Longevity and mortality of owned dogs in England

D.G. O'Neill [a, *], D.B. Church [b], P.D. McGreevy [c], P.C. Thomson [c], D.C. Brodbelt [a]

[a] *Veterinary Epidemiology, Economics and Public Health, The Royal Veterinary College, Hawkshead Lane, North Mymms, Hatfield, Herts AL9 7TA, UK*
[b] *Small Animal Medicine and Surgery Group , The Royal Veterinary College, Hawkshead Lane, North Mymms, Hatfield, Herts AL9 7TA, UK*
[c] *R.M.C. Gunn Building (B19), Faculty of Veterinary Science, The University of Sydney, NSW 2006, UK*

* Corresponding author. Tel.: +44 775 1057161.
E-mail address: doneill@rvc.ac.uk (D.G. O'Neill).

Abstract

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

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

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

Introduction

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

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

The most frequent causes of canine death identified among UK purebred dogs were cancer, ‘old age’ and cardiac disease (Adams et al., 2010), while Swedish dogs died most frequently from cancer, trauma, locomotory disorders, cardiac disease and neurological disease (Bonnett et al., 2005). In the US, referral dogs aged under 1 year died most frequently from traumatic and congenital disorders compared with neoplastic, traumatic and infectious disorders for older dogs (Fleming et al., 2011).

Inherent biases within data sources may limit application for longevity and mortality studies. Referral caseloads may be biased towards more complicated disorders (Fleming et al., 2011), questionnaire surveys may suffer from selection, recall and misclassification biases (Adams et al., 2010) and pet insurance data are limited by selection bias from the financial excess for claims, age restrictions on insured animals and owner attributes (Egenvall et al., 2009). Research using electronic patient records (EPRs) collected from a broad spectrum of primary veterinary practices has been proposed to redress these limitations. Longitudinal collection of contemporaneously recorded clinical data by veterinary health professionals for all patients and disorders presented to participating primary practices should minimise selection and recall bias effects and improve generalisability (Bateson, 2010). In the UK, VetCompass Animal Surveillance offers an extensive research database of merged primary practice EPRs[1] for robust studies of health parameters of dogs (Kearsley-Fleet et al., 2013; O'Neill et al., 2013).

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

[1] See: www.rvc.ac.uk/VetCompass

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

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

Materials and methods

The VetCompass Animal Surveillance project[2] collates de-identified EPR data from primary veterinary practices for epidemiological research. This study included all dogs with clinical data uploaded to the VetCompass database between January 2009 and December 2011. Collaborating practices were selected by willingness to participate and the recording of their clinical data within an appropriately configured practice management system (PMS). Practitioners recorded summary diagnosis terms from an embedded VeNom Code list[3] during episodes of care. Information collected related to the owned dog population and included patient demographic (species, breed, date of birth, sex, neuter status, insurance status and weight) and clinical information (free-form text clinical notes, summary diagnosis terms,

[2] See: www.rvc.ac.uk/VetCompass
[3] See: www.venomcoding.org

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

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

Following data checking and cleaning in Excel (Microsoft Office Excel 2007, Microsoft Corp.), analyses were conducted using Stata Version 11.2 (Stata Corporation). Overall and breed-specific (for study breeds with 20 or more dogs) longevities were reported using median, interquartile range (IQR) and range. Purebred and crossbred median longevities were compared using the Mann-Whitney U test. Causes of mortality were tabulated separately for dogs overall, dogs dying before 3 years of age and dogs dying aged 3 years or older. Risk factors of primary interest (purebred status, sex/neuter, weight category) and confounding factors (insured status) were evaluated for association with longevity for dogs dying at 3 years of age or older using general linear regression modelling. Risk factors liberally associated in univariable modelling (P<0.2) were taken forward for multivariable evaluation. Model development used backwards stepwise elimination. Clinic attended was evaluated as a random effect and pair-wise interaction effects were evaluated for the final model (Dohoo et al., 2009). Final model predictivity was evaluated with the adjusted r^2 value while model diagnostics included visual inspection of residual and residual-versus-fitted plots to assess normality and homoscedasticity, respectively (Dohoo et al., 2009). Statistical significance was set at P<0.05.

Results

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

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

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

For dogs dying at or after 3 years (*n*=4,606), all risk factors of primary interest evaluated using univariable linear regression modelling (purebred status, sex/ neuter, weight category) and for possible confounding (insurance status) were associated with longevity. Multivariable modelling which included adjusting for bodyweight category indicated a crossbred survival advantage of 1.2 years (95% CI 0.9-1.4; *P*<0.001) over purebred dogs. Increasing bodyweight was associated with decreasing longevity (*P*<0.001). Compared with dogs weighing under 10.00 kg, lifespan was reduced by 0.5 years (95% CI 0.1-0.8, P=0.014) for dogs weighing 10.00-19.99 kg, by 0.7 years (95% CI 0.3-1.1, P<0.001) for dogs weighing 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, 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 (95% CI 3.2-4.8, P<0.001) for dogs weighing at or above 50.0 kg. ~~Neutering was associated with 0.5 years (95% CI 0.3-07; *P*<0.001) greater longevity while being insured was associated with 1.5 years (95% CI 1.3-1.7; *P*<0.001) reduced longevity, although these values should be interpreted cautiously (see Discussion; Table 5)~~. Compared with entire females, the other sex/neuter groups showed significantly longer lifespan: female neutered (0.8 years, 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 neutered (0.4 years, 95% CI: 0.1-0.7, P=0.003). Insurance status did not substantially confound the final model values (Table 4).

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

Discussion

The current study reports an overall median longevity for dogs of 12.0 years. Dogs died before 3 years of age mainly from behavioural, gastro-intestinal and traumatic causes while later deaths were mainly from neoplastic, musculoskeletal and neurological causes. Crossbred dogs as a group lived 1.2 years longer than purebreds independently of bodyweight. Increasing bodyweight was associated with decreasing mean longevity. Entire females lived shorter lives than neutered females, entire males or neutered males.

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

The longest-lived breeds identified (Miniature Poodle (median 14.2 years), Bearded Collie (13.7 years) and Border Collie (13.5 years)) also featured among the most long-lived UK purebred dogs (Miniature Poodle (13.9 years), Bearded Collie (13.5 years) and Border Collie (14.0 years)) (Adams et al., 2010) while Poodles (12.0 years) and the Shetland Sheepdog (12.0 years) were among the longest living breeds in Denmark (Proschowsky et al., 2003). The shortest lived breeds in the current study (Dogue de Bordeaux (5.5 years), Great Dane (6.0 years) and the Mastiff (7.1 years)) also featured among the 11 UK purebreds with the lowest median age at death (Dogue de Bordeaux (3.8 years), Great Dane (6.5 years) and the Mastiff (6.8 years)) (Adams et al., 2010). These results indicate consistently wide longevity variation between breeds and worryingly short lifespans for some breeds.

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

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

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

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

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

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

There were some study limitations. Only practice-attending dogs were included, so data were not captured on unowned dogs or dogs that did not receive veterinary attention. It was possible that death data were not captured on some dogs that died at home or at emergency out-of-hours clinics, but many owners of such dogs informed their practices to update the EPRs accordingly while emergency clinics routinely shared clinical notes with the primary-care practices. The results for neutering should be interpreted with caution because this variable was modelled as time-independent (i.e. a single value applies throughout life) due to the nature of the available data but, in reality, neutering is time-dependent with the probability of attaining neutered status increasing with age (van Hagen et al., 2005). A recent paper has demonstrated how categorising female dogs as spayed or intact at time of death can distort the relationship between lifetime ovary exposure and longevity (Waters et al., 2011). Cause of death was available for only 87.0% of cases. Adult (over one year of age) weight data were available for only 50.3% of dogs overall. Imputation to replace the missing weight values was explored (Royston and White, 2011) but, because of the high proportional imputation requirement, it was decided instead to add a category covering dogs without weight data to allow inclusion of the maximal number of dogs into the final model. The results from both methods were broadly similar. The low adjusted r^2 value indicated that other unmeasured variables contributed substantially to longevity variation for individual animals and that, while the study results may explain effects at the overall population level, accurate prediction of longevity for individual animals remains elusive.

Conclusions

Crossbred dogs overall had significantly greater median longevity than purebred dogs, independently of bodyweight. Increasing bodyweight was negatively correlated with longevity. The most long-lived breeds were the Miniature poodle, Bearded collie, Border collie and Miniature dachshund while the shortest surviving were the Dogue de Bordeaux and Great Dane. Dogs died before 3 years of age predominantly because of behavioural abnormalities, gastrointestinal disorders and road traffic accidents while dogs died at 3 years of age or older predominantly because of neoplastic, musculoskeletal and neurological disorders. Using these findings to tailor breed selection and veterinary health management decisions could increase the quantity and quality of life enjoyed by dogs overall and improve canine welfare.

Conflict of interest statement

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

Acknowledgments

Support by the Royal Society for the Prevention of Cruelty to Animals (RSPCA) for this study is gratefully acknowledged. We thank Peter Dron (Royal Veterinary College) for database development and the Kennel Club for collaboration in validation of the study database. We are especially grateful to the Medivet Veterinary Partnership and other UK practices and clients for participating in VetCompass.

References

Adams, V.J., Evans, K.M., Sampson, J., Wood, J.L.N., 2010. Methods and mortality results of a health survey of purebred dogs in the UK. Journal of Small Animal Practice 51, 512-524.

Alderton, D., Morgan, T., 1993. Dogs. Dorling Kindersley, London, pp. 1-304.

Asher, L., Buckland, E., Phylactopoulos, C.L., Whiting, M., Abeyesinghe, S., Wathes, C., 2011. Estimation of the number and demographics of companion dogs in the UK. BMC Veterinary Research 7, 74.

Bateson, P., 2010. Independent inquiry into dog breeding. University of Cambridge, Cambridge.

Bonnett, B.N., Egenvall, A., Hedhammar, Å., Olson, P., 2005. Mortality in over 350,000 insured Swedish dogs from 1995-2000: I. breed-, gender-, age- and cause-specific rates. Acta Veterinaria Scandinavica 46, 105-120.

Bonnett, B.N., Egenvall, A., Olson, P., Hedhammar, Å., 1997. Mortality in insured Swedish dogs: rates and causes of death in various breeds. Veterinary Record 141, 40-44.

Calboli, F.C., Sampson, J., Fretwell, N., Balding, D.J., 2008. Population structure and inbreeding from pedigree analysis of purebred dogs. Genetics 179, 593-601.

Dechow, C.D., Rogers, G.W., Cooper, J.B., Phelps, M.I., Mosholder, A.L., 2007. Milk, fat, protein, somatic cell score, and days open among Holstein, Brown Swiss, and their crosses. Journal of Dairy Science 90, 3542-3549.

Dohoo, I., Martin, W., Stryhn, H., 2009. Veterinary Epidemiologic Research. VER Inc., Charlottetown, Canada.

Egenvall, A., Nodtvedt, A., Penell, J., Gunnarsson, L., Bonnett, B.N., 2009. Insurance data for research in companion animals: benefits and limitations. Acta Veterinaria Scandinavica 51, 42.

Fleming, J.M., Creevy, K.E., Promislow, D.E.L., 2011. Mortality in North American dogs from 1984 to 2004: an investigation into age-, size-, and breed-related causes of death. Journal of Veterinary Internal Medicine 25, 187-198.

Fredrickson, R.J., Siminski, P., Woolf, M., Hedrick, P.W., 2007. Genetic rescue and inbreeding depression in Mexican wolves. Proceedings of the Royal Society B: Biological Sciences 274, 2365-2371.

Galis, F., Van Der Sluijs, I., Van Dooren, T.J.M., Metz, J.A.J., Nussbaumer, M., 2007. Do large dogs die young? Journal of Experimental Zoology Part B: Molecular and Developmental Evolution 308B, 119-126.

Gobar, G.M., 1998. Program for surveillance of causes of death of dogs, using the Internet to survey small animal veterinarians. Journal of the American Veterinary Medical Association 213, 251-256.

Greer, K.A., Canterberry, S.C., Murphy, K.E., 2007. Statistical analysis regarding the effects of height and weight on life span of the domestic dog. Research in Veterinary Science 82, 208-214.

Kearsley-Fleet, L., O'Neill, D.G., Volk, H.A., Church, D.B., Brodbelt, D.C., 2013. Prevalence and risk factors for canine epilepsy of unknown origin in the UK. Veterinary Record 172, 338.

Keller, L.F., Waller, D.M., 2002. Inbreeding effects in wild populations. Trends in Ecology and Evolution 17, 230-241.

Kirkwood, B.R., Sterne, J.A.C., 2003. Essential medical statistics. Blackwell Science, Oxford, pp. 33-41.

Li, Y., van der Werf, J.H., Kinghorn, B.P., 2006. Optimization of a crossing system using mate selection. Genetics, selection, evolution : GSE 38, 147-165.

Liberg, O., Andrén, H., Pedersen, H.-C., Sand, H., Sejberg, D., Wabakken, P., Åkesson, M., Bensch, S., 2005. Severe inbreeding depression in a wild wolf Canis lupus population. Biology Letters 1, 17-20.

McCutcheon, K.A., Fleming, S.J., 2001/2002. Grief resulting from euthanasia and natural death of companion animals. Journal of Death and Dying 44, 169-188.

McGreevy, P.D., Nicholas, F.W., 1999. Some practical solutions to welfare problems in dog breeding. Animal Welfare 8, 329-341.

Michell, A.R., 1999. Longevity of British breeds of dog and its relationships with sex, size, cardiovascular variables and disease. Veterinary Record 145, 625-629.

Milborrow, B.V., 1998. A biochemical mechanism for hybrid vigour. Journal of Experimental Botany 49, 1063-1071.

Moore, G.E., Burkman, K.D., Carter, M.N., Peterson, M.R., 2001. Causes of death or reasons for euthanasia in military working dogs: 927 cases (1993–1996). Journal of the American Veterinary Medical Association 219, 209-214.

Neff, M.W., Rine, J., 2006. A fetching model organism. Cell 124, 229-231.

Nicholas, F.W., 2010. Introduction to veterinary genetics. Wiley-Blackwell, Oxford, pp. 254-266.

O'Neill, D.G., Elliott, J., Church, D.B., McGreevy, P.D., Thomson, P.C., Brodbelt, D.C., 2013. Chronic kidney disease in dogs in UK veterinary practices: prevalence, risk factors, and survival. Journal of Veterinary Internal Medicine 27, 814-821.

Patronek, G.J., Waters, D.J., Glickman, L.T., 1997. Comparative longevity of pet dogs and humans: implications for gerontology research. Journal of Gerontology: Biological Sciences 52, B171-B178.

Penell, J.C., Bonnett, B.N., Pringle, J., Egenvall, A., 2009. Validation of computerized diagnostic information in a clinical database from a national equine clinic network. Acta Veterinaria Scandinavica 51, 50.

Proschowsky, H.F., Rugbjerg, H., Ersbøll, A.K., 2003. Mortality of purebred and mixed-breed dogs in Denmark. Preventive Veterinary Medicine 58, 63-74.

Rockenbauer, M., Olsen, J., Czeizel, A.E., Pedersen, L., Sørensen, H.T., 2001. Recall bias in a case-control surveillance system on the use of medicine during pregnancy. Epidemiology 12, 461-466.

Rollin, B.E., 2009. Ethics and euthanasia. Canadian Veterinary Journal 50, 1081-1086.

Royston, P., White, I.R., 2011. Multiple imputation by chained equations (MICE): implementation in Stata. Journal of Statistical Software 45, 1-20.

Salvin, H.E., McGreevy, P.D., Sachdev, P.S., Valenzuela, M.J., 2012. The effect of breed on age-related changes in behavior and disease prevalence in cognitively normal older community dogs, Canis lupus familiaris. Journal of Veterinary Behavior: Clinical Applications and Research 7, 61-69.

Tallmon, D.A., Luikart, G., Waples, R.S., 2004. The alluring simplicity and complex reality of genetic rescue. Trends in Ecology and Evolution 19, 489-496.

Urfer, S.R., Gaillard, C., Steiger, A., 2007. Lifespan and disease predispositions in the Irish Wolfhound: A review. Veterinary Quarterly 29, 102-111.

van Hagen, M.A.E., Ducro, B.J., van den Broek, J., Knol, B.W., 2005. Life expectancy in a birth cohort of Boxers followed up from weaning to 10 years of age. American Journal of Veterinary Research 66, 1646-1650.

Waters, D.J., Kengeri, S.S., Maras, A.H., Chiang, E.C., 2011. Probing the perils of dichotomous binning: how categorizing female dogs as spayed or intact can misinform our assumptions about the lifelong health consequences of ovariohysterectomy. Theriogenology 76, 1496-1500.

Whitlock, M.C., Ingvarsson, P.K., Hatfield, T., 2000. Local drift load and the heterosis of interconnected populations. Heredity 84 (Pt 4), 452-457.

Yeates, J.W., Main, D.C.J., 2011. Veterinary opinions on refusing euthanasia: justifications and philosophical frameworks. Veterinary Record 168, 263-263.

Table 1

Longevity for dog breeds (with 20 or more study animals) attending primary veterinary practices in England ranked by median age at death. The interquartile range (IQR), range and 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

Table 2

Frequent causes of death among dogs of all ages attending primary veterinary practices in England, ranked by the number of attributed deaths. The median, interquartile range (IQR) 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

Table 3

Frequent attributed causes of death for dogs attending primary veterinary practices in England that died before 3 years of age (n=489) and for dogs dying aged 3 years and older (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%)

Table 4

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

Variable	Coefficient	95% Confidence interval	*P* 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

Figures

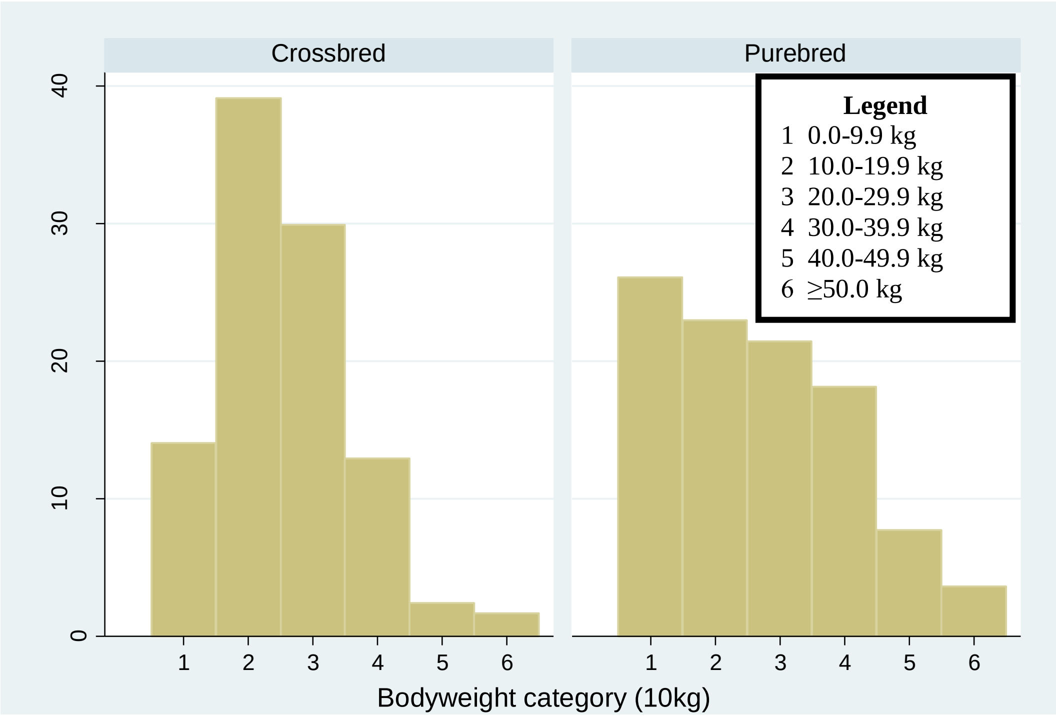

Fig. 1. Bodyweight distribution patterns (maximum recorded bodyweights for dogs aged over 1 year of age) for crossbred (*n*=542) and purebred (*n*=2,023) deceased dogs that had attended primary veterinary practices in England.

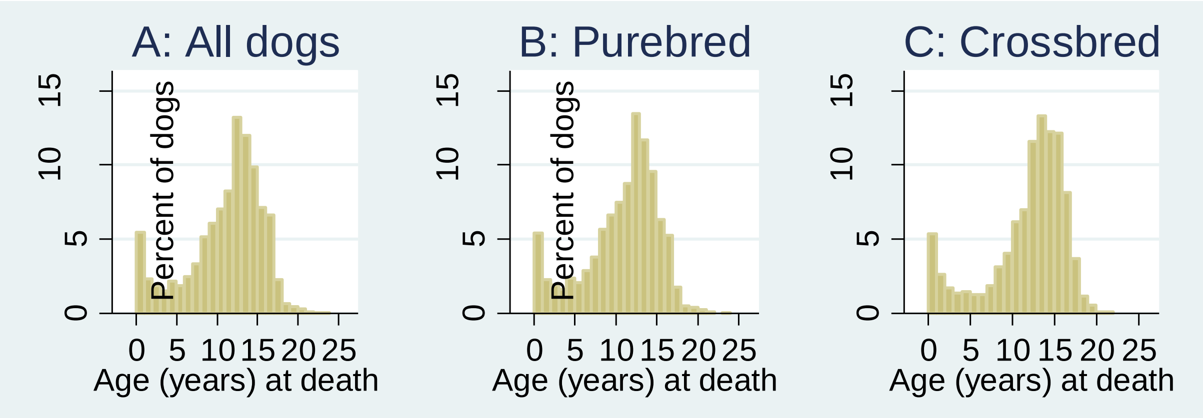

Fig. 2. Distribution patterns for age at death of dogs attending primary veterinary practices in England showing the percentage of dogs that died within one-year age bands. A: all dog types (*n*=5,095). B: purebred dogs (*n*=3,961). C: crossbred dogs (*n*=1,124). Note: 10 records held no breed data.