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# Frequency, breed predisposition and demographic risk factors for overweight status in dogs in the UK

C. Pegram[1,*], E. Raffan[†], E. White*, A. H. Ashworth*, D. C. Brodbelt*, D. B. Church[‡] and D. G. O'Neill *

*Pathobiology and Population Sciences, The Royal Veterinary College, Hawkshead Lane, North Mymms, Hatfield, Herts AL9 7TA, UK
[†]University of Cambridge Metabolic Research Laboratories, Wellcome Trust - MRC Institute of Metabolic Science, University of Cambridge, Cambridge CB2 0QQ, UK
[‡]Clinical Sciences and Services, The Royal Veterinary College, Hawkshead Lane, North Mymms, Hatfield, Herts AL9 7TA, UK

[1]Corresponding author email: cpegram@rvc.ac.uk

**Objectives:** **To evaluate the prevalence and risk factors for overweight status in dogs under primary veterinary care in the UK.**

**Materials and Methods:** **A retrospective study design was used to estimate the 1-year (2016) period prevalence of overweight status. The clinical records were randomly ordered and manually validated for dogs with overweight status during 2016. Univariable and multivariable logistic regression modelling were used to evaluate associations between risk factors (breed, brachycephalic status, adult bodyweight, bodyweight relative to breed-sex mean, age, sex-neuter and insurance) and overweight status.**

**Results:** **There were 1580 of 22,333 dogs identified as overweight during 2016. The estimated 1-year period prevalence for overweight status recorded in dogs under veterinary care was 7.1% (95% confidence interval 6.7–7.4). After accounting for confounding factors, eight breeds showed increased odds of overweight status compared with crossbred dogs. The breeds with the highest odds included the Pug (OR 3.12, 95% confidence interval 2.31 to 4.20), Beagle (OR 2.67, 1.75 to 4.08), Golden Retriever (OR 2.58, 1.79 to 3.74) and English Springer Spaniel (OR 1.98, 1.31 to 2.98). Being neutered, middle-aged and insured were additionally associated with overweight status.**

**Clinical Significance:** **Targeted overweight prevention strategies should be prioritised for predisposed breeds, such as Pugs and Beagles. The findings additionally raise questions about further preventative efforts following neutering. The prevalence estimate suggests veterinary professionals are underreporting overweight status and therefore could be missing key welfare opportunities.**

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## INTRODUCTION

Obesity has been reported as a modern day epidemic in companion animals (Kipperman & German 2018) and is the most common nutritional disorder seen in dogs, resulting from a chronic excess of energy intake in food relative to energy expenditure (Burkholder & Bauer 1998, Bland *et al.* 2009, Bland *et al.* 2010). Obesity in dogs carries some severe welfare consequences from associations with shortened life span (Kealy *et al.* 2002, Salt *et al.* 2019), reduced quality of life (German *et al.* 2012, Yam *et al.* 2016) and a higher incidence of important conditions including osteoarthritis, diabetes mellitus and certain types of neoplasia (German 2006, Lund *et al.* 2006, Raffan 2013a). There has been a recent call for the veterinary profession to formally recognise companion animal obesity as a disease, which has support from a number of veterinary health care professional organisations globally (Day 2017, Ward *et al.* 2018).

There is currently no universally-accepted definition of obesity in dogs, with the terms "overweight" and "obesity" often used interchangeably (Ward *et al.* 2018). A previous report classified dogs as overweight when their bodyweight was >15% above their "optimal," and obese when their bodyweight exceeded 30% of "optimal" (Burkholder & Toll 2000) and body condition scoring (BCS) schemes describe "overweight" and "obese" morphometric categories (Kipperman & German 2018). However, there is little evidence for the nature of an "optimal" bodyweight nor for the cut-off at which weight gain becomes problematic (German 2006).

In canine practice, objective identification of adiposity usually relies upon either documenting bodyweight change relative to previous measurements in the same individual after skeletal maturity, or, less objectively, from the use of BCS (Kipperman & German 2018). BCS involves using a series of visual and haptic cues to assign an individual to a BCS category. Confusingly, several BCS systems are in current use (Laflamme 1997, German *et al.* 2006, German & Morgan 2008), although the one-through-nine scale has been most robustly validated as an ordinal measure of adiposity and has recently been recommended as the preferred universal scoring system (Laflamme 1997, Mawby *et al.* 2004, Ward *et al.* 2018). Using this system, a BCS equal to or greater than 6/9 is over optimal (Laflamme 1997). However, despite BCS being recommended as routine during veterinary examination for ill health and preventative health care visits, reporting of BCS in veterinary clinical notes is uncommon (German & Morgan 2008, Rolph *et al.* 2014).

Prevalence estimates for overweight status in dogs overall have varied widely. Estimates from retrospective studies of dogs under primary veterinary care in the UK, in which the electronic patient records (EPRs) were retrospectively assessed, have ranged from 1.4% to 6.1% (O'Neill *et al.* 2014, Rolph *et al.* 2014, Summers *et al.* 2019). In contrast, cross-sectional studies from the UK have reported much higher results with 59% of dogs visiting veterinary practices in Glasgow being reported as overweight (Courcier *et al.* 2010) and 65% of dogs in a UK study in which owners of adult dogs were approached in a non-clinical setting were reported as overweight (German *et al.* 2018). This discordance between prevalence reported from EPR and other types of studies almost certainly reflects the underreporting of overweight status in veterinary clinical records (German & Morgan 2008, Rolph *et al.* 2014, Bomberg *et al.* 2017).

Many risk factors for the development of overweight status in dogs have been previously reported. Demographic risk factors reported include being middle aged, female and neutered (McGreevy *et al.* 2005, Lund *et al.* 2006). Diet type, feeding patterns and exercise are also important and may underlie the association with factors relating to owners such as owner obesity, low household income and aspects of the human-animal bond (Kienzle *et al.* 1998, Courcier *et al.* 2010, German 2016, Webb *et al.* 2020).

Certain breeds are more at risk of overweight status, suggesting an important contribution of genetics in the development of obesity in dogs (Raffan 2013b). Cocker Spaniels, Labrador Retrievers, Dalmatians, Dachshunds, Rottweilers, Golden Retrievers and Shetland Sheepdogs were identified as predisposed in a US-based study (Lund *et al.* 2006). There is little known about which genes are responsible for a predisposition to becoming overweight, although mutations affecting melanocortin signalling have been reported as predisposing affected dogs to obesity in Retriever breeds and Beagles (Zeng *et al.* 2014, Raffan *et al.* 2016). Certain brachycephalic dog breeds, such as the Pug and British Bulldog, have relatively high prevalence estimates of overweight status based on retrospective UK primary-care data of 13.2% and 8.7%, respectively (O'Neill *et al.* 2016, O'Neill *et al.* 2019b). Evaluating overweight status both at the individual brachycephalic breed level and in brachycephalic dogs collectively could help determine if this is more a breed-specific or brachycephalic-specific issue.

Using anonymised veterinary clinical data from the VetCompass™ Programme (VetCompass 2019), this study aimed to explore the occurrence of overweight status as recorded in clinical records relating to the general population of dogs under primary veterinary care in the UK during 2016. Specifically, the objectives were to estimate the 1-year period prevalence for overweight status in dogs, as recorded in primary-care clinical records, and to identify demographic risk factors associated with overweight status. The study placed a special emphasis on breed associations with overweight status. The study also aimed to specifically explore associations between relative bodyweight within breed and sex and an outcome of overweight status in order to identify whether bodyweight could be useful as a predictor of overweight status.

The application of "big data" using anonymized clinical records from primary-care veterinary practice is radically changing how epidemiological research on companion animals is conducted (O'Neill *et al.* 2019a). Demographic data, such as breed, sex and neuter status, is routinely collected in primary-care databases, and therefore large quantities of data can be collected and used to robustly address the demographic risk factors for disorders. However, retrospective primary-care data are less optimal for gathering information on more nuanced risk factors, such as dog behaviour and owner lifestyle, including diet, and these were therefore not addressed in this study. The health and welfare of companion animals may be more markedly improved by preventing the development of overweight status, rather than by treating it once it has developed (German 2010). Therefore, these results could assist veterinary professionals, owners, breeders and pet food manufacturers in identifying the dogs most at-risk, allowing for the development of targeted prevention strategies.

## METHODS

### Study design and power calculation

VetCompass collates de-identified EPR data from primary-care veterinary practices in the UK for epidemiological research (VetCompass 2019). The study population included all available dogs under primary veterinary care at clinics participating in the VetCompass Programme during 2016. Dogs under veterinary care were defined as those with either (1) at least one electronic patient record (EPR) (VeNom diagnosis term, free-text clinical note, treatment or bodyweight) recorded during 2016 or (2) at least one EPR recorded during both 2015 and 2017. Available data fields included a unique animal identifier along with species, breed, date of birth, sex, neuter status, insurance status and bodyweight, and also clinical information from free-form text clinical notes, summary diagnosis terms (The VeNom Coding Group, 2019) and treatment with relevant dates.

The study used a retrospective design. Based on a previous prevalence estimate of 5.7% for overweight status in dogs under primary veterinary care (Summers *et al*. 2019), sample size calculations in Epi info (CDC) estimated that a sample of 8185 dogs was needed to report a prevalence with a precision of 0.5% at a 95% confidence level, from a population of 905,544 dogs (Epi Info 7 CDC 2019). Ethics approval was obtained from the RVC Ethics and Welfare Committee (reference number SR2018-1652).

## Case finding and definition

The VetCompass database randomly orders patient records for assessment. Data extraction within the online database was carried out by nine researchers who were fourth year veterinary students under the direct supervision of one of the authors (DON). Each researcher aimed to extract data on a minimum of 2000 dogs to ensure an adequate sample size was achieved. All clinical records for the random subset of dogs were manually read to identify all dogs with evidence of overweight status during 2016, based on the case definition. In line with a previous publication based on primary care data, evidence for overweight status required information recorded within the EPR indicating that the dog was either obese or overweight at any point during 2016. This list is not exhaustive, but examples written in the EPRs include “overweight,” “BCS 7/9” and “discussed obesity management food” (Rolph *et al*. 2014). Since the terms “overweight” and “obesity” are often used interchangeably, any dog on the overweight/obesity spectrum was included.

## Data preparation

Data cleaning and preparation for analysis was completed by two of the authors working together (DON and CP). Breed information entered by the participating practices was cleaned and mapped to a VetCompass breed list derived and extended from the VeNom Coding breed list (The VeNom Coding Group, 2019). In order to maintain sufficient power for analysis, the breed variable included all specific breeds with at least 20 cases of overweight status or that was represented by over 500 dogs in the overall study. Remaining dogs were grouped as either “Purebred – Other” or “Crossbred.” Breed was additionally categorised as brachycephalic and non-brachycephalic (with crossbreeds excluded) (Table S1). Neuter status was defined by the final available EPR neuter value and was combined with sex to create four categories: female entire, female neutered, male entire and male neutered.

Adult bodyweight for each dog was defined as the mean of all bodyweight (kg) values recorded in 2016 after reaching 18 months old. Adult bodyweight (kg) was categorised: <10, 10 to <20, 20 to <30 and ≥30. The mean adult bodyweight was calculated for both sexes of each purebred breed with at least 100 dogs in the overall study population; this variable was called “breed-sex mean.” For each purebred dog in the current sample, adult bodyweight was categorised as “within ±15% of breed-sex mean,” “>15% above the breed-sex mean” and “<15% below the breed-sex mean”; this variable was called “bodyweight relative to breed-sex mean.” The absolute percentage difference from the breed-sex mean for each purebred dog was also calculated.

Age defined the age (years) at December 31, 2016 and was categorised: < 3.0, 3.0 to <6.0, 6.0 to <9.0, 9.0 to <12.0 and ≥12.0. Although categorisation of continuous variables can lead to some loss of information and power (Barrio *et al*. 2017), variables were categorised in line with previous reports in the subject area and those with a similar epidemiological approach (Colliard *et al*. 2006, O’Neill *et al*. 2017). Veterinary group attended was categorised as 1 to 5, based on 5 practice groups involved in the study. Insurance status was categorised as insured or not insured at the final EPR. Missing data were recorded as “Not recorded” and included as a separate category in the analysis if they accounted for >10% of the study variable, otherwise missing data were excluded. Following data checking for internal validity and cleaning in Excel (Microsoft Office Excel 2013, Microsoft Corp.), analyses were conducted using SPSS version 24.0 (IBM Corp).

## Statistical analysis

Continuous variables were assessed graphically for their distribution and summarised using median, interquartile range (IQR) and range. Chi-square test was used to compare categorical variables and the Students t-test or Mann–Whitney *U* test to compare continuous variables as appropriate (Kirkwood & Sterne 2003). The 1-year period prevalence with 95% confidence intervals (CI) described the probability of overweight status during 2016.

Binary logistic regression modelling was used to evaluate univariable associations between risk factors (breed, brachycephalic status, adult bodyweight, bodyweight relative to breed-sex mean, age, sex-neuter and insurance) and overweight status. Because breed was a factor of primary interest for the study, brachycephalic status (a variable highly collinear with breed) and adult bodyweight (a defining characteristic of individual breeds) were excluded from the initial breed multivariable modelling. Instead, each of these variables individually replaced the breed variable in the main final model in order to evaluate their effects after taking account of the other variables (O’Neill *et al*. 2018). Risk factors with liberal associations in univariable modelling ($P < 0.2$) were taken forward for multivariable evaluation. However, bodyweight relative to breed-sex mean was evaluated at the univariable stage only, in line with the study aim to specifically explore associations between relative bodyweight within breed and sex and an outcome of obesity (as this only included a subsample of breeds with at least 100 dogs in the dataset). Model development used manual backwards stepwise elimination. Vet group attended was evaluated as a fixed effect. The area under the ROC curve and the Hosmer-Lemeshow test were used to evaluate the quality of the model fit. Statistical significance was set at the 5% level. Figures were created in Excel (Microsoft Office Excel 2013, Microsoft Corp.), GraphPad Prism version 8.0 and R statistical software (R version 3.6.2) using the "forestplot" package (Gordon & Lumley 2019) as appropriate.

## RESULTS

### Overweight prevalence

The study included a random sample of 22,333 dogs from a population of 905,544 dogs under primary veterinary care during 2016 in the UK. Data completeness were: breed 99.6%, age 98.8%, sex-neuter status 99.7%, insurance status 100.0% and adult bodyweight 44.5%. There were 1580/22,333 dogs identified as overweight during 2016. The estimated one-year period prevalence for overweight status recorded in dogs under veterinary care was 7.1% (95% CI 6.7 to 7.4). The breeds with the highest overweight prevalence were Golden Retriever (16.2%, 95% CI 12.1 to 21.4), Pug (15.0%, 95% CI 11.9 to 18.8), Beagle (14.2%, 95% CI 10.0 to 19.8), English Springer Spaniel (12.8%, 95% CI 9.1 to 17.8), and Border Terrier (12.0%, 95% CI 8.6 to 16.6) (Fig 1).

### Descriptive analysis

Descriptive analysis included 1580 overweight cases and 20,753 non-cases (Table 1). The median age of overweight cases (6.0 years, IQR 3.7 to 8.7, range 0.2 to 17.1), was older than the median age of non-cases (4.3 years, IQR 2.8 to 8.0, range 0.1 to 20.5) ($P < 0.001$). The most common breeds amongst overweight cases were the Labrador Retriever (10.1% of overweight dogs; 160), Staffordshire Bull Terrier (5.4%; 86), Jack Russell Terrier (4.8%; 76), Cocker Spaniel (4.3%; 68) and Pug (3.9%; 62) in addition to 394 (25.0%) crossbreds. The most common breeds amongst non-cases were the Labrador Retriever (6.3%; 1302), Staffordshire Bull Terrier (5.9%; 1218), Jack Russell Terrier (5.3%; 1092), Shih-Tzu (3.7%; 765) and Cocker Spaniel (3.4%; 703) in addition to 5587 (27.0%) crossbreds. Breed information was missing for 85 dogs.

### Evaluation of relative bodyweight

To better understand whether true overweight status was being captured by interrogating the clinical notes, we compared the relative bodyweights of dogs in overweight and non-overweight groups to their breed-sex mean body weights (for purebred dogs only). Overweight dogs had higher bodyweight compared to breed-sex mean compared to dogs classified as not overweight, but there was a lot of overlap between groups (Fig 2). Specifically, overweight dogs weighed a median of 14.2% (IQR 0.6 to 31.6, range 55.6 to 120.3) higher than their respective breed-sex mean bodyweights while non-overweight purebred dogs weighed a median of –2.4% (IQR 15.3 to 12.1, range 79.4 to 118.9) lower than their respective breed-sex mean bodyweights (Fig 2). When evaluated in univariable logistic regression analysis, purebreds weighing >15% above the breed-sex mean bodyweight had 2.71 times the odds (95% CI 2.34 to 3.15, $P < 0.001$) of overweight status compared to dogs within ±15% of the breed-sex mean. Conversely, purebreds weighing >15% below the breed-sex mean bodyweight had 0.33 times the odds (95% CI 0.25 to 0.44, $P < 0.001$) of overweight status compared to dogs within ±15% of the breed-sex mean.

### Risk factor analysis

All tested variables were liberally ($P < 0.2$) associated with overweight status in univariable logistic regression modelling and were further evaluated in the main breed-based multivariable logistic

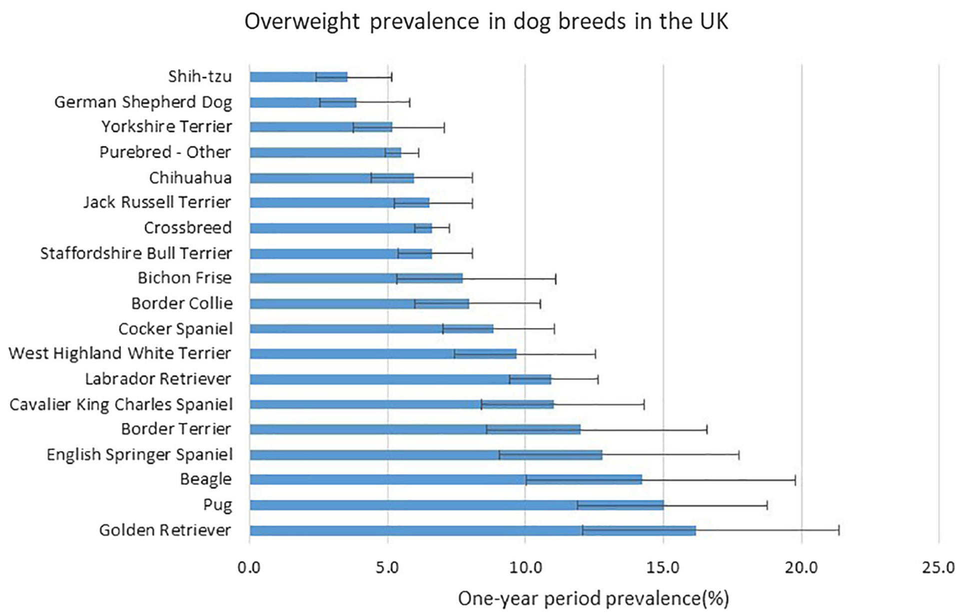


**FIG 1. One-year (2016) period prevalence of overweight status in commonly affected dog breeds attending primary-care veterinary practices in the VetCompass™ Programme in the UK (n=22,248). Error bars show the 95% confidence interval**

**Table 1. Overweight count (% of total cases) and non-overweight count (% of total non-cases) for category variables recorded in dogs attending primary-care veterinary practices in the VetCompass™ Programme in the UK (n=22,333)**

| Variable | Category | Overweight, n (%) | Non-overweight, n (%) |
|---|---|---|---|
| Breed | Crossbred | 394 (25.0) | 5587 (27.0) |
| | Purebred – other | 312 (19.8) | 5382 (26.0) |
| | Labrador Retriever | 160 (10.1) | 1302 (6.3) |
| | Staffordshire Bull Terrier | 86 (5.5) | 1218 (5.9) |
| | Jack Russell Terrier | 76 (4.8) | 1092 (5.3) |
| | Cocker Spaniel | 68 (4.3) | 703 (3.4) |
| | Crossbred – designer | 63 (4.0) | 1219 (5.9) |
| | Pug | 62 (3.9) | 351 (1.7) |
| | West Highland White Terrier | 50 (3.2) | 466 (2.3) |
| | Cavalier King Charles Spaniel | 48 (3.0) | 387 (1.9) |
| | Border Collie | 44 (2.8) | 508 (2.5) |
| | Golden Retriever | 39 (2.5) | 202 (1.0) |
| | Chihuahua | 38 (2.4) | 599 (2.9) |
| | Yorkshire terrier | 37 (2.3) | 680 (3.3) |
| | Border Terrier | 31 (2.0) | 227 (1.1) |
| | English Springer Spaniel | 29 (1.8) | 198 (1.0) |
| | Beagle | 28 (1.8) | 169 (0.8) |
| | Shih-tzu | 28 (1.8) | 765 (3.7) |
| | Bichon Frise | 26 (1.6) | 310 (1.5) |
| | German Shepherd Dog | 21 (1.3) | 525 (2.5) |
| | Not recorded | 3 (0.2) | 82 (0.4) |
| Brachycephalic status | Non-brachycephalic | 917 (77.5) | 11,181 (74.1) |
| | Brachycephalic | 266 (22.5) | 3903 (25.9) |
| | Not recorded | 3 (0.2) | 82 (0.4) |
| Adult (>18 months) bodyweight (kg) | <10 | 302 (19.1) | 3194 (15.4) |
| | 10 to <20 | 362 (22.9) | 2398 (11.6) |
| | 20 to <30 | 245 (15.5) | 1770 (8.5) |
| | ≥30 | 292 (18.5) | 1367 (6.6) |
| | Not recorded | 379 (24.0) | 12,024 (57.9) |
| Bodyweight relative to breed-sex mean | Within ±15% of breed-sex mean | 406 (34.2) | 3475 (16.7) |
| | >15% below | 61 (5.1) | 1567 (7.6) |
| | >15% above | 421 (35.5) | 1328 (6.4) |
| | Not recorded | 298 (25.1) | 14,383 (69.3) |
| Age (years) | <3 | 259 (16.4) | 7881 (38.0) |
| | 3 to <6 | 528 (33.4) | 5029 (24.2) |
| | 6 to <9 | 427 (27.0) | 3586 (17.3) |
| | 9 to <12 | 258 (16.3) | 2348 (11.3) |
| | ≥12 | 99 (6.3) | 1651 (8.0) |
| | Not recorded | 9 (0.6) | 258 (1.24) |
| Sex-Neuter status | Female entire | 283 (17.9) | 5401 (26.0) |
| | Female neutered | 488 (30.9) | 4368 (21.0) |
| | Male entire | 279 (17.7) | 6198 (29.9) |
| | Male neutered | 529 (33.5) | 4712 (22.7) |
| | Not recorded | 1 (0.1) | 74 (0.4) |
| Insurance | Non-insured | 1291 (81.7) | 18,063 (87.0) |
| | Insured | 289 (18.3) | 2690 (13.0) |
| Vet Group | 1 | 728 (46.1) | 9362 (45.1) |
| | 2 | 287 (18.2) | 3528 (17.0) |
| | 3 | 124 (7.8) | 881 (4.2) |
| | 4 | 437 (27.7) | 6909 (33.3) |
| | 5 | 4 (0.3) | 73 (0.4) |

regression modelling (excluding bodyweight relative to breed-sex mean). The final main multivariable model retained five risk factors: breed, age, sex-neuter, insurance and vet group (Fig 3). After accounting for the effects of the other variables evaluated, eight breeds showed increased odds of overweight status compared with crossbred dogs. The breeds with the highest odds included the Pug (OR 3.12, 95% CI 2.31 to 4.20, P < 0.001), Beagle (OR 2.67, 95% CI 1.75 to 4.08, P < 0.001), Golden Retriever (OR 2.58, 95% CI 1.79 to 3.74, P < 0.001) and English Springer Spaniel (OR 1.98, 95% CI 1.31 to 2.98, P=0.001). Two breeds had reduced odds of overweight status compared with crossbreds: Shih-Tzu (OR 0.53, 95% CI 0.36 to 0.78, P=0.001) and German Shepherd Dog (OR 0.55, 95% CI 0.35 to 0.87, P=0.010). Dogs aged 6 to <9 (years) had the highest odds of overweight status (OR 2.99, 95% CI 2.53 to 3.54, P < 0.001) compared with dogs <3. Neutered males (OR 1.90, 95% CI 1.62 to 2.23, P < 0.001) had the highest odds compared with entire females. Insured dogs had 1.28 (95% CI 1.10 to 1.49, P=0.001) times the odds of overweight status compared with uninsured dogs (Fig 3). The Hosmer-Lemeshow test indicated evidence of acceptable model fit (P=0.609) and the area under ROC curve (0.695) indicated acceptable predictive ability.

As described in the methods, two variables (brachycephalic status and adult bodyweight) individually replaced the breed

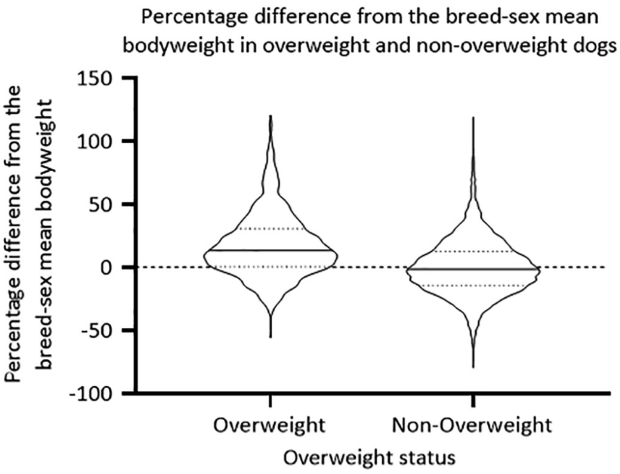


**FIG 2. Violin plot displaying the percentage difference from the breed-sex mean bodyweight of overweight dogs (n=888) and non-overweight dogs (n=6370) attending primary-care veterinary practices in the VetCompass™ Programme in the UK. The solid lines represent the median, whilst the dotted lines represent the upper and lower quartiles, with the shape representing the distribution**

variable in the final multivariable model. Of these, only adult bodyweight was significant in the final multivariable model. Dogs ≥30 kg had the highest odds of overweight status (OR 2.16, 95% CI 1.81 to 2.58, P <0.001) compared with dogs <10 kg (Fig 4).

## DISCUSSION

In line with the increasing recognition and awareness of overweight status as a key health and welfare issue in dogs (Summers *et al.* 2019), this study contributes further to the evidence base on the prevalence and risk factors for overweight status in dogs in the UK. A recent call for the veterinary profession to formally recognise companion animal obesity as a disease (Day 2017, Ward *et al.* 2018), along with the rising prevalence of overweight status in dogs (Bomberg *et al.* 2017) and the associated welfare implications (German *et al.* 2012, Yam *et al.* 2016), highlights the importance of continued research in to this subject area. The genetic role suggests that new breed risk information could allow overweight status to be selected against in predisposed breeds.

The current study estimates 1-year period prevalence for overweight status of 7.1%. A previous UK study with similar methodology, based on primary-care data from 2009 to 2013, estimated the prevalence of overweight status in dogs at 6.1% (O'Neill *et al.* 2014). This increase is in agreement with previous reports that overweight prevalence in dogs is increasing (German 2016, Bomberg *et al.* 2017), which is in line with the trend seen in humans (Blüher 2019).

Despite an increased overweight status prevalence in the current study, the estimate is lower than prospective study reports, which have ranged from 22 to 65% (McGreevy *et al.* 2005, German *et al.* 2018). It has previously been suggested that overweight status is underreported and underdiagnosed in primary care practice (German & Morgan 2008, Rolph *et al.* 2014), although the precise reasons for this are not fully clear. It is likely the explanations for underreporting are multifactorial, with the time constraints and completeness of record keeping of primary care consultations, the tendency for owners of overweight dogs to underestimate their dogs' body condition and the reluctance of veterinarians to offend owners all likely playing a part (Courcier *et al.* 2011, White *et al.* 2011, Eastland-Jones *et al.* 2014, Rolph *et al.* 2014). The probability that dogs were recorded with overweight status differed between the veterinary groups. Whilst veterinary group was only included in the modelling to account for potential confounding and was not a variable of primary interest, it could be that different practice cultures of recording clinical records or of focussing on overweight states contributed to these differences. Clinical audit within individual practices or larger practice groups could help to deconstruct these questions and explore opportunities for improved weight-control support to dog owners (Rose *et al.* 2016).

Breeds at increased risk of overweight status compared to crossbreds were Pug, Beagle, Golden Retriever, English Springer Spaniel, Border Terrier, Labrador Retriever, Cavalier King Charles Spaniel and Cocker Spaniel. Conversely, Shih-Tzus and German Shepherd Dog were at significantly reduced risk. The predisposed breeds identified are in line with a previous report, which reported high overweight status prevalence in Labrador Retrievers, Golden Retrievers, Cocker Spaniels, Beagles, Cavalier King Charles Spaniels and mixed breed dogs (Lund *et al.* 2006, Summers *et al.* 2019). It is possible that non-genetic factors (*e.g.* management style of 'typical' breed owners) could, in part, drive those breed predispositions. This could be particularly true for Pugs, as it has been shown that Pug owners exhibit particularly high emotional closeness with their dog (Packer *et al.* 2019), therefore they may be more likely to be overindulged compared with other breeds. Evaluation of non-genetic factors, such as management style, would be a valuable area for future research. However, such clear and consistent breed predispositions are likely to have a strong genetic basis. That would be consistent with data from other species including humans and production animals which suggest the heritability of obesity is 40 to 70% (Stachowiak *et al.* 2016). Genes associated with obesity in other species predominantly exert their effect by altering the neurological control of appetite and energy homeostasis and there is emerging evidence that the same is true in dogs. For example, mutations which disrupt hypothalamic melanocortin signalling, a critical nexus for energy homeostasis, are associated with obesity in Labrador and Flat-coat Retrievers (Raffan *et al.* 2016) and Beagles (Zeng *et al.* 2014). Furthermore, breed groups at high obesity risk have been shown to be highly food-motivated in the home environment (Raffan *et al.* 2015). Therefore, the current study findings could be used by owners to apply prophylaxis in predisposed breeds.

Pugs were the breed with the highest predisposition (OR 3.12), which concurs with a previous report that overweight status was the most common disorder identified in Pugs under primary-veterinary care in the UK (O'Neill *et al.* 2016). Overweight status presents particular challenges for brachycephalic dogs, such as Pugs, because it increases the risk of Brachycephalic Obstructive Airway Syndrome (Packer *et al.* 2015, Liu *et al.* 2016), which in

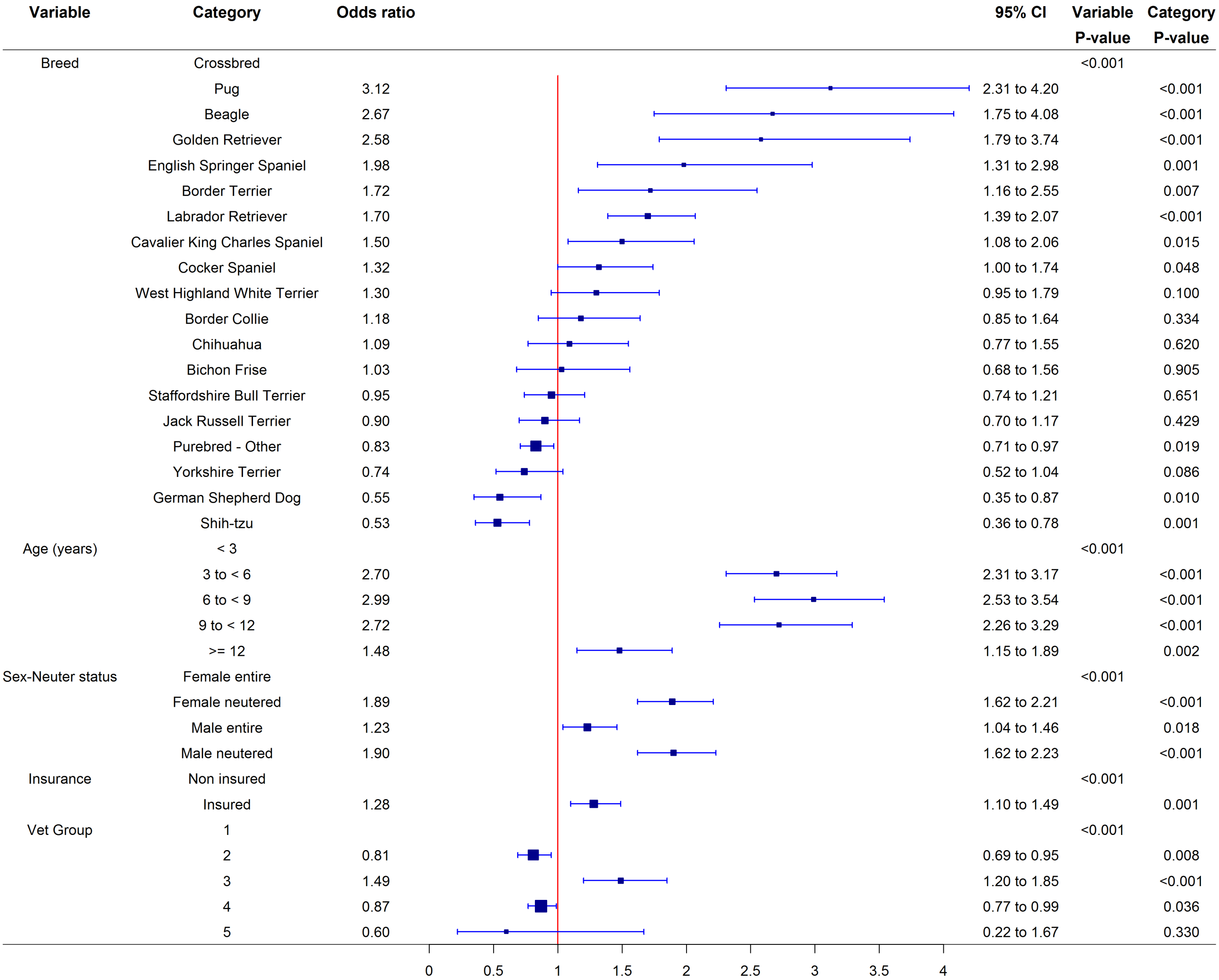


**FIG 3. Forest plot of the multivariable logistic regression odds ratios with corresponding 95% CIs (confidence intervals) for risk factors associated with overweight status in dogs attending primary-care veterinary practices in the VetCompass™ Programme in the UK (n=22,333). Categories without an odds ratio were the baseline**

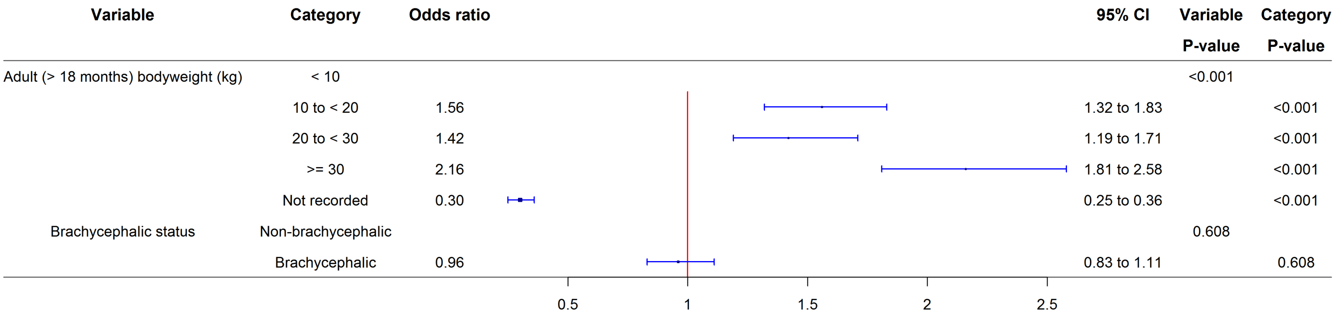


**FIG 4. Forest plot for variables that individually replaced the breed variable in the final multivariable logistic regression model (with age, sex-neuter, insurance status and vet group) to evaluate risk factors associated with overweight status in dogs attending primary-care veterinary practices in the VetCompass™ Programme in the UK (n=22,333). Adult bodyweight <10 kg and non-brachycephalic dogs were used as the baseline in their respective variables**

itself is a critical welfare issue (Ladlow *et al.* 2018). We investigated whether brachycephalic dogs as a group were predisposed to obesity, but the brachycephalic status variable was not identified as a significant risk factor. Rather, individual breed risk was the predominant factor, exemplified by higher risk of overweight status in Pugs but decreased risk in Shih-Tzus, both of which are brachycephalic breeds. This is an important finding as it suggests that control programmes for overweight status in brachycephalic dogs need to be targeted at individual predisposed breeds rather than at brachycephalic dogs overall.

Middle-aged dogs were at greatest risk of overweight status in the current study; dogs aged 6 to <9 years had 2.99 times the odds compared with dogs <3 years. This is in agreement with previous studies that showed middle-aged dogs were most at risk (McGreevy *et al.* 2005, Lund *et al.* 2006). In both the current and previous studies, prevalence was less during the growth phase and during the senior years (McGreevy *et al.* 2005, Lund *et al.* 2006). It has been suggested that reduced risk in older dogs may be a result of chronic diseases that result in weight loss (German 2016). Conversely, it might be that the prevalence is higher than reported, but other life-limiting chronic conditions are prioritised in veterinarian-owner discussions. These results suggest that overweight is a progressive disorder as dogs age from puppyhood to middle age and therefore interventions in puppyhood are likely to most effectively control overweight status, rather than waiting until middle age when the dog has already become overweight.

Sex and neuter status were identified as risk factors in previous studies, with female dogs more likely to be overweight than male dogs and neutered dogs more likely than entire dogs (McGreevy *et al.* 2005, Colliard *et al.* 2006, Lund *et al.* 2006). The current study evaluated neuter status in combination with sex to create four categories: female entire, female neutered, male entire and male neutered. Female neutered and male neutered dogs had similar risk estimates (OR 1.89 and 1.90, respectively), whilst male entire dogs had 1.23 times the odds (95% CI 1.04 to 1.46) of overweight status compared with entire female dogs. Although male entire dogs had marginally increased risk of overweight status compared with female entire dogs, these results suggest it is neuter status, rather than sex, that is the predominant risk factor for overweight status. The pathophysiology behind this process has been explored, with changes in sex hormones following neutering thought to result in alterations in behaviour, most specifically increased food seeking and decreased physical activity (Bermingham *et al.* 2014, Raffan *et al.* 2015). Veterinarians have reported weight gain as the most common disadvantage of neutering dogs (Diesel *et al.* 2010), therefore this should play a major part in owner discussions around neutering and close monitoring of bodyweight following surgery would aid in prevention of overweight status. Together, these findings that breed and neuter status predispose dogs to gaining weight provide evidence that overweight status in dogs is not simply down to lax management of diet and exercise by owners. Rather, genetic and physiological factors make some dogs particularly susceptible to weight gain, most likely by altering the neuroendocrine milieu to promote food intake and/or reduce energy expenditure. The authors suggest that acknowledging that in conversations with dog owners can lead to more effective prevention and treatment of overweight status.

The data provides some evidence that UK veterinary professionals routinely record a bodyweight value in a minority of dogs (44.5% of dogs registered during 2016) presenting to veterinary practices. There were 379/1580 overweight dogs (24.0%) recorded as overweight in 2016 without a bodyweight recorded. Whilst it might be that bodyweight in some cases was recorded in the free text clinical notes rather than in the specified bodyweight cell in the practice management system, and hence was not included in the current analysis, it seems likely veterinarians are identifying overweight status by assessment of visual and haptic clues analogous to BCS, even if no BCS is reported. Bodyweight data were more commonly reported in overweight dogs than non-overweight dogs (76.0% compared with 42.1%, respectively), suggesting veterinary professionals may be more assiduous in reporting weight when they have cause for concern, although this could have occurred by chance. However, regular weight recording in all dogs would provide useful baseline data and allow early identification of even modest changes in weight to be detected and prevention/treatment strategies implemented (German & Morgan 2008).

There were limitations to the current study. Underreporting of overweight status by veterinary professionals is well-recognised (German & Morgan 2008, Rolph *et al.* 2014), meaning that the prevalence reported in the study is likely to be significantly lower than true prevalence, as discussed above. Ideally, only dogs with complete BCS data would be included (although that would be subject to reporter bias and suitable data were not available). Reporting of BCS in veterinary clinical notes is uncommon (German & Morgan 2008, Rolph *et al.* 2014). Therefore, definition of overweight status based on BCS might be more appropriate for a prospective study in which veterinary professionals are asked to document the BCS and bodyweight of dogs a priori.

Evidence for the failure to classify truly overweight dogs as such comes from the large overlap between the violin plots in Fig 2, which shows dogs with similar percentage difference in weight compared to breed-sex average were classified in both categories. That could occur rightfully because a lean, tall dog would have a similar percentage difference to an average-height, overweight dog but it is likely that many dogs were overweight but not reported as such in clinical notes. This finding might encourage veterinary professionals to better document bodyweight and BCS in dogs, facilitating open discussions between veterinarians and owners about overweight status in dogs. The attempt to mitigate the absence of BCS or serial weight data by using weight compared to breed-sex average was sensible, but limited because of the absence of a 'gold standard' of breed-age matched dogs of known healthy BCS (to which a comparison might have been made), and because recorded weights were the mean throughout 2016, not just the bodyweight at point overweight status was reported. These limitations are likely to have decreased the power of the study to identify risk factors but are unlikely to have led to false positive findings meaning the key findings about the relative prevalence of obesity across breeds, and other risk factors, are valid. We use multiple comparisons in this study and adherence to a cut-off P-value of <0.05 to infer significance can lead to a Type 1 error of accepting false positive results. We recommend that readers do not rely on the P-values of odds ratios alone, but consider the confidence levels and other results to interpret our findings (Leek & Peng 2015).

The prevalence of overweight status in dogs under primary veterinary care was reported as 7.1%. Dogs with similar percentage difference in bodyweight compared to breed-sex average were classified as both overweight and non-overweight, suggesting many dogs were overweight but not reported as such in clinical notes. This finding could be used to focus efforts in encouraging veterinary professionals to routinely record bodyweight and BCS of dogs, facilitating open discussions with owners. Breed associations for overweight predisposition and protection were identified, offering the potential for targeted selection programmes within predisposed breeds to select towards dogs with better weight control. Pugs, Beagles, Golden Retrievers, English Springer Spaniels, Border Terriers, Labrador Retrievers, Cavalier King Charles Spaniels and Cocker Spaniels were at significantly higher risk of overweight status compared with crossbreeds. Middle-aged (3 to 11 years), neutered and insured dogs also had higher odds of overweight status. The risk factors identified should inform targeted prevention strategies, since the results provide an evidence-base for veterinarians and owners to address dogs most at-risk. In addition, researchers can use the findings to focus studies aimed at detection, management and prevention of overweight status in dogs. Further prospective studies might also evaluate the influence of non-genetic factors, such as owner and dog behaviours and lifestyle, including diet, on the development of overweight status in at-risk dogs identified in the current study.

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## Conflict of interest

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

## Data availability statement

The datasets generated during and/or analysed during the current study will be made available at the RVC Research Online repository.

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## Supporting Information

The following supporting information is available for this article:

**Table S1.** Individual breeds grouped as brachycephalic (n=34) and non-brachycephalic (n=237) among dogs under UK primary veterinary care at practices participating in the VetCompass™ Programme.

 