Dogs' lives are too short. Their only fault, really.

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How long should a dog live? The obvious answer for any dog lover, of course, is "Forever!" Unfortunately, since this does not appear possible, we must settle for trying to understand the current patterns of longevity in dogs, including lifespan, causes of death, and the variables that may influence these. There is a substantial body of research investigating longevity and mortality in dogs, and we are beginning to develop sufficient knowledge to enable us to understand, and even influence, how long dogs live.

The optimal way to assess longevity and risk factors for mortality is a prospective cohort study, in which a large number of individuals are followed from early in life until death and extensive data is collected on lifestyle and environmental exposures, clinical laboratory values, disease occurrence, and the circumstances associated with their deaths. Such studies are standard in human epidemiology, but nearly non-existent in veterinary medicine. The first canine study of this kind is the Golden Retriever Lifetime Study (GRLS),[1] run by the Morris Animal Foundation, which promises to be an invaluable source of data about longevity, morbidity, and mortality in this breed. Other efforts, such as the Dog Aging Project are also under way.[2]

Most of the data we currently have about canine longevity is derived from retrospective analyses of a variety of data sets. Data sources have included veterinary medical college patient data,[3–7] medical records from private practice,[8–10] and pet insurance company records.[11–15] Owner surveys have also been used to investigate mortality and longevity in companion dogs.[16–18] Some studies have even used records from pet cemeteries to investigate lifespan in dogs.[19,20] Each of these sources has their own strengths and limitations.

Veterinary medical school datasets are often large and contain extensive diagnostic test results. They are also likely to have complete and accurate diagnoses. However, the population of dogs seen at such tertiary care institutions is not representative of the general owned dog population. Patients in such settings may have more severe and more uncommon disease and owners who provide different husbandry and medical care and make different decisions regarding treatment and euthanasia than canine patients in primary care settings. Generalizations based on data derived in this setting can be unreliable.

Primary care records are likely to be much more representative of owned dogs in general, and the types of health issues, husbandry, and owners they have. However, such records can be difficult to access due to the variety of medical record systems in use and the lack of standardization in record keeping practices. Primary care patients also may not receive as extensive a diagnostic evaluation as those seen in academic centers, so the information available may be more limited and potentially inaccurate. The benefits of such "real-world" data sources are somewhat offset by the lack of standardization and quality control.

Surveys of owners are the most convenient and least expensive type of morbidity and mortality to collect. They are also likely the least reliable, with numerous potential sources of uncontrolled bias and error not seen in medical records. Likewise, pet cemetery data rely primarily on

information from a small subset of pet owners unlikely to be representative of the general population or consistently accurate.

Considering the variety of data sources used to study canine longevity, the general findings are remarkably consistent. Overall median lifespans for all breeds have been reported between about 8 and 15 years, with most estimates falling between 10 and 12 years, though given the differences in study populations and methods, these figures are not strictly comparable.[8,9,22,10,12,16–21] (Table 1)

Study	Overall	Great Dane	Golden Retriever	Chihuahua	Source
Hayashidani, 1988	8.3 (expectation at age 0, life table)				Cemetery records
Michell, 1999	12	8.4	12	13	Owner survey
Proschowsky, 2003	10		11 (50% quintile)		Owner survey
Adams, 2010	11.25	6.5	12.5	12.42	Owner survey
Hoffman, 2013	7.9 (intact) 9.4 (neutered)				VMDB data
O'Neill, 2013	12 (median)	6.0	12.5	7.1	Private practice records
Inoue, 2015	13.7 (expectation at age 0-1yr, life table)	10.6 (>40kg)	12.5 (20-40kg)	13.8 (<5kg)	Cemetery records
Lewis, 2018	10.33		11.75		Owner survey
Inoue, 2018	13.7 (expectation at age 0-1yr, life table)		12.9	11.8	Cemetery records
Urfer, 2019	FI=13.77 FS=14.35 MI=14.09 MN=14.15	9.63	12.93	15.01	Private practice records
Urfer, 2020	15.4	13.4 (>40.9kg)	14	16	Private practice records

Table 1. Life expectancy in years (median unless otherwise indicated) overall and for breeds representative of size classes small (<9kg), large (18-41kg), and giant (>41kg). VMDB: Veterinary Medical Database.

Different data sets also show similar lifespan distributions, typically with a dip in mortality in young adulthood followed by a steady increase in deaths peaking at about 10-14 years of age and then a sharp decline after age 15. (Figure 1) The truncation of the right end of these distributions may reflect some limitations in the data collection as well as a sharp decline in survival past the early to mid-teens.

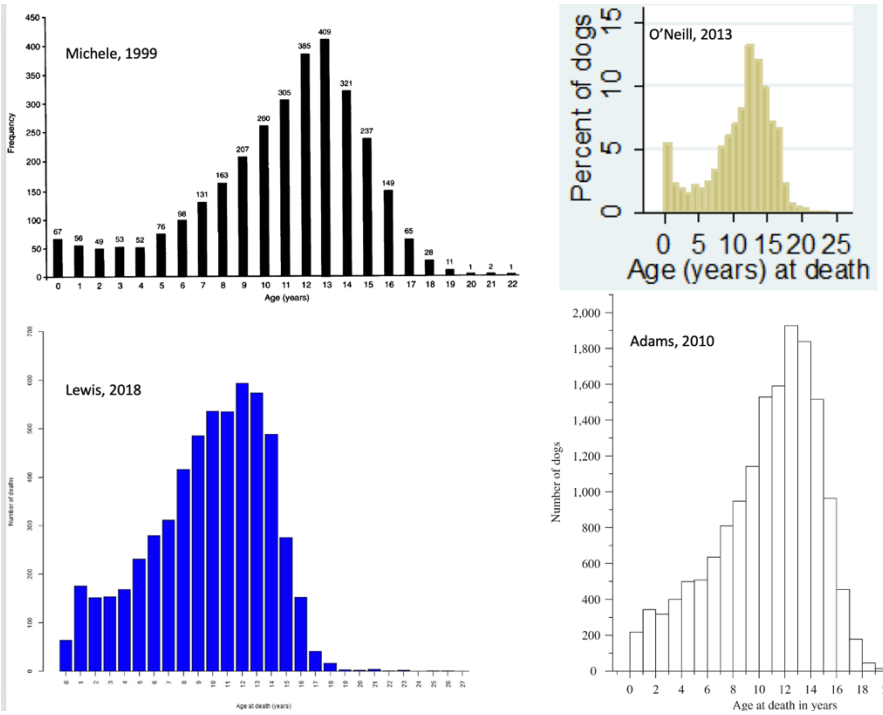

Figure 1. Distribution of deaths in several canine lifespan studies.[6,10,15,16]

Little effort has been made to assess changes in global canine life expectancy over time. Many owners and veterinarians believe dogs are living longer than they used to due to improvements in preventative and therapeutic interventions, nutrition, husbandry, and other factors. There is not much evidence to confirm this suspicion. Periodic analyses of the medical record systems at Banfield have been cited to show that dog life expectancy is increasing. Comparisons of life expectancy estimates from different years have also suggested increased longevity in dogs. Analysis of cemetery and insurance records in Japan, for example, have estimated higher life expectancy in recent decades compared with earlier studies.[19,20,23] However, these are not results from prospective studies specifically designed to evaluate changes in canine life expectancy over time, and studies done at different times are not truly comparable due to changes in sample populations and methods.

Similarly questionable comparisons between surveys at different times have been used to make the opposite argument, that dogs are dying younger than they used to due to purported harm from environmental toxins and contemporary husbandry, nutrition, and healthcare practices. Surveys conducted by the U.K. Kennel Club in 2004 and 2014 show different results for lifespan in specific breeds. Some breeds have a longer lifespan in the earlier study and others have a longer reported life expectancy in the more recent study. There is no clear overall pattern showing a change in lifespan, but even if such a pattern were evident, comparison between the two studies would not be appropriate due to differences between them. As the authors point out:

> "Given the difference in methodologies between the surveys, the data from each is not fully comparable and differences observed do not definitively imply changes in population parameters. Furthermore, there were 5,864 deaths reported in the 2014 survey compared to 15,881 deaths reported in the 2004 survey. This significant drop reduces the likelihood of the sample accurately representing the

> wider dog population, and so would likely have an impact on median longevity figures if the two sets of data were compared, which would not be reliable."

Of course, assessments of overall longevity and mortality aren't particularly useful since there is significant variation in lifespan by breed, size, neuter status, and other factors. The one datum owners are most interested in, of course, is "How long will my dog live?" That is, sadly, not something we are likely to ever be able to predict with great accuracy. However, in terms of setting reasonable expectations and thinking about what we and owners can do to maximize the chances of as long and healthy a life as possible for each dog, it is helpful to understand some of the variables that influence lifespan on a population level.

One of the most complex factors is neuter status. I have written previously about the health effects and overall risks and benefits of neutering,[24] as well as considerations for what age is optimal for neutering dogs. The general conclusions we can draw from the extensive literature is that neutering has both risks and benefits, and these will vary by breed in complex and often unpredictable ways. Neutering increases the risk of some health conditions in some breeds and lowers the risks of others. However, with respect to lifespan, the evidence is pretty consistent that neutered dogs tend to live longer than intact dogs.[5,9,10,24–27]

Typically, this effect is more pronounced in females, which may be due to the high incidence of diseases such as mammary neoplasia and pyometra, which are much more common in intact females. However, neutering has been associated with increased longevity in both males and females of other species as well.[28] The relationship between sex hormones, environmental conditions, and lifespan is complex, and we do not yet have a complete understanding of it. It is reasonable to tell dog owners that neutering appears to increase lifespan in dogs, especially female dogs, but there are risks as well as benefits, and there is still significant uncertainty about the impact on the life of any individual dog.

Body size is another factor that clearly impacts longevity. One aspect of this is largely beyond the control of owners, which is the size of a dog determined by its breed. There is a roughly linear inverse relationship between body size and lifespan, with giant breed dogs often living half as long as small breeds.[3,6,9,10,16,17,20,22,25,27] (Figure 2) This relationship holds even when breed is factored in, showing that it is not simply genetic risk factors for specific diseases in specific breeds causing the apparent association but a true causal relationship between body size and overall mortality.

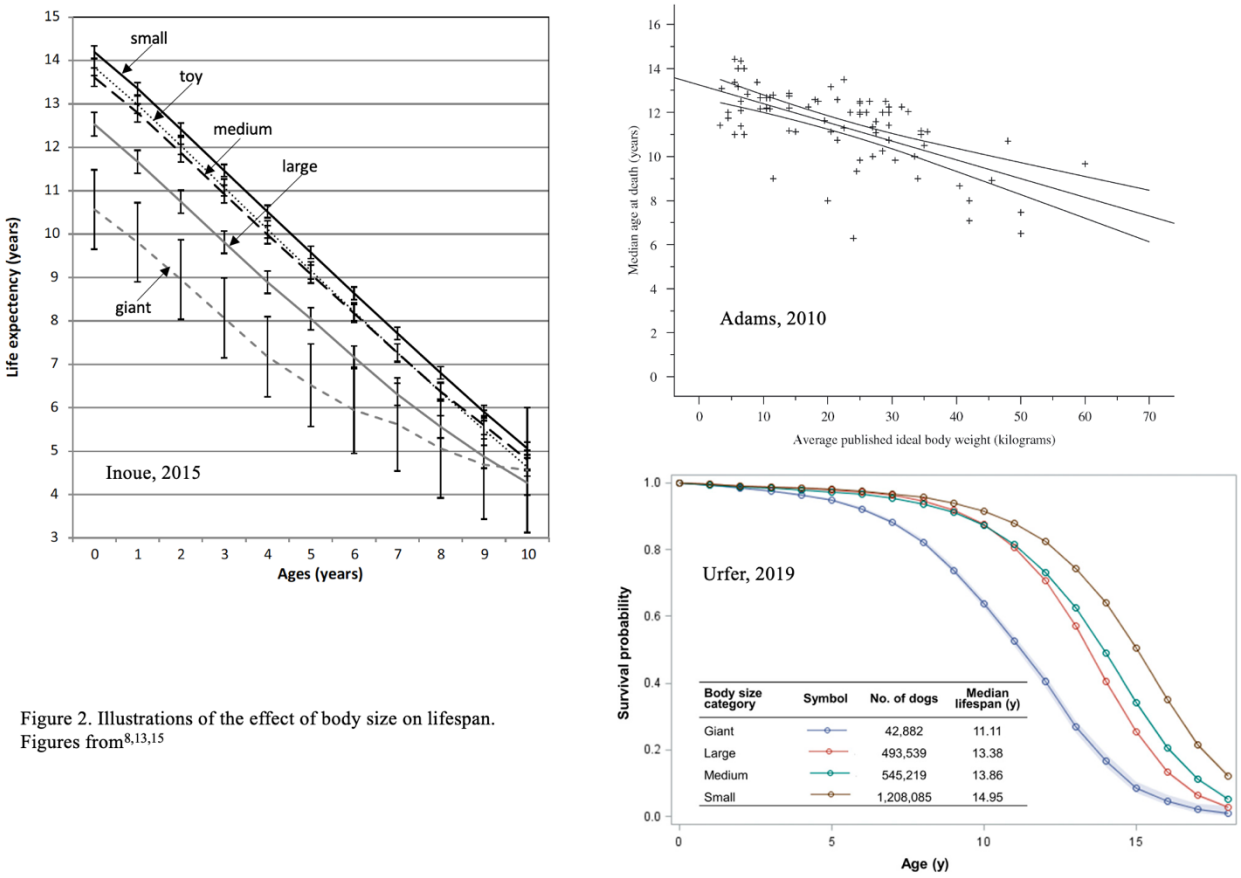

Figure 2. Illustrations of the effect of body size on lifespan. Figures from[8,13,15]

There are a number of possible mechanisms for negative effect of body size on longevity. Several researchers argue that large and giant breed dogs age at a faster rate, and this accelerated aging is responsible for their shorter lifespan.[6,7,29] Body size is determined by a small number of genes in dogs,[30,31] and one hypothesis is that the shortened life expectancy for larger breeds is an example of antagonistic pleiotropy. This is an evolutionary explanation for age-associated disease that argues genes which convey fitness advantages during the early, reproductive period of life will be retained by natural selection even if they cause harm or shorten overall lifespan through effects later in life, when reproductive output is less. Dogs, of course, have been the subject of very intensive artificial selection, and it is possible that the selection for large body size has preserved genes which contribute to accelerated aging and shorter overall lifespan.

Of course, way in which body size can influence lifespan is through the harmful impact of obesity on health. The prevalence of obesity in companion dogs is high and growing, and there are many demonstrated adverse health consequences, from increased incidence of specific diseases to shortened lifespan compared with dogs who are calorically restricted.[32,33] Maintenance of a healthy lean body condition is one of the few clearly demonstrated methods by which owners can extend canine longevity and healthspan.

Breed is another key variable influencing longevity, influencing lifespan in all available studies. Some of this variation may be attributed to body size, but when that is controlled for in analysis, some breeds do still live longer on average than others. These differences sometimes have straightforward explanations in terms of the incidence of specific diseases, but some breeds may

have consistently shorter lives that cannot be explained by obvious genetic predisposition to particular maladies. It is likely that there are differences in the underlying mechanisms of aging between breeds, but this is not a subject that has been extensively investigated in enough breeds to allow confident explanations for many breeds.

One interesting finding concerns telomeres. Telomeres are repetitive non-coding base sequences at the ends of chromosomes that allow for complete replication of the coding portion of the DNA. These shorten with each replication event in the absence of the reparative enzyme telomerase, which is not usually present in somatic cells. When telomeres become too short to protect the coding section of a chromosome, replication is impeded, and cells become dysfunctional. Telomere shortening accompanies aging, and accelerated aging is associated with telomerase deficiency or induced telomere attrition.

Research has shown that telomeres shorten with age in dogs much more rapidly than in humans at a ratio roughly corresponding to the difference in average lifespan between the species. The length of telomeres also differs between breeds, and those breeds with longer telomeres tend to have longer lifespan than breeds with shorter telomeres. These findings support the importance of telomere attrition in canine aging and suggest that one of the fundamental underlying mechanisms of aging may explain some of the difference in longevity between breeds.[34,35]

Another breed-related variable that does seem consistently related to longevity is purebred versus mixed-breed status. Mixed breeds appear to have greater lifespans in most[7,10,16,19,25,36,37], though not all[9] studies. Genetic analyses suggest that there is some relationship between the degree of inbreeding and lifespan, both between and within breeds, but this relationship is not simple or straightforward, and it is complicated by confounding variables such as body size.[7]

When considering longevity in dogs, it is of course necessary to look at what causes of death limit lifespan. Patterns in cause of death can be informative for understanding variability in lifespan and for formulating strategies to extend canine lifespan (the number of years lived) and healthspan (the number of years without significant disease or disability). Once again, differences in study populations and methods limit direct comparisons, but research has identified some apparent patterns in the causes of death seen in dogs. Table 2 lists the most common causes of death reported in various epidemiologic studies.

Study	#1	#2	#3	#4	#5	Source
Bonnett, 1997[11]	tumour	trauma	locomotor	cardiac	CNS	Insurance data
Michell, 1999[25]	illness	euthanasia (disease)	euthanasia (old age)	natural causes	accident (road)	Owner survey
Proschowsky, 2003[16]	old age	cancer	combinations	behaviour problems	accidents	Owner survey
Bonnett, 2005[38]	tumour	trauma	locomotor	cardiac	neurologic	Insurance data
Adams, 2010[17]	cancer	old age	cardiac	urologic	combinations	Owner survey
Fleming, 2011[4]	neoplastic	traumatic	Infectious	metabolic	inflammatory	VMDB
O'Neill, 2013[39]	neoplastic	musculoskeletal	neurologic	gastrointestinal	cardiac	Private practice records
Inoue, 2015[23]	neoplasia	cardiovascular	urinary	respiratory	digestive	Cemetery records
Lewis, 2018[40]	old age	cancer	heart failure	kidney failure	old age combinations	Owner survey
Urfer, 2020[9]	neurologic	musculoskeletal	hematopoetic	cardiovascular	respiratory	Private practice records

Table 2. Top 5 causes of death in adult dogs (excluding undetermined or "other").

Overall, neoplasia is almost always a leading cause of death. Diseases of the nervous, musculoskeletal, urinary, and respiratory systems are also very commonly listed. The order in which these appear, and the specific diagnoses identified as leading to death, vary between studies, again due to differences in the populations studied, the methods used to acquire data, and the definitions employed of various causes of death.

The specific diseases leading to death and the organ systems involved also vary in association with several key patient variables. Old dogs tend to die of neoplasia and degenerative diseases more often than young dogs, who experience more mortality related to trauma and infectious disease. Differences are also seen associated with sex, neuter status, and breed. The details are complex and not always consistent between studies, but again the patterns are useful in targeting interventions. Reduction in infectious disease through vaccination, for example, has much more impact on mortality early in life than interventions targeting neoplasia. Treatments for degenerative musculoskeletal diseases may prolong healthspan and lifespan significantly for dogs in the latter phases of the life cycle, while they are less likely to be useful or to justify potential adverse effects in younger dogs.

Many studies include a generic category of "old age" in asking owners about cause of death. While this is not a very specific nor clearly defined diagnosis, it represents the deleterious

functional impact aging can have on dogs even in the absence of specific diagnoses. In humans, frailty is a recognized phenomenon of aging that has significant effects on quality of life and mortality rates, and while such a syndrome is not yet well-characterized in dogs, it is likely also present and relevant to end-of-life decisions for dog owners.[41,42]

The proximate cause of death for the majority of owned dogs is almost always euthanasia.[25,37,43] Though there is usually some underlying ultimate disease or dysfunction precipitating the decision to euthanize, it is important to recognize that death in dogs is most often the result of a human decision-making process. This has significant implications for any efforts to prolong lifespan and healthspan and mitigate the impact of specific causes of mortality. Understanding the reasons owners choose to euthanize their dogs, and the clinical presentations that drive such decisions, is vital to such efforts.

While specific clinical diagnoses are often part of owners' decisions to euthanize their canine companions, more commonly people cite symptoms or perceived deficits in comfort and quality of life.[44–48] Dogs without a defined fatal disease will often be euthanized when they exhibit symptoms that suggest to owners they are in pain or in some other way uncomfortable, or when they exhibit behaviors that are unacceptable for companion dogs. Loss of mobility, changes in social behavior, housesoiling, and many other symptoms that are not inherently life-threatening can still be life-limiting in dogs due to their impact on owners.

Finally, we cannot hope to understand longevity patterns in dogs without understanding canine aging. For a phenomenon we all experience, aging is challenging to define precisely. It involves changes that occur over time, but time is not necessarily the primary driver of those changes. A useful general definition in this frame is that aging is "the progressive accumulation of changes with time associated with or responsible for the ever-increasing susceptibility to disease and death."[49] Individual dogs experience progressive loss of function, greater risk of certain types of disease, and a greater likelihood of death as they get older.

Aging involves many different processes at multiple levels, from changes in molecules and genes at the microscopic scale to changes in appearance and function identifiable to dog owners and veterinarians. There are recognizable patterns to these changes that are seen in most dogs, and even in humans and other animals. However, aging is also a variable and individual process. Biologically, some individuals age faster than others. Biological age is related to, but not synonymous with, chronological age. This is especially clear in the dog, in which larger dogs typically experience deleterious consequences of aging earlier and die younger than smaller breeds.[6,50,51]

Decades of research into the mechanisms of aging, in laboratory models, humans, and dogs, have revealed both variation and complexity as well as recognizable patterns and evolutionarily conserved processes involved in aging. Research efforts are ongoing, and rapidly expanding, to use our understanding of how aging happens to develop preventative and therapeutic interventions to delay age-associated disease, disability, and death. In addition to prevention and treatment of specific diseases, overall improvement in health, comfort, and function in older dogs and compression of frailty and illness into a shorter period preceding death (i.e., an extension of

healthspan) may be possible, which would be a fundamental shift in the perspective and practice of veterinary preventative medicine.

The patterns so far identified in longevity and mortality give us some very limited ability to offer general prognoses for lifespan and causes of death to individual dog owners. They also offer a baseline against which to measure our efforts to improve canine health and give our clients and their dogs more quality time together.

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