

Prevalence of Disorders Recorded in Dogs Attending Primary-Care Veterinary Practices in England

Dan G. O'Neill^{1*}, David B. Church², Paul D. McGreevy³, Peter C. Thomson³, Dave C. Brodbelt¹

1 Veterinary Epidemiology, Economics and Public Health, Royal Veterinary College, London, United Kingdom, **2** Small Animal Medicine and Surgery Group, Royal Veterinary College, London, United Kingdom, **3** Faculty of Veterinary Science, University of Sydney, Sydney, New South Wales, Australia

Abstract

Purebred dog health is thought to be compromised by an increasing occurrence of inherited diseases but inadequate prevalence data on common disorders have hampered efforts to prioritise health reforms. Analysis of primary veterinary practice clinical data has been proposed for reliable estimation of disorder prevalence in dogs. Electronic patient record (EPR) data were collected on 148,741 dogs attending 93 clinics across central and south-eastern England. Analysis in detail of a random sample of EPRs relating to 3,884 dogs from 89 clinics identified the most frequently recorded disorders as otitis externa (prevalence 10.2%, 95% CI: 9.1–11.3), periodontal disease (9.3%, 95% CI: 8.3–10.3) and anal sac impaction (7.1%, 95% CI: 6.1–8.1). Using syndromic classification, the most prevalent body location affected was the head-and-neck (32.8%, 95% CI: 30.7–34.9), the most prevalent organ system affected was the integument (36.3%, 95% CI: 33.9–38.6) and the most prevalent pathophysiologic process diagnosed was inflammation (32.1%, 95% CI: 29.8–34.3). Among the twenty most-frequently recorded disorders, purebred dogs had a significantly higher prevalence compared with crossbreds for three: otitis externa ($P=0.001$), obesity ($P=0.006$) and skin mass lesion ($P=0.033$), and popular breeds differed significantly from each other in their prevalence for five: periodontal disease ($P=0.002$), overgrown nails ($P=0.004$), degenerative joint disease ($P=0.005$), obesity ($P=0.001$) and lipoma ($P=0.003$). These results fill a crucial data gap in disorder prevalence information and assist with disorder prioritisation. The results suggest that, for maximal impact, breeding reforms should target commonly-diagnosed complex disorders that are amenable to genetic improvement and should place special focus on at-risk breeds. Future studies evaluating disorder severity and duration will augment the usefulness of the disorder prevalence information reported herein.

Citation: O'Neill DG, Church DB, McGreevy PD, Thomson PC, Brodbelt DC (2014) Prevalence of Disorders Recorded in Dogs Attending Primary-Care Veterinary Practices in England. PLoS ONE 9(3): e90501. doi:10.1371/journal.pone.0090501

Editor: Cheryl S. Rosenfeld, University of Missouri, United States of America

Received: December 4, 2013; **Accepted:** February 3, 2014; **Published:** March 4, 2014

Copyright: © 2014 O'Neill et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Funding: This study was part of a Ph.D. study that was financially supported by the RSPCA (<http://www.rspca.org.uk/sciencegroup/companionanimals>). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

* E-mail: doneill@rvc.ac.uk

Introduction

The domestic dog (*Canis lupus familiaris*) has become integral to modern human family life, with the UK dog population estimated to be 8–10 million [1,2,3] and 24–31% of UK households estimated to own at least one dog [1,2]. Although humans benefit from dog ownership both physically [4,5] and mentally [6,7], it is increasingly questioned whether modern breeding practices have allowed dog health and welfare to derive comparable benefits [8,9]. Although the dog is now the most phenotypically diverse mammal at a species level [10], genetic diversity has been greatly reduced within modern breeds [11] because of breeding practices that include closed stud books [12], structured inbreeding [11] and reproductive dominance of popular sires [13]. Additionally, selection pressure within breeds towards phenotypic exaggeration driven by breed standards [8], have increased the potential for conformation-associated disease [14]. Each of the 50 most popular breeds in the UK has at least one reported conformational predisposition to disease [15] and almost 400 non-conformational inherited disorders have been identified [16]. Conversely, implicit acceptance of the statement that purebred dogs are plagued with many inherited diseases [17] has contributed to a widespread

belief that crossbred dogs are substantially healthier than purebreds [18].

Following claims in the BBC documentary *Pedigree Dogs Exposed* that purebred dog health was deteriorating because of inbreeding and ill-advised breed standards [19], three major reports concurred that pedigree breeding practices did impose welfare costs on dogs but, more crucially, concluded that a critical data gap on disorder prevalence information in UK dogs constrained effective reforms [20,21,22]. Prevalence data have been published on only 1% of inherited disorders affecting popular UK dog breeds [23]. Effective welfare reform of pedigree dog-breeding must be underpinned by scientifically valid prioritisation of disorders based on reliable and comparable prevalence data [12,24]. However, differing case definitions, study populations, geographical locations, data quality and data collection periods between published studies, combined with substantial data gaps, have constrained efforts to prioritise disorders in domestic dogs [9]. Application of health data collected via a single national surveillance system has been proposed for effective disorder prioritisation, with the critical first step being the generation of reliable disorder prevalence values [12].

Systematised collection, mergence and analysis of electronic patient record (EPR) data from primary-care veterinary practices

has been proposed for generation of reliable prevalence data relating to the overall dog population [12,20]. Contemporaneous recording of clinical information by veterinary health professionals during episodes of care for every patient treated minimises selection and recall biases in primary-care practice EPR data [20]. By contrast, referral caseloads may show selection bias towards more complicated disorders [25], questionnaire surveys may incur selection, recall and misclassification biases [26], and pet insurance data are limited by selection bias emerging from age restrictions, financial excesses and owner attributes [27].

This study aimed to use a database of merged primary-care practice EPRs to estimate the prevalence of the most frequently recorded disorders and syndromes in dogs attending primary-care veterinary practices in England. The study further aimed to evaluate associations between the occurrence of common disorders with purebred/crossbred status and with popular breeds. It was hypothesised that purebred dogs have a higher prevalence of common disorders compared with crossbred dogs.

Materials and Methods

Ethics statement: Ethics approval was granted by the RVC Ethics and Welfare Committee (reference number 2010 1076).

The VetCompass Animal Surveillance project collates de-identified EPR data from primary-care veterinary practices in the UK for epidemiological research [28]. The current study included data collected from all clinics within the Medivet Veterinary Group, a large network of integrated veterinary practices covering central and south-eastern England [29]. Practitioners recorded summary diagnosis terms from an embedded standard nomenclature, the VeNom codes [30], at episodes of clinical care. EPR data were extracted from practice management systems (PMSs) using integrated clinical queries [31] and uploaded to a secure structured query language (SQL) database. Information collected included patient demographic (animal identification number, species, breed, date of birth, sex, neuter status, insurance status, microchip number and weight) and clinical information (free-form text clinical notes, VeNom summary diagnosis terms and treatment, with relevant dates) data fields.

The study sampling frame included all dogs that had at least one EPR (clinical note, weight recording or treatment dispensed) recorded within the VetCompass Animal Surveillance database from September 1, 2009 to March 31, 2013. Sample size calculations estimated that, from a study population of 140,000 dogs, a sample of 3,648 animals was required to represent a disorder with 2.5% expected frequency with a precision of 0.5% at a 95% confidence level [32].

A random sample of dogs was selected from the overall sampling frame using an online random number generator (www.random.org). Clinical notes and VeNom summary diagnosis terms recorded during the study period were reviewed in detail, and the most definitive diagnostic term recorded for each disorder diagnosed within individual dogs was manually coded using the most appropriate VeNom term. Elective (e.g. neutering) or prophylactic (e.g. vaccination) clinical events were not included. Multiple counting of disorder events for ongoing cases was avoided by including recurring diagnoses of ongoing conditions only once (e.g. repeated events of otitis externa) and by including only the final diagnosis term recorded in cases with diagnosis revision over time (e.g. following clinical work-up or trial therapy), based on the assumption that diagnostic accuracy increased over time [33]. The parent term was used for disorders that encompassed multiple child terms [34] (e.g. a parent term *road traffic accident* (RTA) may have multiple child terms such as *laceration*, *fracture* and *hypovolaemic*

shock). Disorder events that were aetiologically independent despite sharing the same disorder term name (e.g. novel traumatic events) were included separately. No distinction was made between pre-existing and incident disorder presentations. Disorders described within the clinical notes using presenting sign terms (e.g. 'vomiting and diarrhoea'), but without a formal clinical diagnostic term being recorded, were included using the first sign listed (e.g. vomiting). Dental disorders were included only if surgical or medical intervention were recommended.

Recognisable single breeds [35] were grouped as 'purebred' while all other dogs were grouped as 'crossbred'. Purebreds were further categorised by Kennel Club (KC) breed-recognition (recognised/not recognised) and KC breed group (gundog, hound, pastoral, terrier, toy, utility, working) [36]. Neuter status was defined by the final EPR neuter value and was combined with sex to create four categories: female entire, female neutered, male entire and male neutered. Insurance and microchip values characterized the existence of a positive status at any time during the study period. The maximum bodyweight (kg) recorded for dogs aged over one year was categorised into seven groups (<10.0, 10.0–19.9, 20.0–29.9, 30.0–39.9, 40.0–49.9, \geq 50.0, and 'no recorded weight'). The age (years) at the final EPR was categorised into five groups (<1.0, 1.0–2.9, 3.0–5.9, 6.0–9.9, \geq 10.0). Time contributed to the study for each dog was calculated as the period from the date of the earliest EPR to the date of the latest EPR. The date and manner (euthanasia or non-assisted) [37] of deaths recorded during the study were identified.

VeNom diagnostic terms for all recorded disorders were extracted and mapped to three systems of terms for analysis: diagnosis-level precision, mid-level precision and syndromic classification. Diagnosis-level terms were one-to-one descriptors of the original extracted terms at the maximal diagnostic precision recorded within the clinical notes (e.g. *inflammatory bowel disease* would remain as *inflammatory bowel disease*). Mid-level precision terms were one-to-one descriptors of original diagnosis terms defined at a general level of diagnostic precision (e.g. *inflammatory bowel disease* would map to *enteropathy*). Syndromic classification used three taxonomic groupings: body location, organ system and pathophysiologic process. The number of syndromic terms that could be mapped from each original diagnostic term was not limited.

Study data were exported from the VetCompass database to a spreadsheet (Microsoft Office Excel 2007, Microsoft Corp.) for checking and cleaning before further export to Stata Version 11.2 (Stata Corporation) for statistical analyses. Demographic variables were described statistically for the overall study population and the sample group. Prevalence values with 95% confidence intervals (CI) were tabulated for the twenty most prevalent diagnosis-level and mid-level disorders and for all syndromic terms, and were reported across all sampled dogs, purebreds only and crossbreds only. Prevalence values for purebred and crossbred dogs were compared statistically using the chi-squared test with Holm-adjusted P-values to account for multiple testing effects [38]. Statistical significance was set at the 5% level. The CI estimates were derived from standard errors based on approximation to the normal distribution for disorders with ten or more events recorded [39], but the Wilson approximation method was used for disorders with fewer than ten events recorded [40]. Prevalence (95% CI) values for the twenty most prevalent diagnosis-level and mid-level disorders and for all syndromic terms were similarly derived, reported and compared for popular breeds and crossbreds (popular breeds had \geq 100 dogs in the sample group).

Results

The overall population comprised 148,741 dogs attending 93 clinics across central and south-eastern England. Demographic examination of dogs with information available indicated that 117,179 (78.9%) were purebred, 71,002 (48.0%) were female, 61,120 (41.1%) were neutered, 43,435 (29.2%) were insured and 41,071 (27.6%) were microchipped. The median weight was 18.2 kg (interquartile range (IQR): 9.4–29.0, range: 0.68–105.0) and the median age was 4.5 years (IQR: 1.6–8.7, range: 0.0–27.4) (Table 1).

The study sample comprised 3,884 dogs attending 89 clinics. Of dogs with information available, 3,079 (79.4%) were purebred, 1,817 (47.0%) were female, 1,735 (44.7%) were neutered, 1,226 (31.6%) were insured and 1,151 (29.6%) were microchipped. The median weight was 17.3 kg (IQR: 9.1–28.4, range: 1.3–100.6) and the median age was 4.8 years (IQR: 1.8–9.1, range: 0.0–21.24). The most popular seven breeds accounted for 1,431 (36.8%) of the study sample dogs (Table 1). Of the sampled dogs, 378 (9.7%) died during the study period, with a median (IQR, range) age at death of 12.3 years (9.2–14.4, 0.0–21.0) and 336 (88.9%) deaths involving euthanasia. Overall, 2,945 (75.8%) dogs had at least one disorder diagnosed, with the remainder having no disorders diagnosed during the study period. The median (IQR, range) number of disorders diagnosed per dog was 1.0 (1.0–3.0, 0.0–21.0). The median (IQR, range) time contributed to the study per dog was 0.7 years (0.0–3.5, 0.0–1.9). The sample and study populations were similar across all measures assessed.

Among the sampled dogs, 8,025 unique disorder events were recorded encompassing 430 distinct diagnosis-level disorder terms. The most prevalent diagnosis-level disorders recorded were otitis externa (number of events: 396, prevalence: 10.2%, 95% CI: 9.1–11.3), periodontal disease (361, 9.3%, 95% CI: 8.3–10.3), anal sac impaction (277, 7.1%, 95% CI: 6.1–8.1) and overgrown nails (276, 7.1%, 95% CI: 6.1–8.2). Purebred dogs had a significantly higher prevalence compared with crossbreds for three of the twenty most-prevalent diagnosis-level disorders: otitis externa ($P=0.001$), obesity ($P=0.006$) and skin mass lesion ($P=0.033$) (Table 2). The prevalence of five of the twenty most-prevalent diagnosis-level disorders differed statistically significantly between popular breeds: periodontal disease ($P=0.002$), overgrown nails ($P=0.004$), degenerative joint disease ($P=0.005$), obesity ($P=0.001$) and lipoma ($P=0.003$) (Table 3).

Within 54 mid-level diagnosis terms, the most prevalent disorders were enteropathic ($n=692$, prevalence: 17.8%, 95% CI: 16.0–19.6), dermatological (602, 15.5%, 95% CI: 13.9–17.1), musculoskeletal (457, 11.8%, 95% CI: 10.6–12.9) and aural (426, 11.0%, 95% CI: 9.8–12.2). Purebred dogs showed a significantly higher prevalence than crossbreds for four of the twenty most-prevalent mid-level disorders: dermatological ($P=0.004$), aural ($P=0.001$), ophthalmological ($P=0.032$) and obesity ($P=0.009$) (Table 4). Statistically significant differences in prevalence values were shown between the most popular breeds in eight of the twenty most-frequent mid-level disorders: musculoskeletal ($P=0.002$), claw/nail ($P=0.008$), dental ($P=0.007$), neoplastic ($P=0.001$), anal sac ($P=0.006$), obesity ($P=0.004$), cardiac ($P=0.005$) and brain ($P=0.003$) (Table 5).

Syndromic classification analysis indicated that the most prevalent body locations affected in dogs were the head-and-neck ($n=1,273$, prevalence = 32.8%, 95% CI: 30.7–34.9), abdomen (993, 25.6%, 95% CI: 23.6–27.5) and limb (679, 17.5%, 95% CI: 15.9–19.1). Purebreds had significantly higher prevalence values compared with crossbreds for two of the eight body locations: head-and-neck ($P=0.003$) and tail ($P=0.038$) disorders. The most

prevalent organ systems affected were the integument (1,408, 36.3%, 95% CI: 33.9–38.6), digestive (1,144, 29.5%, 95% CI: 27.5–31.5) and musculoskeletal (573, 14.8%, 95% CI: 13.8–16.0) (Table 6). Purebreds had significantly higher prevalence values than crossbreds for two of fifteen organ systems, namely integument ($P=0.001$) and auditory ($P=0.002$) (Table 6). The most prevalent pathophysiological processes recorded were inflammation (1,246, 32.1%, 95% CI: 29.8–34.3), mass/swelling (625, 16.1%, 95% CI: 14.6–17.6) and traumatic (557, 14.3%, 95% CI: 12.8–15.9). Purebreds had significantly higher prevalence values than crossbreds for two of twenty-one pathophysiological processes: inflammatory ($P=0.006$) and nutritional ($P=0.0014$) disorders (Table 7). Statistically significant differences in prevalence values between the most popular breeds were shown for 5/8 body location terms, 5/15 organ system terms and 5/21 pathophysiological processes (Tables 8, 9 & 10).

Discussion

This study reported the most prevalent disorders recorded in dogs attending primary-care veterinary practices in England as otitis externa, periodontal disease and anal sac impaction, while the most prevalent disorder groups were enteropathic, dermatological and musculoskeletal. The head-and-neck was the most prevalent body location affected, the integument was the most prevalent organ system affected, and inflammation was the most prevalent pathophysiological process. Some evidence was shown to support higher disorder prevalence in purebred dogs compared with crossbred dogs and for important differences in disorder prevalence between breeds.

The current study was designed to fill a critical data gap relating to disorder prevalence information that has been identified as a constraint to improving dog welfare by effective reform of purebred dog-breeding [20,21,22]. Unacceptably high occurrence of inherited disorders in purebred dogs has been discussed since over half a century ago [41,42,43,44], leading to implementation of disease control measures such as defined health schemes [45,46,47,48] and revised KC recommendations and rules for registration and showing [44,49]. However, the current state and predicted trajectory of purebred dog health remain contentious despite these and other ongoing health measures, suggesting that these earlier breeding reforms that were developed without access to prioritisation information on the overall disorder burden may at best have been sub-optimal, and potentially even counter-productive [50].

Primary-care veterinary clinical data have been proposed as a superior data resource for clinical research in dogs [12,20]. Although useful, alternative data sources including referral practice data [51,52,53], pet insurance databases [27], official health schemes [54,55,56] and large scale questionnaire surveys [26,57,58,59] are reported to suffer many limitations for the generation of prevalence values that can be generalised to the wider dog population. Analyses based on primary-care veterinary EPR data benefit from open-ended data collection allowing generation of stronger evidence from cohort compared with cross-sectional study designs [60,61,62]. Selection bias is reduced by merging data collected from a miscellany of practices [63] and recall and misclassification biases are reduced by collection of clinical notes recorded contemporaneously by veterinary clinicians during episodes of care [64]. Veterinary primary-care denominator populations are well-characterised demographically within PMSs and include all practice-attending animals, whether presenting healthy or sick, linked with comprehensive clinical documentation that facilitates internal validation [27]. Registra-

Table 1. Demographic information for sampled (n = 3,884) and overall study population (n = 148,741) dogs attending primary veterinary practices in England.

Variable	Category	Sample: No. (%)	Population: No. (%)
Sex/neuter	Female entire	981 (25.4)	40,514 (27.4)
	Female neutered	836 (21.6)	30,488 (20.6)
	Male entire	1,152 (29.8)	46,459 (31.4)
	Male neutered	899 (23.2)	30,635 (20.7)
Microchip	Not microchipped	2,733 (70.4)	107,670 (72.4)
	Microchipped	1,151 (29.6)	41,071 (27.6)
Purebred status	Crossbred	797 (20.6)	31,354 (21.1)
	Purebred	3,079 (79.4)	117,179 (78.9)
Popular breeds	Crossbred	797 (20.5)	31,354 (21.1)
	Labrador Retriever	339 (8.7)	13,328 (9.0)
	Staffordshire Bull Terrier	334 (8.6)	12,212 (8.2)
	Jack Russell Terrier	262 (6.8)	10,006 (6.7)
	Cocker Spaniel	133 (3.4)	5,579 (3.8)
	German Shepherd Dog	132 (3.4)	5,314 (3.6)
	Yorkshire Terrier	127 (3.3)	4,880 (3.3)
	Border Collie	104 (2.7)	3,997 (2.7)
	Other named breeds	1,656 (42.6)	62,071 (41.7)
KC^a- breed^b	Not KC-recognised	306 (9.9)	11,717 (10.0)
	KC-recognised	2,773 (90.1)	105,462 (90.0)
KC^a group^c	Gundog	737 (26.6)	28,832 (27.3)
	Hound	178 (6.4)	6,505 (6.2)
	Pastoral	284 (10.2)	11,530 (10.9)
	Terrier	561 (20.2)	21,481 (20.4)
	Toy	474 (17.1)	17,215 (16.3)
	Utility	330 (11.9)	11,573 (11.0)
	Working	209 (7.5)	8,326 (7.9)
	No recorded weight	1,260 (32.4)	52,308 (35.2)
Weight (kg)	<10.0	769 (19.8)	26,786 (18.0)
	10.0–19.9	695 (17.9)	25,278 (17.0)
	20.0–20.99	579 (14.9)	21,869 (14.7)
	30.0–30.9	390 (10.0)	15,255 (10.3)
	40.0–40.9	130 (3.4)	5,118 (3.4)
	≥50.0	61 (1.6)	2,127 (1.4)
	Age (years)	<1.0	588 (15.2)
1.0–2.9		791 (20.4)	30,747 (20.7)
3.0–5.9		877 (22.6)	33,500 (22.5)
6.0–9.9		811 (20.9)	30,811 (20.7)
≥10.0		814 (21.0)	28,664 (19.3)
Insurance	Non-insured	2,658 (68.4)	105,306 (70.8)
	Insured	1,226 (31.6)	43,435 (29.2)

^aKC The Kennel Club.^bPercentage values based on purebred only.^cPercentage values based on KC-recognised dogs only.

doi:10.1371/journal.pone.0090501.t001

tion databases from primary-care practices are more representative of the national dog population than other databases available for research purposes; 77% of UK dogs are registered with a veterinary practice compared with just 42% of UK dogs that are insured and 31% of UK dogs that are registered with the KC [2].

Previous large-scale studies using primary-care practice clinical data have been variably successful and have encountered problems with sustainability. A cross-sectional study of paper-based clinical records for 7,146 dogs from eight UK practices described demographic and morbidity results but concluded that direct electronic extraction of clinical data and implementation of

Table 2. Prevalence results for the most frequent disorders recorded in dogs, purebreds only and crossbreds only that attended primary veterinary practices in England.

Disorder	Overall			Purebred		Crossbred		P-value
	No.	Prev ^a %	95% CI ^b	Prev ^a %	95% CI ^b	Prev ^a %	95% CI ^b	
Otitis externa	396	10.2	9.1–11.3	11.2	10.0–12.4	6.5	4.7–8.3	0.001
Periodontal disease	361	9.3	8.3–10.3	9.4	8.2–10.5	9.2	7.4–11.0	1.000
Anal sac impaction	277	7.1	6.1–8.1	7.1	6.0–8.1	7.5	5.7–9.4	1.000
Overgrown nails	276	7.1	6.1–8.2	6.9	5.8–8.0	8.0	6.1–9.9	1.000
Degenerative joint disease	256	6.6	5.7–7.5	6.4	5.3–7.4	7.5	5.7–9.4	1.000
Diarrhoea	249	6.4	5.5–7.4	6.8	5.6–8.0	4.9	3.4–6.4	0.255
Obesity	238	6.1	5.2–7.1	6.7	5.6–7.9	3.9	2.3–5.5	0.006
Traumatic injury	214	5.5	4.7–6.4	5.5	4.4–6.5	5.7	3.6–7.7	1.000
Conjunctivitis	192	4.9	4.1–5.8	5.2	4.2–6.2	4.1	2.8–5.5	1.000
Vomiting	159	4.1	3.3–4.9	4.0	3.1–4.9	4.5	3.0–6.0	1.000
Heart murmur	153	3.9	3.3–4.5	4.1	3.5–4.7	3.4	2.1–4.7	1.000
Lipoma	137	3.5	2.8–4.2	3.5	2.7–4.2	3.8	2.7–4.9	1.000
Dermatitis	134	3.5	2.8–4.1	3.5	2.8–4.3	3.1	1.9–4.4	1.000
Skin hypersensitivity	113	2.9	2.3–3.5	3.2	2.5–3.9	1.8	0.9–2.6	0.116
Skin mass	110	2.8	2.3–3.4	3.2	2.6–3.8	1.5	0.6–2.4	0.033
Claw injury	103	2.7	2.1–3.2	2.6	2.0–3.2	2.6	1.5–3.8	1.000
Behavioural	99	2.6	2.1–3.0	2.6	2.1–3.1	2.4	1.4–3.4	1.000
Gastroenteritis	99	2.6	2.0–3.1	2.4	1.9–2.9	3.1	2.0–4.3	1.000
Dog bite injury	97	2.5	1.9–3.1	2.4	1.7–3.1	2.9	1.8–4.0	1.000
Laceration	92	2.4	1.8–2.9	2.5	1.8–3.1	2.0	1.1–2.9	0.446

P-values (Holm-adjusted) represent comparison between purebreds and crossbreds.

^aPrev prevalence.

^b95% CI 95% confidence interval.

doi:10.1371/journal.pone.0090501.t002

standardised coding for breeds and disorders were required to sustain long-term data collection [65]. In the US, the National Companion Animal Study (NCAS) reported overall disorder prevalence values using electronic records from 86,772 dogs attending 63 private practices. However, prevalence estimation was based only on the 36% of animals that had at least one coded disorder term recorded and the full clinical notes were not accessible for case-finding and internal validation exercises [66]. The National Companion Animal Surveillance System (NCASP) was established using EPR data from over 500 Banfield Pet Hospitals, but this system focused on the threat of emerging infection, terrorist attack or natural disaster rather than disorder prevalence [67] and has since been discontinued [68].

A standardised veterinary lexicon is critical for large-scale epidemiological application of secondary clinical data [52,65,69,70]. The VeNom codes [30] offers an open-access veterinary nomenclature that has been developed collaboratively between university and primary-care practice groups and facilitates both direct coding by attending clinicians at the point of clinical care and also retrospective coding by researchers during analysis. The VeNom coding ontology that is made available for point-of-care coding defines multiple clinical fields including species (45 terms), dog breeds (767), cat breeds (101), presenting complaints (201), diagnostic tests (39), diagnoses (2,291) and procedures (780).

The current study indicated that otitis externa (10.2%), periodontal disease (9.3%), anal sac impaction (7.1%) and overgrown nails (7.1%) were the most prevalent disorders recorded

in dogs attending veterinary practices in England. A US primary-care study similarly identified dental calculus (20.5%), gingivitis (19.5) and otitis externa (13.0%) as the most prevalent diagnoses in dogs, but reported the prevalence of anal sac disease at only 2.5%, and did not even include nail disorders within the common disorders diagnosed [70]. An under-developed coding system, inconsistent case definitions and selection bias from inclusion of only the one-third of animals that had at least one coded diagnosis term within the US study may explain these differing prevalence trends and underscores the importance of standardised coding systems for reliable comparisons between studies. The high frequency of dental disease reported in the US study may have resulted from inclusion of animals with any recorded dental abnormality, regardless of severity. By contrast, the current study aimed to report the occurrence of dental disorders that currently warranted treatment in the opinion of the attending clinician. Study-inclusion of dental abnormalities of any nature provides information on the summative effects from both current and potential future clinically-significant dental disease whereas including just current clinically-significant cases provides evidence on the current welfare implications of dental disease. Both approaches have merit and add to our understanding of the substantial clinical relevance of dental disorders to the health and welfare of dogs. A UK primary-care study using paper-based clinical records identified the most prevalent disorders of dogs as overgrown nails (2.7%), ascarid worm problems (2.3%), anal sac impaction (2.1%), dental calculus (1.8%), fleas (1.8%), bacterial otitis externa (1.7%), waxy otitis externa (1.2%), diarrhoea/

Table 3. Prevalence results for frequent disorders recorded in popular breeds (number of dogs) from 3,884 randomly sampled dogs attending primary veterinary practices in England.

Disorder	Prevalence percentage (95% confidence interval)										P-Value
	Crossbred (797)	Labrador Retriever (339)	Staffordshire Bull Terrier (334)	Jack Russell Terrier (262)	Cocker Spaniel (133)	German Shepherd Dog (132)	Yorkshire Terrier (127)	Border Collie (104)			
Otitis externa	6.5 (4.7–8.3)	11.8 (8.8–15.7)	9.9 (7.1–13.6)	6.9 (4.4–10.6)	8.3 (4.7–14.2)	11.4 (7.0–17.9)	7.9 (4.3–13.9)	1.9 (0.5–6.7)	0.084		
Periodontal disease	9.2 (7.4–11.0)	3.2 (1.8–5.7)	2.4 (1.2–4.7)	9.5 (6.6–13.7)	12.8 (8.1–19.5)	4.5 (2.1–9.6)	25.2 (18.6–33.4)	6.7 (3.3–13.3)	0.002		
Anal sac impaction	7.5 (5.7–9.4)	4.7 (2.9–7.5)	3.3 (1.9–5.8)	6.9 (4.4–10.6)	12.0 (7.5–18.6)	6.1 (3.1–11.5)	6.3 (3.2–11.9)	2.9 (1.0–8.1)	0.066		
Overgrown nails	8.0 (6.1–9.9)	6.5 (4.3–9.6)	3.9 (2.3–6.5)	13.7 (10.1–18.4)	2.3 (0.8–6.4)	1.5 (0.4–5.4)	15.0 (9.8–22.2)	1.0 (0.2–5.3)	0.004		
Degenerative joint disease	7.5 (5.9–9.6)	11.5 (8.5–15.3)	5.4 (3.4–8.4)	4.2 (2.4–7.4)	1.5 (0.4–5.3)	6.8 (3.6–12.5)	1.6 (0.4–5.6)	11.5 (6.7–19.1)	0.005		
Diarrhoea	4.9 (3.4–6.4)	8.3 (5.8–11.7)	4.8 (3.0–7.6)	4.6 (2.6–7.8)	9.8 (5.8–16.0)	8.3 (4.7–14.3)	5.5 (2.7–10.9)	7.7 (4.0–14.5)	1.000		
Obesity	3.9 (2.3–5.5)	13.0 (9.8–17.0)	6.0 (3.9–9.1)	5.3 (3.2–8.8)	8.3 (4.7–14.2)	2.3 (0.8–6.5)	0.8 (0.1–4.3)	6.7 (3.3–13.3)	0.001		
Traumatic injury	5.7 (3.6–7.7)	5.3 (3.4–8.2)	4.5 (2.7–7.3)	6.1 (3.8–9.7)	5.3 (2.6–10.5)	4.6 (2.1–9.6)	3.2 (1.2–7.8)	4.8 (2.1–10.8)	1.000		
Conjunctivitis	4.1 (2.8–5.5)	4.1 (2.5–6.8)	5.1 (3.2–8.0)	4.2 (2.4–7.4)	6.8 (3.6–12.4)	0.0 (0.0–2.8)	7.1 (3.8–12.9)	4.8 (2.1–10.8)	1.000		
Vomiting	4.5 (3.0–6.0)	3.8 (2.3–6.5)	3.9 (2.3–6.5)	5.7 (3.5–9.2)	2.3 (0.8–6.4)	4.6 (2.1–9.6)	3.2 (1.2–7.8)	1.9 (0.5–6.7)	1.000		
Heart murmur	3.4 (2.1–4.7)	1.5 (0.6–3.4)	2.7 (1.4–5.0)	3.8 (2.1–6.9)	3.8 (1.6–8.5)	1.5 (0.4–5.4)	7.1 (3.8–12.9)	4.8 (2.1–10.8)	0.837		
Lipoma	3.8 (2.7–4.9)	9.1 (6.5–12.7)	2.1 (1.0–4.3)	2.7 (1.3–5.4)	6.0 (3.1–11.4)	1.5 (0.4–5.4)	2.1 (0.0–2.9)	5.8 (2.7–12.0)	0.003		
Dermatitis	3.1 (1.9–4.4)	1.5 (0.6–3.4)	3.6 (2.1–6.2)	3.4 (1.8–6.4)	3.0 (1.2–7.5)	3.0 (1.2–7.5)	4.7 (2.2–9.9)	6.7 (3.3–13.3)	1.000		
Skin hypersensitivity	1.8 (0.9–2.6)	3.8 (2.3–6.5)	5.1 (3.2–8.0)	3.1 (1.6–5.9)	1.5 (0.4–5.3)	3.0 (1.2–7.5)	3.2 (1.2–7.8)	2.9 (1.0–8.1)	1.000		
Skin mass	1.5 (0.6–2.4)	3.2 (1.8–5.7)	3.9 (2.3–6.5)	2.3 (1.1–4.9)	3.8 (1.6–8.5)	3.0 (1.2–7.5)	2.4 (0.8–6.7)	3.0 (1.0–8.1)	1.000		
Claw injury	2.6 (1.5–3.8)	3.8 (2.3–6.5)	3.6 (2.1–6.2)	2.7 (1.3–5.4)	2.3 (0.8–6.4)	3.0 (1.2–7.5)	3.9 (1.7–8.9)	2.9 (1.0–8.1)	1.000		
Undesirable behaviour	2.4 (1.4–3.4)	3.0 (1.6–5.3)	2.7 (1.4–5.0)	1.5 (0.6–3.9)	3.0 (1.2–7.5)	7.6 (4.2–13.4)	2.4 (0.8–6.7)	5.8 (2.7–12.0)	0.208		
Gastro-enteritis	3.1 (2.0–4.3)	4.4 (2.7–7.3)	1.5 (0.6–3.5)	1.9 (0.8–4.4)	3.0 (1.2–7.5)	0.8 (0.1–4.2)	3.9 (1.7–8.9)	3.9 (1.5–9.5)	1.000		
Dog bite injury	2.9 (1.8–4.0)	1.5 (0.6–3.4)	3.0 (1.6–5.4)	3.8 (2.1–6.9)	3.8 (1.6–8.5)	1.5 (0.4–5.4)	0.0 (0.0–2.9)	1.0 (0.2–5.3)	1.000		
Laceration	2.0 (1.2–3.2)	3.5 (2.0–6.1)	2.4 (1.2–4.7)	2.7 (1.3–5.4)	3.0 (1.2–7.5)	0.8 (0.1–4.2)	1.6 (0.4–5.6)	2.9 (1.0–8.1)	1.000		

P-values (Holm-adjusted) represent comparison between breeds.
doi:10.1371/journal.pone.0090501.t003

Table 4. Prevalence results for the most frequent mid-level disorders recorded in dogs, purebreds only and crossbreds only that attended primary veterinary practices in England.

Mid-level disorder	Overall			Purebred		Crossbred		P-value
	No.	Prev ^a %	95% CI ^b	Prev ^a %	95% CI ^b	Prev ^a %	95% CI ^b	
Enteropathic	692	17.8	16.0–19.6	17.7	15.8–19.7	18.3	15.4–21.2	1.000
Dermatological	602	15.5	13.9–17.1	16.5	14.6–18.4	11.9	10.0–13.9	0.004
Musculoskeletal	457	11.8	10.6–12.9	11.2	9.8–12.6	14.1	11.8–16.3	0.130
Aural	426	11.0	9.8–12.2	12.0	10.7–13.3	7.2	5.3–9.0	0.001
Ophthalmological	406	10.5	9.1–11.8	11.1	9.7–12.6	7.9	6.1–9.7	0.032
Claw/nail	400	10.3	9.1–11.5	10.1	8.8–11.5	10.9	9.0–12.9	1.000
Dental	386	9.9	8.8–11.1	10.0	8.8–11.2	9.8	7.9–11.7	1.000
Neoplastic	367	9.5	8.2–10.7	9.6	8.2–10.9	9.2	7.2–11.1	1.000
Traumatic injury (not incl. bites)	351	9.0	8.0–10.1	9.1	7.8–10.3	8.9	6.6–11.2	1.000
Anal sac	337	8.7	7.5–9.8	8.6	7.3–9.9	9.0	7.1–11.0	1.000
Obesity	238	6.1	5.2–7.1	6.7	5.6–7.9	3.9	2.3–5.5	0.009
Mass lesion	235	6.1	5.2–6.9	6.4	5.3–7.4	4.9	3.4–6.4	0.726
Behavioural	233	6.0	5.3–6.85	5.8	4.9–6.7	6.9	5.1–8.7	1.000
Upper respiratory tract	223	5.7	4.9–6.5	5.6	4.6–6.6	6.4	4.6–8.2	1.000
Cardiac	219	5.6	4.8–6.5	5.9	5.0–6.7	4.9	3.1–6.7	1.000
Parasitic	172	4.4	3.8–5.1	4.2	3.5–5.0	5.3	3.7–6.8	1.000
Congenital	171	4.4	3.7–5.1	4.6	3.7–5.4	3.9	2.6–5.2	1.000
Bite injury	148	3.8	3.0–4.6	3.7	2.9–4.6	4.1	2.8–5.5	1.000
Urinary	126	3.2	2.7–3.8	3.4	2.7–4.1	2.8	1.6–3.9	1.000
Brain	122	3.1	2.5–3.7	3.2	2.6–3.8	3.1	1.9–4.4	1.000

P-values (Holm-adjusted) represent comparison between purebreds and crossbreds.

^aPrev prevalence.

^b95% CI 95% confidence interval.

doi:10.1371/journal.pone.0090501.t004

vomiting (1.0%) and *Otodectes otitis externa* (0.9%) [65]. Although the predominance of aural, nail, anal sac and dental disorders identified was consistent with the current study, the older study reported *prevalence per consultation* values, leading to apparently lower prevalence values than the current study that reported *period prevalence per dog*. The substantially lower prevalence of parasitic disorders reported in the current study may also reflect increasing adoption and effectiveness of prophylactic parasiticides in the intervening fifteen years since the previous study [71,72].

Although diagnosis-level disorder terms are useful to describe disorders at their precision of clinical diagnosis, sole reliance on these terms for research may mask important underlying disorder concepts because of fragmentation into multiple terms along diagnostic pathways. The current study grouped clinically-related diagnosis-level terms (430 unique terms) into appropriate, composite mid-level disorder terms (54 unique terms) for further analysis. Selection of cut-off points for amalgamation along diagnostic precision pathways aimed to optimise interpretability whilst still retaining adequate precision [73]. The predominant mid-level disorders (enteropathic, dermatological, musculoskeletal and aural) differed from the predominant diagnosis-level disorders (otitis externa, periodontal disease, anal sac impaction, overgrown nails), suggesting that such hierarchical analysis can offer useful insights that may otherwise be missed.

Syndromic surveillance is based on clinical features that are discernible even from early presentation and are not dependent on complete or even correct diagnosis for elucidation of diagnostic patterns [74]. Although veterinary clinical diagnostic accuracy

may have improved over recent years, diagnostic discrepancies have been identified in 15% of cases undergoing necropsy [75]. Syndromic surveillance has been applied within human bioterrorism surveillance [76] and for analysis of canine insurance data [77,78]. The three syndromic classification systems used in the current study (body location, organ system and pathophysiology) were selected for their potential welfare importance via breed conformation and genetic effects [15]. The syndromic coding system used in the current study was adapted from VeNom codes and other published veterinary lexicons in line with the disorder types recorded within the study [25,79]. Progression towards a standardised syndromic terminology would facilitate future inter-study comparisons and meta-analyses [80].

The results from syndromic analyses in the current study identified the most prevalent body locations affected by disorders in dogs as the head-and-neck (32.8%), abdomen (25.6%) and limb (17.5%). Morphologic diversity between breeds resulting from artificial selection towards the extremes of breed standard morphometrics [81] has been associated with conformational predisposition for disorders [15,20]. The predominance of disorders identified affecting the head-and-neck reaffirm the importance of this body area to dog health [82].

The most affected organ systems identified by the current study were the integument (36.3%), digestive (29.5%) and musculoskeletal (14.8%). Swedish insurance data analysis similarly identified the most prevalently affected organs systems as the integument (3.2%), gastrointestinal (2.7%) and genital (2.5%) [83]. A consistently high prevalence reported by these studies for disorders

Table 5. Prevalence results for frequent mid-level disorders recorded in popular breeds (number of dogs) attending primary veterinary practices in England.

Mid-level disorder	Prevalence percentage (95% confidence interval)										P-value
	Crossbred (797)	Labrador Retriever (339)	Staffordshire Bull Terrier (334)	Jack Russell Terrier (262)	Cocker Spaniel (133)	German Shepherd Dog (132)	Yorkshire Terrier (127)	Border Collie (104)			
Enteropathic	18.3 (15.4–21.2)	22.7 (18.6–27.5)	13.2 (10.0–17.2)	15.3 (11.4–20.1)	18.8 (13.1–26.3)	20.5 (14.5–28.1)	16.5 (11.1–24.0)	17.3 (11.2–25.7)	1.000		
Dermatological	11.9 (10.0–13.9)	16.8 (13.2–21.2)	14.7 (11.38–18.9)	13.0 (9.4–17.6)	9.8 (5.8–16.0)	18.9 (13.2–26.5)	18.1 (12.4–25.7)	18.3 (12.0–26.8)	0.715		
Musculoskeletal	14.1 (11.8–16.3)	16.2 (12.7–20.5)	8.4 (5.9–11.9)	7.3 (4.7–11.1)	3.0 (1.2–7.5)	16.7 (11.3–24.0)	6.3 (3.2–11.9)	16.4 (10.5–24.6)	0.002		
Aural	7.2 (5.3–9.0)	12.1 (9.0–16.0)	11.1 (8.1–14.9)	7.6 (5.0–11.5)	9.0 (5.2–15.1)	11.4 (7.0–17.9)	7.9 (4.3–13.9)	4.8 (2.1–10.8)	0.828		
Ophthalmological	7.9 (6.1–9.7)	6.8 (4.6–10.0)	8.1 (5.6–11.5)	8.0 (5.3–11.9)	12.0 (7.5–18.7)	2.3 (0.8–6.5)	12.6 (7.9–19.5)	12.5 (7.5–20.2)	0.261		
Claw/nail	10.9 (9.0–12.9)	10.9 (8.0–14.7)	7.5 (5.1–10.8)	14.9 (11.1–19.7)	5.3 (2.6–10.5)	5.3 (2.6–10.5)	19.7 (13.7–27.5)	5.8 (2.7–12.0)	0.008		
Dental	9.8 (7.9–11.7)	3.8 (2.3–6.5)	3.0 (1.6–5.4)	11.5 (8.1–15.9)	12.8 (8.1–19.5)	5.3 (2.6–10.5)	25.2 (18.5–33.4)	7.7 (4.0–14.5)	0.007		
Neoplastic	9.2 (7.2–11.1)	14.8 (11.4–18.9)	6.6 (4.4–9.8)	4.6 (2.6–7.8)	13.5 (8.7–20.4)	4.6 (2.1–9.6)	6.3 (3.2–11.9)	8.7 (4.6–15.6)	0.001		
Traumatic injury (not bites or claw)	8.9 (6.6–11.2)	11.2 (8.3–15.0)	7.88 (5.4–11.2)	9.2 (6.2–13.3)	10.5 (6.4–16.9)	6.1 (3.1–11.5)	3.9 (1.7–8.9)	9.6 (5.3–16.8)	1.000		
Anal sac	9.0 (7.1–11.0)	5.9 (3.9–8.9)	3.6 (2.1–6.2)	9.9 (6.9–14.1)	13.5 (8.7–20.4)	6.8 (3.6–12.5)	6.3 (3.2–11.9)	2.9 (1.0–8.1)	0.006		
Obesity	3.9 (2.3–5.5)	12.98 (9.81–16.98)	6.0 (3.9–9.1)	5.3 (3.2–8.8)	8.3 (4.7–14.2)	2.3 (0.8–6.5)	0.8 (0.1–4.3)	6.7 (3.3–13.3)	0.004		
Mass lesion	4.9 (3.4–6.4)	8.26 (5.78–11.68)	6.6 (4.4–9.8)	5.0 (2.9–8.3)	6.8 (3.6–12.4)	6.1 (3.1–11.5)	7.9 (4.3–13.9)	8.7 (4.6–15.6)	1.000		
Behavioural	6.9 (5.1–8.7)	4.7 (2.9–7.5)	5.1 (3.2–8.0)	7.6 (5.0–11.5)	6.8 (3.6–12.4)	12.9 (8.2–19.7)	3.9 (1.7–8.9)	8.7 (4.6–15.6)	0.460		
Upper respiratory tract	6.4 (4.6–8.2)	6.2 (4.1–9.3)	6.3 (4.2–9.4)	5.7 (3.5–9.2)	2.3 (0.8–6.4)	3.0 (1.2–7.5)	7.1 (3.8–12.9)	2.9 (1.0–8.1)	1.000		
Cardiac disorder	4.9 (3.1–6.7)	1.5 (0.6–3.4)	3.0 (1.6–5.4)	6.5 (4.1–10.1)	4.5 (2.1–9.5)	1.5 (0.4–5.4)	10.2 (6.1–16.7)	5.8 (2.7–12.0)	0.005		
Parasitic	5.3 (3.7–6.8)	3.5 (2.0–6.1)	4.8 (3.0–7.6)	3.4 (1.8–6.4)	8.3 (4.7–14.2)	2.3 (0.8–6.5)	4.7 (2.2–9.9)	1.9 (0.5–6.7)	1.000		
Congenital	3.9 (2.6–5.2)	2.4 (1.2–4.6)	2.1 (1.0–4.3)	3.8 (2.2–6.9)	3.8 (1.6–8.5)	0.8 (0.1–4.2)	6.3 (3.2–11.9)	1.9 (0.5–6.7)	1.000		
Bite injury	4.1 (2.8–5.5)	3.8 (2.3–6.5)	4.29 (2.5–6.9)	5.0 (2.9–8.3)	4.5 (2.1–9.5)	2.3 (0.8–6.5)	1.6 (0.4–5.6)	1.9 (0.5–6.7)	1.000		
Urinary	2.8 (1.6–3.9)	4.7 (2.9–7.5)	2.4 (1.2–4.6)	1.9 (0.8–4.4)	3.0 (1.2–7.5)	3.0 (1.2–7.5)	2.4 (0.8–6.7)	3.9 (1.5–9.5)	1.000		
Brain	3.1 (1.9–4.4)	3.2 (1.8–5.7)	0.6 (0.2–2.2)	2.3 (1.1–4.9)	3.0 (1.2–7.5)	4.6 (2.1–9.6)	1.6 (0.4–5.6)	9.6 (5.3–16.8)	0.003		

P-values (Holm-adjusted) represent comparison between breeds. ($n = 3,884$).
doi:10.1371/journal.pone.0090501.t005

Table 6. Prevalence of syndromic disorders affecting body location and organ system recorded in overall dogs, purebreds only and crossbreds only that attended primary veterinary practices in England.

	Overall			Purebred		Crossbred		P-value
	No.	Prev ^a %	95% CI ^b	Prev ^a %	95% CI ^b	Prev ^a %	95% CI ^b	
Body Location								
Head/neck	1,273	32.8	30.7–34.9	34.0	31.7–36.2	28.5	24.9–32.0	0.003
Abdomen	993	25.6	23.6–27.5	25.9	23.7–28.0	24.6	21.5–27.7	1.000
Limb	679	17.5	15.9–19.1	17.3	15.5–19.1	18.3	15.7–20.9	1.000
Anus/perineum	359	9.2	8.1–10.4	9.1	7.8–10.5	9.8	7.6–12.0	1.000
Thorax	353	9.1	8.1–10.1	9.2	8.1–10.4	8.7	6.5–10.8	1.000
Vertebral column	78	2.0	1.5–2.5	2.0	1.5–2.6	2.0	1.0–3.0	1.000
Pelvis	33	0.9	0.6–1.2	0.9	0.7–1.4	0.5	0.2–1.3	0.684
Tail	21	0.5	0.4–0.8	0.7	0.5–1.0	0.0	0.0–0.5	0.038
Organ system								
Integument	1,408	36.3	33.9–38.6	37.6	35.0–40.2	31.4	28.0–34.7	0.001
Digestive	1,144	29.5	27.5–31.5	29.4	27.2–31.6	30.0	26.6–33.3	1.000
Musculoskeletal	573	14.8	13.5–16.0	14.1	12.6–15.6	17.3	14.8–19.8	0.110
Connective/Soft tissue	503	13.0	11.6–14.3	13.2	11.6–14.7	12.3	10.2–14.4	1.000
Ocular	447	11.5	10.2–12.8	12.2	10.6–13.7	9.2	7.2–11.1	0.057
Auditory	437	11.3	10.0–12.5	12.3	11.0–13.6	7.4	5.5–9.3	0.002
Nervous	301	7.8	6.8–8.7	7.7	6.7–8.7	7.9	6.2–9.6	1.000
Respiratory	273	7.0	6.2–7.9	7.0	6.0–8.1	7.2	5.2–9.1	1.000
Cardiovascular	241	6.2	5.3–7.1	6.5	5.5–7.4	5.3	3.5–7.1	1.000
Urinary	227	5.8	5.1–6.6	5.9	4.9–6.8	5.8	4.1–7.5	1.000
Reproductive	184	4.7	4.1–5.4	4.7	4.0–5.5	4.9	3.5–6.3	1.000
Endocrine	72	1.9	1.5–2.3	1.8	1.3–2.3	2.1	1.2–3.1	1.000
Haematopoietic	53	1.4	1.0–1.7	1.4	1.0–1.8	1.3	0.5–2.1	1.000
Hepatobiliary	29	0.8	0.5–1.1	0.9	0.6–1.3	0.1	0.0–0.7	0.088
Lymphatic	26	0.7	0.5–1.0	0.6	0.4–1.0	0.9	0.4–1.8	1.000

P-values (Holm-adjusted) represent comparison between purebreds and crossbreds.

^aPrev prevalence.

^b95% CI 95% confidence interval.

doi:10.1371/journal.pone.0090501.t006

Table 7. Prevalence of syndromic disorders related to pathophysiologic processes recorded in overall dogs, purebreds only and crossbreds only that attended primary veterinary practices in England.

Pathophysiologic process	Overall			Purebred		Crossbred		P-value
	No.	Prev ^a %	95% CI ^b	Prev ^a %	95% CI ^b	Prev ^a %	95% CI ^b	
Inflammation	1,246	32.1	29.8–34.3	33.2	30.7–35.7	28.1	25.1–31.2	0.006
Mass/swelling	625	16.1	14.6–17.6	16.7	15.0–18.4	14.1	11.8–16.3	0.222
Traumatic	557	14.3	12.8–15.9	14.3	12.7–16.0	14.3	11.6–17.0	1.000
Degenerative	411	10.6	9.4–11.8	10.4	9.0–11.7	11.4	9.1–13.8	1.000
Infectious	388	10.0	9.0–11.0	10.3	9.1–11.4	9.0	6.9–11.2	1.000
Neoplastic	336	8.7	7.6–9.8	8.6	7.3–9.8	9.0	7.2–10.9	1.000
Congenital/developmental	332	8.6	7.4–9.7	8.9	7.6–10.2	7.3	5.6–9.2	0.870
Nutritional	320	8.2	7.1–9.4	8.9	7.5–10.2	5.9	4.3–7.5	0.014
Behavioural	262	6.8	5.9–7.6	6.5	5.5–7.4	7.9	6.0–9.8	1.000
Hereditary	232	6.0	5.1–6.9	6.2	5.1–7.3	5.3	3.5–7.0	1.000
Parasitic	221	5.7	5.0–6.4	5.5	4.6–6.3	6.7	5.0–8.4	1.000
Iatrogenic	150	3.9	3.3–4.5	3.7	3.1–4.4	4.4	2.9–5.9	1.000
Foreign body	109	2.8	2.3–3.3	2.8	2.3–3.4	2.8	1.6–3.9	1.000
Death	65	1.7	1.2–2.2	1.6	1.1–2.1	2.1	1.2–3.1	1.000
Intoxicative	49	1.3	1.0–1.7	1.3	1.0–1.8	1.1	0.6–2.1	1.000
Haemostatic	38	1.0	0.7–1.3	1.1	0.8–1.5	0.5	0.2–1.3	0.496
Immune-mediated	38	1.0	0.7–1.3	1.1	0.8–1.5	0.5	0.2–1.3	0.620
Allergic	35	0.9	0.7–1.3	0.9	0.6–1.3	0.9	0.4–1.8	1.000
Thermoregulatory	17	0.4	0.3–0.7	0.4	0.2–0.7	0.6	0.3–1.5	1.000
Metabolic	8	0.2	0.1–0.4	0.2	0.1–0.4	0.3	0.1–0.9	1.000
Effusion	1	0.0	0.0–0.2	0.0	0.0–0.2	0.0	0.0–0.5	1.000

P-values (Holm-adjusted) represent comparison between purebreds and crossbreds.

^aPrev prevalence.

^b95% CI 95% confidence interval.

doi:10.1371/journal.pone.0090501.t007

affecting the integument and digestive systems suggests the importance of clinical emphasis on maintaining the health of these systems.

The current study identified inflammation (32.1%), mass/swelling (16.1%) and trauma (14.3%) as the most prevalent pathophysiologic processes affecting dogs. Similarly, a Swedish insurance study identified inflammation (5.4%), symptomatic (3.0%), trauma (2.7%) and neoplasia (2.1%) as the pathological processes with the highest risk of morbidity [83]. Although an essential adaptive response to injury, inflammation can behave both physiologically (restoring homeostasis) and pathologically (contributing to ongoing disease) [84]. The preponderance of inflammatory disorders affecting dogs identified by the current study suggests welfare gains from increased awareness by owners of judicious use of anti-inflammatory medications and also the value from ongoing research to better harness the healing aspects of inflammation while limiting detrimental effects [85].

The current study hypothesised that purebred dogs have higher prevalence of common disorders compared with crossbreds. This hypothesis was founded on reports and studies that concluded substantial detriment to purebred dog welfare from increasing inherited health problems induced by inbreeding and selection for extreme morphologies [15,16,20,21,22]. The study hypothesis was tested by comparing prevalence values between purebreds and crossbreds for each of the twenty most prevalent diagnosis-level and mid-level disorders and for all syndromic presentations. Purebreds showed significantly higher prevalence values for 13 of

the 84 (15.5%) disorders and syndromes evaluated. No instances were identified in which prevalence values were significantly higher in crossbred than in purebred dogs. These results provided moderate evidence for higher disorder prevalence in purebreds compared with crossbreds. However, additional analyses of severity and duration data for these disorders would enable a more comprehensive understanding of health disparities between the groups [23].

Failure to show overwhelming evidence for disorder disparity between purebred and crossbred dogs appears initially at odds with the large body of literature apparently to the contrary [20,21,22,86,87]. There are a number of possibilities for this dissonance. Breed-specific conformational disorders within purebreds may be under-reported or under-recognised by both veterinarians and owners because 'normal for breed' may have become confused with 'normal' [88]. A study of dogs clinically diagnosed with brachycephalic obstructive airway syndrome (BOAS) identified that 58% of owners reported these dogs not to have 'breathing problems' [82]. Purebred and crossbred dog categories comprise heterogeneous mosaics of size, shape and genetics. Merging this variation into single categories may have masked important effects related to specific conformational, physiological or behavioural features. Analyses of purebred or crossbred subgroups based on breed, behaviour or body attributes may better elucidate important health hazards, benefits and associations.

Table 8. Prevalence of syndromic diagnoses affecting body location recorded in crossbred dogs and popular breeds (number of dogs) from 3,884 randomly sampled dogs attending primary veterinary practices in England.

Body Location	Prevalence percentage (95% confidence interval)											P-Value
	Crossbred (797)	Labrador Retriever (339)	Staffordshire Bull Terrier (334)	Jack Russell Terrier (262)	Cocker Spaniel (133)	German Shepherd Dog (132)	Yorkshire Terrier (127)	Border Collie (104)				
Head/neck	28.5 (24.9–32.0)	28.6 (24.1–33.6)	24.0 (19.7–28.8)	30.5 (25.3–36.4)	33.1 (25.7–41.5)	22.7 (16.4–30.6)	43.3 (35.0–52.0)	35.6 (27.0–45.1)	0.006			
Abdomen	24.6 (21.5–27.7)	32.4 (27.7–37.6)	21.0 (16.9–25.6)	21.0 (16.5–26.3)	27.1 (20.2–35.2)	25.8 (19.1–33.8)	20.5 (14.4–28.3)	30.8 (22.7–40.2)	0.045			
Limb	18.3 (15.7–20.9)	20.4 (16.4–25.0)	14.1 (10.7–18.2)	20.2 (15.8–25.5)	7.5 (4.1–13.3)	13.6 (8.8–20.5)	22.0 (15.7–30.0)	16.3 (10.5–24.6)	0.036			
Anus/perineum	9.8 (7.6–12.0)	6.2 (4.1–9.3)	3.9 (2.3–6.5)	9.9 (6.9–14.1)	15.0 (10.0–22.1)	9.1 (5.3–15.2)	7.1 (3.8–12.9)	3.8 (1.5–9.5)	0.001			
Thorax	8.7 (6.5–10.8)	6.5 (4.3–9.6)	6.0 (3.9–9.1)	8.8 (5.9–12.8)	6.0 (3.1–11.4)	3.0 (1.2–7.5)	13.4 (8.5–20.4)	6.7 (3.3–13.2)	0.294			
Vertebral column	2.0 (1.0–3.0)	1.5 (0.6–3.4)	0.3 (0.1–1.7)	1.1 (0.4–3.3)	3.8 (1.6–8.5)	1.5 (0.4–5.4)	0.8 (0.1–4.3)	2.9 (1.0–8.1)	1.000			
Pelvis	0.5 (0.2–1.3)	0.6 (0.2–2.1)	0.6 (0.2–2.2)	0.0 (0.0–1.4)	0.0 (0.0–2.8)	0.0 (0.0–2.8)	1.6 (0.4–5.6)	1.0 (0.2–5.2)	1.000			
Tail	0.0 (0.0–0.5)	2.4 (1.2–4.6)	0.3 (0.1–1.7)	0.0 (0.0–1.4)	1.5 (0.4–5.3)	0.0 (0.0–2.8)	0.0 (0.0–2.9)	1.0 (0.2–5.2)	0.002			

P-values (Holm-adjusted) represent comparison between breeds.
doi:10.1371/journal.pone.0090501.t008

Purebred dogs comprise 75-80% of the overall UK dog population [3,28], suggesting that a high proportion of crossbreds are likely to be first or second filial offspring from purebred progenitors and could be reasonably expected to show conformational and polygenic disorder occurrence at the midpoint between the values for their parent breeds, with any additional health benefits in crossbreds resulting from hybrid vigour effects [89]. From this perspective, the less-than-overwhelming evidence provided by the current study for substantially lower prevalence values in crossbred compared with purebred dogs does not refute claims in the literature of rising prevalence values for inherited disorders within purebred dogs. Instead, this suggests that the overall disorder burden within crossbred dogs may reflect the overall disorder burden in purebreds at any point in time. For optimal understanding, disorder prevalence in purebreds should be quantified by analysing cohort health data to identify trends over time.

The most prevalent disorders identified in dogs within the current study were complex disorders that have multiple interacting environmental and genetic casual factors [90]: otitis externa [91], periodontal disease [92], anal sac disorders [93], nail disorders [94,95], degenerative joint disease [96], diarrhoea [97,98], obesity [99], traumatic injury [100], conjunctivitis [101], vomiting [101,102] and heart murmur [103,104]. It may be useful for canine health research to move away from viewing individual disorders as necessarily either inherited or non-inherited [105] and towards an acknowledgement of relevant roles for both genetic and environmental components in the majority of canine disorders [106,107,108]. This acceptance will improve decision-making on effective disease-control and breeding programs [109]. Application of estimated breeding values (EBVs) developed from summative health information derived from a range of sources, including health schemes and veterinary primary-care data, could contribute integrally to novel disorder-control programs [14,110,111].

A large body of literature supports the existence of disorder predispositions affecting most dog breeds [15,16,112]. Despite inclusion of just seven breeds in the current analysis, breed associations were identified for 33.3% (28/84) of the disorders and syndromes evaluated (diagnosis-level disorders 20% (5/20), mid-level disorders 40% (8/20) and syndromic terms 34% (15/44)). The high-risk breeds differed considerably between the disorders in the current study, suggesting that rational health control measures should focus on highly-predisposed disorders within at-risk breeds. Future breed-specific studies are recommended to report more precise prevalence estimates and for a wider range of breeds. Early studies could focus on the fourteen high-profile breeds identified by the KC as having higher health risks, mainly due to conformational problems [113].

There were some limitations to the current study. The practices participating in the study formed a single veterinary group that extended across central and south-east England and may not be representative of the overall veterinary practice structure in England. Case definitions and diagnosis recording relied heavily on the clinical acumen and note-making of attending practitioners. The researchers made no attempts to second-guess underlying disorders in cases with presenting signs (e.g. vomiting) recorded *in lieu* of formal diagnoses. Inclusion of umbrella terms such as *road traffic accident* without additional inclusion of the individual specific injuries sustained within the primary event may have reduced the apparent prevalence of fractures and lacerations but avoided multiple counting of disorder events along axes of diagnostic precision. The analyses based on popular breeds were exploratory in nature and should be validated within larger confirmatory

Table 9. Prevalence of syndromic diagnoses affecting organ system recorded in crossbred dogs and popular breeds (number of dogs) from 3,884 randomly sampled dogs attending primary veterinary practices in England.

Organ system	Prevalence percentage (95% confidence interval)										P-Value
	Crossbred (797)	Labrador Retriever (339)	Staffordshire Bull Terrier (334)	Jack Russell Terrier (262)	Cocker Spaniel (133)	German Shepherd Dog (132)	Yorkshire Terrier (127)	Border Collie (104)			
Integument	31.4 (28.0–34.7)	39.2 (34.2–44.5)	36.2 (31.3–41.5)	34.0 (28.5–39.9)	33.8 (26.3–42.2)	34.8 (27.3–43.3)	42.5 (34.3–51.2)	29.8 (21.9–39.2)	0.816		
Digestive	30.0 (26.6–33.3)	29.8 (25.2–34.9)	19.2 (15.3–23.7)	28.6 (23.5–34.4)	36.1 (28.4–44.5)	27.3 (20.4–35.4)	44.1 (35.8–52.8)	26.9 (19.3–36.2)	0.002		
Musculoskeletal	17.3 (14.8–19.8)	19.2 (15.3–23.7)	9.6 (6.9–13.2)	9.5 (6.5–13.7)	6.8 (3.6–12.4)	18.9 (13.2–26.5)	8.7 (4.9–14.8)	22.1 (15.2–31.0)	0.005		
Connective/Soft tissue	12.3 (10.2–14.4)	16.2 (12.7–20.5)	9.9 (7.1–13.6)	9.5 (6.5–13.7)	14.3 (9.3–21.2)	5.3 (2.6–10.5)	9.4 (5.5–15.8)	17.3 (11.2–25.7)	0.060		
Ocular	9.2 (7.2–11.1)	9.1 (6.5–12.7)	8.7 (6.1–12.2)	8.8 (5.9–12.8)	12.8 (8.1–19.5)	2.3 (0.8–6.5)	13.4 (8.5–20.4)	14.4 (8.9–22.4)	0.203		
Auditory	7.4 (5.5–9.3)	12.4 (9.3–16.3)	11.1 (8.1–14.9)	8.4 (5.6–12.4)	10.5 (6.4–16.9)	11.4 (7.0–17.9)	7.9 (4.3–13.9)	5.8 (2.7–12.0)	1.000		
Nervous	7.9 (6.2–9.6)	8.3 (5.8–11.7)	3.0 (1.6–5.4)	5.7 (3.5–9.2)	9.0 (5.2–15.1)	12.9 (8.2–19.7)	3.1 (1.2–7.8)	15.4 (9.7–23.5)	0.003		
Respiratory	7.2 (5.2–9.1)	8.0 (5.5–11.3)	6.9 (4.6–10.1)	7.3 (4.7–11.0)	3.0 (1.2–7.5)	3.8 (1.6–8.6)	8.7 (4.9–14.8)	3.8 (1.5–9.5)	1.000		
Cardiovascular	5.3 (3.5–7.1)	1.5 (0.6–3.4)	3.3 (1.8–5.8)	7.6 (5.0–11.5)	5.3 (2.6–10.5)	1.5 (0.4–5.4)	11.0 (6.7–17.7)	6.7 (3.3–13.2)	0.001		
Urinary	5.8 (4.1–7.5)	5.3 (3.4–8.2)	3.6 (2.1–6.2)	4.6 (2.6–7.8)	6.8 (3.6–12.4)	4.5 (2.1–9.6)	6.3 (3.2–11.9)	6.7 (3.3–13.2)	1.000		
Reproductive	4.9 (3.5–6.3)	2.7 (1.4–5.0)	6.0 (3.9–9.1)	5.0 (2.9–8.3)	5.3 (2.6–10.5)	2.3 (0.8–6.5)	3.9 (1.7–8.9)	1.0 (0.2–5.2)	1.000		
Endocrine	2.1 (1.2–3.1)	1.5 (0.6–3.4)	1.2 (0.5–3.0)	2.3 (1.1–4.9)	0.0 (0.0–2.8)	0.8 (0.1–4.2)	2.4 (0.8–6.7)	1.9 (0.5–6.7)	1.000		
Haematopoietic	1.3 (0.7–2.3)	2.1 (1.0–4.2)	1.2 (0.5–3.0)	0.4 (0.1–2.1)	1.5 (0.4–5.3)	1.5 (0.4–5.4)	0.0 (0.0–2.9)	0.0 (0.0–3.6)	1.000		
Hepatobiliary	0.1 (0.0–0.7)	1.8 (0.8–3.8)	0.0 (0.0–1.1)	0.4 (0.1–2.1)	0.0 (0.0–2.8)	0.0 (0.0–2.8)	0.0 (0.0–2.9)	3.8 (1.5–9.5)	0.004		
Lymphatic	0.9 (0.4–1.8)	0.6 (0.2–2.1)	0.6 (0.2–2.2)	0.4 (0.1–2.1)	0.8 (0.1–4.1)	0.0 (0.0–2.8)	0.0 (0.0–2.9)	1.0 (0.2–5.2)	1.000		

P-values (Holm-adjusted) represent comparison between breeds.
doi:10.1371/journal.pone.0090501.t009

Table 10. Prevalence of syndromic diagnoses relating to pathophysiological processes recorded in crossbred and popular breeds (number of dogs) attending primary veterinary practices in England.

Pathophysiological process	Prevalence percentage (95% confidence interval)											P-Value
	Crossbred (797)	Labrador Retriever (339)	Staffordshire Bull Terrier (334)	Jack Russell Terrier (262)	Cocker Spaniel (133)	German Shepherd Dog (132)	Yorkshire Terrier (127)	Border Collie (104)				
Inflammation	28.1 (25.1–31.2)	37.8 (32.8–43.0)	29.6 (25.0–34.7)	25.2 (20.3–30.8)	27.8 (20.9–36.0)	32.6 (25.2–41.0)	35.4 (27.7–44.1)	27.9 (20.2–37.2)	0.120			
Mass/swelling	14.1 (11.8–16.3)	23.3 (19.1–28.1)	14.1 (10.7–18.2)	11.1 (7.8–15.4)	20.3 (14.3–27.9)	12.1 (7.6–18.8)	14.2 (9.2–21.3)	24.0 (16.8–33.1)	0.004			
Traumatic	14.3 (11.6–17.0)	18.3 (14.5–22.8)	14.1 (10.7–18.2)	14.5 (10.8–19.3)	16.5 (11.2–23.8)	11.4 (7.0–17.9)	7.1 (3.8–12.9)	15.4 (9.7–23.5)	1.000			
Degenerative	11.4 (9.1–13.8)	15.6 (12.2–19.9)	7.5 (5.1–10.8)	7.6 (5.0–11.5)	4.5 (2.1–9.5)	9.8 (5.8–16.1)	6.3 (3.2–11.9)	18.3 (12.0–26.8)	0.001			
Infectious	9.0 (6.9–11.2)	13.9 (10.6–17.9)	7.8 (5.4–11.2)	8.0 (5.3–11.9)	9.0 (5.2–15.1)	10.6 (6.4–17.0)	7.9 (4.3–13.9)	13.5 (8.2–21.3)	0.990			
Neoplastic	9.0 (7.2–10.9)	15.3 (11.9–19.6)	6.3 (4.1–9.4)	4.6 (2.6–7.8)	12.8 (8.1–19.5)	2.3 (0.8–6.5)	3.9 (1.7–8.9)	9.6 (5.3–16.8)	0.003			
Congenital	7.3 (5.6–9.2)	5.0 (3.2–7.9)	4.8 (3.0–7.6)	6.5 (4.1–10.1)	7.5 (4.1–13.3)	6.1 (3.1–11.5)	11.0 (6.7–17.7)	5.8 (2.7–12)	1.000			
Nutritional	5.9 (4.3–7.5)	16.5 (12.9–20.8)	7.5 (5.1–10.8)	6.9 (4.4–10.6)	9.8 (5.8–16.0)	3.8 (1.6–8.6)	2.4 (0.8–6.7)	9.6 (5.3–16.8)	0.002			
Behavioural	7.9 (6.0–9.8)	5.0 (3.2–7.9)	6.6 (4.4–9.8)	8.8 (5.9–12.8)	6.8 (3.6–12.4)	13.6 (8.8–20.5)	3.9 (1.7–8.9)	8.7 (4.6–15.6)	0.400			
Hereditary	5.3 (3.5–7.0)	4.4 (2.7–7.2)	3.3 (1.8–5.8)	3.4 (1.8–6.4)	3.0 (1.2–7.5)	7.6 (4.2–13.4)	11.8 (7.3–18.6)	2.9 (1.0–8.1)	0.025			
Parasitic	6.7 (5.0–8.4)	6.2 (4.1–9.3)	5.7 (3.7–8.7)	5.0 (2.9–8.3)	9.8 (5.8–16.0)	3.0 (1.2–7.5)	5.5 (2.7–10.9)	2.9 (1.0–8.1)	1.000			
Iatrogenic	4.4 (2.9–5.9)	4.4 (2.7–7.2)	3.0 (1.6–5.4)	4.2 (2.4–7.4)	3.8 (1.6–8.5)	4.5 (2.1–9.6)	4.7 (2.2–9.9)	4.8 (2.1–10.8)	1.000			
Foreign body	2.8 (1.6–3.9)	3.2 (1.8–5.7)	1.2 (0.5–3.0)	2.7 (1.3–5.4)	2.3 (0.8–6.4)	2.3 (0.8–6.5)	0.0 (0.0–2.9)	3.8 (1.5–9.5)	1.000			
Death	2.1 (1.2–3.1)	1.8 (0.8–3.8)	1.5 (0.6–3.5)	0.8 (0.2–2.7)	0.8 (0.1–4.1)	2.3 (0.8–6.5)	3.1 (1.2–7.8)	4.8 (2.1–10.8)	1.000			
Intoxicative	1.1 (0.6–2.1)	1.5 (0.6–3.4)	0.9 (0.3–2.6)	1.5 (0.6–3.9)	0.8 (0.1–4.1)	0.0 (0.0–2.8)	1.6 (0.4–5.6)	1.0 (0.2–5.2)	1.000			
Haemostatic	0.5 (0.2–1.3)	1.5 (0.6–3.4)	1.8 (0.8–3.9)	1.1 (0.4–3.3)	0.0 (0.0–2.8)	0.8 (0.1–4.2)	0.0 (0.0–2.9)	2.9 (1.0–8.1)	1.000			
Immune-mediated	0.5 (0.2–1.3)	0.0 (0.0–1.1)	0.3 (0.1–1.7)	0.8 (0.2–2.7)	2.3 (0.8–6.4)	0.0 (0.0–2.8)	2.4 (0.8–6.7)	1.0 (0.2–5.2)	0.189			
Allergic	0.9 (0.4–1.8)	2.1 (1.0–4.2)	0.6 (0.2–2.2)	0.8 (0.2–2.7)	0.8 (0.1–4.1)	0.8 (0.1–4.2)	1.6 (0.4–5.6)	0.0 (0.0–3.6)	1.000			
Thermoregulatory	0.6 (0.3–1.5)	0.0 (0.0–1.1)	0.6 (0.2–2.2)	0.8 (0.2–2.7)	0.8 (0.1–4.1)	0.0 (0.0–2.8)	1.6 (0.4–5.6)	1.0 (0.2–5.2)	1.000			
Metabolic	0.3 (0.1–0.9)	0.0 (0.0–1.1)	0.0 (0.0–1.1)	0.0 (0.0–1.4)	0.8 (0.1–4.1)	0.0 (0.0–2.8)	0.0 (0.0–2.9)	0.0 (0.0–3.6)	1.000			
Effusion	0.0 (0.0–0.5)	0.0 (0.0–1.1)	0.0 (0.0–1.1)	0.0 (0.0–1.4)	0.0 (0.0–2.8)	0.0 (0.0–2.8)	0.0 (0.0–2.9)	0.0 (0.0–3.6)	1.000			

P-values (Holm-adjusted) represent comparison between breeds.
doi:10.1371/journal.pone.0090501.t010

studies [114,115]. Holm adjustments to P-values were used to constrain the number of false-positive findings resulting from interpretation of multiple comparisons [38,115,116]. The current study reported prevalence values but effective welfare prioritisation would additionally benefit from the generation of accurate data on disorder severity and duration [117].

Conclusion

This study describes the most frequently recorded disorders in dogs in England and provides a prevalence baseline against which to measure progress in canine health. The most prevalent disorders recorded in dogs attending primary-care veterinary practices in England were otitis externa, periodontal disease and anal sac impaction, and the most prevalent disorder groups were enteropathic, dermatological and musculoskeletal. The head-and-neck was the body location most frequently affected by the disorders recorded, the integument was the most prevalent organ system affected and inflammation was the most prevalent pathophysiological process. The study identified some evidence that purebred dogs had higher disorder prevalence compared with crossbred dogs. Substantial variation was shown across breeds in

their prevalence of common disorders. These results suggest that breeding reforms should target commonly diagnosed complex disorders that are amenable to genetic improvement on a breed-by-breed basis for the greatest population impact. The prevalence information provided by this study fills a crucial data gap. Future studies of disorder severity and duration would augment the current results and contribute to increasingly effective strategies to improve dog welfare based on disorder prioritisation.

Acknowledgments

We thank Peter Dron (RVC) for VetCompass database development and Noel Kennedy (RVC) for software and programming development. We are especially grateful to the Medivet Veterinary Partnership and the other UK practices and clients who are participating in VetCompass.

Author Contributions

Conceived and designed the experiments: DON DBC PDM PCT DCB. Performed the experiments: DON DBC PDM PCT DCB. Analyzed the data: DON DBC PDM PCT DCB. Contributed reagents/materials/analysis tools: DON DBC PDM PCT DCB. Wrote the paper: DON DBC PDM PCT DCB.

References

- Murray JK, Browne WJ, Roberts MA, Whitmarsh A, Gruffydd-Jones TJ (2010) Number and ownership profiles of cats and dogs in the UK. *Veterinary Record* 166: 163–168.
- Asher L, Buckland E, Phylactopoulos CL, Whiting M, Abeyesinghe S, et al. (2011) Estimation of the number and demographics of companion dogs in the UK. *BMC Veterinary Research* 7: 74.
- PFMA (2012) The Pet Food Manufacturers' Association 'Statistics'. In: Association TPFM, editor: The Pet Food Manufacturers' Association.
- Owby DR, Johnson C, Peterson EL (2002) Exposure to dogs and cats in the first year of life and risk of allergic sensitization at 6 to 7 years of age. *Journal of the American Medical Association* 288: 963–972.
- Friedmann E, Son H (2009) The human-companion animal bond: how humans benefit. *Veterinary Clinics of North America: Small Animal Practice* 39: 293–326.
- Virués-Ortega J, Buela-Casal G (2006) Psychophysiological effects of human-animal interaction: theoretical issues and long-term interaction effects. *Journal of Nervous and Mental Disease* 194: 52–57.
- Walsh F (2009) Human-animal bonds I: the relational significance of companion animals. *Family Process* 48: 462–480.
- McGreevy PD, Nicholas FW (1999) Some practical solutions to welfare problems in dog breeding. *Animal Welfare* 8: 329–341.
- Rooney NJ (2009) The welfare of pedigree dogs: cause for concern. *Journal of Veterinary Behavior: Clinical Applications and Research* 4: 180–186.
- Wayne RK, Leonard JA, Vila C (2006) Genetic analysis of dog domestication. In: Zeder MA, editor. *Documenting domestication: new genetic and archaeological paradigms*. Berkeley, California: University of California Press. pp. 279–293.
- Leroy G (2011) Genetic diversity, inbreeding and breeding practices in dogs: results from pedigree analyses. *The Veterinary Journal* 189: 177–182.
- McGreevy PD (2007) Breeding for quality of life. *Animal Welfare* 16: 125–128.
- Calboli FC, Sampson J, Fretwell N, Balding DJ (2008) Population structure and inbreeding from pedigree analysis of purebred dogs. *Genetics* 179: 593–601.
- Lewis TW (2010) Optimisation of breeding strategies to reduce the prevalence of inherited disease in pedigree dogs. *Animal Welfare* 19: 93–98.
- Asher L, Diesel G, Summers JF, McGreevy PD, Collins LM (2009) Inherited defects in pedigree dogs. Part 1: disorders related to breed standards. *The Veterinary Journal* 182: 402–411.
- Summers JF, Diesel G, Asher L, McGreevy PD, Collins LM (2010) Inherited defects in pedigree dogs. Part 2: Disorders that are not related to breed standards. *The Veterinary Journal* 183: 39–45.
- Mellersh CS, Ostrander EA (1997) The canine genome. In: Dodds WJ, James EW, editors. *Advances in Veterinary Medicine*: Academic Press. pp. 191–216.
- Starkey MP, Scase TJ, Mellersh CS, Murphy S (2005) Dogs really are man's best friend: canine genomics has applications in veterinary and human medicine! *Briefings in Functional Genomics & Proteomics* 4: 112–128.
- BBC (2008) *Pedigree Dogs Exposed*.
- Bateson P (2010) *Independent inquiry into dog breeding*. Cambridge: University of Cambridge.
- Rooney N, Sargan D (2008) Pedigree dog breeding in the UK: a major welfare concern? Horsham, West Sussex: RSPCA.
- APGAW (2009) *A healthier future for pedigree dogs*. London: The Associate Parliamentary Group for Animal Welfare.
- Collins LM, Asher L, Summers J, McGreevy P (2011) Getting priorities straight: risk assessment and decision-making in the improvement of inherited disorders in pedigree dogs. *The Veterinary Journal* 189: 147–154.
- Collins LM, Asher L, Summers JF, Diesel G, McGreevy PD (2010) Welfare epidemiology as a tool to assess the welfare impact of inherited defects on the pedigree dog population. *Animal Welfare* 19: 67–75.
- Fleming JM, Creevy KE, Promislow DEL (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.
- Adams VJ, Evans KM, Sampson J, Wood JLN (2010) Methods and mortality results of a health survey of purebred dogs in the UK. *Journal of Small Animal Practice* 51: 512–524.
- Egenvall A, Nødtvedt A, Penell J, Gunnarsson L, Bonnett BN (2009) Insurance data for research in companion animals: benefits and limitations. *Acta Veterinaria Scandinavica* 51: 42.
- VetCompass (2013) *VetCompass: Health surveillance for UK companion animals*. <http://www.rvc.ac.uk/VetCompass>. London: RVC Electronic Media Unit.
- Medivet (2014) *Medivet: the veterinary partnership*. Medivet Partnership LLP.
- The VeNom Coding Group (2013) *VeNom Veterinary Nomenclature*. In: Group TVC, editor. <http://www.venomcoding.org>: VeNom Coding Group.
- Kearsley-Fleet L, O'Neill DG, Volk HA, Church DB, Brodbelt DC (2013) Prevalence and risk factors for canine epilepsy of unknown origin in the UK. *Veterinary Record* 172: 338.
- Epi Info 7 CDC (2012) Centers for Disease Control and Prevention (US): *Introducing Epi Info 7*. <http://www.cdc.gov/epiinfo/7>. Atlanta, Georgia: CDC.
- Willard MD, Tvedten H (2004) *Small animal clinical diagnosis by laboratory methods*. St. Louis, Miss.: Saunders.
- Sleator DD, Endre Tarjan R (1983) A data structure for dynamic trees. *Journal of Computer and System Sciences* 26: 362–391.
- Irion DN, Schaffer AL, Famula TR, Eggleston ML, Hughes SS, et al. (2003) Analysis of genetic variation in 28 dog breed populations with 100 microsatellite markers. *Journal of Heredity* 94: 81–87.
- The Kennel Club (2012) *Kennel Club's Breed Information Centre*. In: Club TK, editor. <http://www.the-kennel-club.org.uk/services/public/breed/Default.aspx>. London: The Kennel Club.
- McMillan FD (2001) Rethinking euthanasia: death as an unintentional outcome. *Journal of the American Veterinary Medical Association* 219: 1204–1206.
- Aickin M, Gensler H (1996) Adjusting for multiple testing when reporting research results: the Bonferroni vs Holm methods. *American Journal of Public Health* 86: 726–728.
- Kirkwood BR, Sterne JAC (2003) *Essential Medical Statistics*. Oxford: Blackwell Science.
- Agresti A, Coull BA (1998) Approximate is better than "exact" for interval estimation of binomial proportions. *The American Statistician* 52: 119–126.
- Hein HE (1963) Abnormalities and defects in pedigree dogs-II. Hereditary aspects of hip dysplasia. *Journal of Small Animal Practice* 4: 457–462.
- Hodgman SEJ (1963) Abnormalities and defects in pedigree dogs-I. An investigation into the existence of abnormalities in pedigree dogs in the British Isles. *Journal of Small Animal Practice* 4: 447–456.

43. Knight GC (1963) Abnormalities and defects in pedigree dogs—III. Tibio-femoral joint deformity and patella luxation. *Journal of Small Animal Practice* 4: 463-464.
44. Willis MB (1963) Abnormalities and defects in pedigree dogs—V. Cryptorchidism. *Journal of Small Animal Practice* 4: 469-474.
45. BVA/KC (2013) Hip Dysplasia Scheme. In: British Veterinary Association/Kennel Club, editor. London: British Veterinary Association,.
46. BVA/KC (2013) Chiari Malformation/Syringomyelia Scheme (CM/SM Scheme). In: Club BVAK, editor. London: British Veterinary Association.
47. BVA/KC (2013) Elbow Scheme. London: British Veterinary Association.
48. BVA/KC/ISS (2013) Eye Scheme. In: Society BVAKCIS, editor. London: British Veterinary Association,.
49. KC (2013) DNA Screening Schemes and Results. In: The Kennel Club, editor. London: The Kennel Club,.
50. Indrebo A (2007) Animal welfare in modern dog breeding. *Acta Veterinaria Scandinavica* 50 Supplement S6.
51. Froom P, Froom J (1992) Selection bias in using data from one population to another: common pitfalls in the interpretation of medical literature. *Theoretical Medicine* 13: 255-259.
52. Bartlett PC, Van Buren JW, Neterer M, Zhou C (2010) Disease surveillance and referral bias in the veterinary medical database. *Preventive Veterinary Medicine* 94: 264-271.
53. Soll-Johanning H, Hannerz H, Tüchsen F (2004) Referral bias in hospital register studies of geographical and industrial differences in health. *Danish Medical Bulletin* 51: 207-210.
54. KC (2013) The Kennel Club. London: The Kennel Club,.
55. Platt S, Freeman J, di Stefani A, Wiczorek L, Henley W (2006) Prevalence of unilateral and bilateral deafness in Border Collies and association with phenotype. *Journal of Veterinary Internal Medicine* 20: 1355-1362.
56. Powers MY, Karbe GT, Gregor TP, McKelvie P, Culp WTN, et al. (2010) Evaluation of the relationship between Orthopedic Foundation for Animals' hip joint scores and PennHIP distraction index values in dogs. *Journal of the American Veterinary Medical Association* 237: 532-541.
57. Slater MR, Scarlet JM, Donoghue S, Erb HN (1992) The repeatability and validity of a telephone questionnaire on diet and exercise in dogs. *Preventive Veterinary Medicine* 13: 77-91.
58. Pearce N, Checkoway H, Kriebel D (2007) Bias in occupational epidemiology studies. *Occupational and Environmental Medicine* 64: 562-568.
59. Gobar GM (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.
60. Hudson JI, Pope HG, Glynn RJ (2005) The cross-sectional cohort study: an underutilized design. *Epidemiology (Cambridge, Mass)* 16: 355-359.
61. Dohoo I, Martin W, Stryhn H (2009) *Veterinary Epidemiologic Research*. Charlottetown, Canada: VER Inc.
62. Aragon CL, Budsberg SC (2005) Applications of evidence-based medicine: cranial cruciate ligament injury repair in the dog. *Veterinary Surgery* 34: 93-98.
63. John U, Rumpf H-J, Hapke U (1999) Estimating prevalence of alcohol abuse and dependence in one general hospital: an approach to reduce sample selection bias. *Alcohol and Alcoholism* 34: 786-794.
64. Chodick G, Freedman MD, Kwok RK, Fears TR, Linet MS, et al. (2007) Agreement between contemporaneously recorded and subsequently recalled time spent outdoors: implications for environmental exposure studies. *Annals of Epidemiology* 17: 106-111.
65. Edney ATB (1997) An observational study of presentation patterns in companion animal veterinary practices in England. London: University of London. 290 p.
66. Lund EM (1997) Development and evaluation of a model for diagnostic surveillance in companion animal practice. St Paul: University of Minnesota.
67. Glickman L, Glickman N (2012) The National Companion Animal Surveillance System NCASP. Purdue University.
68. Brady S, Norris JM, Kelman M, Ward MP (2012) Canine parvovirus in Australia: the role of socio-economic factors in disease clusters. *The Veterinary Journal* 193: 522-528.
69. Egenvall A, Bonnett BN, Olson P, Hedhammar Å (1998) Validation of computerized Swedish dog and cat insurance data against veterinary practice records. *Preventive Veterinary Medicine* 36: 51-65.
70. Lund EM, Armstrong PJ, Kirk CA, Kolar LM, Klausner JS (1999) Health status and population characteristics of dogs and cats examined at private veterinary practices in the United States. *Journal of the American Veterinary Medical Association* 214: 1336-1341.
71. Rust MK (2005) Advances in the control of *Ctenocephalides felis* (cat flea) on cats and dogs. *Trends in Parasitology* 21: 232-236.
72. NOAH (2013) Facts and Figures About the UK Animal Medicines Industry. In: National Office of Animal Health, editor: NOAH,.
73. Royston P, Altman DG, Sauerbrei W (2006) Dichotomizing continuous predictors in multiple regression: a bad idea. *Statistics in Medicine* 25: 127-141.
74. Mandl KD, Overhage JM, Wagner MM, Lober WB, Sebastiani P, et al. (2004) Implementing syndromic surveillance: a practical guide informed by the early experience. *Journal of the American Medical Informatics Association* 11: 141-150.
75. Dank G, Segev G, Moshe D, Kent MS (2012) Follow-up study comparing necropsy rates and discrepancies between clinical and pathologic diagnoses at a veterinary teaching hospital: 2009 versus 1989 and 1999. *Journal of Small Animal Practice* 53: 679-683.
76. Lober WB, Thomas Karras B, Wagner MM, Marc Overhage J, Davidson AJ, et al. (2002) Roundtable on bioterrorism detection: information system-based surveillance. *Journal of the American Medical Informatics Association* 9: 105-115.
77. Egenvall A, Hedhammar A, Bonnett BN, Olson P (2000) Gender, age and breed pattern of diagnoses for veterinary care in insured dogs in Sweden during 1996. *Veterinary Record* 146: 551-557.
78. Vilson Å, Bonnett B, Hansson-Hamlin H, Hedhammar Å (2013) Disease patterns in 32,486 insured German Shepherd Dogs in Sweden: 1995-2006. *Veterinary Record* 173: 116.
79. Bonnett BN, 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.
80. Stone AB, Hautala JA (2008) Meeting Report: Panel on the potential utility and strategies for design and implementation of a National Companion Animal Infectious Disease Surveillance System. *Zoonoses and Public Health* 55: 378-384.
81. Neff MW, Rine J (2006) A fetching model organism. *Cell* 124: 229-231.
82. Packer RMA, Hendricks A, Burn CC (2012) Do dog owners perceive the clinical signs related to conformational inherited disorders as 'normal' for the breed? A potential constraint to improving canine welfare. *Animal Welfare* 21: 81-93.
83. Egenvall A, Bonnett BN, Olson P, Hedhammar Å (2000) Gender, age, breed and distribution of morbidity and mortality in insured dogs in Sweden during 1995 and 1996. *Veterinary Record* 146: 519-525.
84. Medzhitov R (2010) Inflammation 2010: new adventures of an old flame. *Cell* 140: 771-776.
85. Mountziaris PM, Spicer PP, Kasper FK, Mikos AG (2011) Harnessing and modulating inflammation in strategies for bone regeneration. *Tissue Engineering Part B, Reviews* 17: 393-402.
86. Rooney NJ, Sargan DR (2010) Welfare concerns associated with pedigree dog breeding in the UK. *Animal Welfare* 19: 133-140.
87. Crispin S (2011) Tackling the welfare issues of dog breeding. *Veterinary Record* 168: 53.
88. Anon (2009) Balancing pedigree dog breed standards and animal welfare - is it possible? *Veterinary Record* 164: 481-482.
89. Bell J. The clinical truths about pure breeds, mixed breeds, and designer breeds; 2012 Feb 19-23; Las Vegas. 22-23.
90. Page GP, George V, Go RC, Page PZ, Allison DB (2003) "Are we there yet?": Deciding when one has demonstrated specific genetic causation in complex diseases and quantitative traits. *The American Journal of Human Genetics* 73: 711-719.
91. Marsella R, Girolomoni G (2009) Canine models of atopic dermatitis: a useful tool with untapped potential. *The Journal of Investigative Dermatology* 129: 2351-2357.
92. Albuquerque C, Morinha F, Requicha J, Martins T, Dias I, et al. (2012) Canine periodontitis: the dog as an important model for periodontal studies. *The Veterinary Journal* 191: 299-305.
93. Scott DW, Miller WH, Griffin CE, Muller GH (2001) *Muller & Kirk's Small Animal Dermatology*. Philadelphia: Saunders.
94. Neuber A (2009) Nail diseases in dogs. *Companion Animal* 14: 56-62.
95. Smith FJD (2003) The molecular genetics of keratin disorders. *American Journal of Clinical Dermatology* 4: 347-364.
96. Lewis T, Blott S, Woolliams J (2013) Comparative analyses of genetic trends and prospects for selection against hip and elbow dysplasia in 15 UK dog breeds. *BMC Genetics* 14: 16.
97. German AJ, Hall EJ, Day MJ (2003) Chronic intestinal inflammation and intestinal disease in dogs. *Journal of Veterinary Internal Medicine* 17: 8-20.
98. Kathrani A, Werling D, Allenspach K (2011) Canine breeds at high risk of developing inflammatory bowel disease in the south-eastern UK. *Veterinary Record* 169: 635.
99. German AJ (2006) The growing problem of obesity in dogs and cats. *The Journal of Nutrition* 136: 1940S-1946S.
100. Houlton JE (2008) A survey of gundog lameness and injuries in Great Britain in the shooting seasons 2005/2006 and 2006/2007. *Veterinary and comparative Orthopaedics and Traumatology* 21: 231-237.
101. Lourenço-Martins AM, Delgado E, Neto I, Peleteiro MC, Morais-Almeida M, et al. (2011) Allergic conjunctivitis and conjunctival provocation tests in atopic dogs. *Veterinary Ophthalmology* 14: 248-256.
102. Batt RM, Hall EJ (1989) Chronic enteropathies in the dog. *Journal of Small Animal Practice* 30: 3-12.
103. Pedersen HD, Häggström J (2000) Mitral valve prolapse in the dog: a model of mitral valve prolapse in man. *Cardiovascular Research* 47: 234-243.
104. Lewis T (2011) Heritability of premature mitral valve disease in Cavalier King Charles Spaniels. *The Veterinary Journal* 188: 73.
105. Bellumori TP, Famula TR, Bannasch DL, Belanger JM, Oberbauer AM (2013) Prevalence of inherited disorders among mixed-breed and purebred dogs: 27,254 cases (1995-2010). *Journal of the American Veterinary Medical Association* 242: 1549-1555.

106. Rand JS, Fleeman LM, Farrow HA, Appleton DJ, Lederer R (2004) Canine and feline diabetes mellitus: nature or nurture? *The Journal of Nutrition* 134: 2072S–2080S.
107. Wood JLN (2002) Heritability and epidemiology of canine hip-dysplasia score and its components in Labrador retrievers in the United Kingdom. *Preventive Veterinary Medicine* 55: 95–108.
108. Hillier A, Griffin CE (2001) The ACVD task force on canine atopic dermatitis (I): incidence and prevalence. *Veterinary Immunology and Immunopathology* 81: 147–151.
109. Mellersh C (2012) DNA testing and domestic dogs. *Mammalian Genome* 23: 109–123.
110. Lewis TW (2010) Genetic evaluation of hip score in UK Labrador Retrievers. *PLoS One* 5.
111. Wilson B, Nicholas FW, Thomson PC (2011) Selection against canine hip dysplasia: success or failure? *The Veterinary Journal* 189: 160–168.
112. Gough A, Thomas A (2010) *Breed Predispositions to Disease in Dogs and Cats*. Chichester, West Sussex: Wiley-Blackwell.
113. Anon. (2013) High profile best of breed winners pass vet checks at Crufts. *Veterinary Record* 172: 277.
114. Bender R, Lange S (2001) Adjusting for multiple testing - when and how? *Journal of Clinical Epidemiology* 54: 343–349.
115. Greenland S (2008) Multiple comparisons and association selection in general epidemiology. *International Journal of Epidemiology* 37: 430–434.
116. Feise R (2002) Do multiple outcome measures require p-value adjustment? *BMC Medical Research Methodology* 2: 8.
117. CAWC (2006) *Breeding and welfare in companion animals: welfare aspects of modifications, through selective breeding or biotechnological methods, to the form, function, or behaviour of companion animals*. Sidmouth, Devon: Companion Animal Welfare Council.