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1 **Longevity and mortality of owned dogs in England**

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17

18 **Abstract**

19 Improved understanding of longevity represents a significant welfare opportunity for
20 the domestic dog, given its unparalleled morphological diversity. Epidemiological research
21 using electronic patient records (EPRs) collected from primary veterinary practices
22 overcomes many inherent limitations of referral clinic, owner questionnaire and pet insurance
23 data. Clinical health data on 102,609 owned dogs attending first opinion veterinary practices
24 ($n=86$) in central and south-east England were analysed with a focus on 5,095 confirmed
25 deaths.

26

27 Of deceased dogs with information available, 3,961 (77.9%) were purebred, 2,386
28 (47.0%) were female, 2,528 (49.8%) were neutered and 1,105 (21.7%) were insured. The
29 overall median longevity was 12.0 years (IQR 8.9-14.2). The longest-lived breeds were the
30 Miniature poodle, Bearded collie, Border collie and Miniature dachshund while the shortest-
31 lived were the Dogue de Bordeaux and Great Dane. The most frequent attributed causes for
32 death were neoplastic, musculoskeletal and neurological disorders. The results of
33 multivariable modelling indicated that longevity in crossbred dogs exceeded purebred dogs
34 by 1.2 years (95% confidence interval 0.9-1.4; $P<0.001$) and that increasing bodyweight was
35 negatively correlated with longevity. The current findings highlight major breed differences
36 for longevity and support the concept of hybrid vigour in dogs.

37

38 *Keywords:* Dog breed; Epidemiology; Hybrid vigour; Lifespan; Primary practice

39 **Introduction**

40 Improved understanding of the epidemiology of longevity represents an important
41 welfare opportunity for the estimated 8-10 million dogs in the UK, of which 75% are
42 estimated to be purebred (Bonnett et al., 2005; Asher et al., 2011). The domestic dog (*Canis*
43 *lupus familiaris*) exhibits unparalleled morphological diversity (Neff and Rine, 2006) from
44 the 1 kg Chihuahua to the 85 kg Mastiff (Alderton and Morgan, 1993; Neff and Rine, 2006)
45 with substantial breed variation in longevity and mortality (Fleming et al., 2011). Overall
46 longevity estimates vary between 10.0 and 12.0 years depending on the population analysed
47 (Michell, 1999; Proschowsky et al., 2003; Adams et al., 2010) while individual breeds vary
48 substantially; median estimates for Border Collies of 13.0 years (Michell, 1999) and 12.7
49 years (Adams et al., 2010) contrast with estimates in Great Danes of 8.4 years (Michell,
50 1999) and 6.5 years (Adams et al., 2010).

51

52 Purebred status, bodyweight and neuter status have been associated with longevity in
53 dogs (Michell, 1999; Galis et al., 2007; Fleming et al., 2011). Crossbred longevity of 8.5
54 years contrasted with 6.7 years for purebred dogs among a referral caseload in the United
55 States (US) (Patronek et al., 1997) while crossbreds lived to 11.0 years compared with 10.0
56 years for purebreds in Denmark (Proschowsky et al., 2003). A negative correlation between
57 increasing breed bodyweight and longevity has been consistently identified (Galis et al.,
58 2007; Greer et al., 2007; Adams et al., 2010). In the UK neutering was associated with
59 increased longevity for females but not males (Michell, 1999) while neutered males outlived
60 entire males among US military dogs (Moore et al., 2001).

61

62 The most frequent causes of canine death identified among UK purebred dogs were
63 cancer, 'old age' and cardiac disease (Adams et al., 2010), while Swedish dogs died most

64 frequently from cancer, trauma, locomotory disorders, cardiac disease and neurological
65 disease (Bonnett et al., 2005). In the US, referral dogs aged under 1 year died most frequently
66 from traumatic and congenital disorders compared with neoplastic, traumatic and infectious
67 disorders for older dogs (Fleming et al., 2011).

68

69 Inherent biases within data sources may limit application for longevity and mortality
70 studies. Referral caseloads may be biased towards more complicated disorders (Fleming et
71 al., 2011), questionnaire surveys may suffer from selection, recall and misclassification
72 biases (Adams et al., 2010) and pet insurance data are limited by selection bias from the
73 financial excess for claims, age restrictions on insured animals and owner attributes
74 (Egenvall et al., 2009). Research using electronic patient records (EPRs) collected from a
75 broad spectrum of primary veterinary practices has been proposed to redress these
76 limitations. Longitudinal collection of contemporaneously recorded clinical data by
77 veterinary health professionals for all patients and disorders presented to participating
78 primary practices should minimise selection and recall bias effects and improve
79 generalisability (Bateson, 2010). In the UK, VetCompass Animal Surveillance offers an
80 extensive research database of merged primary practice EPRs¹ for robust studies of health
81 parameters of dogs (Kearsley-Fleet et al., 2013; O'Neill et al., 2013).

82 ‘Hybrid vigour’ describes superior average performance of crossbred progeny
83 compared with their purebred parents and has been shown for viability, production and
84 reproduction among production species (Dechow et al., 2007; Nicholas, 2010). ‘Inbreeding
85 depression’ describes the converse effect of declining fitness as inbreeding increases
86 (Whitlock et al., 2000; Keller and Waller, 2002). Despite widespread acceptance in
87 production species (Li et al., 2006; Dechow et al., 2007), there is limited evidence for hybrid

¹ See: www.rvc.ac.uk/VetCompass

88 vigour and inbreeding depression among domestic dogs although inbreeding depression
89 (Liberg et al., 2005) and genetic rescue of inbred populations by outbreeding has been shown
90 for wolves (Tallmon et al., 2004; Fredrickson et al., 2007). Increased longevity of crossbreds
91 compared with purebreds would support the existence of hybrid vigour among domestic dogs
92 (Patronek et al., 1997; Proschowsky et al., 2003).

93

94 Improved understanding of the influence of demographic factors on longevity could
95 improve canine health management and breed selection with consequent welfare gains for
96 domestic dogs. This study aimed to analyse a research database of merged EPRs from
97 primary veterinary practices in England to quantify canine longevity, establish the most
98 common causes of mortality and evaluate associations between demographic risk factors and
99 longevity. It was hypothesised that crossbred would exceed purebred longevity,
100 independently of bodyweight.

101

102 **Materials and methods**

103 The VetCompass Animal Surveillance project² collates de-identified EPR data from
104 primary veterinary practices for epidemiological research. This study included all dogs with
105 clinical data uploaded to the VetCompass database between January 2009 and December
106 2011. Collaborating practices were selected by willingness to participate and the recording of
107 their clinical data within an appropriately configured practice management system (PMS).
108 Practitioners recorded summary diagnosis terms from an embedded VeNom Code list³ during
109 episodes of care. Information collected related to the owned dog population and included
110 patient demographic (species, breed, date of birth, sex, neuter status, insurance status and
111 weight) and clinical information (free-form text clinical notes, summary diagnosis terms,

² See: www.rvc.ac.uk/VetCompass

³ See: www.venomcoding.org

112 treatment and deceased status with relevant dates) data fields. EPR data were extracted from
113 PMSs using integrated clinical queries (Kearsley-Fleet et al., 2013) and uploaded to a secure
114 VetCompass structured query language (SQL) database. Ethical approval of the project was
115 granted by the RVC Ethics and Welfare Committee (reference number 2010 1076).

116

117 Potential death cases identified via the 'deceased animal' field were confirmed using
118 associated 'clinical note' and 'summary diagnosis' fields and the veterinary-recorded reason
119 for death and mechanism of death (assisted i.e. euthanasia, or non-assisted (Rollin, 2009)
120 were noted. Records with single named breeds were grouped as 'purebred' while records with
121 mixed-breed or breed-specified crosses were grouped as 'crossbred'. The neuter and
122 insurance status recorded at death was used. The neuter status recorded at death was
123 combined with the sex status to create a sex/neuter variable with four categories: female
124 entire, female neutered, male entire and male neutered. The maximum bodyweight recorded
125 for dogs older than 1 year was used and categorised into six groups (0.0-9.9 kg, 10.0-19.9 kg,
126 20.0-29.9 kg, 30.0-39.9 kg, 40.0-49.9 kg, 50.0 kg and above, no weight recorded).
127 Veterinary-recorded reasons for death were grouped within pathophysiologic (e.g. neoplastic,
128 neurological) and organ-system (e.g. cardiac, musculoskeletal) categories consistent with the
129 primary practice clinical notes.

130

131 Following data checking and cleaning in Excel (Microsoft Office Excel 2007,
132 Microsoft Corp.), analyses were conducted using Stata Version 11.2 (Stata Corporation).
133 Overall and breed-specific (for study breeds with 20 or more dogs) longevities were reported
134 using median, interquartile range (IQR) and range. Purebred and crossbred median
135 longevities were compared using the Mann-Whitney U test. Causes of mortality were
136 tabulated separately for dogs overall, dogs dying before 3 years of age and dogs dying aged 3

137 years or older. Risk factors of primary interest (purebred status, sex/neuter, weight category)
138 and confounding factors (insured status) were evaluated for association with longevity for
139 dogs dying at 3 years of age or older using general linear regression modelling. Risk factors
140 liberally associated in univariable modelling ($P<0.2$) were taken forward for multivariable
141 evaluation. Model development used backwards stepwise elimination. Clinic attended was
142 evaluated as a random effect and pair-wise interaction effects were evaluated for the final
143 model (Dohoo et al., 2009). Final model predictivity was evaluated with the adjusted r^2 value
144 while model diagnostics included visual inspection of residual and residual-versus-fitted plots
145 to assess normality and homoscedasticity, respectively (Dohoo et al., 2009). Statistical
146 significance was set at $P<0.05$.

147

148 **Results**

149 Overall, 86 practices in central and south-east England shared data on 102,609 dogs
150 with 5,095 confirmed deaths. Of deceased dogs with information on the variable recorded,
151 3,961 (77.9%) were purebred, 1,082 (21.3%) were female entire, 1,304 (25.7%) were female
152 neutered, 1,464 (28.9%) were male entire, 1,224 (24.1%) were male neutered, and 1,105
153 (21.7%) were insured. The distribution of maximum recorded bodyweights was: 0.0-10.0 kg,
154 $n=605$ (11.9%); 10.0-19.9 kg, 677 (13.3%); 20.0-29.9 kg, 596 (11.7%); 30.0-39.9 kg, 437
155 (8.6%); 40.0-49.9 kg, 169 (3.3%); 50.0 kg and above, 82 (1.6%) and no weight recorded after
156 1 year of age, 2,529 (49.6%). The median bodyweights (kg) for crossbreeds (19.4; IQR 13.0-
157 26.0; range 2.0-60.0) and purebreds (20.4; IQR 9.7-31.5; range 0.8-97.8) were not
158 statistically different ($P=0.330$) but their distribution patterns differed substantially;
159 purebreds showed wider bodyweight distribution than crossbreeds (Fig. 1). Euthanasia
160 accounted for 4,153 (86.4%) deaths while 656 (13.6%) deaths were non-assisted.

161

162 Longevity was bi-modally distributed overall, peaking in years 1 and 14, with similar
163 distribution patterns for purebred and crossbred dogs (Fig. 2). The overall median longevity
164 was 12.0 years (IQR 8.9-14.2; range 0.0-24.0). The median longevity for crossbreds (13.1
165 years, IQR 10.1-15.0; range 0.0-22.0) was greater than for purebreds (11.9 years; IQR 8.4-
166 14.0; range 0.0-24.0; $P<0.001$). The longest-lived breeds were the Miniature poodle $n= 20$;
167 median 14.2 years; IQR 11.1-15.6), Bearded collie ($n=25$; 13.7 years; IQR 12.2-14.3), Border
168 collie ($n=184$; 13.5 years; IQR 11.5-15.0), Miniature dachshund ($n=25$; 13.5 years; IQR 9.2-
169 14.3) and the West Highland white terrier ($n=128$; 13.5 years; IQR 10.4-14.9) while the
170 shortest-lived breeds were the Dogue de Bordeaux ($n=21$; 5.5 years; IQR 3.3-6.1) and the
171 Great Dane ($n=23$; 6.0 years; IQR 4.0-9.0 years; Table 1).

172

173 Where a cause of death was recorded ($n=4,434$; 87.0%), the most frequent overall
174 reasons were neoplastic diseases ($n=841$; 16.5%), musculoskeletal disorders ($n=575$; 11.3%)
175 and neurological disorders ($n=569$; 11.2%; Table 2). No substantial differences were noted
176 between purebreds and crossbreds in ranking or proportions for causes of death. Among dogs
177 dying before 3 years of age ($n=489$), the most frequent reasons were behavioural
178 abnormalities ($n=72$; 14.7%), gastrointestinal disorders ($n=71$; 14.5%) and road traffic
179 accidents ($n=62$; 12.7%; Table 3).

180

181 For dogs dying at or after 3 years ($n=4,606$), all risk factors of primary interest
182 evaluated using univariable linear regression modelling (purebred status, sex/ neuter, weight
183 category) and for possible confounding (insurance status) were associated with longevity.
184 Multivariable modelling which included adjusting for bodyweight category indicated a
185 crossbred survival advantage of 1.2 years (95% CI 0.9-1.4; $P<0.001$) over purebred dogs.
186 Increasing bodyweight was associated with decreasing longevity ($P<0.001$). Compared with

187 dogs weighing under 10.00 kg, lifespan was reduced by 0.5 years (95% CI 0.1-0.8, P=0.014)
188 for dogs weighing 10.00-19.99 kg, by 0.7 years (95% CI 0.3-1.1, P<0.001) for dogs weighing
189 20.00-29.99 kg, by 1.4 years (95% CI 1.0-1.8, P<0.001) for dogs weighing 30.00-39.99 kg,
190 by 2.4 years (95% CI 1.8-2.9, P<0.001) for dogs weighing 40.00-49.99 kg and by 4.0 years
191 (95% CI 3.2-4.8, P<0.001) for dogs weighing at or above 50.0 kg. ~~Neutering was associated~~
192 ~~with 0.5 years (95% CI 0.3-0.7; P<0.001) greater longevity while being insured was~~
193 ~~associated with 1.5 years (95% CI 1.3-1.7; P<0.001) reduced longevity, although these values~~
194 ~~should be interpreted cautiously (see Discussion; Table 5).~~ Compared with entire females, the
195 other sex/neuter groups showed significantly longer lifespan: female neutered (0.8 years,
196 95% CI: 0.5-1.1, P<0.001), male entire (0.4 years, 95% CI: 0.1-0.7, P=0.010) and male
197 neutered (0.4 years, 95% CI: 0.1-0.7, P=0.003). Insurance status did not substantially
198 confound the final model values (Table 4).

199

200 Graphical inspection of final-model residuals did not suggest major departures from
201 normality nor homoscedasticity but a relatively low adjusted r^2 value (0.081) indicated that
202 only 8.1% of variation in the data was accounted for within the model. Adjusting for
203 clustering within veterinary clinics did not materially affect the results. No significant
204 interactions were detected between final model variables.

205

206 **Discussion**

207 The current study reports an overall median longevity for dogs of 12.0 years. Dogs
208 died before 3 years of age mainly from behavioural, gastro-intestinal and traumatic causes
209 while later deaths were mainly from neoplastic, musculoskeletal and neurological causes.
210 Crossbred dogs as a group lived 1.2 years longer than purebreds independently of

211 bodyweight. Increasing bodyweight was associated with decreasing mean longevity. Entire
212 females lived shorter lives than neutered females, entire males or neutered males.

213

214 The overall median longevity for dogs of 12.0 years reported here agrees with the
215 median estimate of 12.0 years from UK insured or dog-show attending dogs (Michell, 1999)
216 but exceeds the 10.0 years reported for Danish dogs perhaps because of that study
217 population's reduced crossbred component (9.5%) compared with the current study (22.1%)
218 (Proschowsky et al., 2003). The substantially lower median longevity (7.1 years) reported for
219 US referral dogs (of which 23.8% were crossbreds) prompts caution when generalising from
220 referral to the general dog population (Patronek et al., 1997). The median longevity of 11.9
221 years identified for purebred dogs in the current study is comparable to the 11.3 years
222 identified among Kennel Club registered dogs in the UK (Adams et al., 2010). We chose to
223 report median rather than mean values for overall longevity because extreme values from
224 non-normally distributed longevity distributions exert disproportionate effects on the mean
225 (Kirkwood and Sterne, 2003).

226

227 The longest-lived breeds identified (Miniature Poodle (median 14.2 years), Bearded
228 Collie (13.7 years) and Border Collie (13.5 years)) also featured among the most long-lived
229 UK purebred dogs (Miniature Poodle (13.9 years), Bearded Collie (13.5 years) and Border
230 Collie (14.0 years)) (Adams et al., 2010) while Poodles (12.0 years) and the Shetland
231 Sheepdog (12.0 years) were among the longest living breeds in Denmark (Proschowsky et
232 al., 2003). The shortest lived breeds in the current study (Dogue de Bordeaux (5.5 years),
233 Great Dane (6.0 years) and the Mastiff (7.1 years)) also featured among the 11 UK purebreds
234 with the lowest median age at death (Dogue de Bordeaux (3.8 years), Great Dane (6.5 years))

235 and the Mastiff (6.8 years)) (Adams et al., 2010). These results indicate consistently wide
236 longevity variation between breeds and worryingly short lifespans for some breeds.

237

238 A bimodal longevity distribution suggested separation of young and older dogs to
239 optimise statistical analysis and biological interpretation. Younger dogs died mainly from
240 behavioural, gastro-intestinal and traumatic processes while older dogs died mainly from
241 degenerative disorders. Bimodal age pattern for death were previously shown for dogs in the
242 UK (Michell, 1999) and US (Gobar, 1998) but were not dissected to direct further analyses.

243

244 The most frequent causes of overall mortality identified in the current study
245 (neoplasia (16.6%), musculoskeletal disease (11.4%) and neurological disease (11.2%))
246 contrast with the causes described from a survey of owners of UK purebred dogs (neoplasia
247 (27.0%), 'old age' (17.8%) and cardiac disease (11.1%) (Adams et al., 2010) while a DKC
248 owner survey prioritised 'old age' (20.8%) and cancer (14.5%) (Proschowsky et al., 2003).
249 Recall and misclassification bias within questionnaire surveys (Rockenbauer et al., 2001)
250 combined with breeders' focus on specific disorders may explain the differing patterns
251 reported. 'Old age' fails to describe a pathological process underlying mortality and so was
252 avoided as a cause of death in the current study. The most frequent causes of death reported
253 among insured Swedish dogs (aged under 10 years) were neoplasia (17.83%), traumatic
254 injuries (16.88%) and locomotory disorders (13.46%) (Bonnett et al., 2005). The high
255 proportion of traumatic deaths recorded in that study may reflect a reporting bias towards
256 claims related to conditions in younger dogs (Bonnett et al., 1997) as well as international
257 differences in dog characteristics and their environments (Bonnett et al., 2005).

258

259 There are limited published data that quantify assisted and non-assisted modes of
260 death for dogs. The euthanasia value for the current study (86.4%) exceeds the results of a
261 UK owner survey reporting 52% euthanasia (Michell, 1999) and a US online surveillance
262 study of veterinary surgeons reporting 71% euthanasia (Gobar, 1998) and a US referral study
263 showing 68.5% and 70.2% euthanasia for purebreds and crossbreeds respectively (Patronek et
264 al., 1997). Euthanasia decisions can present moral dilemmas for veterinary surgeons (Yeates
265 and Main, 2011) and emotional turmoil for owners (McCutcheon and Fleming, 2001/2002).
266 The higher euthanasia values reported in the current study may reflect increasing
267 prioritisation for quality over quantity of life.

268

269 This study tested a hypothesis that crossbred dogs show increased longevity compared
270 with purebreds independently of bodyweight based on predicted effects from hybrid vigour.
271 A previous US study of referral dogs compared purebred and crossbred longevity across 5
272 weight categories and showed that age at death for purebred dogs was significantly less
273 ($P=0.0001$) than for crossbreeds for each weight group (Patronek et al., 1997). In the current
274 study among primary care dogs dying after 3 years of age, crossbreeds showed a 1.2 year
275 survival advantage over purebreds after adjusting for differences in bodyweight status, sex
276 and neuter status. This finding suggests that hybrid vigour for longevity applies to dogs. No
277 single unifying theory is accepted to explain hybrid vigour (Milborrow, 1998) but a plausible
278 explanation for the current findings is that hybrid dogs are simply less likely to be
279 homozygous for deleterious genes (McGreevy and Nicholas, 1999) although other genetic
280 and non-genetic differences between purebreds and crossbreeds, including management styles,
281 may contribute. However, despite the greater overall longevity of crossbreeds compared with
282 purebreds, the wide variation in longevity identified between individual breeds is worth
283 noting, with some pure breeds living longer than crossbreeds.

284

285 Validity of findings from scientific studies using practice records requires evidence of
286 high quality data. The accuracy of clinical data can be measured by evaluating completeness
287 (proportion of records that contain information) and correctness (proportion of records that
288 agree with an accepted gold standard) (Penell et al., 2009). Analysis of the VetCompass
289 database for dogs identified completeness values greater than 99% for breed, sex, neuter
290 status, insured status and date of birth (Dan O'Neill, unpublished results). The Kennel Club
291 dog registration database is the most comprehensive record of UK pedigree dogs, registering
292 over 200,000 dogs annually (Calboli et al., 2008) and can be accepted as a gold standard. In a
293 sample of approximately 3,000 dogs that were cross-linked between the VetCompass and KC
294 pedigree database based on their microchip number, there was over 99% agreement for breed
295 and sex and 97% agreement for date of birth (within 90 days) (Dan O'Neill, unpublished
296 results). These high accuracy values support the use of EPR data for research purposes.

297 Larger mammalian species generally outlive smaller species (Galis et al., 2007).
298 However, the current study identified a substantial negative correlation between bodyweight
299 and longevity within dogs as a species, in agreement with previous reports in dogs (Patronek
300 et al., 1997; Michell, 1999; Greer et al., 2007; Adams et al., 2010). Earlier mortality among
301 larger dog breeds has been attributed to genetic differences and pathological conditions
302 induced by artificial selection and accelerated growth (Galis et al., 2007; Urfer et al., 2007;
303 Fleming et al., 2011; Salvin et al., 2012).

304

305 There were some study limitations. Only practice-attending dogs were included, so
306 data were not captured on unowned dogs or dogs that did not receive veterinary attention. It
307 was possible that death data were not captured on some dogs that died at home or at
308 emergency out-of-hours clinics, but many owners of such dogs informed their practices to

309 update the EPRs accordingly while emergency clinics routinely shared clinical notes with the
310 primary-care practices. The results for neutering should be interpreted with caution because
311 this variable was modelled as time-independent (i.e. a single value applies throughout life)
312 due to the nature of the available data but, in reality, neutering is time-dependent with the
313 probability of attaining neutered status increasing with age (van Hagen et al., 2005). A recent
314 paper has demonstrated how categorising female dogs as spayed or intact at time of death can
315 distort the relationship between lifetime ovary exposure and longevity (Waters et al., 2011).
316 Cause of death was available for only 87.0% of cases. Adult (over one year of age) weight
317 data were available for only 50.3% of dogs overall. Imputation to replace the missing weight
318 values was explored (Royston and White, 2011) but, because of the high proportional
319 imputation requirement, it was decided instead to add a category covering dogs without
320 weight data to allow inclusion of the maximal number of dogs into the final model. The
321 results from both methods were broadly similar. The low adjusted r^2 value indicated that
322 other unmeasured variables contributed substantially to longevity variation for individual
323 animals and that, while the study results may explain effects at the overall population level,
324 accurate prediction of longevity for individual animals remains elusive.

325

326 **Conclusions**

327 Crossbred dogs overall had significantly greater median longevity than purebred dogs,
328 independently of bodyweight. Increasing bodyweight was negatively correlated with
329 longevity. The most long-lived breeds were the Miniature poodle, Bearded collie, Border
330 collie and Miniature dachshund while the shortest surviving were the Dogue de Bordeaux and
331 Great Dane. Dogs died before 3 years of age predominantly because of behavioural
332 abnormalities, gastrointestinal disorders and road traffic accidents while dogs died at 3 years
333 of age or older predominantly because of neoplastic, musculoskeletal and neurological

334 disorders. Using these findings to tailor breed selection and veterinary health management
335 decisions could increase the quantity and quality of life enjoyed by dogs overall and improve
336 canine welfare.

337

338 **Conflict of interest statement**

339 None of the authors of this paper has a financial or personal relationship with other
340 people or organisations that could inappropriately influence or bias the content of the paper.

341

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348

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- 451

452 **Table 1**

453 Longevity for dog breeds (with 20 or more study animals) attending primary veterinary
 454 practices in England ranked by median age at death. The interquartile range (IQR), range and
 455 number of study dogs are also shown ($n=5,095$).

Breed	Median (years)	IQR	Range	No. of dogs
Miniature poodle	14.2	11.1-15.6	2.0-19.4	20
Bearded collie	13.7	12.2-14.3	4.0-17.0	25
Border collie	13.5	11.5-15.0	0.1-19.1	184
Miniature dachshund	13.5	9.2-14.3	2.0-19.5	25
West Highland white terrier	13.5	10.4-14.9	0.2-21.0	128
Cairn terrier	13.4	10.6-15.4	0.2-21.6	27
Jack Russell terrier	13.4	9.3-15.7	0.0-24.0	298
Shih-tzu	13.3	9.2-15.6	0.0-18.6	79
English Springer spaniel	13.3	10.4-14.8	0.3-19.4	111
Dalmatian	13.3	11.5-14.0	0.9-17.2	27
Crossbreed	13.1	10.1-15.0	0.0-22.0	1120
Yorkshire terrier	13.0	10.0-15.1	0.01-20.6	217
Lhasa Apso	13.0	7.7-15.3	0.0-16.7	32
Bichon Frise	12.7	9.5-14.8	0.1-18.5	56
Weimaraner	12.6	11.1-13.5	6.5-17.0	36
Labrador retriever	12.5	10.6-14.0	0.0-18.0	418
Golden retriever	12.5	11.0-14.09	0.1-17.6	114
Shetland sheepdog	12.5	11.7-13.8	8.5-14.6	20
Rough collie	12.0	9.4-13.8	1.0-17.1	28
Border terrier	12.0	8.9-13.1	1.2-21.2	31
King Charles spaniel	12.0	10.0-14.2	0.0-15.3	26
Scottish terrier	12.0	9.1-12.7	0.3-15.9	21
Cocker spaniel	11.5	7.5-13.7	0.0-18.0	145
Bull terrier	11.2	7.3-13.0	1.4-16.3	36
German shepherd dog	11.0	9.2-12.9	0.0-18.0	312
Greyhound	10.8	8.1-12.0	2.5-16.3	88
Staffordshire bull terrier	10.7	4.7-14.0	0.0-18.1	300
Boxer	10.0	7.7-11.6	0.0-16.5	91
Cavalier King Charles spaniel	9.9	8.1-12.3	0.0-17.2	124
Doberman	9.2	6.2-11.0	2.1-13.0	37
Bulldog	8.4	3.2-11.3	0.4-15.2	26
Rottweiler	8.0	5.5-10.2	0.0-16.6	105
Chihuahua	7.1	1.0-11.9	0.0-19.9	36
Mastiff	7.1	2.01-9.01	0.0-13.8	35
Great Dane	6.0	4.0-9.0	0.0-11.0	23
Dogue de Bordeaux	5.5	3.3-6.1	0.0-8.8	21

456

457

458 **Table 2**

459 Frequent causes of death among dogs of all ages attending primary veterinary practices in
 460 England, ranked by the number of attributed deaths. The median, interquartile range (IQR)
 461 and range for the age (years) at death are reported ($n=5,095$).

Attributed cause	No. deaths	Median age	IQR	Range
Neoplastic	841 (16.5%)	11.7	9.4-13.5	0.4-22.0
No cause recorded	661 (13.0%)	12.5	9.3-14.5	0.0-21.0
Musculoskeletal	575 (11.3%)	13.5	11.7-15.0	0.3-20.0
Neurological	569 (11.2%)	13.0	10.0-14.8	0.1-23.0
Gastrointestinal	332 (6.5%)	10.5	5.0-13.7	0.0-21.0
Cardiac	265 (5.2%)	12.0	9.0-14.2	0.0-20.0
Behavioural abnormality	202 (4.0%)	4.2	2.0-8.0	0.4-16.0
Respiratory	197 (3.9%)	11.9	9.0-13.6	0.0-18.0
Collapse	186 (3.7%)	13.8	11.5-15.0	0.0-20.3
Renal/urinary	178 (3.5%)	12.0	9.7-14.2	0.8-21.6
Anorexia/losing weight	123 (2.4%)	13.3	11.3-15.8	0.0-20.8
Road traffic accident (RTA)	102 (2.0%)	2.0	1.0-5.0	0.2-17.0
Incontinence	96 (1.9%)	13.9	12.9-15.3	0.7-18.2
Abdominal problem	77 (1.5%)	11.8	9.5-13.5	0.0-18.0
Trauma	70 (1.4%)	4.0	0.7-9.0	0.1-18.7
Reproductive	56 (1.1%)	11.2	8.0-13.2	0.9-17.3
Dermatological	50 (1.0%)	10.0	7.8-13.0	0.6-17.5
Diabetes mellitus	50 (1.0%)	11.2	10.0-13.8	4.2-17.9
Congenital defect	25 (0.5%)	0.0	0.0-0.1	0.0-5.1
Dangerous Dogs Act	15 (0.3%)	2.0	1.0-2.0	0.3-5.0

462

463

464 **Table 3**

465 Frequent attributed causes of death for dogs attending primary veterinary practices in
 466 England that died before 3 years of age ($n=489$) and for dogs dying aged 3 years and older
 467 ($n=4,606$), ranked by the number of attributed deaths.

Attributed cause of death	<3 years		≥3 years	
	Rank	No. deaths	Rank	No. deaths
Behavioural abnormality	1	72 (14.7%)	10	130 (2.8%)
Gastrointestinal (GIT)	2	71 (14.5%)	5	261 (5.7%)
No cause recorded	3	65 (13.3%)	2	596 (13.0%)
Road traffic accident (RTA)	4	62 (12.7%)		
Neurological	5	36 (7.4%)	4	533 (11.6%)
Trauma	6	32 (6.5%)		
Congenital defect	7	24 (4.9%)		
Respiratory	8	18 (3.7%)	7	179 (3.9%)
Cardiac	9	13 (2.7%)	6	252 (5.5%)
Dangerous Dogs Act	10	12 (2.5%)		
Collapse	11	10 (2.0%)	8	176 (3.8%)
Neoplastic	12	10 (2.0%)	1	831 (18.2%)
Anorexia/losing weight	13	9 (1.8%)	11	114 (2.5%)
Musculoskeletal	14	8 (1.6%)	3	567 (12.4%)
Renal/urinary	15	7 (1.4%)	9	171 (3.7%)
Incontinence			13	94 (2.1%)
Abdominal (non-GIT)			14	75 (1.6%)
Reproductive			15	54 (1.2%)
Diabetes mellitus			16	50 (1.1%)

468

469

470 **Table 4**

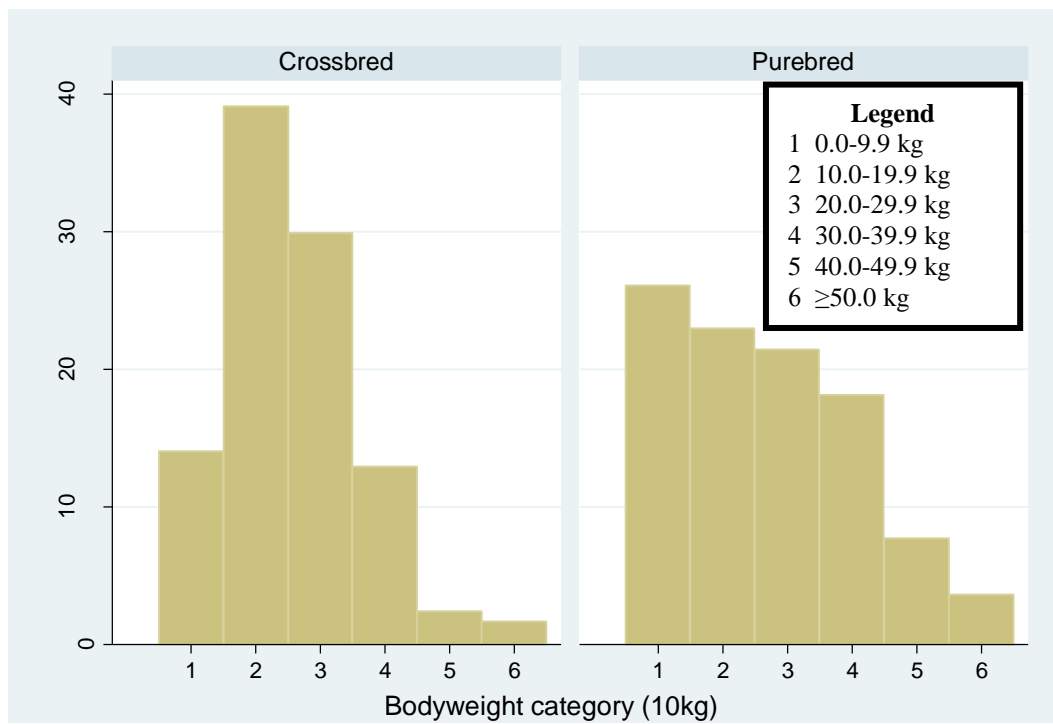
471 Final multivariable linear regression results for risk factors associated with longevity (years)
 472 in owned dogs ($n=2,481$) attending veterinary practices in England that died at or over 3
 473 years of age. The co-efficient indicates the average longevity difference in years compared
 474 with the baseline group.

Variable	Coefficient	95% Confidence interval	<i>P</i> value
Crossbred/Purebred			
Crossbred	Baseline	-	-
Purebred	-1.2	-1.4 to -0.9	<0.001
Bodyweight			
<10.00 kg	Baseline	-	-
10.00-19.99 kg	-0.5	-0.8 to -0.1	0.014
20.00-29.99 kg	-0.7	-1.1 to -0.3	<0.001
30.00-39.99 kg	-1.4	-1.8 to -1.0	<0.001
40.00-49.99 kg	-2.4	-2.9 to -1.8	<0.001
≥ 50.00 kg	-4.0	-4.8 to -3.2	<0.001
No weight recorded	0.2	-0.1 to 0.5	0.174
Sex			
Female entire	Baseline	-	-
Female neutered	0.8	0.5 to 1.1	<0.001
Male entire	0.4	0.1 to 0.7	0.010
Male neutered	0.4	0.1 to 0.7	0.003

475

476 **Figures**

477

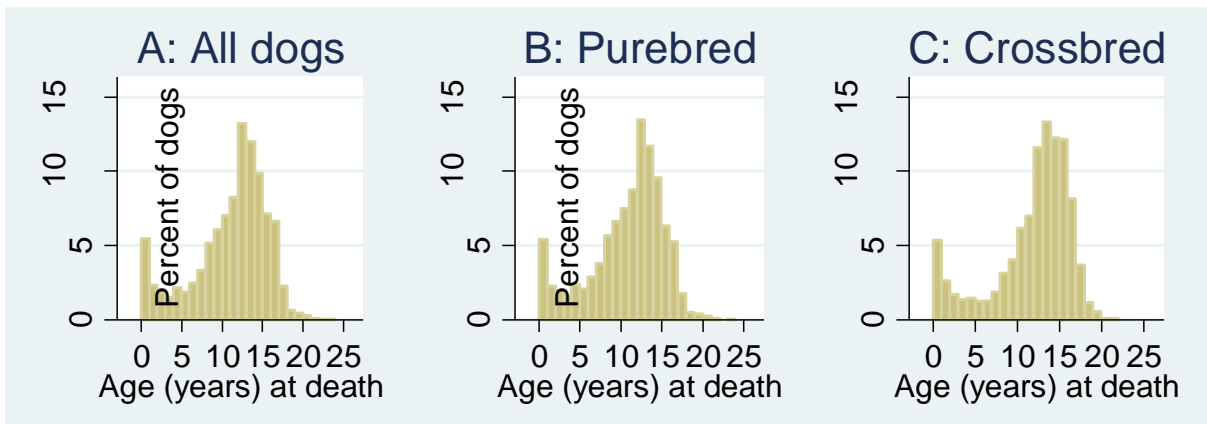


478

479 Fig. 1. Bodyweight distribution patterns (maximum recorded bodyweights for dogs aged over
480 1 year of age) for crossbred ($n=542$) and purebred ($n=2,023$) deceased dogs that had attended
481 primary veterinary practices in England.

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484

485 Fig. 2. Distribution patterns for age at death of dogs attending primary veterinary practices in

486 England showing the percentage of dogs that died within one-year age bands. A: all dog types

487 ($n=5,095$). B: purebred dogs ($n=3,961$). C: crossbred dogs ($n=1,124$). Note: 10 records held

488 no breed data.