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Epidemiology of haemangiosarcoma diagnosed in dogs under primary veterinary care in the United Kingdom: Frequency and risk factors

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Abstract

Background This study aimed to estimate the frequency and risk factors for haemangiosarcoma diagnosis in dogs.

Methods Cases diagnosed in UK primary care practices in 2019 were identified from VetCompass records, and potential risk factors were manually extracted. Two nested case-control studies were conducted: one including all diagnosed haemangiosarcoma with or without histopathological confirmation (clinical diagnosis), and another limited to histopathologically confirmed haemangiosarcoma. Logistic regression modelling was used to identify risk factors among dogs aged five years or older.

Results Of 2,250,741 dogs of all ages, 801 were diagnosed with haemangiosarcoma in 2019, giving an annual incidence risk of 0.036% (95% confidence interval [CI] 0.033–0.038%). Of the 1,066,381 dogs aged at least five years, there were 790 incident cases (0.074%, 95% CI 0.069–0.079%). After excluding dogs that belonged to a small practice group, risk factor analysis compared 788 clinically diagnosed cases with 1,064,187 controls. Ten breeds had increased odds of clinical haemangiosarcoma diagnosis compared to crossbreed dogs. Breeds with the highest odds were Dogue de Bordeaux (OR 9.56, 95% CI 4.17–21.91), Flat Coated Retriever (OR 8.33, 95% CI 4.03–17.20) and German Shepherd Dog (OR 6.35, 95% CI 4.86–8.29). In the histopathological subset, the Flat Coated Retriever showed highest odds (OR 17.5, 95% CI 7.88–38.67). Compared to dogs aged 7 < 9 years old, older age was a significant risk factor in both clinical (11 < 13 years, OR 2.83, 95% CI 2.31–3.48) and histopathological diagnoses (9 < 11 years, OR 1.90, 95% CI 1.40–2.58). In the broader clinically diagnosed analysis, increased odds were also associated with neutered males (OR 1.49, 95% CI 1.17–1.90) and clinics in the least deprived areas (OR 1.66, 95% CI 1.18–2.34). Dogs attending clinics in mixed urban-rural areas had decreased odds of clinical haemangiosarcoma diagnosis compared to those in urban areas (OR 0.71, 95% CI 0.57–0.89).

Conclusions Several strong breed associations for diagnosis of haemangiosarcoma were identified which can support earlier clinical suspicion and targeted diagnostics, especially where early signs are non-specific. Breed-related associations with haemangiosarcoma diagnosis may suggest a genetic predisposition which may be targeted through changes in breeding practices and promotion of outcrossing in high-risk breeds.

Keywords Haemangiosarcoma, VetCompass, Risk factor, Epidemiology

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Introduction

Canine haemangiosarcoma is a tumour arising from bone marrow-derived endothelial cell precursors or vascular endothelial cells [1–3]. The incidence of haemangiosarcoma was estimated in insured dogs in the UK at 25 cases per 100,000 dogs per year [4]. Haemangiosarcoma has been reported to account for 40–64% of primary splenic disease [5–8], 46% of cardiac tumours in dogs [9] and 2–8% of cutaneous masses [10, 11]. With the exception of the cutaneous form, haemangiosarcoma is typically biologically aggressive [3] leading to significant welfare concerns for affected dogs such as tumour metastasis, pain or discomfort, frequent veterinary visits or death [12].

Age and breed have been consistently reported in the literature as important demographic risk factors for canine haemangiosarcoma [4, 10, 11, 13–17]. However, there is less consensus regarding the association with sex, neuter status and bodyweight [9, 13–26]. The risk of haemangiosarcoma is reported to increase with increasing age [9, 13, 16], though dogs over 15 years old may have lower odds of cardiac and cutaneous haemangiosarcoma compared to middle-aged dogs [9, 10]. Breed predisposition also plays an important role, with retriever breeds, shepherd breeds and Boxers reportedly particularly susceptible. Golden Retrievers and German Shepherd Dogs are reported to have the highest risk overall [17]. However, breed predispositions vary by tumour location [9–11, 14, 15]; for example, cutaneous haemangiosarcoma has been associated with a higher risk in Jack Russell Terriers [11], Boxers, Greyhounds, Airedale Terriers, Golden Retrievers and English Pointers [10].

Sex has not been identified as a significant risk factor for haemangiosarcoma in most studies [9, 13, 14, 16, 18], though one retrospective study using data from 27 US academic hospitals reported males at increased risk after matching cases and controls by age and diagnosis period, and adjusting for neuter status and breed [17]. Findings regarding neuter status are mixed; however, neutered females show a more consistent association with increased haemangiosarcoma risk compared to neutered males [9, 14, 16, 17, 19, 20]. Dogs diagnosed with haemangiosarcoma also tend to be larger in bodyweight [16, 21, 25], although interpretations of bodyweight effects are complicated by inconsistent weight categories across studies and the confounding effect of breed [23].

Environmental risk factors for haemangiosarcoma have been less thoroughly studied. One Italian study did not identify an association between living environment (indoor vs. outdoor) or estimated pollution exposure and visceral haemangiosarcoma [16]. To date, there are no published studies examining socioeconomic risk factors in relation to haemangiosarcoma in dogs, although it is plausible that variables such as owner income, employment, education, and living conditions influence pet care, husbandry and access to veterinary care, thereby indirectly affecting diagnosis risk.

The ability to generalise findings from previous epidemiological studies on haemangiosarcoma to the broader UK dog population is limited. Many studies rely on insured or referral populations that may poorly represent the wider dog population [27], and geographic differences in breeding practices and environmental exposures may further limit comparability. VetCompass collects de-identified electronic health record (EHR) data from approximately 25% of primary care veterinary practices across the UK for epidemiological research [28]. Available data fields include fixed values for species, breed, date of birth, sex, and neuter status, as well as date-specific information on free-form clinical notes, bodyweight, and treatment. This current study aimed to evaluate the epidemiology of canine haemangiosarcoma in UK primary veterinary care practices. Objectives included exploring the frequency of clinical haemangiosarcoma diagnosis in dogs of all ages and in a subset of those aged five years or older, and to identify demographic and environmental risk factors for haemangiosarcoma diagnosis in dogs aged five years or older.

Based on the literature, the current study hypothesised that older dogs, Golden Retrievers, German Shepherd Dogs, and larger-sized dogs are associated with higher odds of haemangiosarcoma diagnosis.

Materials and methods

A cohort study of dogs under veterinary care in 2019 at participating practices in VetCompass was conducted to estimate the annual incidence risk and 12-month period prevalence of clinical haemangiosarcoma diagnosis for dogs of all ages and in a subset of those aged five years or older. Two nested case-control studies were used – one including all diagnosed haemangiosarcoma with or without histopathological confirmation (clinical), and another limited to the subset of histopathologically confirmed haemangiosarcoma (histopathological) - to assess demographic and environmental risk factors for this diagnosis in dogs aged five years or older during 2019. Ethical approval for using VetCompass data was granted by the Social Science Research Ethical Review Board at the Royal Veterinary College (SR2018-1652). The study included all dogs under primary veterinary care at participating VetCompass clinics in 2019. Dogs were defined as under veterinary care if they had at least one EHR recorded during 2019.

A clinical haemangiosarcoma case was defined as a case with a final recorded diagnosis of haemangiosarcoma, of any anatomical location. Clinical cases included all final diagnoses of haemangiosarcoma, regardless of whether or not histopathological confirmation was available in the EHR. A histopathological haemangiosarcoma case was defined as a case with a final recorded diagnosis of haemangiosarcoma of any anatomical location, and with supporting histopathological evidence documented in the EHR. Therefore, in this study, histopathological cases were a subset of the clinical cases. Prevalent cases included all cases with a final recorded diagnosis of haemangiosarcoma at any time point prior to January 1, 2020, as long as there was evidence of at least one EHR recorded during 2019 to indicate the case was ongoing for at least one day of 2019. Incident cases included the subset of new cases that were first diagnosed between January 1, 2019, and December 31, 2019 (inclusive). If a dog had a final recorded diagnosis of haemangiosarcoma in more than one location, the dog was counted as a case only once, given the high likelihood for those lesions to be related [3, 29].

Table 1 Summary of the extraction and categorisation of risk factor variables for haemangiosarcoma diagnosis in dogs five years or older under primary veterinary care during 2019 in the VetCompass programme in the united Kingdom

Variable	Method of data extraction and categorisation
Breed	Recognised purebreds and designer crossbreeds extracted from electronic health records (EHRs), cleaned and mapped to a VetCompass breed list derived from the VeNom Coding breed list [32].
Breed purity	Categorised as 'purebred' if they were of recognisable breeds or as 'crossbred' if recorded as mixes [33].
Kennel Club breed group	Classified UK Kennel Club-recognised breeds as gundog, hound, pastoral, terrier, toy, utility or working, with all others classified as unassigned [33].
Ancestral breed group	Classified recorded breeds into branches identified from a canine phylogenetic tree by Parker [34, 35]: ancient, herding-sighthound, mastiff-terrier, modern or mountain. Uncategorised breeds were classified as unassigned.
Genotype breed group	Classified recorded breeds into branches identified from a canine phylogenetic tree by Davies and Taylor [7, 34]: GG1 (German Shepherds, Portuguese Water Dogs, Doberman Pinschers), GG2 (Spaniels, Poodles, Dachshunds, Beagles), GG3 (Terriers and brachycephalic dogs), GG4 (Retrievers and mountain breeds) and GG5 (Sighthounds and Collies). Uncategorised breeds were classified as unassigned.
Reproductive status	For cases, reproductive status in the EHR at the time of first diagnosis. For controls, reproductive status defined by the final EHR value.
Adult bodyweight (kg)	All recorded bodyweights for each dog after 18 months of age (to exclude the juvenile growth phase) were extracted from the EHR. The mean of these values was used to approximate adult bodyweight and categorised as < 7.5, 7.5 to < 15.0, 15.0 to < 22.5, 22.5 to < 30.0, 30.0 to < 37.5, ≥ 37.5, and unassigned.
Age (years)	The age at the date of first diagnosis for cases and on June 30, 2019 for controls. Age was categorised as 5 to < 7, 7 to < 9, 9 to < 11, 11 to < 13, 13 to < 15, and ≥ 15.
Practice group	1–5 based on the corporate veterinary practice group the clinic the dog attended belonged to.
Clinic Indices of Multiple Deprivation (IMD)	Veterinary clinic postcodes from VetCompass linked to Lower Super Output Areas (LSOAs) or the devolved nation equivalent. Each LSOA was assigned a ranked IMD value from open-access governmental databases for England, Northern Ireland, Scotland, and Wales [36]. IMD ranks for LSOA areas of each devolved nation were divided into quintiles and categorised from quintile 1 (most deprived) to 5 (least deprived).
Clinic land type	Veterinary clinic postcodes from VetCompass linked to LSOAs or the devolved nation equivalent. LSOAs classified by urban-rural location status as defined by the Office for National Statistics [37].
Clinic identification (ID) number	Extracted directly from the EHR.

To identify potential haemangiosarcoma cases, the clinical free-text field for all 2,250,417 dogs under primary veterinary care in 2019 within VetCompass was searched using search terms related to haemangiosarcoma (haemangios*, hemangios*, HSA, angiosa*, haemangiosarcoma ~ 1, hemangiosarcoma ~ 1, hameangios*). All 4,997 candidate cases identified were randomly ordered and manually reviewed against the case definition. Candidate cases were excluded if haemangiosarcoma was listed only as a differential diagnosis or if there was no final clinical diagnosis. Incident haemangiosarcoma cases had additional clinical information extracted on clinical signs, diagnosis and survival times, results of which are reported elsewhere [30]. Dogs not identified as candidate cases were considered as controls in the risk factor analysis, even if they were affected by a different neoplasia, to represent the general canine population of dogs under veterinary care from which the cases were derived [31]. Because nearly all dogs diagnosed with haemangiosarcoma in the current study were at least five years old, risk factor analysis focused on dogs aged five years or older, either at diagnosis (cases) or on June 30, 2019 (controls). Frequency estimates included all dogs at all practice groups, but risk factor analysis excluded one small practice group with few cases (cases $n = 2$, controls $n = 1,195$) for statistical reasons. For cases and controls, risk factor data were either extracted directly from the EHR or derived from data linked to the breed and veterinary clinics' postcodes (Table 1). Age and adult bodyweight were extracted as continuous variables and categorised (Table 1). The adult bodyweight categories were loosely informed by those commonly used in primary-care veterinary practice, such as for prescribing preventive antiparasitic treatments and their widths were standardised to facilitate ease of interpretation and comparison.

The variable for breed included individual pure breeds and designer crossbreeds with over 7,000 dogs in the overall population or at least five diagnosed haemangiosarcoma cases overall, along with a group for all crossbreeds and a single group for all remaining breeds.

Data were checked and cleaned using Excel (Microsoft Office Excel 2013, Microsoft Corp.) and analyses were performed in R Studio version 4.4.1 (R Core Team, Vienna, Austria) using the following packages: lme4, car, performance, pROC, ResourceSelection, dplyr, broom, and broom.mixed. For risk factor analysis, approximately 700 cases and 2,800 non-haemangiosarcoma controls were required to identify breeds as risk factors with an odds ratio of ≥ 2 compared to crossbreeds (95% confidence interval (CI), 80% power, 2% breed exposure among controls, 1:4 case ratio) [31, 38, 39]. These estimates were based on previous reports that German Shepherd Dogs had four-fold increase in odds of haemangiosarcoma [13, 16] and accounted for approximately 2.1% of the 2019 UK dog population [40].

Binary logistic regression modelling was used in clinical and histopathological haemangiosarcoma risk factor analyses. Following initial assessment for univariable associations between risk factors and all incident cases in 2019, factors whose association with a haemangiosarcoma diagnosis had a P-value < 0.2 in univariable analysis were considered for multivariable evaluation. Because breed was a primary focus, variables derived from breed information or key breed characteristics (breed purity, Kennel Club breed group, genotype breed group, ancestral breed group, adult bodyweight) were excluded from initial multivariable modelling. Instead, these variables individually replaced breed in the final breed-focused model to evaluate their associations. Final multivariable model selection followed a manual backward stepwise elimination process, and pairwise interaction effects were assessed for the variables in the final models [31]. The clinic was evaluated as a random effect, and practice group was included as a fixed effect to account for data clustering at these levels. Practice group was included as fixed effect due to the small numbers of categories (n = 5) [41].

To assess collinearity, generalised variance inflation factors (GVIF) were calculated for all fixed effect variables. Model quality and discrimination were assessed using the area under the receiver operating characteristic (ROC) curve and the Hosmer-Lemeshow test [31, 42]. The intraclass correlation coefficient (ICC) measured clinic-level clustering in the mixed-effect models. Statistical significance was set at P < 0.05.

Results

Prevalence and incidence

From a study population of 2,250,741 dogs under primary veterinary care in 2019, 1,030 dogs met the case definition for a clinically diagnosed haemangiosarcoma case at any date up to January 1, 2020. Of these, 229 (22.23%) were pre-existing diagnoses from before January 1, 2019, and 801 (77.77%) were incident diagnoses in 2019. The 12-month period prevalence (2019) of haemangiosarcoma was 0.046% (95% CI: 0.043–0.049%) and annual incidence risk (2019) was 0.036% (95% CI: 0.033–0.038%). Of the 1,030 cases overall, 999 (96.99%) were aged five years or older.

The 999 cases aged five years or older were derived from 1,066,381 study dogs aged five years or older. Of these 999 cases, 209 (20.92%) were pre-existing diagnoses from before January 1, 2019, and 790 (79.08%) were incident diagnoses in 2019. The 12-month period prevalence (2019) of haemangiosarcoma diagnosis in dogs aged five years or older was 0.094% (95% CI: 0.088–0.099%) and annual incidence risk (2019) was 0.074% (95% CI: 0.069–0.079%).

The breeds with the highest annual incidence risk of clinical haemangiosarcoma across all ages included Flat Coated Retriever (0.57%, 95% CI 0.29–0.82), Hungarian Vizsla (0.44%, 95% CI 0.24–0.65) and German Shepherd Dog (0.42%, 95% CI 0.35–0.49) (Fig. 1).

Risk factor analysis

Clinically diagnosed haemangiosarcoma cases

In the 788 clinically diagnosed incident cases aged at least five years from the five larger veterinary groups included in the risk factor analysis, the median age of first haemangiosarcoma diagnosis was 10.5 years (interquartile range [IQR] 9.0 to 12.0 years, range 5.0 to 17.1 years). A total of 92 individual breeds were recorded; 178 dogs (22.59%) were crossbreed dogs, and 3 dogs (0.38%) had no breed recorded. The most common breeds among the cases were Labrador Retriever (96/788, 12.18%), German Shepherd Dog (84/788, 10.66%) and Staffordshire Bull Terrier (43/788, 5.46%). There were 360 female dogs (45.69%), 424 male dogs (53.81%) and 4 dogs of unrecorded reproductive status (0.51%). At the point of diagnosis, 580 dogs (73.60%) were neutered, and 208 dogs (26.40%) were entire. The median adult bodyweight of cases was 26.4 kg (IQR 16.8 to 33.6 kg, range 4.2 to 70.8 kg).

In the 1,064,187 controls used in risk factor analysis, the median age on 30th June 2019 was 8.7 years (IQR 6.7 to 11.1 years, range 5.0 to 24.5 years). A total of 656 individual Breeds were recorded; 260,372 dogs (24.4%) were crossbreed dogs, and 3,189 dogs (0.3%) had no breed recorded. The most common breeds among controls were Labrador Retriever (83,565/1,064,187, 7.8%), Jack Russell Terrier (69,111/1,064,187, 6.5%) and Staffordshire Bull Terrier (57,791/1,064,187, 5.4%). There were 513,764 female dogs (48.2%), 546,661 male dogs (51.3%) and 4,957 dogs of unrecorded reproductive status (0.5%). Neutered dogs accounted for 663,892 (62.3%) of controls and entire dogs for 396,533 (37.2%). The median adult bodyweight of controls was 14.4 kg (IQR 8.6 to 25.2 kg, range 1.4 to 106 kg).

All study variables other than breed purity were liberally associated with haemangiosarcoma diagnosis in univariable logistic regression modelling (P < 0.2) (Table 2)

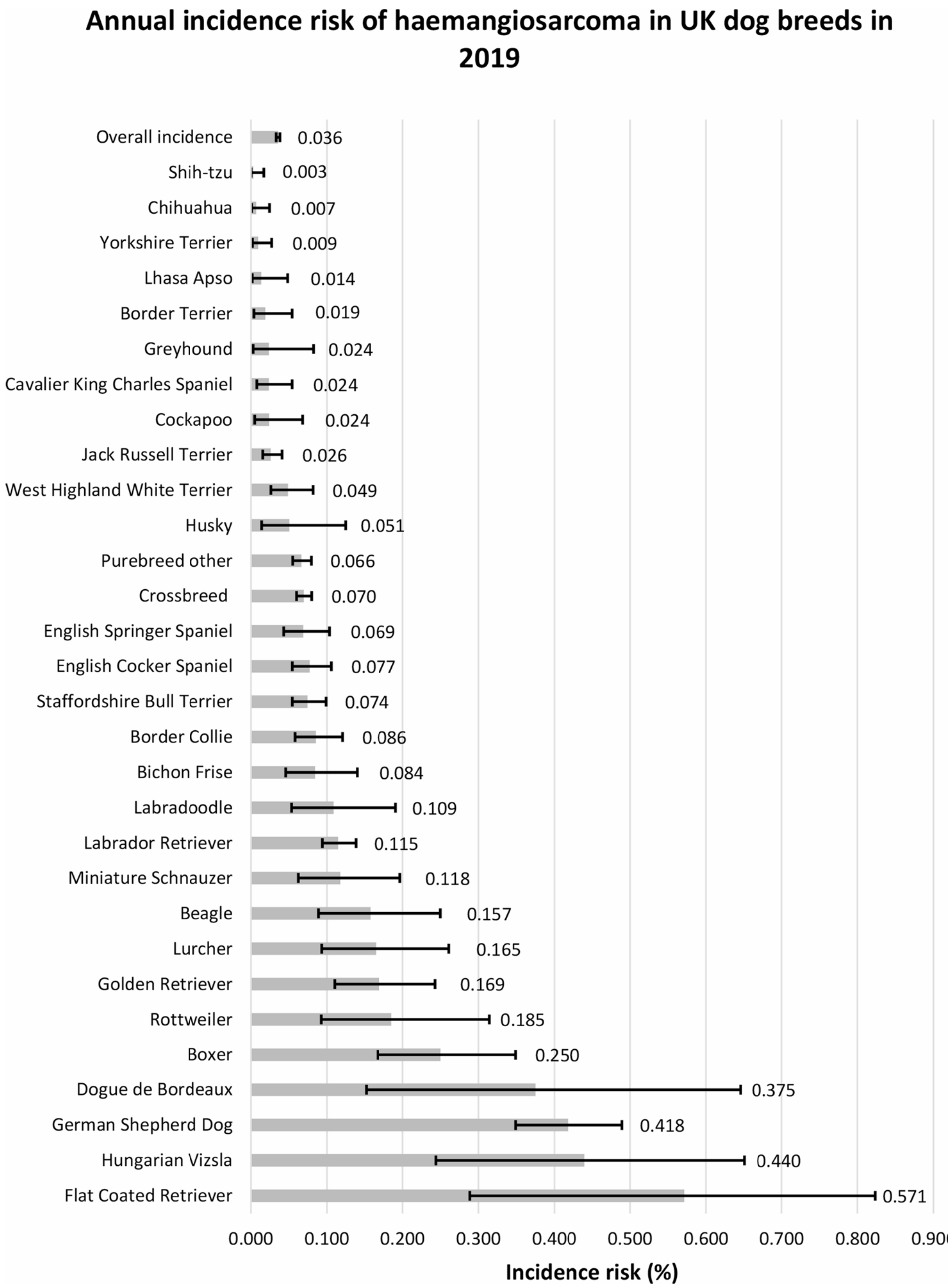

Fig. 1 The annual incidence of clinically diagnosed haemangiosarcoma in dog breeds under primary veterinary care during 2019 in the VetCompass Programme in the United Kingdom. The black lines represent 95% confidence intervals

and were taken forward for consideration in multivariable logistic regression modelling.

The final breed-focused mixed effects multivariable model for clinical haemangiosarcoma diagnosis in dogs aged at least five years old retained six risk factors: breed, reproductive status, age, clinic IMD quintile, clinic land type and practice group (Fig. 2) with clinic ID included as a random effect. The final non-random effect model showed acceptable model-fit and discrimination (Hosmer-Lemeshow test statistic: $P = 0.733$, area under the ROC curve: 0.784). The adjusted GVIF of fixed effects were calculated to be between 1.00 and 1.06, indicating very little collinearity. The ICC was 0.24 (95% CI 0.17–0.25), indicating little clustering of clinical haemangiosarcoma diagnosis at individual clinic level.

Table 2 Descriptive and univariable logistic regression results for risk factors evaluated for clinical diagnosis of haemangiosarcoma in dogs at least five years old under primary veterinary care during 2019 in the VetCompass programme in the United Kingdom. Clinic ID was included as a random effect to account for clustering at clinic level

Variable	Category	Case no. (%) *n* = 788	Non-case no. (%) *n* = 1,064,187	Odds ratio	95% Confidence Interval	Category *P*-value	Variable *P*-value
Reproductive status	Female entire	91 (11.55)	178,648 (16.79)	Ref			0.001
	Female neutered	269 (34.14)	334,562 (31.44)	1.55	1.22–1.97	< 0.001	
	Male entire	144 (18.27)	217,511 (20.44)	1.30	1.00-1.69	0.053	
	Male neutered	280 (35.53)	328,513 (30.87)	1.62	1.27–2.06	< 0.001	
	Unassigned	4 (0.51)	4,953 (0.47)	1.82	0.66–5.01	0.246	
Breed purity	Crossbred	209 (26.52)	298,552 (28.05)	Ref			0.278
	Purebred	576 (73.10)	762,447 (71.65)	1.08	0.92–1.27	0.348	
	Unassigned	3 (0.38)	3,188 (0.30)	2.51	0.80–7.92	0.115	
Breed	Crossbreed	178 (22.59)	260,049 (24.44)	Ref			< 0.001
	Beagle	14 (1.78)	8,863 (0.83)	2.20	1.27–3.82	0.005	
	Bichon Frise	13 (1.65)	15,378 (1.45)	1.25	0.71–2.20	0.441	
	Border Collie	26 (3.30)	33,857 (3.18)	1.17	0.77–1.76	0.464	
	Border Terrier	3 (0.38)	15,919 (1.50)	0.28	0.09–0.89	0.031	
	Boxer	24 (3.05)	9,611 (0.90)	3.61	2.35–5.55	< 0.001	
	Cavalier King Charles Spaniel	5 (0.63)	21,146 (1.99)	0.34	0.14–0.84	0.019	
	Chihuahua	2 (0.25)	29,334 (2.76)	0.10	0.02–0.40	0.001	
	Cockapoo	3 (0.38)	12,583 (1.18)	0.33	0.11–1.04	0.058	
	Dogue de Bordeaux	6 (0.76)	1,554 (0.15)	5.69	2.51–12.94	< 0.001	
	English Cocker Spaniel	33 (4.19)	45,253 (4.25)	1.04	0.71–1.51	0.850	
	English Springer Spaniel	21 (2.66)	30,461 (2.86)	1.04	0.66–1.64	0.857	
	Flat Coated Retriever	8 (1.02)	1,370 (0.13)	8.25	3.99–17.08	< 0.001	
	German Shepherd Dog	84 (10.66)	19,980(1.88)	6.25	4.80–8.13	< 0.001	
	Golden Retriever	23 (2.92)	13,536 (1.27)	2.37	1.53–3.68	< 0.001	
	Greyhound	2 (0.25)	8,477 (0.80)	0.35	0.09–1.41	0.140	
	Hungarian Vizsla	11 (1.40)	2,474 (0.23)	5.89	3.17–10.91	< 0.001	
	Husky	4 (0.51)	7,932(0.75)	0.77	0.28–2.07	0.598	
	Jack Russell Terrier	18 (2.28)	69,049(6.49)	0.37	0.23–0.61	< 0.001	
	Labradoodle	10 (1.27)	9,184(0.86)	1.47	0.77–2.79	0.244	
	Labrador Retriever	96 (2.18)	83,520(7.85)	1.65	1.28–2.12	< 0.001	
	Lhasa Apso	2 (0.25)	14,718(1.38)	0.20	0.05–0.82	0.026	
	Lurcher	14 (1.78)	8,499(0.80)	2.50	1.44–4.32	0.001	
	Miniature Schnauzer	12 (1.52)	10,232(0.96)	1.73	0.96–3.11	0.068	
	Rottweiler	10 (1.27)	5,357(0.50)	2.80	1.47–5.30	0.002	
	Staffordshire Bull Terrier	43 (5.46)	57,700(5.42)	1.11	0.79–1.55	0.544	
	West Highland White Terrier	13 (1.65)	26,716(2.51)	0.74	0.42–1.30	0.295	
	Yorkshire Terrier	3 (0.38)	31,961(3.00)	0.14	0.05–0.44	0.001	
	Purebreed other	107 (13.58)	209,474 (19.68)	0.74	0.58–0.94	0.015	
Kennel Club breed group	Gundog	203 (25.76)	192,318 (18.07)	Ref			< 0.001
	Terrier	91 (11.55)	191,718 (18.02)	0.46	0.36–0.59	< 0.001	
	Toy	26 (3.30)	126,936 (11.93)	0.20	0.13–0.29	< 0.001	
	Utility	38 (4.82)	97,280(9.14)	0.37	0.26–0.53	< 0.001	
	Pastoral	121 (15.36)	63,455 (5.96)	1.89	1.50–2.37	< 0.001	
	Hound	33 (4.19)	41,186(3.87)	0.74	0.51–1.08	0.116	
	Working	54 (6.85)	34,647(3.26)	1.49	1.10–2.02	0.010	
	Unassigned	222 (28.17)	316,647 (29.75)	0.68	0.56–0.82	< 0.001	

Table 2 (continued)

Variable	Category	Case no. (%) *n* = 788	Non-case no. (%) *n* = 1,064,187	Odds ratio	95% Confidence Interval	Category *P*-value	Variable *P*-value
Genotype breed group	GG4 (Retrievers and mountain breeds)	141 (17.89)	106,647 (10.02)	Ref			< 0.001
	GG3 (Terriers and brachycephalic dogs)	108 (13.71)	215,526 (20.25)	0.39	0.31–0.51	< 0.001	
	GG2 (Spaniels, Poodles, Dachshunds, Beagles)	86 (10.91)	122,945 (11.55)	0.54	0.41–0.70	< 0.001	
	GG5 (Sighthounds and Collies)	40 (5.08)	54,302 (5.10)	0.59	0.41–0.83	0.003	
	GG1 (German Shepherds, Portuguese Water Dogs, Doberman Pinschers)	87 (11.04)	24,801 (2.33)	2.75	2.10–3.61	< 0.001	
	Unassigned	326 (41.37)	539,966 (50.74)	0.47	0.38–0.57	< 0.001	
Ancestral breed group	Mastiff-Terrier	235 (29.82)	314,101 (29.52)	Ref			0.105
	Modern	182 (23.10)	239,231 (22.48)	1.01	0.83–1.23	0.888	
	Herding-Sighthound	39 (4.95)	52,396 (4.92)	1.02	0.72–1.43	0.929	
	Ancient	7 (0.89)	15,006 (1.41)	0.65	0.31–1.39	0.270	
	Mountain	13 (1.65)	7,272 (0.68)	2.31	1.31–4.08	0.004	
	Unassigned	312 (39.59)	436,181 (40.99)	0.95	0.80–1.13	0.589	
Adult bodyweight (kg) median (range)		26.4 (4.2–70.8)	14.4 (1.4–106.0)	< 0.001			
Adult bodyweight (kg)	< 7.5	20 (2.54)	155,174 (14.58)	0.32	0.20–0.51	< 0.001	< 0.001
	7.5 to < 15	124 (15.74)	298,271 (28.03)	Ref			
	15 to < 22.5	112 (14.21)	157,975 (14.84)	1.72	1.33–2.23	< 0.001	
	22.5 to < 30	139 (17.64)	132,851 (12.48)	2.54	1.99–3.24	< 0.001	
	30 to < 37.5	164 (20.81)	93,392 (8.78)	4.17	3.30–5.28	< 0.001	
	≥ 37.5	84 (10.66)	48,092 (4.52)	4.28	3.24–5.65	< 0.001	
	Unassigned	145 (18.40)	178,432 (16.77)	1.77	1.38–2.27	< 0.001	
Age (years) median (range)		10.5 (5.0–17.1)	8.7 (5.0–24.5)	< 0.001			
Age (years)	5 to < 7	39 (4.95)	308,821 (29.02)	0.21	0.15–0.30	< 0.001	< 0.001
	7 to < 9	158 (20.05)	267,559 (25.14)	Ref			
	9 to < 11	259 (32.87)	213,947 (20.10)	2.09	1.71–2.55	< 0.001	
	11 to < 13	235 (29.82)	155,099 (14.57)	2.71	2.21–3.32	< 0.001	
	13 to < 15	86 (10.91)	84,873(7.98)	1.81	1.39–2.36	< 0.001	
	≥ 15	11 (1.40)	33,888(3.18)	0.57	0.31–1.05	0.070	
Practice group	Group 1	288 (36.55)	336,121 (31.58)	Ref			< 0.001
	Group 2	221 (28.05)	211,019 (19.83)	1.03	0.79–1.33	0.830	
	Group 3	164 (20.81)	294,136 (27.64)	0.20	0.15–0.26	< 0.001	
	Group 4	100 (12.69)	203,388 (19.11)	0.18	0.13–0.25	< 0.001	
	Group 5	15 (1.90)	19,523 (1.83)	0.34	0.18–0.65	0.001	
Clinic land type	Urban	269 (34.14)	355,644 (33.42)	Ref			< 0.001
	Mixed urban/rural	401 (50.89)	581,490 (54.64)	0.79	0.62–1.01	0.058	
	Rural	115 (14.59)	121,380 (11.41)	2.11	1.50–2.97	< 0.001	
	Unassigned	3 (0.38)	5,673 (0.53)	NA	NA	NA	
Clinic Indices of Multiple Deprivation (IMD) quintile	1 (most deprived)	97 (12.31)	203,559 (19.13)	Ref			< 0.001
	2	169 (21.45)	233,664 (21.96)	1.62	1.13–2.33	0.009	
	3	162 (20.56)	217,458 (20.43)	1.96	1.36–2.82	< 0.001	
	4	172 (21.83)	211,987 (19.92)	1.97	1.36–2.84	< 0.001	
	5 (least deprived)	185 (23.48)	191,846 (18.03)	2.65	1.84–3.81	< 0.001	
	Unassigned	3 (0.38)	5,673 (0.53)	NA	NA	NA	

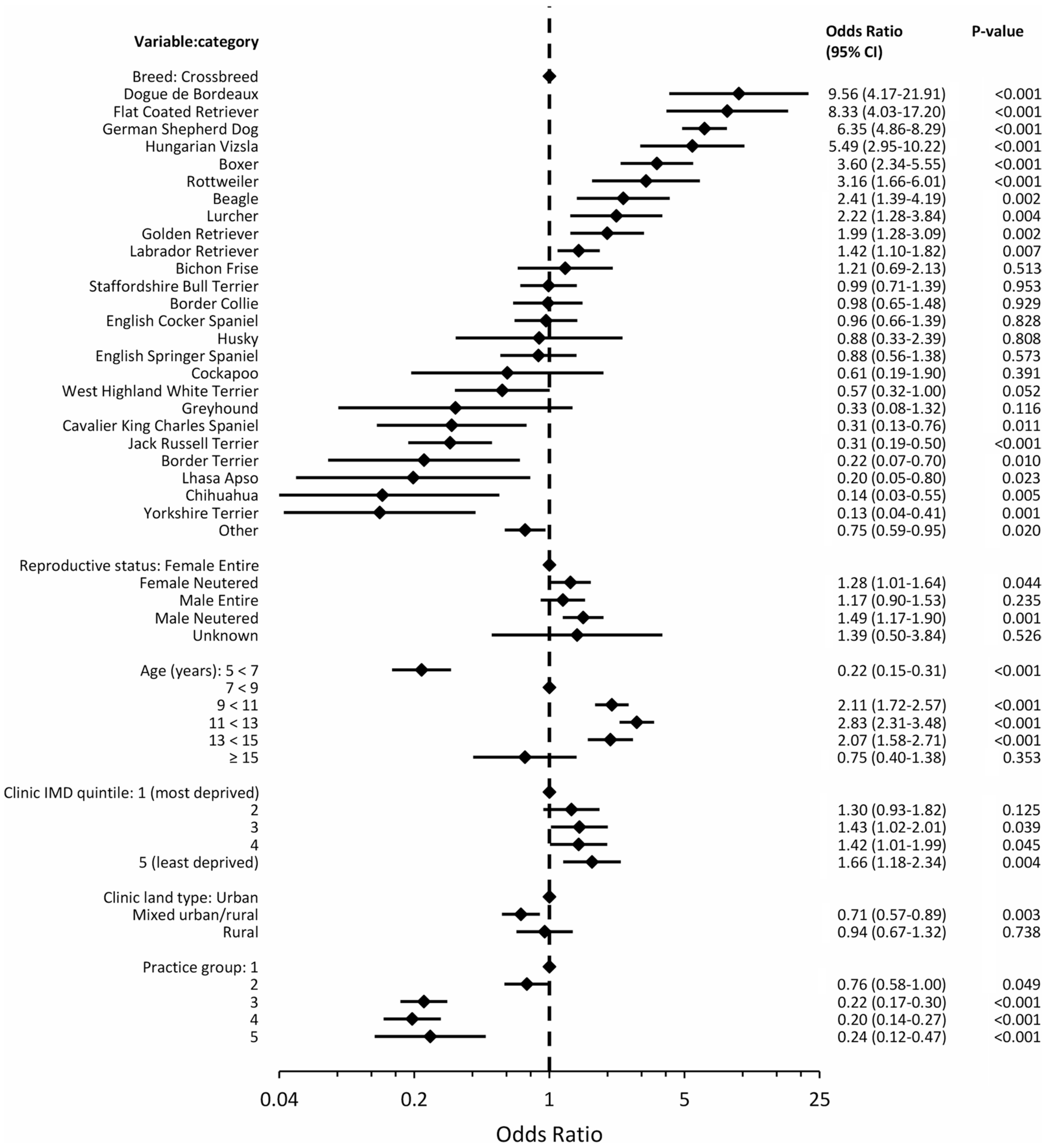

Fig. 2 Multivariable logistic regression modelling results that include breed for risk factors evaluated for clinical haemangiosarcoma diagnosis in dogs at least five years old under primary veterinary care during 2019 in the VetCompass Programme in the United Kingdom. Clinic ID was included as a random effect. Categories without an odds ratio were the reference value. 95% CI – 95% confidence interval

After accounting for the effects of the other variables evaluated, ten breeds showed increased odds of clinical haemangiosarcoma compared with crossbreed dogs. Breeds with the highest odds included Dogue de Bordeaux (OR 9.56, 95% CI 4.17–21.91), Flat Coated Retriever (OR 8.33, 95% CI 4.03–17.20), German Shepherd Dog (OR 6.35, 95% CI 4.86–8.29), and Hungarian Vizsla (OR 5.49, 95% CI 2.95–10.22). Six breeds showed reduced odds of haemangiosarcoma compared with crossbreeds.

Neutered females and neutered males showed increased odds compared to entire females (OR 1.28, 95% CI 1.01–1.64, and OR 1.49, 95% CI 1.17–1.90, respectively). Compared to dogs aged 7 to < 9 years old, dogs aged 11 to < 13 years old were at highest odds of clinical haemangiosarcoma diagnosis (OR 2.83, 95% CI 2.31–3.48). Dogs in the youngest age category of 5 to < 7 years old had reduced odds of clinical haemangiosarcoma compared to dogs aged 7 to < 9 years (OR 0.22, 95% CI 0.15–0.31). Of deprivation levels assessed, dogs attending clinics in the least deprived areas (quintile 5) of the UK had the highest odds of clinical haemangiosarcoma diagnosis compared to those attending clinics in the most deprived areas (quintile 1) (OR 1.66, 95% CI 1.18–2.34). Dogs attending clinics in mixed urban/rural areas were at reduced odds of clinical haemangiosarcoma compared to those attending clinics in urban areas (OR 0.71, 95% CI 0.57–0.89).

As described in the methods, breed-derived variables and bodyweight were introduced individually to replace breed in the final breed-focused multivariable model (Fig. 3). Compared to the Kennel Club gundog group, the pastoral and working groups showed similarly increased odds of clinical haemangiosarcoma diagnosis (OR 1.94, 95% CI 1.54–2.43 and OR 1.90, 95% CI 1.40–2.58, respectively). Compared to the GG4 genotype breed group, GG1 had increased odds of clinical haemangiosarcoma (OR 3.13, 95% CI 2.38–4.10). Compared to the mastiff-Tterrier ancestral breed group, the mountain group showed increased odds of clinical haemangiosarcoma diagnosis (OR 3.12, 95% CI 1.78–5.49). Dogs in the lowest bodyweight category of < 7.5 kg had reduced odds of clinical haemangiosarcoma compared to dogs weighing 7.5 to < 15 kg (OR 0.35, 95% CI 0.22–0.56). As the bodyweight categories increased over 15 kg, the odds of clinical haemangiosarcoma diagnosis increased in each category to the highest odds of 4.42 (95% CI 3.34–5.85) in the ≥ 37.5 kg category.

Haemangiosarcoma cases confirmed with histopathology

In the subset of 273 incident cases confirmed with histopathology, over five years old and from the five largest veterinary groups used in the risk factor analysis, the median age of first histopathological haemangiosarcoma diagnosis was 10.0 years (IQR 8.6 to 11.3 years, range 5.0 to 16.6 years). A total of 51 individual breeds were recorded; 68 (24.91%) dogs were crossbreed dogs, and all dogs had a breed recorded. The most common breeds among the histopathological cases were Labrador Retriever (35/273, 12.82%) and German Shepherd Dog (28/273, 10.26%). There were 130 female dogs (47.62%), 142 male dogs (52.01%) and 1 dog of unrecorded reproductive status (0.37%). At the time of diagnosis, 185 dogs were neutered (67.77%), and 87 dogs were entire (31.87%). The median adult bodyweight of histopathological cases was 27.1 kg (IQR 16.0 to 34.1 kg, range 5.0 to 54.2 kg). The controls used in this risk factor analysis were as described previously.

The study variables liberally associated with histopathological haemangiosarcoma diagnosis in univariable logistic regression modelling ($P < 0.2$) were reproductive status, breed, Kennel Club breed group, genotype breed group, adult bodyweight, age and practice group (Table 3 in Appendix 1). These variables were taken forward for consideration in multivariable logistic regression modelling with breed-derived variables replacing breed in the main model separately.

The final mixed effects multivariable model that focused on breed for histopathological haemangiosarcoma diagnosis in dogs aged at least five years old retained three risk factors: breed, age, and practice group (Fig. 4) with clinic ID included as a random effect. The final non-random effect model showed acceptable model-fit and discrimination (Hosmer-Lemeshow test statistic: $P = 0.427$, area under the ROC curve: 0.773). The adjusted GVIF of fixed effects were all calculated to be 1.00, indicating very little collinearity. The ICC was 0.23 (95% CI 0.18–0.25), indicating little clustering of histopathological haemangiosarcoma diagnosis at individual clinic level.

After accounting for the effects of the other variables evaluated, five breeds showed increased odds of histopathological haemangiosarcoma diagnosis compared with crossbreed dogs. Breeds with increased odds were Flat Coated Retriever (OR 17.5, 95% CI 7.88–38.67), Hungarian Vizsla (OR 6.97, 95% CI 2.79–17.42), German Shepherd Dog (OR 5.18, 95% CI 3.32–8.09), Beagle

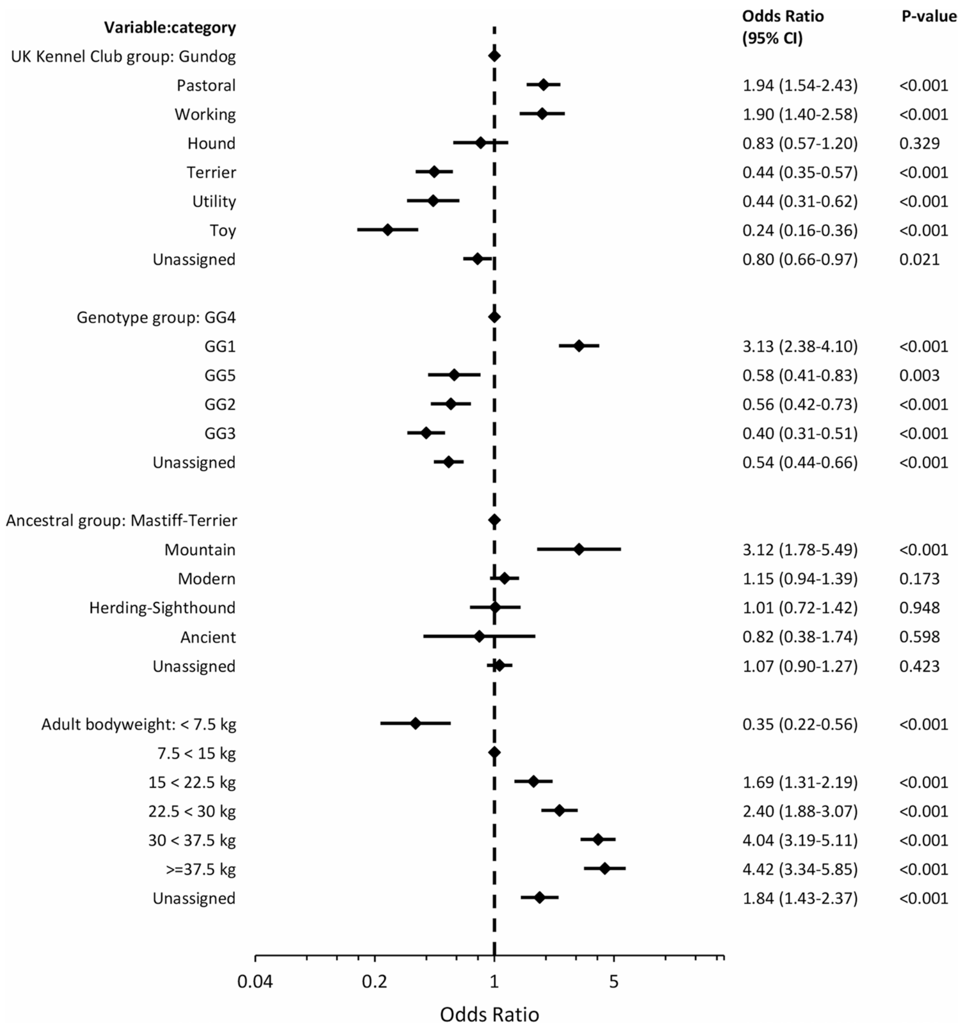

Fig. 3 Multivariable logistic regression results for variables that each replaced breed in risk factor analysis for clinical haemangiosarcoma diagnosis in dogs at least five years old under primary veterinary care during 2019 in the VetCompass Programme in the United Kingdom. These results are each adjusted for reproductive status, age, clinic index of multiple deprivation, clinic land type and veterinary practice group, with clinic ID included as a random effect. Categories without an odds ratio were the reference value. 95% CI – 95% confidence interval

(OR 4.42, 95% CI 2.27–8.62) and Boxer (OR 3.75, 95% CI 1.92–7.33). Conversely, Jack Russell Terrier and Yorkshire Terrier, showed reduced odds of histopathological haemangiosarcoma diagnosis compared with crossbreeds (OR 0.40, 95% CI 0.19–0.84 and OR 0.23, 95% CI 0.06–0.96, respectively).

Compared to dogs aged 7 to <9 years, dogs aged 9 to <11 years and 11 to <13 years had increased odds of histopathological haemangiosarcoma diagnosis (OR 1.90, 95% CI 1.40–2.58 and OR 1.55, 95% CI 1.09–2.21, respectively). Dogs in the youngest age category of 5 to <7 years old had reduced odds of histopathological haemangiosarcoma compared to dogs aged 7 to <9 years (OR 0.22, 95% CI 0.13–0.37).

Breed-derived variables and bodyweight were introduced individually to replace breed in the final model (Fig. 5). Compared to the Kennel Club breed group gundog, the pastoral group showed increased odds of histopathological haemangiosarcoma diagnosis (OR 1.87, 95% CI 1.28–2.73). Compared to GG4, GG1 had increased odds of histopathological haemangiosarcoma (OR 2.53, 95% CI 1.59–4.01). Dogs in the lowest bodyweight category of <7.5 kg had reduced odds of histopathological haemangiosarcoma compared to dogs weighing 7.5 to <15 kg (OR 0.35, 95% CI 0.17–0.74). Dogs weighing 15 to <22.5 kg and 22.5 kg to <30 kg had almost the same

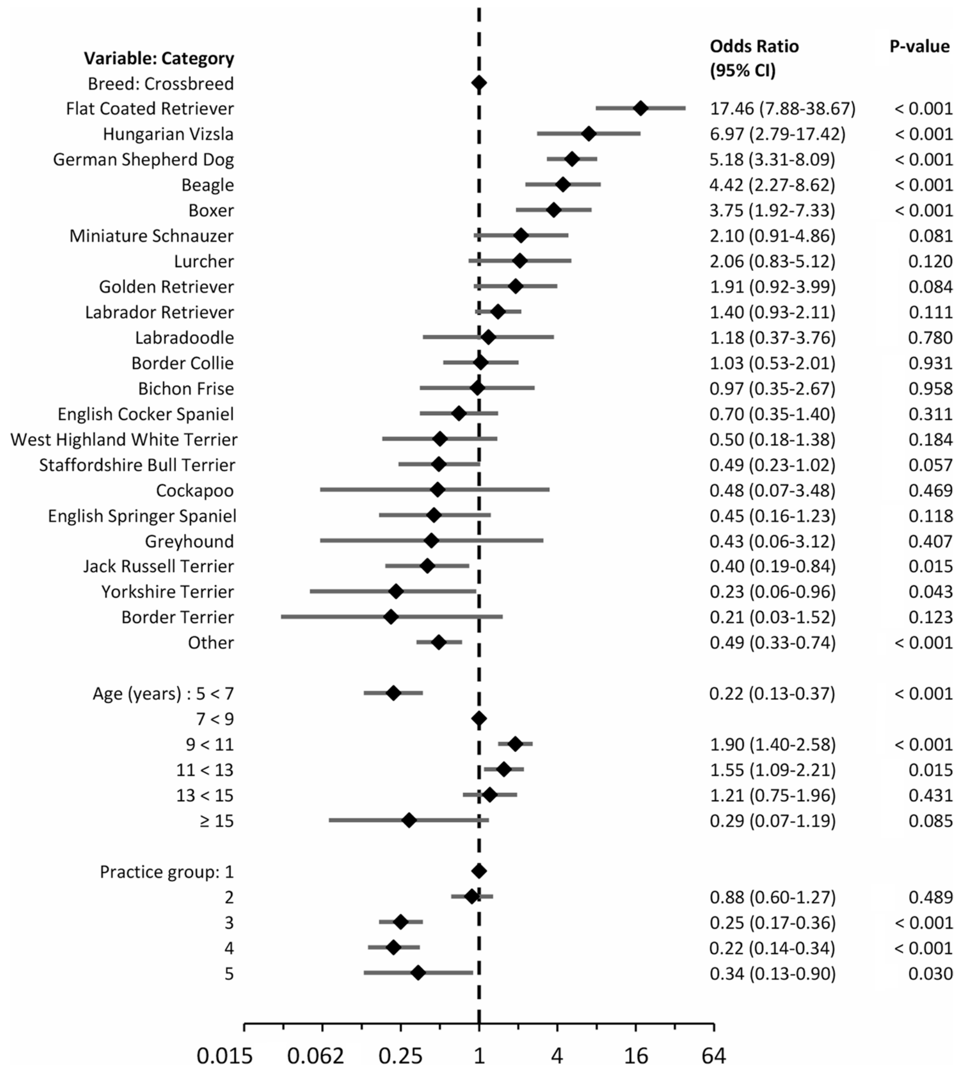

Fig. 4 Multivariable logistic regression results that include breed for risk factors evaluated for haemangiosarcoma diagnosis confirmed with histopathology in dogs at least five years old under primary veterinary care during 2019 in the VetCompass Programme in the United Kingdom. Clinic ID was included as a random effect. Categories without an odds ratio were the reference value. 95% CI – 95% confidence interval

increase in odds of histopathological haemangiosarcoma diagnosis (OR 1.86, 95% CI 1.24–2.78 and OR 1.86, 95% CI 1.22–2.83, respectively). As the bodyweight categories increased over 30 kg, the odds of histopathological haemangiosarcoma diagnosis increased further to the highest odds of 5.17 (95% CI 3.38–7.89) in the ≥ 37.5 kg category.

Comparison of clinical with histopathological haemangiosarcoma cases and multivariable model outcomes

Univariable logistic regression modelling explored possible variables associated with a histopathologically confirmed diagnosis of haemangiosarcoma in dogs with a clinical haemangiosarcoma diagnosis (Table 4 in Appendix 2). The study variables liberally associated with a histopathological diagnosis in clinical haemangiosarcoma cases were breed, adult bodyweight and age ($P < 0.2$).

Generally, the odds ratios produced by the clinical and histopathological haemangiosarcoma risk factor analyses were similar (Table 5 in Appendix 3), except for age, which showed a more marked effect of increasing age with reduction of odds of histopathological haemangiosarcoma diagnosis (Fig. 6).

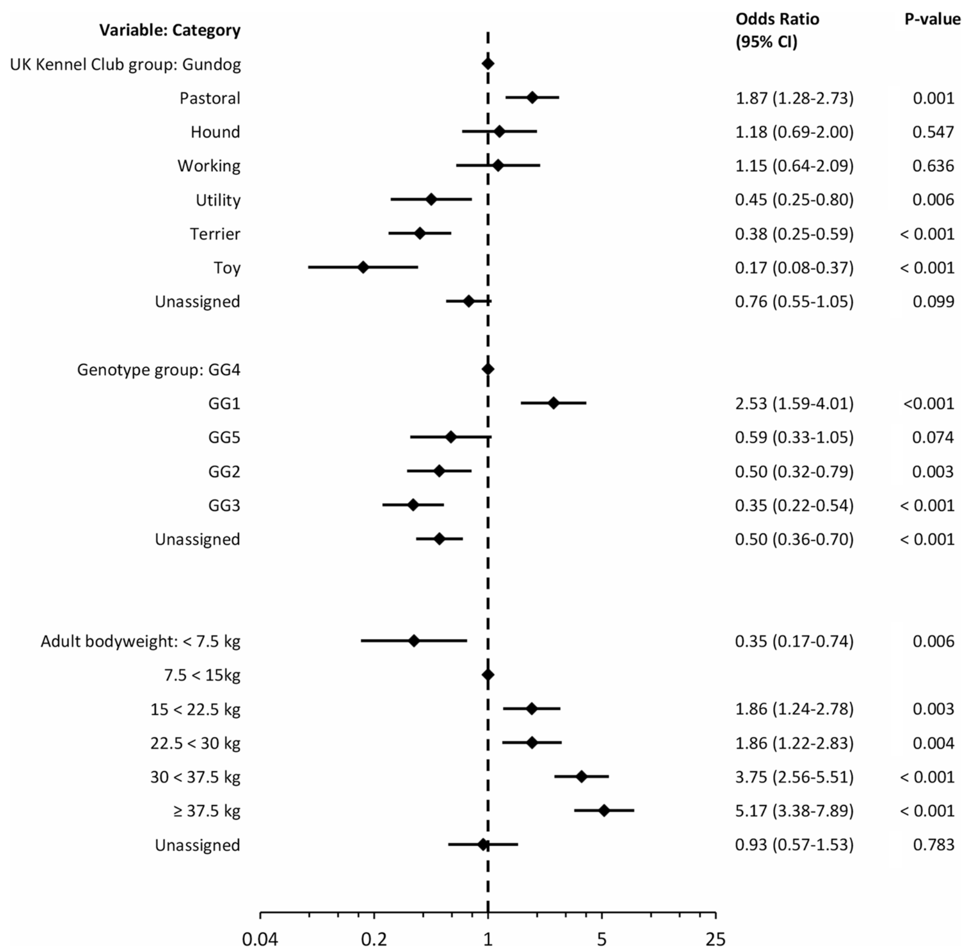

Fig. 5 Multivariable logistic regression results for variables that each replaced breed in risk factor analysis for haemangiosarcoma diagnosis confirmed with histopathology in dogs at least five years old under primary veterinary care during 2019 in the VetCompass Programme in the United Kingdom. Each model adjusts for age and veterinary practice group, with clinic ID included as a random effect. Categories without an odds ratio were the reference value. 95% CI – 95% confidence interval

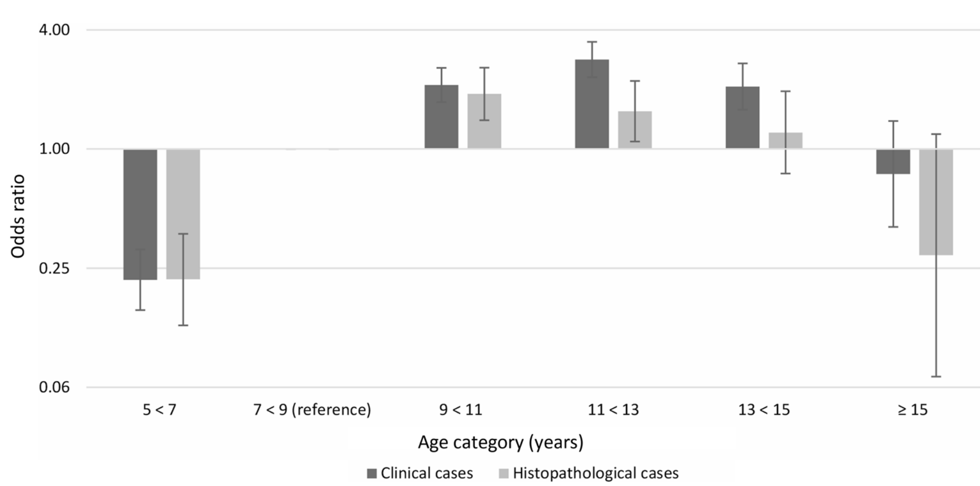

Fig. 6 Comparison of odds ratios produced for age category (years) variable between clinical and histopathological haemangiosarcoma diagnosis in multivariable logistic regression modelling in dogs at least five years old under primary veterinary care during 2019 in the VetCompass Programme in the United Kingdom. Clinic ID was included as a random effect to account for clustering at clinic level. The black lines represent 95% confidence intervals

Discussion

The current study is the first to report incidence, prevalence and risk factors associated with haemangiosarcoma diagnosis in dogs under primary veterinary care in the UK. The current study benefitted from access to a large study population of 2,250,741 dogs to identify 1,030 clinical haemangiosarcoma cases, of which 273 were confirmed with histopathology. While excluding cases without histopathological confirmation may enhance diagnostic reliability, it risks selection bias by omitting those true cases where invasive or costly diagnostics were deemed inappropriate due to an advanced disease stage. By including all cases with a clinical veterinary diagnosis, this study aims to provide a more representative estimate of haemangiosarcoma in the wider UK dog population than previous referral papers. Breed, breed group, reproductive status, age, adult bodyweight, clinic-associated deprivation and land type were all identified as risk factors for clinical haemangiosarcoma diagnosis.

The annual incidence risk (0.036%) and prevalence (0.046%) reported in the current study provide new information on the frequency of clinical haemangiosarcoma in dogs attending primary care veterinary practice in the UK. In the subset of dogs aged five years or older, the incidence and prevalence risks increased twofold to 0.074% and 0.094%, respectively. Where complete resolution of haemangiosarcoma is rarely achieved, the relatively similar incidence and prevalence risk estimates reported in the current study support the short survival of most forms of haemangiosarcoma [30]. These current annual incidence values were greater than that reported by previous studies which assessed frequency of haemangiosarcoma from referral service (0.007%) or insured (0.025%) populations [4, 17]. Although referral centre data may provide high diagnostic confidence on individual cases, referral and insured populations show selection bias towards owners wishing to pursue greater diagnostic workups or with fewer financial concerns which limits generalisability to wider primary care populations [27, 43].

The findings from the clinical haemangiosarcoma diagnosis multivariable model reflected several similarities to the histopathological diagnosis model, suggesting that the broader clinical diagnoses have value for assessing risk factors. All the breeds shown to be at increased and decreased odds in the histopathological model had significant odds in the clinical model, although not always to the same degree. The difference in odds reported in the histopathological model were likely due to some breeds lacking any histopathological cases and a reduction in statistical power for less common breeds due to a smaller case sample size. Additionally, in univariable analysis between histopathological and non-histopathological haemangiosarcoma cases, some breeds were more (Flat Coated Retriever and Beagle) and less (Staffordshire Bull Terrier) likely to obtain a histopathological diagnosis. For the age variable, odds of a clinical diagnosis peaked at 11 to < 13 years old, whilst dogs aged 9 to < 11 years old had the highest odds of histopathological haemangiosarcoma diagnosis. Univariable analysis between histopathological and non-histopathological haemangiosarcoma cases showed decreasing odds of histopathology with increasing age. This could reflect owners being more likely to pursue surgery in younger dogs if malignant neoplasia is suspected less or they are more likely to be insured [44]. Interestingly, clinic deprivation level was not found to be associated with odds of a histopathological haemangiosarcoma diagnosis in univariable analysis of clinical cases. This may suggest that clinic deprivation level may not be an accurate proxy for financial decisions of owners or that other factors than finances drive the decision to pursue surgery in haemangiosarcoma cases. It would be reasonable to hypothesise that the variables not found to be significant in the histopathological model compared to the clinical model - reproductive status, clinic IMD quintile and clinic land type – may also be linked to insurance status.

Breeds with previously identified predispositions for haemangiosarcoma that are further supported in the current study include the Golden Retriever, German Shepherd Dog and Boxer [17]. The current study additionally identified three breeds not previously reported at increased risk – Flat Coated Retriever, Hungarian Vizsla, and Beagle. These newly identified breeds at increased odds may be due to the very large sample size used in the current study, allowing higher powered statistical analysis for breeds sampled in smaller numbers or not at all in previous studies. Notably, none of the haemangiosarcoma diagnoses in Dogue de Bordeaux or Rottweiler dogs in the current study were supported by histopathological confirmation. This may reflect reduced surgical intervention in these large breeds, potentially due to the higher costs associated with their size. Alternatively, these findings may illustrate a self-fulfilling diagnostic bias, whereby dogs weighing over 37.5 kg – who were found to have the highest odds of any haemangiosarcoma diagnosis – were diagnosed based on clinical suspicion alone, with histopathological confirmation not pursued. Although there is some diagnostic uncertainty, the clinical haemangiosarcoma cases in Dogue de Bordeaux and Rottweiler dogs did present similarly to confirmed cases, with varied clinical signs reported, tumours located in multiple sites in the body and metastasis recorded in some. Therefore, despite these breeds lacking any histopathological cases, it is not unreasonable to report the increased breed odds based on only these clinical cases. The additional breeds identified at increased odds compared to a previous large-scale study [17] may reflect differences in sampling methods. The current study included breeds with as few as five cases if they were represented by at least 7,000 dogs in the overall population, whereas Robinson et al. required a minimum of 50 cases per breed. Variations may also stem from the infrequency of specific breeds in the population. While breed information in this study was derived from owner or veterinary reporting, prior research comparing such reports to genetic testing found agreement in 85.8% of dogs overall and in 98.7% of registered pedigree dogs [45], supporting the reliability of these data for epidemiological analyses. Identifying breeds at increased odds of haemangiosarcoma is valuable for both clinicians and dog owners, by supporting earlier clinical suspicion and more targeted diagnostic work-up, particularly in cases of visceral haemangiosarcoma where early signs may be vague, intermittent, and easily attributed to other conditions. This study highlights several breeds not previously reported in US-based studies, and documents possible geographical differences in level of risk among some traditionally associated breeds, such as the Golden Retriever [9, 17, 46]. These findings may inform future investigations into the genetic and environmental factors underlying geographic variations in haemangiosarcoma risk.

Assessing breed risk through broader breed groups may reveal genetic associations with haemangiosarcoma. The current study identified GG1 breeds (German Shepherd dog, Portuguese Water Dog, Doberman Pinscher) as having a higher likelihood of both a clinical and histopathological haemangiosarcoma diagnosis, aligning with a previous UK study of splenic haemangiosarcoma where GG1 breeds had the highest odds [7]. However, the prominence of German Shepherd Dogs within GG1 may skew the results in the current study, suggesting that GG1's increased odds might be unduly influenced by this breed's dominance and assuming all GG1 breeds are at increased odds of haemangiosarcoma may be an ecological fallacy. The Kennel Club pastoral breed group was similarly found to be at increased odds for both clinical and histopathological haemangiosarcoma diagnosis but again, this group contains the German Shepherd Dog, and the level of odds increase could have been influenced. The current study also found dogs belonging to the Kennel Club working breed group and ancestral mountain group at increased odds of clinical haemangiosarcoma diagnosis. Understanding possible genetic predispositions to haemangiosarcoma is valuable academically, as it can guide genetic research into the pathogenesis of the disease which is still poorly understood [26, 47, 48]. It may also identify high-risk groups which may benefit from changes to breeding practices such as the use of outcrossing, in order to increase genetic variation, and potentially reduce frequency of haemangiosarcoma in future populations. Clinically, identifying genetic risk factors can aid in diagnosing crossbreed dogs by categorising parentage and assessing the suspected risk level.

The odds of clinical and histopathological haemangiosarcoma diagnosis increased with bodyweight in the current study. This finding aligns with previous research showing a weak positive relationship between bodyweight and the odds of splenic haemangiosarcoma [21]. The observed risk pattern likely reflects the predominance of larger breeds at higher risk, as most high-risk breeds in this study are classified as large by the UK Kennel Club, except for Beagle (small) and Lurcher (unrecognised) [33]. This pattern could aid veterinarians in assessing haemangiosarcoma risk in crossbreeds of unknown parentage, where bodyweight may serve as a proxy in the absence of known breed information.

Neutered females and neutered males were at a slightly increased odds of clinical haemangiosarcoma diagnosis compared to entire females. These results are consistent with findings from an Italian study of visceral haemangiosarcoma, though the effect was smaller here [16]. Unlike the Italian study, the current study did not find entire males at increased odds of clinical haemangiosarcoma, and reproductive status was not found to be a significant risk factor for histopathological haemangiosarcoma. The exact cause of these differences - whether related to sex, neuter status, or a combination of both - is unclear.

The odds of clinical haemangiosarcoma diagnosis increased with age from 5 to 13 years but declined slightly in dogs older than 13 years. This non-linear trend aligns with previous findings in cutaneous and cardiac haemangiosarcoma [9, 10]. The apparent odds reduction for dogs over 13 years may be due to owners not recognising or prioritising symptoms in elderly pets, possibly attributing them to old age and delaying veterinary visits [49]. This could lead to underdiagnosis, particularly if haemangiosarcoma causes death before being diagnosed. If elderly dogs are at reduced odds, the reasons are unclear and warrant further investigation. Veterinarians should play a role in helping owners to recognise concerning clinical signs in senior dogs to prevent potential suffering from undiagnosed but life-threatening conditions like haemangiosarcoma.

In the current study, the odds of clinical haemangiosarcoma diagnosis increased as clinic deprivation levels decreased, a trend partially consistent with findings from a study on socioeconomic factors and canine multicentric lymphoma [50]. That study suggested that owners in less deprived areas were more likely to pursue a definitive diagnosis. In contrast, the current study showed 14.65% of histopathological cases attended clinics in the most deprived quintile of the UK compared with 12.31% of all clinical cases. It could be that clinic deprivation level is associated with the proportion of owners insuring their pets, whereby the clinics in more deprived areas encourage insurance cover for those owners with less disposable income. Since insured dogs were more likely to receive a definitive diagnosis in the lymphoma study, further research is needed to explore the relationship between insurance status, deprivation levels, and haemangiosarcoma diagnosis.

Dogs from clinics in mixed urban/rural areas had lower odds of clinical haemangiosarcoma diagnosis compared to those from urban clinics. This finding is novel, as previous research on land type and haemangiosarcoma has been inconclusive. For instance, an Italian study using land type and residence within Rome's city ring-road as proxies for pollution exposure found no association with visceral haemangiosarcoma [16]. Similarly, clinic land type was not associated with histopathological haemangiosarcoma diagnosis in the current study. Social differences between urban and rural living have been reported, with rural dogs potentially receiving less preventative care or fewer veterinary visits [51–53]. Future research could further investigate land type by examining specific pollution levels and the frequency of veterinary care.

This study had some limitations; data were not collected primarily for research purposes. The assumption that haemangiosarcoma was not present if it was not recorded in the clinical notes or included only as a differential diagnosis may have led to underestimation of haemangiosarcoma. Approximately 35% of incident clinical cases showed evidence of histological confirmation of haemangiosarcoma, with the remaining 65% of cases diagnosed clinically by a veterinarian. It is possible that some haemangiosarcoma cases that were not histologically confirmed may have been misclassified as false-positive diagnosis, leading to overestimation of cases. Any such misclassification could have been further biased from confirmation bias by veterinarians based on previously found risk factors for haemangiosarcoma [10, 11, 15–17, 20, 25, 54–56]. However, due to financial and other considerations, the reality of primary care veterinary practice is that many diagnoses are based on clinical criteria alone and therefore the current study reflects this primary care setting. The risk factor analysis of histopathologically confirmed haemangiosarcoma cases is likely to be underpowered given the smaller sample size and is at risk of biases such as insurance cover. Additionally, in both risk factor analyses, some of the less common Breeds may have been underpowered as sample size estimates were calculated based on data available for German Shepherd Dogs. Restriction of the risk factor analysis to dogs five years and older made the current findings particularly relevant to a mature population but the risk factors identified here may be less generalisable to dogs under five years of age.

In conclusion, this study estimates the annual incidence risk of canine clinical haemangiosarcoma diagnoses in primary care practice at 0.036%. The Dogue de Bordeaux, Flat Coated Retriever, and German Shepherd Dog had the highest odds of clinical diagnosis among ten individual breeds with increased odds. Increasing adult bodyweight and senior age were strongly associated with clinical and histopathological haemangiosarcoma diagnoses. Reproductive status, clinic deprivation levels and clinic land type appear to be minor risk factors for clinical diagnoses only. However, some care should be taken when interpreting findings based on clinical diagnoses given two thirds of these cases were not confirmed with histopathology. These findings can help guide veterinarians in primary care practice by providing valuable insights into the risks of haemangiosarcoma.

Appendix 1

Table 3 Descriptive and univariable logistic regression results for risk factors evaluated for histopathological diagnosis of haemangiosarcoma in dogs at least five years old under primary veterinary care during 2019 in the VetCompass Programme in the United Kingdom. Clinic ID was included as a random effect to account for clustering at clinic level

Variable	Category	Case no. (%) n = 273	Non-case no. (%) n = 1,064,187	Odds ratio	95% Confidence Interval	Category *P*-value	Variable *P*-value
Reproductive status	Female entire	30 (10.99)	178,648 (16.79)	Ref			0.074
	Female neutered	100 (36.63)	334,562 (31.44)	1.73	1.24-2.40	0.001	
	Male entire	57 (20.88)	217,511 (20.44)	1.57	1.11-2.23	0.012	
	Male neutered	85 (31.14)	328,513 (30.87)	1.46	1.05-2.03	0.024	
	Unassigned	1 (0.37)	4,953 (0.47)	1.39	0.67-2.86	0.377	
Breed purity	Crossbred	77 (28.21)	298,552 (28.05)	Ref			
	Purebred	196 (71.79)	762,447 (71.65)	1.02	0.80-1.31	0.876	
Breed	Crossbreed	68 (24.91)	260,049 (24.44)	Ref			< 0.001
	Beagle	10 (3.66)	8,863 (0.83)	4.72	2.64-8.45	< 0.001	
	Bichon Frise	4 (1.47)	15,378 (1.45)	1.19	0.53-2.68	0.675	
	Border Collie	10 (3.66)	33,857 (3.18)	1.30	0.65-2.61	0.451	
	Border Terrier	1 (0.37)	15,919 (1.50)	0.31	0.11-0.88	0.029	
	Boxer	10 (3.66)	9,611 (0.90)	4.60	2.48-8.55	< 0.001	
	Cockapoo	1 (0.37)	12,583 (1.18)	0.34	0.11-1.08	0.067	
	English Cocker Spaniel	9 (3.30)	45,253 (4.25)	0.82	0.44-1.55	0.548	
	English Springer Spaniel	4 (1.47)	30,461 (2.86)	0.59	0.27-1.28	0.180	
	Flat Coated Retriever	7 (2.56)	1,370 (0.13)	21.6	10.9-42.7	< 0.001	
	German Shepherd Dog	28 (10.26)	19,980 (1.88)	6.01	4.00-9.03	< 0.001	
	Golden Retriever	8 (2.93)	13,536 (1.27)	2.43	1.27-4.65	0.007	
	Greyhound	1 (0.37)	8,477 (0.80)	0.56	0.12-2.66	0.466	
	Hungarian Vizsla	5 (1.83)	2,474 (0.23)	8.53	4.07-17.9	< 0.001	
	Jack Russell Terrier	8 (2.93)	69,049 (6.49)	0.50	0.27-0.93	0.028	
	Labradoodle	3 (1.10)	9,184 (0.86)	1.27	0.55-2.98	0.576	
	Labrador Retriever	35 (12.82)	83,520 (7.85)	1.76	1.21-2.56	0.003	
	Lurcher	5 (1.83)	8,499 (0.80)	2.49	1.09-5.72	0.031	
	Miniature Schnauzer	6 (2.20)	10,232 (0.96)	2.55	1.20-5.41	0.014	
	Staffordshire Bull Terrier	8 (2.93)	57,700 (5.42)	0.60	0.31-1.18	0.139	
	West Highland White Terrier	4 (1.47)	26,716 (2.51)	0.66	0.31-1.42	0.288	
	Yorkshire Terrier	2 (0.73)	31,961 (3.00)	0.29	0.06-1.32	0.108	
	Purebreed other	36 (13.19)	289,515 (27.21)	0.51	0.35-0.75	< 0.001	
Kennel Club breed group	Gundog	73 (26.74)	192,318 (18.07)	Ref			< 0.001
	Terrier	27 (9.89)	191,718 (18.02)	0.37	0.24-0.56	< 0.001	
	Toy	7 (2.56)	126,936 (11.93)	0.14	0.07-0.26	< 0.001	
	Utility	14 (5.13)	97,280 (9.14)	0.37	0.22-0.61	< 0.001	
	Pastoral	43 (15.75)	63,455 (5.96)	1.79	1.27-2.53	< 0.001	
	Hound	17 (6.23)	41,186 (3.87)	1.02	0.64-1.62	0.947	
	Working	13 (4.76)	34,647 (3.26)	0.95	0.54-1.67	0.862	
	Unassigned	79 (28.94)	316,647 (29.75)	0.63	0.47-0.85	0.002	
Genotype breed group	GG4 (Retrievers and mountain breeds)	52 (19.05)	106,647 (10.02)	Ref			< 0.001
	GG3 (Terriers and brachycephalic dogs)	34 (12.45)	215,526 (20.25)	0.33	0.23-0.49	< 0.001	
	GG2 (Spaniels, Poodles, Dachshunds, Beagles)	29 (10.62)	122,945 (11.55)	0.49	0.32-0.74	< 0.001	
	GG5 (Sighthounds and Collies)	15 (5.49)	54,302 (5.10)	0.59	0.36-0.96	0.033	
	GG1 (German Shepherds, Portuguese Water Dogs, Doberman Pinschers)	28 (10.26)	24,801 (2.33)	2.40	1.60-3.61	< 0.001	
	Unassigned	115 (42.28)	539,966 (50.74)	0.44	0.33-0.59	< 0.001	

Table 3 (continued)

Variable	Category	Case no. (%) n = 273	Non-case no. (%) n = 1,064,187	Odds ratio	95% Confidence Interval	Category *P*-value	Variable *P*-value
Ancestral breed group	Mastiff-Terrier	84 (30.77)	314,101 (29.52)	Ref			0.759
	Modern	59 (21.61)	239,231 (22.48)	0.91	0.68-1.23	0.556	
	Herding-Sighthound	15 (5.49)	52,396 (4.92)	1.09	0.69-1.71	0.722	
	Ancient	1 (0.37)	15,006 (1.41)	0.26	0.12-0.55	< 0.001	
	Mountain	2 (0.73)	7,272 (0.68)	1.03	0.51-2.08	0.931	
	Unassigned	112 (41.03)	436,181 (40.99)	0.95	0.73-1.23	0.674	
Adult bodyweight (kg) median (range)		27.1 (5.0–54.2)	14.4 (1.4–106.0)	< 0.001			
Adult bodyweight (kg)	< 7.5	8 (2.93)	155,174 (14.58)	0.33	0.17-0.65	0.001	< 0.001
	7.5 < 15	47 (17.22)	298,271 (28.03)	Ref			
	15 < 22.5	47 (17.22)	157,975 (14.84)	1.90	1.33-2.71	< 0.001	
	22.5 < 30	42 (15.38)	132,851 (12.48)	1.99	1.36-2.91	< 0.001	
	30 < 37.5	59 (21.61)	93,392 (8.78)	4.01	2.86-5.64	< 0.001	
	≥ 37.5	40 (14.65)	48,092 (4.52)	5.35	3.70-7.75	< 0.001	
	Unassigned	30 (10.99)	178,432 (16.77)	0.93	0.60-1.43	0.726	
Age (years) median (range)		10.0 (5.0–16.6)	8.7 (5.0–24.5)	< 0.001			
Age (years)	5 < 7	17 (6.23)	308,821 (29.02)	0.21	0.12-0.36	< 0.001	< 0.001
	7 < 9	70 (25.64)	267,559 (25.14)	Ref			
	9 < 11	103 (37.73)	213,947 (20.10)	1.89	1.41-2.54	< 0.001	
	11 < 13	58 (21.25)	155,099 (14.57)	1.52	1.08-2.13	0.016	
	13 < 15	23 (8.42)	84,873 (7.98)	1.10	0.70-1.74	0.668	
	≥ 15	2 (0.73)	33,888 (3.18)	0.24	0.10-0.58	0.002	
Practice group	Group 1	106 (38.83)	336,121 (31.58)	Ref			0.002
	Group 2	67 (24.54)	211,019 (19.83)	0.89	0.60-1.30	0.540	
	Group 3	60 (21.98)	294,136 (27.64)	0.20	0.13-0.31	< 0.001	
	Group 4	35 (12.82)	203,388 (19.11)	0.18	0.11-0.31	< 0.001	
	Group 5	5 (1.83)	19,523 (1.83)	0.30	0.08-1.17	0.083	
Clinic land type	Urban	86 (31.50)	355,644 (33.42)	Ref			0.485
	Mixed urban/rural	147 (53.85)	581,490 (54.64)	0.90	0.58-1.41	0.647	
	Rural	39 (14.29)	121,380 (11.41)	2.31	1.23-4.35	0.009	
	Unassigned	1 (0.37)	5,673 (0.53)	NA	NA	NA	
Clinic IMD quintile	1 (most deprived)	40 (14.65)	203,559 (19.13)	Ref			0.367
	2	66 (24.18)	233,664 (21.96)	1.66	0.86-3.17	0.129	
	3	56 (20.51)	217,458 (20.43)	1.69	0.86-3.33	0.126	
	4	52 (19.05)	211,987 (19.92)	1.60	0.81-3.18	0.175	
	5 (least deprived)	58 (21.25)	191,846 (18.03)	2.16	1.11-4.23	0.024	
	Unassigned	1 (0.37)	5,673 (0.53)	NA	NA	NA	

Appendix 2

Table 4 Descriptive and univariable logistic regression results for risk factors evaluated for a histopathological diagnosis in dogs with a clinical haemangiosarcoma diagnosis at least five years old under primary veterinary care during 2019 in the VetCompass Programme in the United Kingdom. Clinic ID was included as a random effect to account for clustering at clinic level

Variable	Category	Histopathological case no. (%) n = 273	Non-histopathological case no. (%) n = 515	Odds ratio	95% Confidence Interval	Category *P*-value	Variable *P*-value
Reproductive status	Female entire	30 (10.99)	61 (11.84)	Ref			0.287
	Female neutered	100 (36.63)	169 (32.82)	1.18	0.68-2.06	0.561	
	Male entire	57 (20.88)	87 (16.89)	1.33	0.72-2.44	0.363	
	Male neutered	85 (31.14)	195 (37.86)	0.82	0.47-1.44	0.494	
	Unassigned	1 (0.37)	3 (0.58)	0.65	0.05-7.92	0.732	
Breed purity	Crossbred	77 (28.21)	132 (25.63)	Ref			0.443
	Purebred	196 (71.79)	380 (73.79)	0.86	0.61-1.23	0.411	
	Unassigned	0 (0.00)	3 (0.58)	NA	NA	0.999	
Breed	Crossbreed	68 (24.91)	110 (21.36)	Ref			0.033
	Beagle	10 (3.66)	4 (0.78)	5.03	1.30-19.50	0.020	
	Bichon Frise	4 (1.47)	9 (1.75)	0.51	0.14-1.94	0.327	
	Border Collie	10 (3.66)	16 (3.11)	1.03	0.40-2.68	0.951	
	Border Terrier	1 (0.37)	2 (0.39)	0.84	0.06-11.60	0.896	
	Boxer	10 (3.66)	14 (2.72)	1.08	0.41-2.88	0.874	
	Cockapoo	1 (0.37)	2 (0.39)	0.82	0.05-12.70	0.889	
	English Cocker Spaniel	9 (3.30)	24 (4.66)	0.55	0.22-1.38	0.205	
	English Springer Spaniel	4 (1.47)	17 (3.30)	0.37	0.11-1.28	0.116	
	Flat Coated Retriever	7 (2.56)	1 (0.19)	15.10	1.57-145.00	0.019	
	German Shepherd Dog	28 (10.26)	56 (10.87)	0.79	0.43-1.46	0.445	
	Golden Retriever	8 (2.93)	15 (2.91)	0.80	0.29-2.21	0.663	
	Greyhound	1 (0.37)	1 (0.19)	1.39	0.06-30.80	0.834	
	Hungarian Vizsla	5 (1.83)	6 (1.17)	1.35	0.45-4.07	0.676	
	Jack Russell Terrier	8 (2.93)	10 (1.94)	1.35	0.45-4.07	0.592	
	Labradoodle	3 (1.10)	7 (1.36)	0.67	0.14-3.13	0.613	
	Labrador Retriever	35 (12.82)	61 (11.84)	0.98	0.55-1.75	0.945	
	Lurcher	5 (1.83)	9 (1.75)	0.84	0.24-3.02	0.794	
	Miniature Schnauzer	6 (2.20)	6 (1.17)	1.76	0.46-6.64	0.407	
	Staffordshire Bull Terrier	8 (2.93)	35 (6.80)	0.32	0.13-0.79	0.013	
	West Highland White Terrier	4 (1.47)	9 (1.75)	0.66	0.17-2.56	0.545	
	Yorkshire Terrier	2 (0.73)	1 (0.19)	4.13	0.27-63.60	0.309	
	Purebreed other	36 (13.19)	90 (17.48)	0.54	0.32-0.94	0.029	
Kennel Club breed group	Gundog	73 (26.74)	130 (25.24)	Ref			0.276
	Terrier	27 (9.89)	64 (12.43)	0.70	0.39-1.26	0.235	
	Toy	7 (2.56)	19 (3.69)	0.54	0.20-1.46	0.228	
	Utility	14 (5.13)	24 (4.66)	1.00	0.45-2.22	0.993	
	Pastoral	43 (15.75)	78 (15.15)	0.96	0.57-1.62	0.887	
	Hound	17 (6.23)	16 (3.11)	1.90	0.83-4.36	0.128	
	Working	13 (4.76)	41 (7.96)	0.52	0.25-1.10	0.087	
	Unassigned	79 (28.94)	143 (27.77)	0.99	0.64-1.54	0.971	
Genotype breed group	GG4 (Retrievers and mountain breeds)	52 (19.05)	89 (17.28)	Ref			0.941
	GG3 (Terriers and brachycephalic dogs)	34 (12.45)	74 (14.37)	0.72	0.40-1.29	0.268	
	GG2 (Spaniels, Poodles, Dachshunds, Beagles)	29 (10.62)	57 (11.07)	0.84	0.45-1.57	0.589	
	GG5 (Sighthounds and Collies)	15 (5.49)	25 (4.85)	1.00	0.44-2.24	0.992	

Table 4 (continued)

Variable	Category	Histopathological case no. (%) n = 273	Non-histopathological case no. (%) n = 515	Odds ratio	95% Confidence Interval	Category *P*-value	Variable *P*-value
	GG1 (German Shepherds, Portuguese Water Dogs, Doberman Pinschers)	28 (10.26)	59 (11.46)	0.76	0.41-1.43	0.396	
	Unassigned	115 (42.28)	211 (40.97)	0.88	0.56-1.39	0.595	
Ancestral breed group	Mastiff-Terrier	84 (30.77)	151 (29.32)	Ref			0.545
	Modern	59 (21.61)	123 (23.88)	0.85	0.54-1.33	0.478	
	Herding-Sighthound	15 (5.49)	24 (4.66)	1.14	0.53-2.47	0.739	
	Ancient	1 (0.37)	6 (1.17)	0.31	0.03-2.84	0.296	
	Mountain	2 (0.73)	11 (2.14)	0.31	0.06-1.57	0.157	
	Unassigned	112 (41.03)	200 (38.83)	0.99	0.68-1.46	0.972	
Adult bodyweight (kg)	< 7.5	8 (2.93)	12 (2.33)	1.17	0.40-3.38	0.773	< 0.001
	7.5 < 15	47 (17.22)	77 (14.95)	Ref			
	15 < 22.5	47 (17.22)	65 (12.62)	1.22	0.69-2.17	0.499	
	22.5 < 30	42 (15.38)	97 (18.83)	0.71	0.41-1.25	0.239	
	30 < 37.5	59 (21.61)	105 (20.39)	0.97	0.57-1.65	0.899	
	≥ 37.5	40 (14.65)	44 (8.54)	1.62	0.87-3.03	0.130	
	Unassigned	30 (10.99)	115 (22.33)	0.41	0.23-0.75	0.003	
Age (years)	5 < 7	17 (6.23)	22 (4.27)	0.94	0.93-0.94	< 0.001	< 0.001
	7 < 9	70 (25.64)	88 (17.09)	Ref			
	9 < 11	103 (37.73)	156 (30.29)	0.79	0.79-0.79	< 0.001	
	11 < 13	58 (21.25)	177 (34.37)	0.37	0.37-0.37	< 0.001	
	13 < 15	23 (8.42)	63 (12.23)	0.41	0.41-0.41	< 0.001	
	≥ 15	2 (0.73)	9 (1.75)	0.24	0.23-0.24	< 0.001	
Practice group	Group 1	106 (38.83)	182 (35.34)	Ref			0.601
	Group 2	67 (24.54)	154 (29.90)	0.73	0.47-1.13	0.161	
	Group 3	60 (21.98)	104 (20.19)	0.97	0.61-1.54	0.895	
	Group 4	35 (12.82)	65 (12.62)	0.94	0.54-1.63	0.827	
	Group 5	5 (1.83)	10 (1.94)	0.84	0.25-2.88	0.785	
Clinic land type	Urban	86 (31.50)	183 (35.53)	Ref			0.646
	Mixed urban/rural	147 (53.85)	254 (49.32)	1.25	0.86-1.83	0.241	
	Rural	39 (14.29)	76 (14.76)	1.13	0.66-1.95	0.649	
	Unassigned	1 (0.37)	2 (0.39)	1.09	0.06-19.00	0.953	
Clinic IMD quintile	1 (most deprived)	40 (14.65)	57 (11.07)	Ref			0.311
	2	66 (24.18)	103 (20.00)	0.89	0.49-1.60	0.687	
	3	56 (20.51)	106 (20.58)	0.69	0.38-1.27	0.234	
	4	52 (19.05)	120 (23.30)	0.60	0.33-1.10	0.096	
	5 (least deprived)	58 (21.25)	127 (24.66)	0.64	0.36-1.16	0.142	
	Unassigned	1 (0.37)	2 (0.39)	0.70	0.04-12.30	0.806	

Appendix 3

Table 5 Comparison of odds ratios produced for variables a) breed, b) age category (years), c) practice group, d) Kennel Club breed group, e) genotype breed group, f) ancestral breed group and g) adult bodyweight (kg) between clinical and histopathological haemangiosarcoma diagnosis in multivariable logistic regression modelling in dogs at least five years old under primary veterinary care during 2019 in the VetCompass Programme in the United Kingdom. Clinic ID was included as a random effect to account for clustering at clinic level. The black lines represent 95% confidence intervals

Variable	Category	Histopathological case no. (%) n = 273	Non-histopathological case no. (%) n = 515	Odds ratio	95% Confidence Interval	Category *P*-value	Variable *P*-value
Reproductive status	Female entire	30 (10.99)	61 (11.84)	Ref			0.287
	Female neutered	100 (36.63)	169 (32.82)	1.18	0.68-2.06	0.561	
	Male entire	57 (20.88)	87 (16.89)	1.33	0.72-2.44	0.363	
	Male neutered	85 (31.14)	195 (37.86)	0.82	0.47-1.44	0.494	
	Unassigned	1 (0.37)	3 (0.58)	0.65	0.05-7.92	0.732	
Breed purity	Crossbred	77 (28.21)	132 (25.63)	Ref			0.443
	Purebred	196 (71.79)	380 (73.79)	0.86	0.61-1.23	0.411	
	Unassigned	0 (0.00)	3 (0.58)	NA	NA	0.999	
Breed	Crossbreed	68 (24.91)	110 (21.36)	Ref			0.033
	Beagle	10 (3.66)	4 (0.78)	5.03	1.30-19.50	0.020	
	Bichon Frise	4 (1.47)	9 (1.75)	0.51	0.14-1.94	0.327	
	Border Collie	10 (3.66)	16 (3.11)	1.03	0.40-2.68	0.951	
	Border Terrier	1 (0.37)	2 (0.39)	0.84	0.06-11.60	0.896	
	Boxer	10 (3.66)	14 (2.72)	1.08	0.41-2.88	0.874	
	Cockapoo	1 (0.37)	2 (0.39)	0.82	0.05-12.70	0.889	
	English Cocker Spaniel	9 (3.30)	24 (4.66)	0.55	0.22-1.38	0.205	
	English Springer Spaniel	4 (1.47)	17 (3.30)	0.37	0.11-1.28	0.116	
	Flat Coated Retriever	7 (2.56)	1 (0.19)	15.10	1.57-145.00	0.019	
	German Shepherd Dog	28 (10.26)	56 (10.87)	0.79	0.43-1.46	0.445	
	Golden Retriever	8 (2.93)	15 (2.91)	0.80	0.29-2.21	0.663	
	Greyhound	1 (0.37)	1 (0.19)	1.39	0.06-30.80	0.834	
	Hungarian Vizsla	5 (1.83)	6 (1.17)	1.35	0.45-4.07	0.676	
	Jack Russell Terrier	8 (2.93)	10 (1.94)	1.35	0.45-4.07	0.592	
	Labradoodle	3 (1.10)	7 (1.36)	0.67	0.14-3.13	0.613	
	Labrador Retriever	35 (12.82)	61 (11.84)	0.98	0.55-1.75	0.945	
	Lurcher	5 (1.83)	9 (1.75)	0.84	0.24-3.02	0.794	
	Miniature Schnauzer	6 (2.20)	6 (1.17)	1.76	0.46-6.64	0.407	
	Staffordshire Bull Terrier	8 (2.93)	35 (6.80)	0.32	0.13-0.79	0.013	
	West Highland White Terrier	4 (1.47)	9 (1.75)	0.66	0.17-2.56	0.545	
	Yorkshire Terrier	2 (0.73)	1 (0.19)	4.13	0.27-63.60	0.309	
	Purebreed other	36 (13.19)	90 (17.48)	0.54	0.32-0.94	0.029	
Kennel Club breed group	Gundog	73 (26.74)	130 (25.24)	Ref			0.276
	Terrier	27 (9.89)	64 (12.43)	0.70	0.39-1.26	0.235	
	Toy	7 (2.56)	19 (3.69)	0.54	0.20-1.46	0.228	
	Utility	14 (5.13)	24 (4.66)	1.00	0.45-2.22	0.993	
	Pastoral	43 (15.75)	78 (15.15)	0.96	0.57-1.62	0.887	
	Hound	17 (6.23)	16 (3.11)	1.90	0.83-4.36	0.128	
	Working	13 (4.76)	41 (7.96)	0.52	0.25-1.10	0.087	
	Unassigned	79 (28.94)	143 (27.77)	0.99	0.64-1.54	0.971	

Table 5 (continued)

Variable	Category	Histopathological case no. (%) n = 273	Non-histopathological case no. (%) n = 515	Odds ratio	95% Confidence Interval	Category *P*-value	Variable *P*-value
Genotype breed group	GG4 (Retrievers and mountain breeds)	52 (19.05)	89 (17.28)	Ref			0.941
	GG3 (Terriers and brachycephalic dogs)	34 (12.45)	74 (14.37)	0.72	0.40-1.29	0.268	
	GG2 (Spaniels, Poodles, Dachshunds, Beagles)	29 (10.62)	57 (11.07)	0.84	0.45-1.57	0.589	
	GG5 (Sighthounds and Collies)	15 (5.49)	25 (4.85)	1.00	0.44-2.24	0.992	
	GG1 (German Shepherds, Portuguese Water Dogs, Doberman Pinschers)	28 (10.26)	59 (11.46)	0.76	0.41-1.43	0.396	
	Unassigned	115 (42.28)	211 (40.97)	0.88	0.56-1.39	0.595	
Ancestral breed group	Mastiff-Terrier	84 (30.77)	151 (29.32)	Ref			0.545
	Modern	59 (21.61)	123 (23.88)	0.85	0.54-1.33	0.478	
	Herding-Sighthound	15 (5.49)	24 (4.66)	1.14	0.53-2.47	0.739	
	Ancient	1 (0.37)	6 (1.17)	0.31	0.03-2.84	0.296	
	Mountain	2 (0.73)	11 (2.14)	0.31	0.06-1.57	0.157	
	Unassigned	112 (41.03)	200 (38.83)	0.99	0.68-1.46	0.972	
Adult bodyweight (kg)	< 7.5	8 (2.93)	12 (2.33)	1.17	0.40-3.38	0.773	< 0.001
	7.5 < 15	47 (17.22)	77 (14.95)	Ref			
	15 < 22.5	47 (17.22)	65 (12.62)	1.22	0.69-2.17	0.499	
	22.5 < 30	42 (15.38)	97 (18.83)	0.71	0.41-1.25	0.239	
	30 < 37.5	59 (21.61)	105 (20.39)	0.97	0.57-1.65	0.899	
	≥ 37.5	40 (14.65)	44 (8.54)	1.62	0.87-3.03	0.130	
	Unassigned	30 (10.99)	115 (22.33)	0.41	0.23-0.75	0.003	
Age (years)	5 < 7	17 (6.23)	22 (4.27)	0.94	0.93-0.94	< 0.001	< 0.001
	7 < 9	70 (25.64)	88 (17.09)	Ref			
	9 < 11	103 (37.73)	156 (30.29)	0.79	0.79-0.79	< 0.001	
	11 < 13	58 (21.25)	177 (34.37)	0.37	0.37-0.37	< 0.001	
	13 < 15	23 (8.42)	63 (12.23)	0.41	0.41-0.41	< 0.001	
	≥ 15	2 (0.73)	9 (1.75)	0.24	0.23-0.24	< 0.001	
Practice group	Group 1	106 (38.83)	182 (35.34)	Ref			0.601
	Group 2	67 (24.54)	154 (29.90)	0.73	0.47-1.13	0.161	
	Group 3	60 (21.98)	104 (20.19)	0.97	0.61-1.54	0.895	
	Group 4	35 (12.82)	65 (12.62)	0.94	0.54-1.63	0.827	
	Group 5	5 (1.83)	10 (1.94)	0.84	0.25-2.88	0.785	
Clinic land type	Urban	86 (31.50)	183 (35.53)	Ref			0.646
	Mixed urban/rural	147 (53.85)	254 (49.32)	1.25	0.86-1.83	0.241	
	Rural	39 (14.29)	76 (14.76)	1.13	0.66-1.95	0.649	
	Unassigned	1 (0.37)	2 (0.39)	1.09	0.06-19.00	0.953	
Clinic IMD quintile	1 (most deprived)	40 (14.65)	57 (11.07)	Ref			0.311
	2	66 (24.18)	103 (20.00)	0.89	0.49-1.60	0.687	
	3	56 (20.51)	106 (20.58)	0.69	0.38-1.27	0.234	
	4	52 (19.05)	120 (23.30)	0.60	0.33-1.10	0.096	
	5 (least deprived)	58 (21.25)	127 (24.66)	0.64	0.36-1.16	0.142	
	Unassigned	1 (0.37)	2 (0.39)	0.70	0.04-12.30	0.806	

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Authors' contributions
DON and DCB were responsible for the acquisition of the clinical data used in the study. GJB, DON, AG, CT and DCB were responsible for the conception and design. GJB, PPP and DON were responsible for the extraction and collation of data. GJB carried out the analysis. GJB drafted the manuscript. GJB, DON, AG, CT, JL and DCB were involved in interpreting the results, revising the manuscript and gave final approval of the version to be published. DCB and DON were responsible for acquiring funding.

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Data availability
The data supporting the conclusions of this article is available at https://doi.org/10.6084/m9.figshare.29349467.

Declarations

Ethics approval and consent to participate
Ethical approval for using VetCompass data was granted by the Social Science Research Ethical Review Board at the Royal Veterinary College (SR2018-1652).

Consent for publication
All authors have approved the manuscript for submission and we can confirm the manuscript has not been published or submitted elsewhere.

Competing interests
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