Mortality in North American Dogs from 1984 to 2004: An Investigation into Age-, Size-, and Breed-Related Causes of Death

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Background: Anecdotal beliefs and limited research suggest variable patterns of mortality in age, size, and breed cohorts of dogs. Detailed knowledge of mortality patterns would facilitate development of tailored health-maintenance practices and contribute to the understanding of the genetic basis of disease.

Hypothesis/Objectives: To describe breed-specific causes of death in all instances of canine mortality recorded in the Veterinary Medical Database (VMDB)[a] between 1984 and 2004. We hypothesized that causes of death, categorized by organ system (OS) or pathophysiologic process (PP), would segregate by age, body mass, and breed.

Animals: 74,556 dogs from the VMDB for which death was the outcome of the recorded hospital visit.

Methods: Retrospective study. Causes of death from abstracted VMDB medical records were categorized by OS and PP and analyzed by age, breed, and breed-standard mass of dog.

Results: Causes of death, categorized by OS or PP, segregated by age, breed, and breed-standard mass. Young dogs died more commonly of gastrointestinal and infectious causes whereas older dogs died of neurologic and neoplastic causes. Increasing age was associated with an increasing risk of death because of cardiovascular, endocrine, and urogenital causes, but not because of hematopoietic or musculoskeletal causes. Dogs of larger breeds died more commonly of musculoskeletal and gastrointestinal causes whereas dogs of smaller breeds died more commonly of endocrine causes.

Conclusions and Clinical Importance: Not all causes of death contribute equally to mortality within age, size, or breed cohorts. Documented patterns now provide multiple targets for clinical research and intervention.

Key words: Age at death; Genetics; Lifespan; Morbidity; Neoplasia.

M ore than any other species of mammal, dogs exhibit dramatic phenotypic variations, most of which have developed in just a few hundred years as a consequence of human interest and deliberate breeding.[1] Concentrated selection pressure for the desired characteristics that define each breed has inadvertently magnified undesirable characteristics through indirect effects of traits under selection (eg, intervertebral disc disease in Dachshunds selected for chondrodystrophy[2]), or through genetic "founder effects" (eg, canine leukocyte adhesion deficiency in Irish Setters[3]).

Breed-specific diseases that arise because of a breed's morphologic or genetic characteristics are commonly recognized. However, certain breeds show higher prevalence of specific diseases the origins of which are more difficult to discern. Neoplasia, for example, has a multifactorial etiology, with both genetic and environmental influences. In the United States, Golden Retrievers are recognized as having a higher prevalence of neoplasia,[4,5] whereas a retrospective study in Sweden[6] found that Boxers and Bernese Mountain Dogs were substantially

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Abbreviations:

AKC	American Kennel Club
OS	organ system
PP	pathophysiologic process
VMDB	Veterinary Medical Database

overrepresented for death because of neoplasia compared with other breeds, including Golden Retrievers. Several studies have investigated purebred versus mixed-breed dogs and have shown that orthopedic disease, congenital portosystemic shunting, soft palate elongation, intervertebral disc disease, and cataracts are more prevalent in purebred dogs in general, as well as dogs of particular breeds, whereas diabetes mellitus is more common in mixed-breed dogs.[7–13] Many beliefs regarding increased risk of certain diseases within specific breeds are poorly substantiated, yet may be used to direct breeding and diagnostic practices. Furthermore, even in those cases in which breed-based risk is documented, the factors influencing this risk seldom are known.

The few large breed-based disease surveys and age-at-death investigations that have been performed in dogs have produced several interesting findings. Across dog breeds, dogs from smaller breeds generally live longer than dogs from larger breeds. The correlation between lifespan and adult body mass has been shown to be stronger than the correlation between lifespan and adult height of the breed.[14,15] However, within a breed, the larger individuals actually are more likely to live longer, and there is a relationship between small size and the frequency of particular insulin-like growth factor 1 alleles.[16,17] It is also apparent that younger dogs are more likely to die of some causes such as trauma or congenital

abnormalities, whereas older dogs are more likely to die of others such as neoplasia.[4,6,18]

The objective of this study was to describe breed-specific causes of death in all instances of canine mortality recorded in the Veterinary Medical Database (VMDB) between 1984 and 2004. We hypothesized that causes of death, categorized by organ system (OS) or pathophysiologic process (PP), would segregate by age, body mass, and breed.

Although previous studies have examined the breed-specific incidence of particular diseases, few investigators have systematically analyzed the full spectrum of diseases that are overrepresented in particular breeds, and the factors that influence their prevalence. Results of this study will be useful not only to veterinarians, but also to owners and breeders. Anecdotal evidence of specific breed-based disease risks can be refuted, or confirmed and quantified. These results should facilitate development of tailored screening and health-maintenance practices. Eventually, these results may contribute significantly to ongoing work on the underlying genetic basis of breed-specific mortality.[19]

Materials and Methods

Cause of Death Categorization

The VMDB[a] initiated in 1964 by the National Cancer Institute, contains abstracted medical records information submitted by the 27 participating Veterinary Teaching Hospitals in North America. Data can be mined from the VMDB based on breed, age, diagnostic code, sex, or other discrete factors. The authors searched the database for all canine entries reflecting visits between 1984 and 2004 during which the dog died.

Diagnoses, which may be pathophysiologic (eg, immune-mediated hemolytic anemia), histologic (eg, mammary adenocarcinoma), or merely descriptive (eg, vomiting), are entered as 9-digit codes and verbal descriptions in the VMDB. Although a patient visit may have more than 1 diagnostic finding reported, statistical analysis required that mortality at each visit be attributed to a single cause, and thus the entire dataset was inspected visually. For each patient visit, one of the authors (either J.M.F. or K.E.C.) identified a single diagnosis as the cause of death according to the following system:

1. A single pathophysiologic diagnosis that encompassed all other descriptive or symptomatic diagnoses was selected. For example, a patient visit coded as "inflammatory bowel disease, vomiting, diarrhea" would be recorded as "inflammatory bowel disease."
2. If an encompassing disease was not readily apparent, then the disease that had the largest number of associated diagnoses was selected. For example, a patient visit coded as "vomiting, diarrhea, disseminated intravascular coagulation, pancreatitis, coughing, abdominal pain, coxofemoral osteoarthritis" would be recorded as "pancreatitis."
3. If the authors could not readily apply rules 1 or 2, then the 1st diagnosis listed was chosen. Diagnoses were listed in no consistent order within each visit.
4. If the diagnoses included multiple sites affected by neoplasia, the 1st neoplasia diagnosis listed was selected. For example, a patient visit coded as "osteosarcoma femur, osteosarcoma rib, osteosarcoma lung" would be recorded as "osteosarcoma femur."
5. If the only diagnosis listed was any of the following: "dead on arrival," "death due to euthanasia," "healthy," or "undiag-

nosed disease," the patient visit was excluded from categorical analysis.

Each cause of death was classified by OS, and separately by PP by a slight modification of a categorization scheme reported previously.[6,20] In the 9-digit coding system used by the VMDB, the first 4 digits reflect the OS involved and the last 5 digits reflect the PP. These 2 code fragments were separated and visually inspected by two of the authors (J.M.F., K.E.C.) to ensure correct assignment to OS and PP categories. The 11 OS categories were cardiovascular, dermatologic, endocrine, gastrointestinal, hematopoietic, hepatic, musculoskeletal, neurologic, ophthalmologic, respiratory, and urogenital. The 9 PP categories were congenital (includes-anomalous), degenerative, infectious, inflammatory (includes immune-mediated), metabolic, neoplastic, toxic, traumatic, and vascular. A designation of unclassified was used in instances in which the descriptive diagnosis could not be further categorized by either OS or PP. For example, "renal failure due to unknown" was categorized under urogenital for OS, but under unclassified for PP. Conversely, "adenocarcinoma general" was categorized under neoplasia for PP, but under unclassified for OS.

Interobserver agreement was evaluated periodically by assigning sets of 50 patient visits to both observers (J.M.F. and K.E.C.) for inspection and comparing the diagnoses that each observer identified as the cause of death for both OS and PP. To determine the degree of concordance between the 2 observers, we used Cohen's κ statistic.[21] The two observers scored cause of death independently at 3 separate times, for a total of 150 patient visits.

In addition to diagnostic data, each dog was scored for age. The available data included 10 discrete age bins, such that dogs could be categorized as dying at (1) 0–2 weeks; (2) 2 weeks–2 months; (3) 2–6 months; (4) 6–12 months; (5) 1–2 years; (6) 2–4 years; (7) 4–7 years; (8) 7–10 years; (9) 10–15 years; and (10) >15 years. To simplify comparison among larger groups, dogs up to 1 year of age (bins 1–4) were considered juvenile, and dogs >1 year of age (bins 5–10) were considered adult. For purposes of our study, any dog identified as purebred in the VMDB was considered purebred, whether or not the named breed is recognized by the American Kennel Club (AKC). Mixed-breed dogs were evaluated as a single group. Our data did not include precise weights for individual dogs, so the same mass was assigned to all members of the breed. Body masses (kg) for adult dogs of each breed were obtained from the AKC or from the published standards of non-AKC breeds. Mixed-breed dogs were not included in the body mass analyses.

Exclusion Criteria

Dogs for which the sole diagnosis was "dead on arrival," "death due to euthanasia," "healthy," or "death due to unknown" were identified and excluded from subsequent analysis.

Statistical Analysis

Results are presented as frequencies of causes of death within dogs of a given breed, body mass, or age. Statistical analyses were carried out by R[b] and JMP.[c] To reduce the effects of sampling error, we limited breed-based analyses to those breeds with $\geq$100 representatives. In statistical analysis of the effects of body mass on frequency of causes of death, mass was square root transformed, and frequency was arcsine square root transformed to normalize the variance for these variables. Analysis of the effects of age on mortality presents the risk of dying of a particular cause at a given age, relative to the risk of dying of all other causes. We do not present the absolute probability of dying of a particular cause at a given age. This metric is not possible, because we did not include data on the entire at-risk population, but only on those dogs that died during a given time interval.

Results

The total number of dogs in the dataset from 1984 to 2004 that met the inclusion criteria was 80,306. Among all patient visits, 5,748 contained "dead on arrival" (N = 1,119), "death due to euthanasia" (N = 4,452), "healthy" (N = 93), or "death due to unknown" (N = 84). Two records contained no defined diagnosis. These 5,750 dogs were excluded from categorical analysis, resulting in 74,556 dogs available for subsequent analysis of cause of death. For both OS and PP, the concordance between the 2 observers was highly significant (OS: $\kappa = 0.819$, $Z = 27.3$, $P < 10^{-10}$; PP: $\kappa = 0.812$, $Z = 18.9$, $P < 10^{-10}$). In cases in which the precise cause of death selected by the 2 observers varied, the resulting assignment to categorical OS or PP was unaffected in 84 and 85% of cases, respectively.

Among these 74,556 dogs, 15,166 were unable to be categorized for OS and 26,442 were unable to be categorized for PP (ie, were assigned to unclassified). And 31,942 dogs were assigned to unclassified for either OS or PP, and 4,833 dogs were assigned to unclassified for both OS and PP. There were 17,796 mixed-breed dogs, which were evaluated as a single group within the breed-based analyses. There were 82 breeds represented by ≥100 members (N = 72,376 for breed-based analyses).

Tables 1 and 2, respectively, show the percentage of deaths within each OS and PP category, as well as the leading OS and PP cause of death for each breed with ≥100 members in the dataset. Unclassified causes of death are not considered in the ranking of leading causes of death. Comparison among breeds revealed expected

Table 1. Relative frequency of deaths within organ system (OS) categories for each breed (n = 72,376).

Breed	n	CV	Derm	Endo	GI	Hem	Hep	MS	Neuro	Ophth	Resp	Uro	Uncl
Afghan Hound	238	0.13	0.017	0.042	0.105	0.105	0.029	0.101	0.063	0.004	0.16	0.059	0.185
Airedale Terrier	368	0.057	0.011	0.041	0.087	0.152	0.065	0.076	0.111	0.005	0.101	0.163	0.13
Akita	222	0.05	0.018	0.014	0.212	0.05	0.032	0.135	0.122	0.099	0.068	0.072	0.131
Alaskan Malamute	415	0.065	0.022	0.046	0.135	0.099	0.031	0.152	0.113	0.005	0.084	0.075	0.173
American Cocker Spaniel	2,663	0.088	0.021	0.03	0.087	0.148	0.066	0.075	0.13	0.021	0.072	0.079	0.181
American Eskimo	181	0.033	0.011	0.033	0.144	0.066	0.066	0.061	0.122	0.017	0.066	0.122	0.26
American Staffordshire Terrier	423	0.097	0.024	0.021	0.156	0.076	0.017	0.132	0.085	0.002	0.05	0.047	0.293
Australian Heeler	265	0.045	0.015	0.049	0.038	0.049	0.03	0.128	0.128	0.03	0.072	0.098	0.317
Australian Shepherd	592	0.071	0.027	0.02	0.081	0.081	0.044	0.128	0.096	0.027	0.068	0.1	0.257
Basset Hound	650	0.057	0.023	0.034	0.125	0.122	0.037	0.082	0.152	0.02	0.077	0.085	0.188
Beagle	980	0.085	0.015	0.039	0.094	0.05	0.026	0.115	0.13	0.006	0.069	0.126	0.246
Bernese Mountain Dog	119	0.101	0.008	0.017	0.067	0.092	0.059	0.084	0.101	0	0.092	0.076	0.303
Bichon Frise	287	0.101	0.024	0.056	0.108	0.084	0.063	0.042	0.136	0.01	0.101	0.115	0.16
Black and Tan Coonhound	118	0.102	0.008	0.008	0.153	0.059	0.017	0.144	0.085	0.008	0.102	0.059	0.254
Border Collie	314	0.057	0.016	0.022	0.092	0.118	0.045	0.143	0.124	0.013	0.076	0.073	0.22
Borzoi	104	0.067	0.01	0.01	0.144	0.067	0.019	0.163	0.135	0.01	0.163	0.077	0.135
Boston Terrier	473	0.127	0.017	0.051	0.093	0.04	0.013	0.068	0.222	0.017	0.116	0.074	0.163
Bouvier des Flandres	176	0.074	0.011	0.028	0.142	0.119	0.051	0.136	0.085	0.011	0.068	0.08	0.193
Boxer	1,093	0.134	0.017	0.031	0.118	0.118	0.022	0.059	0.182	0.003	0.063	0.065	0.187
Brittany Spaniel	476	0.101	0.017	0.044	0.101	0.038	0.038	0.128	0.105	0.011	0.116	0.09	0.212
Bull Terrier	121	0.091	0.017	0.017	0.149	0.083	0.025	0.099	0.099	0	0.058	0.149	0.215
Bulldog	578	0.154	0.01	0.016	0.087	0.067	0.036	0.106	0.1	0.007	0.182	0.064	0.171
Bullmastiff	134	0.075	0.007	0.03	0.149	0.104	0.045	0.134	0.119	0	0.09	0.09	0.157
Cairn Terrier	242	0.099	0.012	0.041	0.145	0.099	0.05	0.041	0.153	0.004	0.058	0.095	0.202
Cardigan Welsh Corgi	112	0.08	0.018	0.009	0.08	0.089	0.018	0.063	0.17	0.036	0.098	0.152	0.188
Chesapeake Bay Retriever	186	0.054	0.011	0.027	0.097	0.172	0.016	0.118	0.145	0.011	0.065	0.118	0.167
Chihuahua	573	0.185	0.024	0.023	0.11	0.026	0.019	0.07	0.133	0.01	0.072	0.087	0.241
Chow Chow	631	0.076	0.029	0.01	0.174	0.038	0.021	0.127	0.127	0.022	0.063	0.063	0.25
Collie	979	0.083	0.018	0.029	0.124	0.101	0.032	0.102	0.101	0.032	0.114	0.098	0.166
Dachshund	1,605	0.074	0.014	0.042	0.072	0.041	0.023	0.092	0.404	0.004	0.059	0.067	0.108
Dachshund, Miniature	448	0.076	0.013	0.029	0.1	0.025	0.031	0.092	0.397	0.004	0.06	0.063	0.109
Dalmatian	568	0.069	0.005	0.025	0.16	0.048	0.037	0.051	0.125	0.004	0.051	0.162	0.264
Doberman Pinscher	2,773	0.172	0.012	0.032	0.103	0.071	0.042	0.167	0.115	0.004	0.061	0.07	0.152
Dutch Pug	321	0.115	0.022	0.025	0.084	0.053	0.037	0.062	0.274	0.009	0.1	0.05	0.168
English Cocker Spaniel	117	0.077	0.009	0.026	0.154	0.137	0.077	0.085	0.077	0.026	0.094	0.137	0.103
English Pointer	303	0.076	0.036	0.036	0.092	0.053	0.026	0.099	0.122	0.013	0.096	0.109	0.241
English Setter	378	0.098	0.016	0.034	0.108	0.058	0.026	0.108	0.122	0.019	0.106	0.087	0.217
English Springer Spaniel	890	0.08	0.018	0.039	0.117	0.1	0.056	0.07	0.106	0.013	0.081	0.112	0.208
Finnish Spitz	107	0.047	0	0.037	0.103	0.019	0.037	0.075	0.168	0.009	0.112	0.14	0.252
Fox Terrier	221	0.163	0.009	0.072	0.118	0.054	0.045	0.072	0.113	0.018	0.059	0.077	0.199
German Shepherd Dog	3,827	0.079	0.015	0.022	0.151	0.085	0.026	0.136	0.134	0.005	0.063	0.079	0.206
German Shorthaired Pointer	415	0.07	0.022	0.039	0.137	0.046	0.031	0.147	0.116	0.01	0.065	0.111	0.207
Golden Retriever	4,029	0.094	0.016	0.034	0.094	0.15	0.045	0.116	0.103	0.004	0.078	0.065	0.2
Gordon Setter	120	0.025	0.008	0.017	0.225	0.125	0.033	0.067	0.1	0	0.1	0.133	0.167

Table 1. (Continued).

Breed	n	CV	Derm	Endo	GI	Hem	Hep	MS	Neuro	Ophth	Resp	Uro	Uncl
Great Dane	921	0.124	0.011	0.011	0.256	0.039	0.021	0.217	0.094	0.003	0.059	0.037	0.128
Great Pyrenees	188	0.069	0.016	0.027	0.133	0.064	0.016	0.255	0.101	0.005	0.069	0.096	0.149
Greyhound	473	0.08	0.021	0.015	0.14	0.034	0.025	0.214	0.099	0.006	0.055	0.059	0.252
Irish Setter	709	0.069	0.013	0.039	0.164	0.071	0.028	0.175	0.093	0.008	0.097	0.08	0.162
Irish Wolfhound	217	0.134	0.014	0.005	0.147	0.101	0.009	0.221	0.097	0	0.12	0.032	0.12
Jack Russell Terrier	116	0.078	0.026	0.026	0.078	0.069	0.026	0.095	0.207	0.009	0.078	0.043	0.267
Keeshond	257	0.105	0.019	0.054	0.152	0.093	0.058	0.054	0.07	0	0.051	0.121	0.222
Labrador Retriever	4,398	0.077	0.02	0.03	0.112	0.083	0.04	0.146	0.102	0.007	0.089	0.071	0.224
Lhasa Apso	696	0.091	0.016	0.039	0.105	0.063	0.046	0.079	0.165	0.014	0.07	0.149	0.162
Maltese	413	0.211	0.005	0.036	0.094	0.065	0.075	0.051	0.194	0	0.07	0.063	0.136
Mastiff	180	0.106	0.017	0.006	0.1	0.111	0.028	0.178	0.1	0.006	0.094	0.106	0.15
Miniature Pinscher	112	0.107	0.045	0.009	0.143	0.036	0.045	0.098	0.223	0.009	0.045	0.08	0.161
Mixed-Breed Dog	17,795	0.072	0.022	0.038	0.111	0.075	0.034	0.135	0.108	0.006	0.075	0.082	0.243
Newfoundland	286	0.238	0.017	0.01	0.115	0.063	0.024	0.161	0.087	0	0.059	0.07	0.154
Norwegian Elkhound	243	0.091	0.008	0.045	0.115	0.066	0.045	0.091	0.099	0.008	0.103	0.16	0.169
Old English Sheepdog	428	0.1	0.021	0.056	0.138	0.091	0.042	0.124	0.082	0.009	0.07	0.075	0.192
Pekingese	453	0.132	0.022	0.026	0.086	0.033	0.029	0.099	0.146	0.031	0.088	0.108	0.199
Pembroke Welsh Corgi	115	0.087	0.017	0.035	0.087	0.113	0.07	0.07	0.157	0.026	0.113	0.104	0.122
Pomeranian	581	0.141	0.01	0.022	0.15	0.038	0.045	0.09	0.124	0.007	0.136	0.074	0.164
Poodle, Miniature	1,730	0.117	0.013	0.063	0.111	0.059	0.041	0.072	0.139	0.012	0.093	0.095	0.185
Poodle, Standard	812	0.091	0.02	0.037	0.167	0.091	0.058	0.094	0.1	0.007	0.084	0.078	0.174
Poodle, Toy	877	0.124	0.013	0.046	0.104	0.048	0.048	0.079	0.161	0.015	0.081	0.098	0.185
Rhodesian Ridgeback	123	0.073	0.008	0.041	0.13	0.081	0.008	0.13	0.179	0.008	0.081	0.089	0.171
Rottweiler	1,687	0.091	0.012	0.018	0.152	0.097	0.024	0.168	0.094	0.006	0.066	0.05	0.222
Saint Bernard	413	0.104	0.015	0.012	0.15	0.036	0.024	0.262	0.114	0.005	0.07	0.051	0.157
Samoyed	491	0.088	0.01	0.049	0.134	0.067	0.067	0.116	0.084	0.026	0.084	0.086	0.189
Schnauzer, Miniature	1,433	0.124	0.008	0.057	0.126	0.101	0.057	0.029	0.111	0.007	0.07	0.136	0.174
Schnauzer, Standard	276	0.101	0.022	0.051	0.112	0.091	0.072	0.054	0.094	0.014	0.069	0.152	0.167
Scottish Terrier	477	0.071	0.025	0.029	0.134	0.132	0.078	0.069	0.059	0.002	0.088	0.17	0.143
Shar-Pei	497	0.038	0.054	0.006	0.199	0.091	0.024	0.066	0.06	0.014	0.093	0.127	0.227
Shetland Sheepdog	1,429	0.09	0.028	0.032	0.106	0.061	0.057	0.085	0.106	0.011	0.094	0.142	0.188
Shih Tzu	826	0.109	0.016	0.024	0.108	0.086	0.035	0.052	0.131	0.022	0.097	0.139	0.182
Siberian Husky	816	0.096	0.022	0.043	0.125	0.066	0.06	0.102	0.119	0.009	0.072	0.069	0.218
Treeing Walker Coonhound	152	0.079	0.013	0.013	0.079	0.046	0.013	0.138	0.105	0.007	0.151	0.092	0.263
Vizsla	118	0.119	0.025	0.034	0.127	0.093	0.017	0.102	0.068	0	0.136	0.102	0.178
Weimaraner	324	0.093	0.015	0.034	0.176	0.059	0.031	0.083	0.117	0	0.074	0.105	0.213
West Highland White Terrier	453	0.091	0.049	0.062	0.117	0.073	0.057	0.051	0.113	0.002	0.141	0.113	0.132
Yorkshire Terrier	1,026	0.128	0.007	0.028	0.133	0.023	0.031	0.088	0.134	0.004	0.161	0.105	0.159

CV, cardiovascular; Derm, dermatologic; Endo, endocrine; GI, gastrointestinal; Hem, hematopoietic; Hep, hepatic; MS, musculoskeletal; Neuro, neurologic; Ophth, ophthalmologic; OS, organ system; Resp, respiratory; Uncl, unclassified; Uro, urogenital.

Only breeds represented by ≥100 individuals are shown. The leading OS cause of death for each breed is highlighted by a solid box. Unclassified causes of death are shown but not considered when ranking the leading cause of death.

findings, such as the high percentage of deaths in Dachshunds that were attributable to neurologic system disease, and more surprising results, such as the high percentage of cardiovascular system causes of death in Fox Terriers (Table 1). For PP, Golden Retrievers showed the highest percentage of deaths because of neoplasia, whereas Treeing Walker Coonhounds were most likely to die of infectious processes (Table 2).

In the OS categories, the 5 breeds with the highest relative proportion of gastrointestinal causes of death were Great Dane (0.256 of all OS deaths were gastrointestinal), Gordon Setter (0.225), Akita (0.212), Shar-Pei (0.199), and Weimaraner (0.176). The 5 breeds with highest relative proportion of cardiovascular causes of death were Newfoundland (0.238), Maltese (0.211), Chihuahua (0.185), Doberman Pinscher (0.172), and Fox Terrier (0.163). Highest relative proportion of neurologic

disease as the cause of death was seen in the Dachshund (0.404), Miniature Dachshund (0.397), Dutch Pug (0.274), Miniature Pinscher (0.223), and Boston Terrier (0.222). The top 5 breeds represented with musculoskeletal causes of death were Saint Bernard (0.262), Great Pyrenees (0.255), Irish Wolfhound (0.221), Great Dane (0.217), and Greyhound (0.214). Urogenital disease was not a leading cause of death overall, but was most frequent among Scottish Terrier (0.170), Airedale Terrier (0.163), Dalmatian (0.162), Norwegian Elkhound (0.160), and Standard Schnauzer (0.152). Respiratory disease as a cause of death was documented most commonly in Bulldog (0.182), Borzoi (0.163), Yorkshire Terrier (0.161), Afghan Hound (0.160), and Treeing Walker Coonhound (0.151).

Although neoplasia was a leading PP cause of death across all breeds in our population, the 5 dog breeds with

Table 2.   Relative frequency of deaths within pathophysiologic process (PP) categories for each breed (n = 72,376).

Breed	n	Congen	Degen	Infect	Inflam	Metab	Neopl	Toxic	Traum	Vasc	Uncl
Afghan Hound	238	0.013	0.034	0.092	0.008	0.055	0.353	0.008	0.097	0.029	0.311
Airedale Terrier	368	0.011	0.027	0.052	0.073	0.033	0.402	0.014	0.076	0.003	0.310
Akita	222	0.104	0.018	0.072	0.027	0.045	0.207	0.018	0.104	0.005	0.401
Alaskan Malamute	415	0.024	0.007	0.089	0.034	0.055	0.342	0.007	0.089	0.005	0.347
American Cocker Spaniel	2,663	0.029	0.030	0.067	0.105	0.049	0.200	0.017	0.098	0.007	0.398
American Eskimo	181	0.017	0.006	0.094	0.033	0.061	0.238	0.050	0.138	0.000	0.365
American Staffordshire Terrier	423	0.035	0.007	0.210	0.007	0.024	0.220	0.012	0.203	0.012	0.270
Australian Heeler	265	0.026	0.019	0.136	0.023	0.045	0.192	0.053	0.208	0.011	0.287
Australian Shepherd	592	0.054	0.014	0.105	0.025	0.034	0.236	0.051	0.179	0.010	0.292
Basset Hound	650	0.037	0.014	0.063	0.015	0.032	0.378	0.018	0.085	0.012	0.345
Beagle	980	0.020	0.019	0.115	0.017	0.049	0.231	0.017	0.160	0.005	0.365
Bernese Mountain Dog	119	0.076	0.000	0.084	0.076	0.025	0.546	0.000	0.034	0.000	0.160
Bichon Frise	287	0.042	0.028	0.066	0.049	0.080	0.213	0.014	0.084	0.000	0.425
Black and Tan Coonhound	118	0.042	0.000	0.144	0.000	0.059	0.229	0.025	0.110	0.008	0.381
Border Collie	314	0.025	0.010	0.108	0.048	0.035	0.261	0.010	0.175	0.000	0.328
Borzoi	104	0.010	0.019	0.077	0.010	0.019	0.337	0.000	0.077	0.000	0.452
Boston Terrier	473	0.034	0.032	0.061	0.025	0.074	0.304	0.025	0.066	0.011	0.368
Bouvier des Flandres	176	0.063	0.006	0.051	0.017	0.023	0.466	0.011	0.080	0.006	0.278
Boxer	1,093	0.026	0.011	0.057	0.024	0.059	0.443	0.014	0.070	0.003	0.295
Brittany Spaniel	476	0.036	0.038	0.090	0.017	0.044	0.265	0.017	0.155	0.004	0.334
Bull Terrier	121	0.041	0.033	0.132	0.017	0.050	0.215	0.017	0.132	0.008	0.355
Bulldog	578	0.135	0.019	0.090	0.007	0.052	0.204	0.012	0.073	0.010	0.398
Bullmastiff	134	0.045	0.022	0.075	0.022	0.037	0.440	0.007	0.097	0.015	0.239
Cairn Terrier	242	0.041	0.033	0.095	0.004	0.095	0.322	0.017	0.070	0.008	0.314
Cardigan Welsh Corgi	112	0.063	0.027	0.152	0.036	0.054	0.223	0.018	0.080	0.009	0.339
Chesapeake Bay Retriever	186	0.022	0.016	0.091	0.022	0.032	0.285	0.032	0.129	0.005	0.366
Chihuahua	573	0.051	0.072	0.105	0.014	0.065	0.075	0.010	0.168	0.009	0.433
Chow Chow	631	0.068	0.017	0.114	0.027	0.022	0.206	0.033	0.166	0.008	0.338
Collie	979	0.048	0.020	0.073	0.026	0.037	0.265	0.027	0.127	0.008	0.371
Dachshund	1,605	0.014	0.063	0.050	0.031	0.055	0.089	0.016	0.115	0.007	0.561
Dachshund, Miniature	448	0.022	0.033	0.056	0.022	0.049	0.060	0.020	0.123	0.013	0.600
Dalmatian	568	0.055	0.014	0.104	0.023	0.063	0.181	0.030	0.086	0.002	0.442
Doberman Pinscher	2,773	0.036	0.022	0.082	0.021	0.118	0.260	0.011	0.093	0.005	0.353
Dutch Pug	321	0.084	0.019	0.109	0.028	0.037	0.125	0.016	0.062	0.003	0.517
English Cocker Spaniel	117	0.034	0.009	0.026	0.094	0.026	0.248	0.000	0.034	0.000	0.530
English Pointer	303	0.030	0.007	0.162	0.023	0.046	0.337	0.003	0.096	0.003	0.294
English Setter	378	0.034	0.011	0.148	0.021	0.053	0.357	0.019	0.074	0.003	0.280
English Springer Spaniel	890	0.033	0.020	0.084	0.048	0.057	0.297	0.016	0.102	0.009	0.334
Finnish Spitz	107	0.019	0.009	0.131	0.009	0.065	0.271	0.000	0.103	0.009	0.383
Fox Terrier	221	0.072	0.027	0.081	0.027	0.068	0.244	0.005	0.104	0.018	0.353
German Shepherd Dog	3,827	0.034	0.022	0.102	0.019	0.027	0.277	0.021	0.111	0.007	0.379
German Shorthaired Pointer	415	0.019	0.017	0.113	0.017	0.055	0.270	0.029	0.157	0.002	0.320
Golden Retriever	4,029	0.028	0.011	0.063	0.022	0.029	0.499	0.012	0.078	0.007	0.251
Gordon Setter	120	0.025	0.017	0.067	0.000	0.050	0.383	0.008	0.125	0.000	0.325
Great Dane	921	0.040	0.016	0.063	0.012	0.089	0.228	0.005	0.087	0.014	0.445
Great Pyrenees	188	0.064	0.021	0.096	0.005	0.048	0.362	0.000	0.128	0.016	0.261
Greyhound	473	0.030	0.002	0.165	0.019	0.061	0.216	0.004	0.163	0.015	0.326
Irish Setter	709	0.013	0.035	0.071	0.020	0.042	0.408	0.013	0.080	0.004	0.315
Irish Wolfhound	217	0.046	0.014	0.078	0.023	0.074	0.318	0.009	0.055	0.028	0.355
Jack Russell Terrier	116	0.069	0.026	0.095	0.034	0.034	0.172	0.034	0.198	0.009	0.328
Keeshond	257	0.035	0.023	0.082	0.078	0.097	0.280	0.016	0.082	0.008	0.300
Labrador Retriever	4,398	0.025	0.014	0.105	0.023	0.034	0.340	0.025	0.141	0.007	0.287
Lhasa Apso	696	0.053	0.034	0.065	0.034	0.053	0.171	0.019	0.118	0.003	0.450
Maltese	413	0.097	0.041	0.061	0.051	0.075	0.092	0.007	0.058	0.012	0.506
Mastiff	180	0.061	0.006	0.106	0.022	0.056	0.300	0.006	0.128	0.022	0.294
Miniature Pinscher	112	0.071	0.018	0.071	0.036	0.080	0.036	0.045	0.196	0.009	0.438
Mixed-Breed Dog	17,795	0.013	0.024	0.102	0.026	0.046	0.276	0.023	0.162	0.006	0.324
Newfoundland	286	0.175	0.045	0.063	0.031	0.035	0.199	0.007	0.080	0.010	0.353
Norwegian Elkhound	243	0.025	0.016	0.107	0.008	0.053	0.374	0.037	0.078	0.012	0.288
Old English Sheepdog	428	0.049	0.021	0.082	0.040	0.063	0.360	0.012	0.070	0.005	0.299
Pekingese	453	0.035	0.051	0.084	0.042	0.077	0.079	0.013	0.130	0.007	0.481
Pembroke Welsh Corgi	115	0.078	0.017	0.052	0.026	0.026	0.304	0.026	0.061	0.009	0.400
Pomeranian	581	0.069	0.033	0.086	0.031	0.067	0.079	0.010	0.131	0.005	0.489

Table 2. (Continued).

Breed	n	Congen	Degen	Infect	Inflam	Metab	Neopl	Toxic	Traum	Vasc	Uncl
Poodle, Miniature	1,730	0.024	0.051	0.051	0.039	0.082	0.185	0.013	0.108	0.006	0.441
Poodle, Standard	812	0.015	0.037	0.081	0.053	0.049	0.271	0.009	0.101	0.012	0.372
Poodle, Toy	877	0.041	0.052	0.080	0.038	0.075	0.114	0.016	0.117	0.011	0.455
Rhodesian Ridgeback	123	0.041	0.024	0.081	0.024	0.016	0.374	0.016	0.081	0.016	0.325
Rottweiler	1,687	0.046	0.018	0.148	0.027	0.036	0.296	0.018	0.092	0.010	0.309
Saint Bernard	413	0.022	0.022	0.082	0.017	0.061	0.269	0.007	0.104	0.027	0.390
Samoyed	491	0.055	0.026	0.067	0.035	0.073	0.261	0.029	0.086	0.002	0.367
Schnauzer, Miniature	1,433	0.049	0.031	0.065	0.054	0.089	0.223	0.021	0.045	0.010	0.412
Schnauzer, Standard	276	0.040	0.011	0.051	0.036	0.087	0.254	0.029	0.043	0.025	0.424
Scottish Terrier	477	0.027	0.008	0.059	0.040	0.057	0.476	0.015	0.044	0.006	0.268
Shar-Pei	497	0.062	0.004	0.099	0.048	0.085	0.229	0.010	0.099	0.006	0.358
Shetland Sheepdog	1,429	0.020	0.027	0.059	0.023	0.054	0.303	0.012	0.105	0.015	0.383
Shih Tzu	826	0.067	0.027	0.075	0.064	0.065	0.151	0.012	0.073	0.006	0.460
Siberian Husky	816	0.026	0.015	0.132	0.026	0.040	0.295	0.015	0.115	0.010	0.326
Treeing Walker Coonhound	152	0.007	0.007	0.257	0.013	0.046	0.184	0.020	0.164	0.007	0.296
Vizsla	118	0.008	0.034	0.076	0.017	0.059	0.364	0.008	0.136	0.000	0.297
Weimaraner	324	0.034	0.006	0.105	0.028	0.034	0.250	0.025	0.090	0.019	0.410
West Highland White Terrier	453	0.055	0.011	0.108	0.049	0.062	0.263	0.018	0.051	0.013	0.371
Yorkshire Terrier	1,026	0.105	0.024	0.090	0.019	0.070	0.112	0.015	0.107	0.007	0.450

Congen, congenital; Degen, degenerative; Infect, infectious; Inflam, inflammatory; Metab, metabolic; Neopl, neoplastic; Toxic, toxic; Traum, traumatic; Uncl, unclassified; Vasc, vascular.

Only breeds represented by ≥100 individuals are shown. The leading PP cause of death for each breed is highlighted by a box. Unclassified causes of death are shown but not considered when ranking the leading cause of death.

highest proportion of neoplastic causes of death were Bernese Mountain Dog (0.546), Golden Retriever (0.499), Scottish Terrier (0.476), Bouvier des Flandres (0.466), and Boxer (0.443). The breeds with highest relative proportion of infectious disease causes of death were Treeing Walker Coonhound (0.257), American Staffordshire Terrier (0.210), Greyhound (0.165), English Pointer (0.162), and Cardigan Welsh Corgi (0.152). Congenital disease was most represented as a cause of death in Newfoundland (0.175), Bulldog (0.135), Akita (0.104), Yorkshire Terrier (0.105), and Maltese (0.97). For traumatic causes of death, Australian Heeler (0.208), American Staffordshire Terrier (0.203), Jack Russell Terrier (0.198), Miniature Pinscher (0.196), and Australian Shepherd (0.179) had the highest proportions.

For all dogs, Figure 1 shows the percentage of deaths attributable to each OS and PP category. Among juvenile dogs (n = 9,859), 2,792 were unclassified for OS, and 3,004 were unclassified for PP. Juvenile dogs are depicted in Figure 1A (n = 7,067) and Figure 1B (n = 6,855). Among adult dogs (n = 64,697), 12,374 individuals were unclassified for OS, and 23,438 individuals were unclassified for PP. Adult dogs are depicted in Figure 1C (n = 52,323) and Figure 1D (n = 41,259). Gastrointestinal (OS) and infectious (PP) causes of death predominate for the young dogs, with a dramatic shift toward neurologic (OS) and neoplastic (PP) causes for the adult dogs.

Figures 2 (n = 57,663) and 3 (n = 46,720) depict the effect of age on the frequency of categorical causes of death for dogs within OS and PP classifications, respectively. For example, the frequency of neurologic system causes of death increases within age groups up to 4 years (bins 1–6), then declines through groups up to 10 years of age (bins 7–9), after which point it increases again in the highest age group (bin 10). Conversely, the frequency of death because of endocrine system disease increases within age groups including 2 years up to 10 years (bins 6–9), after which it plateaus in the oldest group. Older dogs have an increased rate of mortality compared with younger dogs, and these data reveal that death because of cardiovascular, endocrine, neurologic, or urogenital disease is relatively more common in dogs within higher age groups, whereas death because of hematopoietic or musculoskeletal disease is relatively less common in those groups (Fig 2). Regarding PPs, trauma is a frequent cause of death for dogs within age groups up to 1 year of age (bins 1–4) and declines steeply thereafter, whereas the frequency of neoplastic processes as the cause of death begins to rise in the group that includes 1-year-old dogs (bin 5), and increases within the next 3 age groups (bins 6–8). Degenerative and metabolic processes contribute to the increasing mortality rate of older dogs, but neoplasia as a cause of death peaks in the group that includes 10-year-old dogs, and then declines as a contributing cause among dogs in the oldest age group (Fig 3).

Figures 4 (n = 57,662) and 5 (n = 46,720) show the influence of comparative mass of dog breeds on categorical causes of death. For example, dogs from larger breeds die of urogenital disease (OS) less frequently than do dogs from smaller breeds whereas the frequency of death because of musculoskeletal disease increases as breed size gets larger. Dogs from larger breeds have shorter lifespans than dogs from smaller breeds, and these data show that musculoskeletal and gastrointestinal causes contribute more to deaths of dogs from larger breeds than do endocrine or urogenital causes (Fig 4).
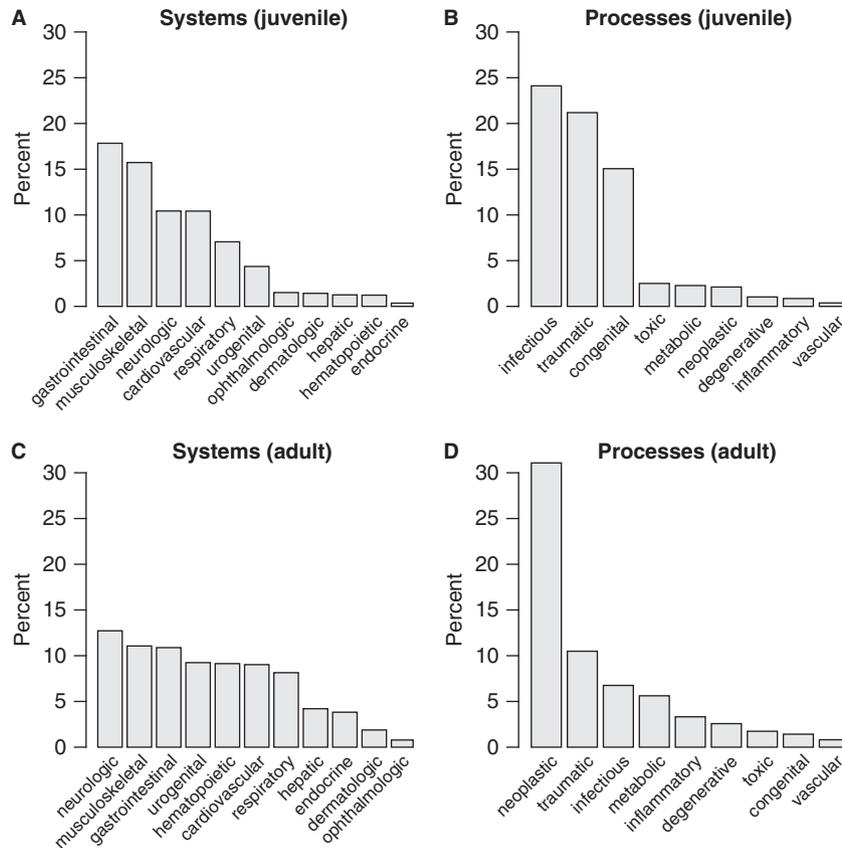
Fig 1. Proportion of deaths attributable to each organ system (OS) and pathophysiologic process (PP) category for juvenile (up to 1 year, **A** and **B**) and adult (1 year or greater, **C** and **D**) dogs. Among 9,859 juvenile dogs, 2,792 were unclassified for OS (A, n = 7,067) and 3,004 were unclassified for PP (B, n = 6,855). Among 64,697 adult dogs, 12,374 individuals were unclassified for OS (C, n = 52,323) and 23,438 individuals were unclassified for PP (D, n = 41,259).

Dogs from smaller breeds die of degenerative and metabolic causes (PP) more frequently than do dogs from larger breeds. Neoplastic processes contribute substantially to deaths among dogs from larger breeds (Fig 5).

Discussion

We confirmed our hypothesis that causes of death, categorized by OS or PP, segregated by age, body mass, and breed in the canine patient population of the VMDB. Mortality rates generally increase with increasing age in all species. However, not all causes of death contribute equally to the rising risk of death in aging populations. Within our study population, diseases of the nervous system were the leading OS cause of death in older dogs, and also showed increasing frequency with increasing age. In contrast, gastrointestinal disease was the 2nd most frequent OS cause of death in adult dogs overall, but the contribution to total deaths by gastrointestinal disease remained relatively constant over the span of adulthood. Although urogenital disease ranked 6th in OS causes of death overall, the proportionate contribution to total deaths by this system increased within the oldest age group.

Similar patterns are seen among PPs associated with death. Although neoplastic processes were the leading cause of death among adult dogs in our study overall, their relative frequency peaked in the group including 10-year-old dogs and then declined within the oldest age group. Conversely, metabolic and degenerative processes ranked 4th and 6th overall, but their proportionate frequency increased with increasing age, as might be expected.

It has long been observed that dogs from larger breeds have shorter lifespans than dogs from smaller breeds, in contrast to the more common pattern among mammals overall, where larger species tend toward longer lifespans than smaller ones. This observation has been the source of much recent interest, increasing with the completion of the canine genome.[2,14–17,22–24] If we can understand which causes account for death among dogs from larger breeds as compared with dogs from smaller breeds, we may better understand why it is that dogs from smaller breeds live longer.

In our study, increasing breed size was associated with increasing risk of death because of musculoskeletal or gastrointestinal system disease. Dogs from larger breeds seemed to be spared death because of neurologic or endocrine diseases. Neoplastic disease was a more frequent cause of death in dogs from larger breeds, whereas dogs
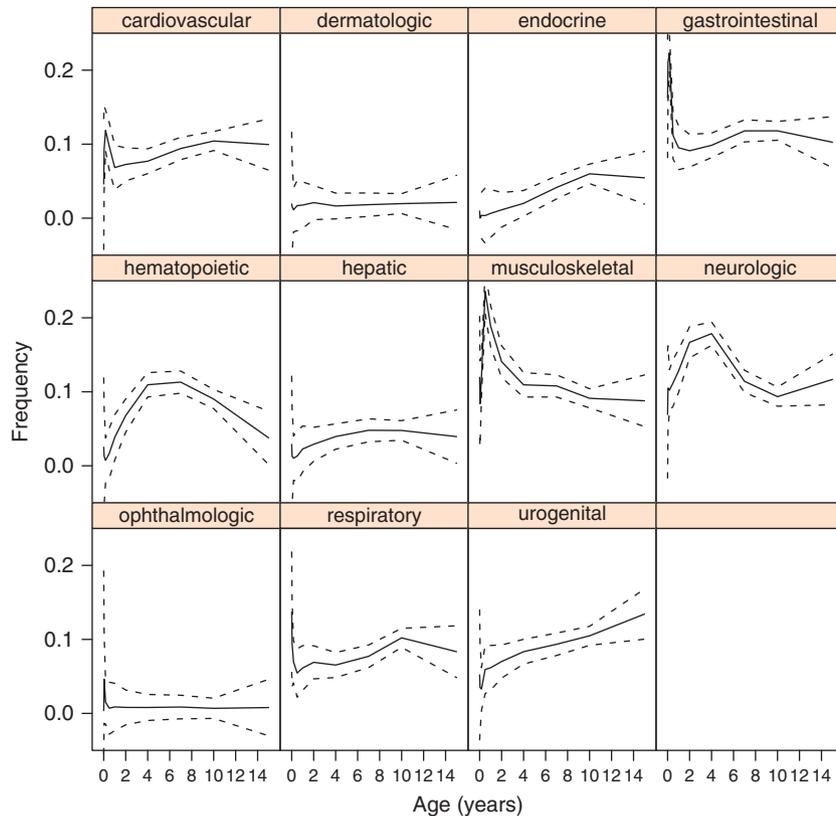
Fig 2. Relative frequency of causes of death by organ system (OS), as a function of age (years) for all breeds with more than 100 representatives (n = 57,662, excluding 14,714 individuals unclassified for OS). Estimates are provided for each of 10 age-classes, with points connected by a solid line to highlight any obvious age-related trends. Dashed lines represent 95% confidence intervals.

from smaller breeds had increased risk of death because of metabolic processes. Traumatic causes were responsible for death in dogs from larger and smaller breeds at similar rates. Given these findings, we support future research into the disproportionate rates of musculoskeletal and neoplastic disorders in dogs from larger breeds to better understand their shorter lifespans. Previous authors have reported that despite the shorter lifespan of dogs from larger breeds overall, larger individuals within given breeds do not exhibit a shorter lifespan. Because our data did not include individual dog weights and we assigned breed-standard body mass to all dogs of each breed, we were not able to evaluate the possible influence on risk of death by individual size within a given breed.

Dog breeds represent genetic islands and as such can manifest unusual disease phenotypes with frequency far greater than an outbred population. Inspection of breed-based results for relative frequency of causes of death yields many examples of this phenomenon, some of which are expected and others of which are surprising. Gastrointestinal and neurologic diseases were the leading OS causes of death in our study by a very slight margin, with musculoskeletal, cardiovascular, and urogenital causes of death occurring nearly as often. These 5 OS categories were responsible for most deaths in most breeds. Consistent with the knowledge of brachycephalic airway

syndrome in Bulldogs, respiratory disease represented the most frequent OS cause of death in this breed. However, respiratory disease was also the most common OS cause of death for both Afghan Hounds and Vizslas, which is not as readily explained. For Chihuahuas and Maltese, the cardiovascular system was the leading OS cause of death, which is compatible with the high incidence of mitral valve disease in toy breeds. However, cardiovascular also was the leading OS cause of death for Fox Terriers, a breed not traditionally associated with this diagnosis. Conversely, musculoskeletal causes of death ranked 5th in this breed. It is not clear whether Fox Terriers are frequently affected by cardiovascular diseases in a manner that has not yet been described, or whether they are somehow protected from death by other OS categories, such as gastrointestinal disease. Either explanation has potential benefit for genetic research or veterinary patient management and now this finding can be further investigated.

Consistent with other studies,[4,5] Golden Retrievers and Boxers in our study died of cancer more commonly than any other PP, and at rates higher than most other breeds. However, the Bouvier des Flandres was the breed with the 2nd highest rate of death because of neoplasia, ranking ahead of the Boxer. This pattern has not been reported previously. Although neoplasia generally was the most common PP resulting in death, there were a few
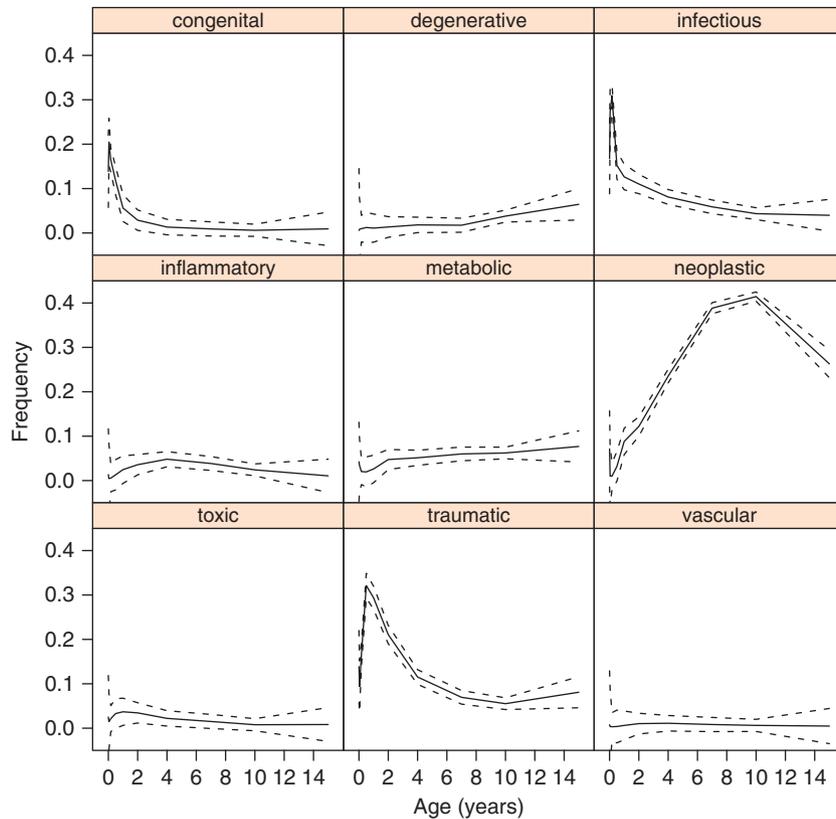
Fig 3. Relative frequency of causes of death by pathophysiologic process (PP), as a function of age (years) for all breeds with more than 100 representatives (n = 46,720, excluding 25,656 individuals unclassified for PP). Lines are as described in Figure 2.

exceptional breeds, including several toy breeds (Chihuahua, Pekingese, Pomeranian, and Toy Poodle), the Australian Heeler, and the Treeing Walker Coonhound. It has already been observed that dogs from smaller breeds had decreased risk of death because of neoplastic processes than dogs from larger breeds overall, and for each of these toy breeds the leading PP cause of death was trauma. For the Australian Heeler, trauma also was the leading PP cause of death, whereas for the Treeing Walker Coonhound, infectious processes were the leading PP cause of death. For those medium-sized breeds, the question of whether this discrepancy reflects increased risk of trauma and infection, or relative protection from neoplasia, can now be considered.

The results of this study must be interpreted with caution for several reasons. First, the VMDB represents that subset of the overall canine population presented to a veterinary teaching hospital. This may tend to bias our results to include more severe, complicated, or unusual diseases than are seen in the canine population at large. Although these data also represent only those owners with the access and the means to pursue referral to a teaching hospital, there is no reason to believe that owner socioeconomic status or teaching hospital proximity biases the causes of death among dogs in any consistent way.

Second, because our primary goal was to investigate causes of death among age cohorts, size cohorts, or breeds of dogs, our data included only patient visits that

resulted in death of the dog. Therefore, there may be categories of illness that impose a large burden of morbidity on demographic groups of dogs, but which do not lead to mortality; these diseases would not be detected within our study design. The inclusion of only VTH presentations associated with patient death also means that we do not know the entire at-risk population of dogs. Thus, any conclusions we draw from our data are only relative frequencies of death within this population subset, and cannot be generalized to describe the risk of mortality among dogs overall.

Third, diagnoses entered into the VMDB are at the discretion of the attending clinician, and are not necessarily necropsy-confirmed. Although this constraint may have led to misdiagnosis or misclassification of some dogs, there is no reason to suspect that such errors are biased in any consistent way. In this very large sample of dogs, it is unlikely that random errors influenced the results. Because of the abstracted medical information, and the retrospective nature of the study design, there may have been disagreement between the authors' identified cause of death and the actual cause of death in some cases. Again, there is no reason to believe that such errors would be biased in any consistent way. Thus, any individual misidentification of the cause of death would not have influenced the results in a sample size this large.

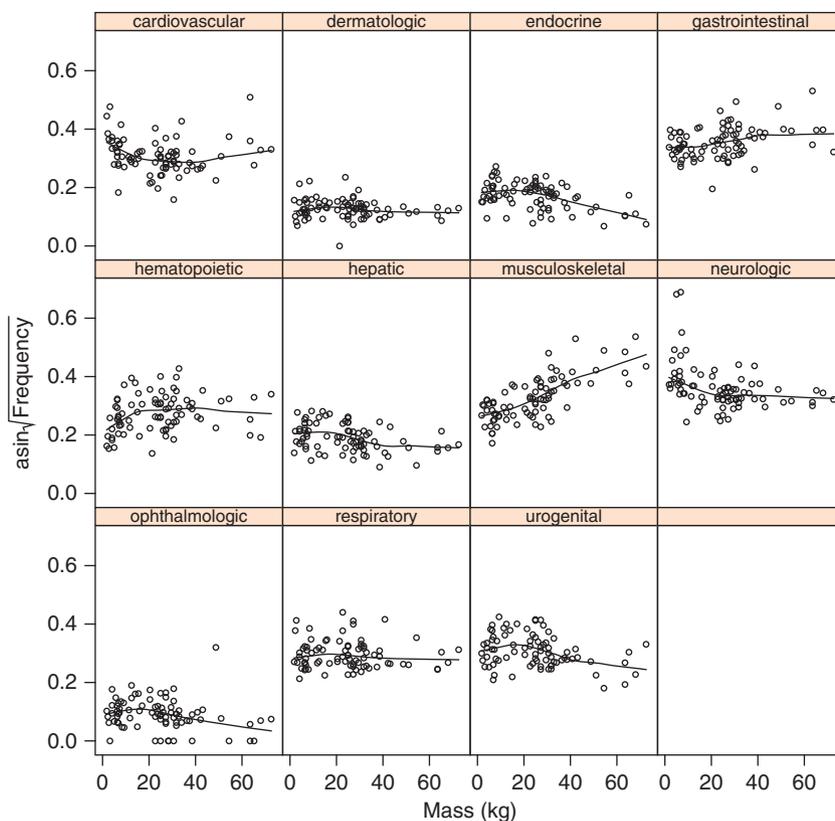Finally, because breed identity was provided by owners at the time of the hospital visit, actual pedigree

Fig 4. Distribution of the frequency of death by organ system (OS, expressed as asin $\sqrt{\text{frequency}}$) as a function of size (expressed as mass in kg) across dog breeds (n = 57,662). Each circle represents a dog breed. The points have been fitted with a LOESS smoothing function in each panel.

certification was not obtained, and it is possible that some dogs were misclassified by breed, or were crossbred dogs resembling common breeds, such as Labrador cross dogs. Because the category of mixed-breed dog contained the most individuals by far, it is reasonable to believe that most such dogs were correctly coded. Again, because of the large numbers of dogs included in this study, misclassification of some dogs would not have had a profound impact on our results.

The retrospective nature of the data limits the conclusions that can be drawn from this study alone. However, the results of this study point us clearly toward areas that will be critical for future investigation. For example, the gastrointestinal system was the OS most frequently associated with death in our study overall. This frequency remained constant in aging dogs, and increased with increasing breed size. Were Afghan Hounds relatively spared this risk of gastrointestinal cause of death because of their risk of death owing to respiratory disease? Alternately, dogs in our study most frequently died of neoplastic processes overall, but the oldest dogs in our study were protected from this cause of death. Being a member of a smaller breed also exhibited some mitigating effect on the frequency of death because of neoplasia. To what extent does protection from the risk of death because of neoplasia contribute to the longer lifespans generally observed in dogs from smaller breeds? Is it possible that genetic factors

conveying some protection from neoplasia can be identified in dogs from smaller breeds? Conversely Treeing Walker Coonhounds, a larger breed, also had unexpectedly low rates of death because of neoplasia. Is this because of a lifestyle that increases risk of exposure to infectious diseases that cause death? Or can a genetic commonality be found between Treeing Walker Coonhounds and smaller breeds of dogs that is protecting both groups from neoplasia?

Additionally, our data were derived from medical records submitted over a 20-year time span by North American veterinary teaching hospitals. Each VTH manages a patient population derived from its geographic region, with little overlap among their constituent areas. Breed preferences, as well as disease prevalence, vary among discrete regional populations. Even a widely popular breed is likely to exhibit a regionally constrained genetic pool. Over the span of any period of 20 years, technology improves, diagnostic approaches change, and diseases emerge. It is likely that the overall patterns of mortality we report would exhibit variation if assessed over time, over distance, or among institutions. Although addressing these subcategories of analysis is beyond the scope of this report, the authors intend to analyze these variations in future studies. It will be particularly interesting to determine if there are geographic differences in breed-specific mortality that persist over the 20-year span of these data.
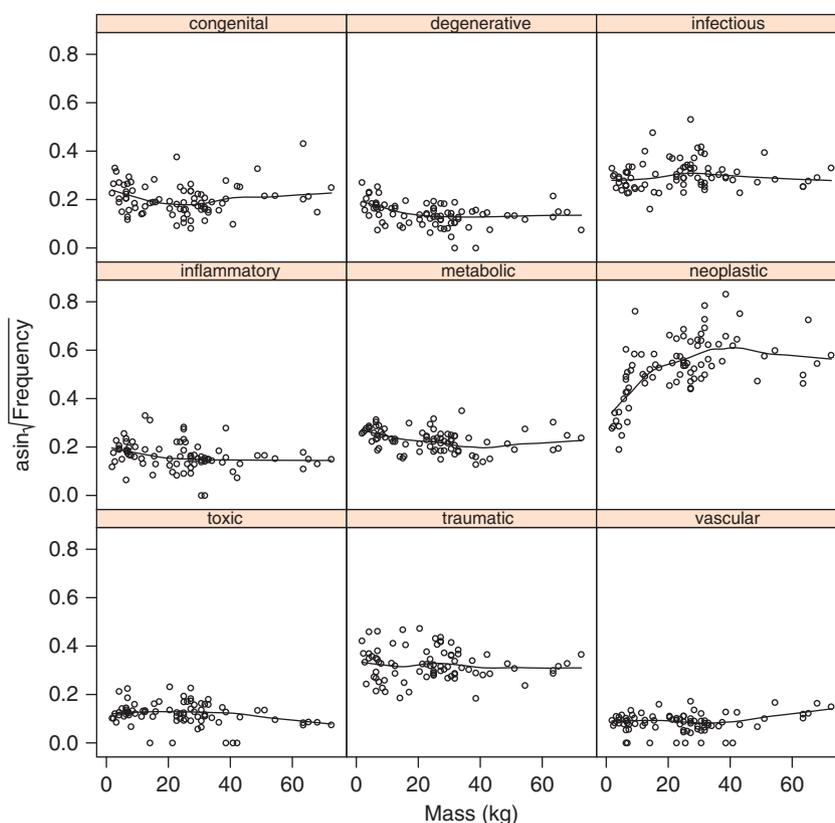
Fig 5. Distribution of the frequency of death by pathophysiologic process (PP) as a function of size across dog breeds (n = 46,720). Data transformations and smoothing functions are described in the legend for Figure 4.

In conclusion, this study identifies the most common OS and PP causes of death in the population of dogs treated at North American teaching hospitals. It corroborates certain beliefs about causes of death in age cohorts, size cohorts, and breeds of dogs, which have been poorly documented previously. It also identifies novel patterns of causation of death in certain groups. Perhaps most importantly, it provides a framework within which such discoveries may be studied in greater depth.

Footnotes

[a] Veterinary Medical DataBase (VMDB), http://www.vmdb.org/; VMDB does not make any implicit or implied opinion on the subject of the paper or study.
[b] R: A Language and Environment for Statistical Computing, R Development Core Team, 2010, R Foundation for Statistical Computing, Vienna, Austria
[c] JMP Version 8, 2009, SAS Institute Inc, Cary, NC

Acknowledgments

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