dogs whose veterinary care ceased before 9.5y,
209 either due to death, euthanasia or moving to a different veterinary practice were excluded, and
210 the in-clinic visit which was closest to 7.5y in age was chosen as the single representative visit
211 for the subsequent matching process, ensuring that dogs with multiple visits between 6.5y and
212 8.5y were only included once. Fifth, dogs listed as sexually intact were removed given their
213 relative paucity within the dataset. Finally, to mitigate any possible lack of balance between
214 groups, a ‘statistical matching’ technique was applied to all 12 data subsets, whereby normal and
215 overweight groups were matched on sex, visit year, or visit age by the coarsened exact matching

216 (CEM) method,²³ using a bespoke package (Package ‘cem’, version 1.1.17, Iacus SM) within an
217 open-source statistical software environment (R, version 3.2.0, R Foundation for Statistical
218 Computing, Vienna, Austria). This method temporarily coarsens the data and then finds exact
219 matches for dogs in the two groups. Each observed variable is coarsened into meaningful groups
220 (for example using age groups instead of exact birth dates). Then, visits with the same values for
221 all the coarsened variables are placed in a single stratum. Strata without at least one ‘normal’
222 and one ‘overweight’ visit are dropped. Only the original un-coarsened values of the matched
223 data are retained. It should be emphasized that the exact matching procedure is applied to the
224 coarsened data to find the matches and discard unmatched units before the un-coarsened values
225 of the matched data are returned. Therefore, similar to other matching techniques, CEM does not
226 produce a 1:1 ratio of normal to overweight dogs; to do so might lead to a large number of
227 observations being discarded, leading to reduced statistical power. Supplementary Table S1
228 outlines the improvement in balance, using the L1 norm for each of the breeds.²⁴ After
229 matching, the median number of dogs with a death date was 911 across the 12 breeds.

230
231 Given that the records database did not include death dates for all dogs, the data were right
232 censored. As a result, comparisons of survival between normal and overweight dogs were made
233 by generating Cox proportional hazards (PH) models given their ability to deal with left and right
234 censored data. A bespoke package (Package ‘survival’, version 2.38-3, Therneau TM) of a
235 statistical software environment (R, version 3.2.0) was used to produce models for male and
236 female dogs, and survival predictions from the Cox PH models were used to compare the median
237 lifespan of normal and overweight dogs. The PH assumption holds if the hazard functions for
238 two individuals remains proportional over time, i.e. constant relative hazard. This assumption
239 was tested for all explanatory variables (sex, BCS, visit year and visit age) using weighted

240 residuals.²⁵ When body condition violated the PH assumption, it was managed by adding a time-
241 dependent body condition variable. This indicator variable depended on the visit age at which
242 the PH assumption failed, specifically 10.5y (when violation of PH could not be mitigated),
243 12.5y or 14.5y. Stratification was used for instances where the PH assumption did not hold for
244 sex, visit year or visit age. Hazard ratios (HR) and 99.79% confidence intervals were calculated
245 for the body condition term in each Cox PH model. For each HR, the "hazard" was the
246 instantaneous event rate in an overweight dog compared with a dog in normal body condition,
247 with the event in question being death. Binomial tests were used to assess propensity in the
248 direction of any association between body condition and risk change in all 12 breeds. A
249 Bonferroni adjustment was used to correct for the effects of multiple testing, with the adjusted
250 significance level being $P=.00208$ (e.g. $.05/24$) for two-sided analyses.

251
252 Median lifespan was calculated for each breed using predictions from the Cox PH models, and
253 these were stratified both by sex (male vs. female) and for both normal and overweight groups
254 stratified by sex. We tested the hypothesis that there would be a difference in median lifespan
255 between dogs with normal body condition and dogs in overweight body condition. The
256 percentage difference in median lifespan for the overweight group relative to the normal group
257 was compared for all 12 breeds and both male and female. The effect of body condition on
258 lifespan was tested using the Cox PH model for each of the 12 breeds using the same open-
259 source statistical software environment (R, version 3.2.0). A Bonferroni adjustment was again
260 used to correct for the effects of multiple testing, with the adjusted significance level being
261 $P=.00208$ (e.g. $.05/24$) for two-sided analyses. Binomial tests were again used to assess trends in
262 the direction of any association between body condition and survival across all 12 breeds. For
263 example, where no underlying trend existed, the overweight group would be expected to have a

264 50% chance of having a longer median lifespan than the normal group, and a 50% chance of
265 having a shorter median lifespan.

266

267 **Results**

268 **Final study population**

269 Before applying eligibility criteria and performing matching, the records database contained 5.4
270 $\times 10^6$ visits available from 1.2×10^6 dogs (Fig 1). After filtering the dataset and matching, the
271 total number of dogs available was 50,787, and date of death was recorded in 14,316 of these
272 (28.2%). The number of dogs available for each breed is shown in Table 1. After data cleaning,
273 the median number of dogs available per breed was 3,865 (range 1,273-11,867), while the
274 median number of dogs with a known death date was 911 (range 328-4,520).

275

276 **Survival predictions and hazards ratios**

277 Body Condition Score violated the PH assumption and required the introduction of a time-
278 dependent body condition variable for 8 out 12 breeds, including: American cocker spaniel,
279 Beagle, Chihuahua, Dachshund, Labrador retriever, Pomeranian, Shih tzu, and Yorkshire terrier.
280 For Labrador retriever and Shih tzu, the PH violation occurred at 12.5y and 10.5y, respectively.
281 The PH violation could not be reduced for Shih tzu. For other breeds, violation occurred at
282 14.5y. Survival probability predictions for male and female dogs of all 12 breeds were then
283 produced from the Cox PH models; examples for five breeds (Yorkshire terrier, Shih tzu,
284 Dachshund, Boxer, and German shepherd dog) are depicted in Figs 2-6, while survival curves for
285 all other breeds are included in supplemental material (Fig S1-S7). For all 12 breeds, the
286 survival probability for dogs in overweight body condition was less than for dogs in ideal body
287 condition throughout the age range studied.

288

289 Hazard Ratios and 99.79% confidence intervals for the body condition term (overweight
290 condition relative to normal condition) from the Cox PH models produced for all 12 breeds are

291 shown in Table 2. The body condition HRs ranged from 1.35 (99.79% confidence interval 1.05
292 to 1.73) for German shepherd dog to 2.86 (99.79% confidence interval 2.14 to 3.83) for
293 Yorkshire terrier. Binomial testing confirmed an increase in relative risk of dying for overweight
294 dogs compared to normal body condition dogs across all 12 breeds ($P<.001$ for all) at the
295 Bonferroni corrected two-sided test level.

296

297 **Lifespan of dogs in ideal and overweight body condition**

298 Median lifespans (with multiple testing adjusted confidence intervals) for dogs in overweight and
299 normal body condition from the 12 breeds are shown in Table 3, while Fig 7 illustrates the
300 reduction in median lifespan for all 12 breeds and both male and female dogs. Binomial testing
301 confirmed a shorter survival for overweight dogs of all 12 breeds would not be expected by
302 chance, indicating the presence of a non-random directional trend ($P<.001$). The estimated
303 reduction in median lifespan for the overweight group relative to the normal group ranged from
304 5mo, for male German shepherd dogs, to 2y 6mo for male Yorkshire terriers (Table 3).

305

306 **Discussion**

307 This study demonstrates an adverse effect of overweight body condition on lifespan in client-
308 owned dogs of a range of breeds, thereby extending the findings from an earlier colony study in
309 Labrador retrievers.¹⁶⁻¹⁹ These results emphasize the need for veterinarians to implement steps to
310 prevent the development of obesity in dogs under their care. Specifically, veterinarians could
311 use the study findings in discussions with owners of new puppies, to highlight the risk that
312 overweight status poses to health and the need for prevention. The findings could also be used in
313 discussions with owners of already-obese dogs to convince them of the need to implement a
314 controlled weight loss program.

315

316 Overweight body condition was associated with a shorter lifespan in all 12 breeds studied, but
317 the magnitude of the effect varied being least for large-breed dogs (e.g. 5mo) and greatest for
318 dogs of the smallest breed (e.g. over 2y in dogs from size class I). Hazards ratios for estimated
319 risk of death in overweight dogs relative to those in normal body condition mirrored these
320 findings. The reason for these results is unclear, but one possibility would be a difference in
321 natural prevalence of the various obesity-associated diseases amongst the breeds studied. For
322 example, orthopedic diseases such as osteoarthritis are more common in larger breeds.²⁶

323 Alternatively, individual breed characteristics might influence the impact of any functional
324 impairments that arise from obesity, for example, metabolic dysfunction or impaired quality of
325 life.^{5-9,18} Whatever the reasons, the importance of this lifespan effect should not be ignored.

326 Indeed, even in the breeds where the effect was least pronounced, such shortening is likely to be
327 important since most owners would wish to ensure that their dog lives a long and healthy life.

328

329 In the authors' opinion, although only 12 breeds were studied, the fact that the negative
330 association between overweight status and lifespan was apparent in all breeds implies that this
331 same effect is likely to be present in any breed. Nonetheless, such extrapolations should be made
332 cautiously until studies including a wider breed range are undertaken. In a similar manner, the
333 inclusion of neutered dogs only and of dogs between 5.5y and 9.5y, means that extrapolation to
334 sexually intact or younger dogs should also be made cautiously.

335
336 Given that the study was retrospective and observational, it was not possible to determine the
337 reasons for the association between overweight body condition and lifespan, and causality cannot
338 necessarily be assumed. One possibility is that overweight status is only indirectly associated
339 with lifespan, for example by predisposing to diseases that are themselves fatal (e.g.
340 neoplasia).^{3,27-28} Alternatively, overweight body condition might exacerbate other diseases that
341 have a negative impact on health (e.g. osteoarthritis) thereby prompting a decision for
342 euthanasia. Indeed, in the previous lifelong feeding study of dogs, chronic diseases including
343 various types of neoplasia and osteoarthritis were diagnosed at an earlier age in the *ad libitum*
344 fed group that were overweight, compared with the calorie-restricted group that remained in
345 ideal body condition.¹⁷ Further, obese dogs have a poorer quality of life than dogs in ideal
346 condition.⁹ A second possibility for the lifespan difference between overweight and ideal weight
347 dogs is that weight status is a proxy measure for caloric intake. In this respect, calorie restriction
348 without malnutrition can increase longevity in a wide variety of species including spiders, fish,
349 invertebrates, and rodents.^{29,30} Further, biomarkers associated with longevity (e.g. fasting insulin
350 concentration and body temperature) were decreased by prolonged calorie restriction in human
351 beings.³¹ Given that, in this study, information on concurrent disease, diet and energy intake

352 were not assessed, further work would be required to determine the reason for the difference in
353 lifespan between overweight dogs and those in ideal condition.

354

355 In analyzing study data, we choose an approach involving matching rather than, for example,
356 using proportional hazards models with weight status as the variable of interest, and all other
357 covariates considered as potential confounders. The main disadvantage of using matching
358 methods is that they can be less 'powerful', so might miss increase the chances of type II
359 statistical error.³² However, this was arguably not a concern in the current study since significant
360 effects were demonstrated even after applying a Bonferroni correction. The main advantage of
361 using a matching method is that it can better deal with observational data that are unbalanced in
362 one or more covariates that themselves might be associated with the dependent variable of
363 interest. For example, in a situation where one of the covariates is a causal variable in its own
364 right but is also correlated with the independent variable of interest, a model without matching
365 can struggle to separate the effect of the independent variable of interest from that of the
366 covariate. Further, even when a significant effect of the independent variable of interest is
367 found, it might simply be related to its association with the covariate. Matching methods can
368 separate these effects thereby avoiding a 'second-hand' association of the independent variable of
369 interest with a noise variable.³³ Therefore, while other methods could have been considered, the
370 advantages of the method chosen outweighed the disadvantages.

371

372 A strength of this study is its size in that, by using a large veterinary hospital network, data from
373 over 50,000 dogs available for assessment even after data cleaning. This enabled differences in
374 lifespan to be identified in male and female neutered dogs in all 12 breeds. A further advantage
375 of the approach taken was the fact that client-owned dogs living in a home environment could be

376 studied and, as such, results are likely to be generalizable to the general pet dog population.
377 However, a disadvantage of the approach is the fact that data were collected by many veterinary
378 professionals in many locations, meaning potential discrepancies in assessment of body
379 condition. Further, data were not specifically collected for this scientific study, rather data were
380 gathered by many veterinarians for clinical reasons and there might have been errors or
381 omissions in terms of data inputting.

382
383 Several other study limitations should also be acknowledged. Firstly, the study was retrospective
384 with data collected over a period of 20 years. As well as both the prevalence and awareness of
385 body condition during this time frame, it is likely that there were numerous changes in practice
386 protocols, expertise, technology, and data recording. Such factors are likely to impact on the
387 reliability of the study data. Moreover, some information that owners provided, such as breed
388 and date of birth, were not verified for accuracy at the time it was recorded, for instance by
389 examining pedigree records. Further, owners might not have known the exact date of birth for
390 their dog, for example if it had been re-homed. There might also have been inaccuracies with
391 date of death when this was owner reported (if the dog died at home), since some owners might
392 understandably have delayed informing the practice until a time that they could cope with such a
393 difficult conversation. It is also possible that veterinary practice staff might have made errors
394 when entering data into the records database. To mitigate such limitations, extensive data
395 cleaning was undertaken, with exclusion of any data thought to be unreliable. One consequence
396 of this cautious approach is the reduction of available data (Fig 1), meaning that the final data set
397 might be less representative of the original study population, and the number of breeds where
398 sufficient data were available for analysis is reduced. That said, the original datasets were large
399 enough to accommodate this.

400

401 A second limitation, is that we cannot be certain that the association between body condition and
402 survival might not truly be related to a shortened natural lifespan. Survival studies are difficult
403 to conduct in companion animals because, unlike in humans, pet dogs can be euthanized rather
404 than allowed to die from natural causes. The reasons for euthanasia and the timing of the
405 decision are variable with many factors involved. Decisions might relate to animal factors such
406 as the development of disease (not least if the disease is a terminal one), presence of multiple
407 concurrent diseases, perceived poor quality of life, aggression or other behavioral disorders. A
408 final possible reason for euthanasia is financial, whereby the costs of pet ownership and,
409 sometimes, costs of therapy might sway the decision for euthanasia. In a recent review, the
410 financial impact of a dog having obesity and obesity-related disease was estimated to be
411 approximately \$2000 per year.³⁴ Given that the current study was retrospective, the reasons for
412 death or euthanasia were not always recorded.

413

414 A third study limitation was the fact that a different approach was used to assess body condition
415 at the start of the study compared with the end. Initially, a 3-category system was used, which
416 was replaced by a more conventional 5-category system in 2010. To maximize the available
417 study data, 5-point scores used after 2010 were mapped onto the 3-category scores used before
418 2010. This approach has been used in a previous study²⁰ and, because it was straightforward
419 (involving merging categories), it is unlikely that errors arose at this stage. That said, it is
420 unclear whether the categories were truly equivalent. A second concern regarding body
421 condition was that it was not a mandatory field within the computer records and, if not
422 completed, the system automatically recorded the body condition as 'normal'. It could be argued
423 that failure to complete this field is more likely to occur when the dog already has a normal body

424 condition than when the body condition is abnormal (overweight or underweight). It cannot be
425 guaranteed that this would always be the case given the relative infrequency with which
426 veterinarians spontaneously record body condition³⁵ or use the terms overweight and obese³⁶ in
427 electronic records. Therefore, to mitigate errors arising at this stage, an extrapolation process
428 was used whereby all default values were compared with assessments that immediately preceded
429 or followed them. Further, body condition assessments were cross-checked for consistency
430 against diagnosis categories that the veterinarian had recorded (e.g. when the veterinarian
431 recorded the diagnosis as underweight, overweight or obesity) and corrected if they deviated.
432 Although it is likely that these stringent data cleaning methods improved the accuracy of the
433 final dataset, some uncertainty over accuracy remains. That said, since most errors would
434 involve dogs with abnormal body condition being erroneously classified as normal rather than
435 the other way around, the effect would be to decrease differences between groups rather than
436 increase them. Further studies should be considered, involving similarly large datasets to
437 confirm the findings of the current study.

438

439 A fourth study limitation was the fact that the decision about whether dogs were selected for the
440 overweight and normal groups was made when dogs were middle-aged (between 5.5y and 9.5y),
441 rather than earlier in life. As a result, the kinetics of weight change throughout life could not be
442 assessed, as they had been in a previous cohort study.¹⁶⁻¹⁹ This was necessary because selecting
443 dogs earlier would have meant fewer dogs with useable data for the study. Firstly, younger dogs
444 are generally healthier than middle-aged dogs (because chronic diseases typically manifest later
445 in life), so they visit the veterinarian less frequently. Secondly, it is common to have notable
446 attrition from owners moving practices, meaning far fewer selected dogs would have had a
447 recorded death dates available for analysis. However, the disadvantage of this approach is that

448 the impact of timing, speed and duration of weight gain could not be examined, for example,
449 whether weight gain early in life has more impact than weight gain later in life. Likewise, we
450 did not examine the effect of any methods used to achieve weight loss or prevent weight gain on
451 lifespan. Moreover, since only two groups were compared (normal condition and overweight
452 condition), we did not consider the impact of magnitude of excess weight. Therefore, additional
453 studies would be required to examine these aspects in more detail.

454

455

456 **Conclusions**

457 There is a negative association between overweight body condition and lifespan in client-owned
458 dogs from 12 common breeds. These findings emphasize the need for veterinary professionals to
459 promote a healthy body condition for dogs, particularly in mid-life onwards.

460

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548

549 24. **Table 1.** Details of the final study population, stratified according to breed, sex and body condition status.

Breed	Size class	All dogs			Male dogs			Female dogs		
		Total	Normal ¹	Overweight ²	Total	Normal ¹	Overweight ²	Total	Normal ¹	Overweight ²
Chihuahua	I	6,306 (1,098)	2,460 (210)	3,846 (888)	2,977 (524)	1,227 (109)	1,750 (415)	3,329 (574)	1,233 (101)	2,096 (473)
Pomeranian	I	2,297 (515)	1,123 (140)	1,174 (375)	1,280 (281)	623 (76)	657 (205)	1,017 (234)	500 (64)	517 (170)
Yorkshire terrier	I	4,065 (574)	2,540 (212)	1,525 (362)	2,287 (313)	1,447 (112)	840 (201)	1,778 (261)	1,093 (100)	685 (161)
Shih tzu	II	5,488 (873)	3,329 (355)	2,159 (518)	2,915 (469)	1,733 (179)	1,182 (290)	2,573 (404)	1,596 (176)	977 (228)
American cocker spaniel	III	2,997 (949)	927 (179)	2,070 (770)	1,398 (402)	452 (85)	946 (317)	1,599 (547)	475 (94)	1,124 (453)
Beagle	III	3,665 (1,095)	703 (106)	2,962 (989)	1,756 (518)	342 (55)	1,414 (463)	1,909 (577)	361 (51)	1,548 (526)
Dachshund	III	4,799 (984)	1,538 (152)	3,261 (832)	2,396 (491)	765 (76)	1,631 (415)	2,403 (493)	773 (76)	1,630 (417)
Boxer	IV	1,659 (718)	807 (264)	852 (454)	740 (315)	348 (109)	392 (206)	919 (403)	459 (155)	460 (248)
Pit bull	IV	1,273 (328)	530 (99)	743 (229)	484 (119)	215 (46)	269 (73)	789 (209)	315 (53)	474 (156)
German shepherd dog	V	1,811 (729)	833 (262)	978 (467)	777 (309)	383 (122)	394 (187)	1,034 (420)	450 (140)	584 (280)
Golden retriever	V	4,560 (1,933)	876 (242)	3,684 (1,691)	2,166 (940)	407 (117)	1,759 (823)	2,394 (993)	469 (125)	1,925 (868)
Labrador retriever	V	11,867 (4,520)	2,672 (598)	9,195 (3,922)	5,511 (2,194)	1,238 (299)	4,273 (1,895)	6,356 (2,326)	1,434 (299)	4,922 (2,027)
TOTAL	---	50,787 (14,316)	18,338 (2,819)	32,449 (11,497)	24,687 (6,875)	32,449 (1,385)	15,507 (5,490)	26,100 (7,441)	9,158 (1,434)	16,942 (6,007)

550 Data reported are total numbers of dogs and dogs with a recorded death age in brackets. ¹ Dogs were classified as ‘normal’ when their
551 body condition was recorded as “normal” between 5.5y and 9.5 y, and if they were never recorded as “thin” or “heavy” at any age; ²
552 Dogs were classified as ‘overweight’ when their body condition was recorded as ‘heavy’ at every visit between 5.5y and 9.5y.

553 **Table 2:** Hazard ratios for the effect of overweight body condition on risk of death in pet dogs

Breed	Size Class	Hazard Ratio	99.79% confidence interval	<i>P</i> value
Chihuahua	I	2.42	1.87 to 3.13	<.001
Pomeranian	I	2.25	1.62 to 3.12	<.001
Yorkshire terrier	I	2.86	2.14 to 3.83	<.001
Shih tzu	II	2.19	1.39 to 3.45	<.001
American cocker spaniel	III	2.21	1.66 to 2.93	<.001
Beagle	III	2.40	1.69 to 3.43	<.001
Dachshund	III	2.77	2.03 to 3.79	<.001
Boxer	IV	1.62	1.27 to 2.07	<.001
Pit bull	IV	1.57	1.08 to 2.29	<.001
German shepherd	V	1.35	1.05 to 1.73	<.001
Golden retriever	V	1.56	1.26 to 1.94	<.001
Labrador retriever	V	1.83	1.54 to 2.17	<.001

554

555 Data reported are hazard ratios, 99.79% confidence interval, and associated *P* values for risk of
556 death for dogs in overweight body condition relative to dogs in normal body condition.

557 **Table 3:** Differences in lifespan between dogs in normal and overweight body condition.

Breed	Size class	Male dogs		Female dogs	
		Normal ¹	Overweight ²	Normal ¹	Overweight ²
Chihuahua	I	16.0 (15.6, 16.4)	13.9 (13.5, 14.2)	16.1 (15.7, 16.7)	14.0 (13.6, 14.3)
Pomeranian	I	15.5 (15.2, 16.3)	13.7 (13.3, 14.1)	15.5 (15.0, 15.9)	13.6 (13.2, 14.0)
Yorkshire terrier	I	16.2 (15.7, 16.5)	13.7 (13.3, 14.2)	15.5 (15.3, 15.7)	13.5 (13.2, 14.0)
Shih tzu	II	14.5 (14.5, 15.3)	13.8 (13.6, 14.3)	14.5 (14.5, 15.4)	13.9 (13.6, 14.3)
American cocker spaniel	III	14.9 (14.4, 15.6)	13.4 (13.2, 13.6)	14.8 (14.3, 15.4)	13.3 (13.0, 13.4)
Beagle	III	15.2 (14.5, 16.1)	13.2 (13.0, 13.5)	15.3 (14.6, 16.2)	13.3 (13.1, 13.6)
Dachshund	III	16.4 (15.8, 16.8)	14.1 (13.8, 14.4)	16.4 (15.9, 16.8)	14.1 (13.8, 14.4)
Boxer	IV	12.4 (12.2, 12.6)	11.8 (11.5, 12.0)	12.3 (12.1, 12.6)	11.7 (11.4, 11.9)
Pit bull	IV	13.8 (13.3, 14.5)	13.0 (12.5, 13.5)	13.8 (13.3, 14.3)	12.9 (12.6, 13.4)
German shepherd dog	V	12.5 (12.2, 12.9)	12.1 (11.8, 12.4)	13.1 (12.7, 13.5)	12.5 (12.3, 12.8)
Golden retriever	V	13.3 (13.0, 13.6)	12.5 (12.4, 12.7)	13.5 (13.1, 13.8)	12.7 (12.6, 12.9)
Labrador retriever	V	13.3 (12.8, 13.6)	12.7 (12.6, 12.8)	13.6 (13.2, 14.0)	13.0 (12.9, 13.2)

558 Data reported are median (99.79% confidence interval) lifespan for male and female dogs of the 12 breeds in the study. ¹ Dogs were
559 classified as ‘normal’ when their body condition was recorded as “normal” between 5.5y and 9.5 y, and if they were never recorded as

560 “thin” or “heavy” at any age; ² Dogs were classified as ‘overweight’ when their body condition was recorded as ‘heavy’ at every visit

561 between 5.5y and 9.5y

562

563 **Figure legends**

564 **Fig 1. Summary of the data cleaning process.** Flow diagram illustrating the data cleaning
565 process to create the final study population. The number of dogs eligible at each stage are
566 depicted, where m denotes million(s) and k denotes thousand(s).

567

568 **Fig 2. Survival probability models for male neutered (a) and female spayed (b) Yorkshire**
569 **terriers.** Middle lines depict the probability of survival for a dog at 7.5y age in 2003 (assuming
570 survival to at least 9.5 years), with the upper and lower lines depicting 99.79 % confidence
571 intervals. The survival of dogs in the normal body condition group is shown in red, whilst that of
572 the overweight group is shown in blue.

573

574 **Fig 3. Survival probability models for male neutered (a) and female spayed (b) Shih tzus.**
575 Middle lines depict the probability of survival for a dog at 7.5y age in 2003 (assuming survival to
576 at least 9.5 years), with the upper and lower lines depicting 99.79 % confidence intervals. The
577 survival of dogs in the normal body condition group is shown in red, whilst that of the overweight
578 group is shown in blue.

579

580 **Fig 4. Survival probability models for male neutered (a) and female spayed (b)**
581 **Dachshunds.** Middle lines depict the probability of survival for a dog at 7.5y age in 2003
582 (assuming survival to at least 9.5 years), with the upper and lower lines depicting 99.79 %
583 confidence intervals. The survival of dogs in the normal body condition group is shown in red,
584 whilst that of the overweight group is shown in blue.

585

586 **Fig 5. Survival probability models for male neutered (a) and female spayed (b) Boxers.**

587 Middle lines depict the probability of survival for a dog at 7.5y age in 2003 (assuming survival to
588 at least 9.5 years), with the upper and lower lines depicting 99.79 % confidence intervals. The
589 survival of dogs in the normal body condition group is shown in red, whilst that of the overweight
590 group is shown in blue.

591

592 **Fig 6. Survival probability models for male neutered (c) and female spayed (d) German**

593 **shepherd dogs.** Middle lines depict the probability of survival for a dog at 7.5y age in 2003
594 (assuming survival to at least 9.5 years), with the upper and lower lines depicting 99.79 %
595 confidence intervals. The survival of dogs in the normal body condition group is shown in red,
596 whilst that of the overweight group is shown in blue.

597

598 **Fig 7. Estimated effect of overweight body condition on lifespan in male (a) and female (b)**

599 **dogs.** The 12 breeds studied have been ordered by size class,²⁰ with columns representing the
600 median, for overweight dogs compared with dogs in normal body condition. The columns
601 indicate medians of 12 breeds and both sexes (MN: male neutered; FS: female spayed). Breeds
602 have been ordered by size class, starting with small breeds.