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Dental disease in companion rabbits under UK primary veterinary care: Frequency and risk factors

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Abstract

Background: Some prior evidence has suggested that lop-eared rabbits and those with brachycephalic skull conformations have a higher dental disease risk. This retrospective cohort study reports the frequency and conformational risk factors for primary-care veterinary diagnosis with dental disease in companion rabbits in the UK.

Methods: Anonymised VetCompass clinical records were manually reviewed to confirm dental disease cases. Risk factor analysis used multivariable binary logistic regression modelling.

Results: From 161,979 rabbits under primary veterinary care in 2019, the 1-year period prevalence of overall dental disease was 15.36% (95% confidence interval [CI]: 14.78–15.96). The prevalence of dental disease affecting incisors was 3.14% (95% CI: 2.87–3.44), and for cheek teeth it was 13.72% (95% CI: 13.17–14.29). Neither lop-eared conformation nor brachycephalic skull conformation was significantly associated with increased odds of dental disease. Dental disease odds increased as age increased and decreased as bodyweight increased.

Limitations: This study retrospectively accessed clinical records, so breed names may sometimes be imprecise.

Conclusion: The high overall prevalence of dental disease represents a major welfare concern for all companion rabbits, regardless of conformation. This information can be used to encourage regular routine dental assessment of rabbits of all conformations to promote earlier diagnosis, paying particular attention to older rabbits and those with low bodyweight.

KEYWORDS
epidemiology, *Oryctolagus cuniculus*, pain, teeth, VetCompass

INTRODUCTION

Rabbits (*Oryctolagus cuniculus*) are a popular companion animal species in the UK, with over 50 breeds and 500 variations formally recognised by the British Rabbit Council (BRC).[1] Many veterinary surgeons consider dental disorders as the most common problem encountered in companion rabbits,[2–4] with studies in the UK reporting dental disease prevalence ranging from 4.3% to 29.4%, depending on study design.[2,5,6]

Aradicular hypsodont rabbit teeth have evolutionarily adapted for mastication of abrasive grasses by continuously erupting throughout life.[7–9] Primary dental disease in rabbits can result from congenital brachygnathism, but more commonly follows the progressive syndrome of acquired dental disease that is theorised to be caused by insufficient dental wear, metabolic bone disease or a genetic predisposition.[10–14]

Ear and skull conformation has been associated with differing dental disease risk in companion rabbits. In a cross-sectional study where rabbits at a single UK rescue centre had their mouths physically examined, lop-eared rabbits had over 20 times higher odds of incisor problems and 12 times higher odds of molar overgrowth.[15] However, the relatively small sample size of just 15 lop-eared and 15 erect-eared rabbits gave huge uncertainty around these values, and sampling from a single rescue centre may have poorly represented the general companion rabbit population. Although at a univariable level of analysis, Mullan and Main reported Dwarf Lops as significantly more likely to have dental issues than any other breed, multivariable analysis accounting for diet and age no longer identified Dwarf Lops as significantly associated with dental disease,[2] highlighting the value of using larger datasets and multivariable analyses for more robust research.

Brachycephaly is defined as a shortened, broadened facial skeleton[16] and results from defective growth of basicranial epiphyseal cartilage, leading to altered and shortened basicranium bones.[17] There is no universally accepted classification of rabbit breeds by brachycephalic status, but dwarf and some lop-eared varieties are generally considered as brachycephalic due to their relatively short ‘snouts’ compared to their braincases.[18,19] In a study of 200 companion rabbits at a Thai university hospital,[20] rabbit breeds with ‘short faces’ were over three times more likely to be diagnosed with dental disease than ‘long-faced’ breeds. Also, lop-eared and dwarf breeds, often considered brachycephalic,[18,19,21] had an almost 100% prevalence of malocclusion and tooth root elongation as assessed through clinical examination and radiographs in Iranian companion rabbits.[22] the high reported frequency of dental disease in lop-eared and brachycephalic rabbits worldwide suggests that selective breeding of rabbits towards brachycephaly and lop-eared conformations may lead to increased welfare issues, but the fuller extent of these associations require deeper investigation.

Dwarfism in rabbits is theorised to be associated with congenital maxillary brachygnathism.[10,23,24] A genetic predisposition to the acquired form of incisor dental disease, separate to maxillary brachygnathism per se, has also been theorised because a higher incidence of acquired dental issues in dwarf breeds (e.g., Ref. 22) may indicate that overall reduction in jaw size predisposes these breeds to acquired incisor malocclusion.[13] However, to date, there is limited empirical evidence for associations between dental disease and dwarfism across different breeds to support these theories.

Other risk factors for increased risk of dental disease include older age,[2,3,6,20,22,25] male sex,[6,20,25] corticosteroid-induced osteoporosis,[26] temporomandibular joint disease[27] and lack of access to natural light,[22] resulting in reduced vitamin D levels.[28,29] Muesli diets were also significantly associated with increased tooth length and curvature in eight rabbits even when fed alongside hay, compared to feeding pelleted food or hay only.[30] An overall lack of abrasive textured food has also been associated with dental issues.[22,31]

Even in companion rabbits without conformational extremes such as dwarfism or brachycephaly, cheek teeth often show elongated crowns compared to teeth from wild rabbits, suggesting that existing changes to non-extreme companion rabbit conformations, along with environmental differences such as unnatural diets, are sufficient to predispose to dental disease.[14] To strengthen the evidence base on conformation and other animal-based factors as risk factors for dental disease in rabbits, the present study used multivariable analysis of a large sample of retrospective veterinary clinical data, thus aiming to overcome several limitations of previous studies. Based on some prior evidence,[15,20] it was hypothesised that lop-eared and brachycephalic breeds have higher odds of dental disease compared to erect-eared and normocephalic breeds, respectively.

MATERIALS AND METHODS

Study design

The study population included all available rabbits with at least one electronic patient record (EPR) logged during 2019 at primary-care veterinary clinics participating in VetCompass.[32] VetCompass collates de-identified EPRs from participating practices for epidemiological research. Data fields available included a unique identifying number, species, breed, date of birth, sex and neuter status, along with bodyweight and free-text clinical notes with relevant dates.

A cross-sectional analysis using retrospective cohort clinical data was used to report prevalence and explore associations between risk factors and diagnosis with dental disease. Sample size calculations estimated that 287 rabbits were required to detect odds two times higher for dental disease in lop-eared rabbits compared to erect-eared rabbits, assuming equal numbers of lop-eared and erect-eared rabbits in the study population and 10.9% prevalence of dental disease in the erect-eared group, with power set to 0.8 and α equals 0.05.[6,15,33] Ethical approval was given by the Royal Veterinary College Social Science Research Ethical Review Board (reference number: SR2018-1652).

Case finding involved initial EPR screening of all study rabbits to identify all candidate dental cases. The clinical free-text field was searched using a range of search terms optimised iteratively with wild-card functionality and letter fuzziness to allow two-letter insertion or deletion,[34] including dent*, ‘cheek teeth’, burr* and extraction ~1. The clinical records of a randomly selected subset of candidate cases were reviewed manually to evaluate for case inclusion and to extract further clinical information.[35] A dental case was defined as any rabbit with evidence in the available clinical records of the presence of any dental abnormality at any point between 1 January 2019 and 31 December 2019. Rabbits diagnosed with dental disease prior to 2019 but with no recorded evidence of ongoing dental disease during 2019 were excluded as cases. Diagnostic decision making was at the discretion of the attending veterinary surgeons.

One-year period prevalence for overall dental disease and by dental grouping (incisor, cheek teeth) with 95% confidence intervals (CIs) was described in rabbits overall, in common breeds, and by ear and skull conformation. One-year incidence risk (and 95% CI) for overall dental disease cases that were first diagnosed in 2019 was also reported. The CI estimates were derived from standard errors based on approximation to the binomial distribution.[36] Prevalence calculations accounted for the subsampling procedure by scaling down the study population by the proportion of candidate rabbits manually checked to generate a notional count of study rabbits that were fully assessed for dental disease, consistent with methods previously used.[37]

Breed descriptive information entered by the participating practices was mapped to a VetCompass list with 247 rabbit breed terms, shown in Supporting Information S1. Crossbreed rabbits and those with limited morphological information in the name were mapped to appropriate breed terms, retaining as much morphological information as possible, in the following order: albinism presence, body size, ear type, fur length and fur type. Skull shape was determined from body size and ear type. For example, a rabbit recorded as a 'Netherland Dwarf Cross' was mapped to 'Crossbreed Dwarf Erect', and 'Lop Rabbit' was mapped to 'Unknown Lop Breed', both later categorised as brachycephalic. Crossbreed groups were later grouped together if dental cases had counts less than 20 to facilitate statistical analysis. Each breed term was mapped to a range of conformational characteristics: ear type (erect, lop, uncategorised), skull shape (normocephalic, brachycephalic, uncategorised), body size (standard, dwarf, giant, uncategorised), fur length (shorthair, semi-longhair, longhair, uncategorised), fur type (standard, angora, lionhead, rex, others, uncategorised) and the presence of albinism (not albino, albino, uncategorised). The VetCompass breed list and mapped conformational characteristics were generated from multiple information sources (e.g., Refs. 1, 38–40).

A purebred status variable categorised rabbits with recognised breed names as 'purebred' and all remaining rabbits as 'non-purebred',[41] heavily based on the breed names recognised by the BRC.[1]

Rabbits recorded as neutered at the final available EPR were categorised as 'neutered' and all remaining rabbits were categorised as 'entire'. Adult bodyweight described the median of all bodyweight (kg) values recorded for each rabbit after reaching 9 months old and was categorised as: 1.49 or less, 1.50–1.99, 2.00–2.49, 2.50–2.99, 3.00–3.49 and 3.50 or more. Age (years) was defined on 31 December 2019 and was categorised as: less than 1.00, 1.00–1.99, 2.00–2.99, 3.00–4.99 and 5.00 or more. Teeth affected were recorded as either incisors (including peg teeth), cheek teeth (including molars and premolars), both or unrecorded.

Statistical methods

Following data cleaning in Microsoft Excel (2022), analyses were conducted using IBM SPSS Statistics (version 28.0.1.1). Risk factor analysis used binary logistic regression modelling. Initial univariable modelling evaluated the associations between risk factors and diagnosis with dental disease. Risk factors with liberal associations in univariable modelling ($p < 0.20$) were considered in multivariable evaluation. The variables of a priori interest (ear type and skull shape) were used to create two core multivariable models with ear type and skull shape forced into the final models regardless of univariable association, using the 'enter' method on SPSS statistics. Each final model retained four additional variables: sex, neuter status, age and bodyweight. Variables derived from the breed type (breed name, body size, fur length, fur type, albinism, purebred status and BRC recognition status) were highly correlated and, therefore, individually replaced the ear type variable in the main ear type-focused model. Only the multivariable results for the replacement variable were reported. The body size variable and median adult bodyweight were tested for collinearity by measuring the variance inflation factor before inclusion in the same model.[42] The area under the receiver operating characteristic (ROC) curve and the Hosmer–Lemeshow test were used to evaluate the quality of the model fit and discrimination.[43,44] Statistical significance was set at a p-value of less than 0.050.

RESULTS

Demographics

Descriptive results for the total study population of 161,979 rabbits are reported in Table 1. Overall, 86,587 (53.46%) rabbits had a specified breed name or description where at least one morphological feature could be inferred. Breed-derived characteristic data completeness were: ear type 51.74%, skull shape 54.75%, body size 44.80%, fur type 44.34%, fur length 43.78% and albinism presence or absence status 40.87%.

Prevalence and incidence of dental disease

From 44,089 candidate cases, the EPRs of a random sample of 3935 (8.93% of candidate cases) rabbits were manually evaluated against the dental disease case definition to confirm 2219 cases of dental disease. Among cases of dental disease, 220 (9.91%) were identified as Miniature Lops, 183 (8.24%) were of an Unknown Lop Breed and 182 (8.20%) were Lionheads. A similar distribution was seen among dental non-cases (Figure 1).

After accounting for subsampling, the 1-year period prevalence for any type of dental disease was 15.36% (95% CI: 14.78–15.96). There were 1185 incident cases

TABLE 1 Descriptive statistics of demographic characteristics in 161,979 rabbits under primary veterinary care in 2019 in the VetCompass programme in the UK

Variable	Category	Number of rabbits	Percentage (%)
Sex	Female	69,929	43.17
	Male	81,428	50.27
	Unrecorded	10,622	6.55
Neuter status	Entire	119,667	73.87
	Neutered	42,312	26.12
Ear type	Erect	35,992	22.22
	Lop	47,814	29.51
	Uncategorised	78,173	48.24
Skull shape	Normocephalic	18,016	11.12
	Brachycephalic	70,662	43.63
	Uncategorised	73,301	45.24
Body size	Standard	24,986	15.42
	Dwarf	41,155	25.41
	Giant	6424	3.97
	Uncategorised	89,414	55.18
Fur length	Shorthair	52,934	32.67
	Semi-longhair	17,560	10.84
	Longhair	421	0.30
	Uncategorised	91,063	56.20
Fur type	Standard	48,648	30.03
	Lionhead	17,540	10.82
	Rex	4792	2.96
	Angora	503	0.31
	Others	345	0.21
	Uncategorised	90,151	55.63
Albinism presence	Not albino	65,919	40.69
	Albino	288	0.18
	Uncategorised	95,772	59.11

in 2019, giving an annual incidence risk of newly diagnosed overall dental disease of 8.20% (95% CI: 7.77–8.66). Table 2 shows the prevalence and incidence of dental disease based on tooth type overall, as well as by ear type and skull shape.

Among individual breeds, the 1-year prevalence of dental disease was highest in rabbits recorded to be a Dwarf Lop at 20.26% (95% CI: 17.65–23.15), English Lop at 20.10% (95% CI: 15.67–25.40) or Netherland Dwarf at 19.67% (95% CI: 17.02–22.63) (Figure 2).

Risk factors for dental disease

Risk factor analysis included 2219 rabbits with confirmed dental disease and 117,890 non-cases that were not identified as candidate cases. Across the 120,109 cases and non-cases in the analysis, data completeness was: neuter status 100%, sex 93.79%, age 91.40% and median adult bodyweight 44.88%. Descriptive and univariable logistic regression results are presented in Tables S2–S4.

The factors of a priori interest (ear type and skull shape) were not liberally associated in univariable analysis with dental disease but were forced into final multivariable models as described in the 'Materials and Methods' section. All other breed-derived variables were liberally associated with dental disease in univariable logistic regression modelling and were therefore evaluated using multivariable logistic regression modelling.

Models for ear type and skull shape showed limited model fit (Hosmer–Lemeshow test statistic: $p < 0.001$ and 0.005, respectively). The final models showed poor discrimination, with area under ROC curve values of 0.451 for ear type and 0.450 for skull shape. However, a certain degree of model misspecification has been reported as likely in very large sample sizes and can still be considered acceptable.[45]

The final multivariable ear type model did not identify a statistically significant difference in odds of dental disease between lop-eared and erect-eared rabbits, compared to a baseline of erect ear type (odds ratio [OR]: 1.12, 95% CI: 0.99–1.26, $p = 0.068$) (Table 3). Males had 1.23 times higher odds than females (95% CI: 1.12–1.35, $p < 0.001$). Neutered rabbits had 1.38 times higher odds than entire rabbits (95% CI: 1.25–1.52, $p < 0.001$). Bodyweight categories over 2.00 kg had significantly lower odds of dental disease presence compared with rabbits weighing 1.49 kg or less. As age increased, the odds of having dental disease also increased; rabbits aged 5 years or more had 7.58 times higher odds of dental disease compared to rabbits aged less than 1 year (95% CI: 6.07–9.45, $p < 0.001$).

Other variables derived from the breed type were individually used to replace ear type in the final ear type multivariable model, as described in the 'Materials and Methods' section, and the results for just these replacement variables are reported here. After replacing ear type, brachycephalic skull conformation did not show higher odds of dental disease compared with normocephalic skull conformation (OR: 1.13, 95% CI: 0.97–1.31, $p = 0.112$). Rabbit breeds with a rex fur type had lower odds of dental disease than a standard fur type (OR: 0.68, 95% CI: 0.50–0.91, $p = 0.009$). BRC-recognised rabbits had 1.19 times the odds than unrecognised breeds (95% CI: 1.09–1.31, $p < 0.001$). Purebred rabbits had 1.20 times higher odds of dental disease than non-purebred rabbits (95% CI: 1.09–1.31, $p < 0.001$). Rex breed rabbits had lower odds of dental disease than Miniature Lops (OR: 0.69, 95% CI: 0.49–0.96, $p = 0.030$). Body size and bodyweight were included in the same model as the variance inflation factor was low at 1.011, suggesting there was no multicollinearity.[42] No other variables reached statistical significance in multivariable modelling (Table 4).

DISCUSSION

This study, based on a large cohort of over 160,000 rabbits under primary veterinary care in the UK, provides an evidence base that can assist in increasing understanding of dental disease frequency and risk in

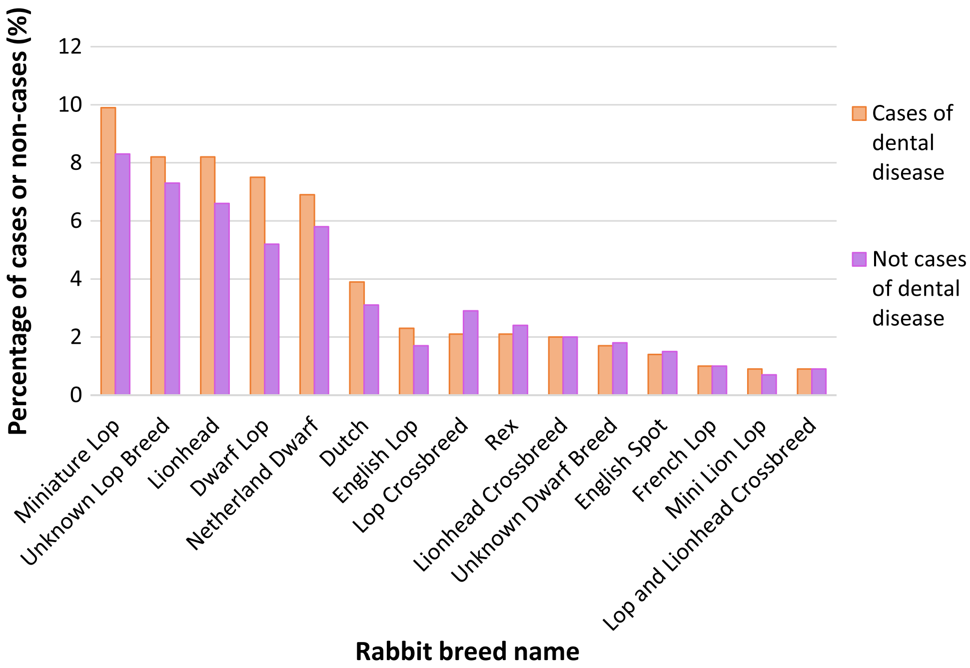

FIGURE 1 Percentages of the most frequently reported breeds with counts of over 20 in the confirmed dental cases and non-cases, from rabbits under primary veterinary care in 2019 in the VetCompass programme in the UK (n = 120,128). Unknown breeds have been removed. Breed names were reported by the veterinary surgeon entering the data

rabbits. The annual prevalence of dental disease overall in 2019 was 15.36%, with 3.14% of rabbits affected with incisor dental disease and 13.71% affected with cheek teeth dental disease. Among individual breeds, the annual prevalence was highest in rabbits reported as Dwarf Lops (20.26%), English Lops (20.10%) and Netherland Dwarves (19.67%). Neither lop ears nor a brachycephalic skull conformation was a significant risk factor for dental disease, although sex, neuter status, median adult bodyweight, age, fur type, purebred status and breed itself were associated with dental disease.

Dental disease prevalence and incidence

The 1-year period prevalence for dental disease of 15.36% identified in the current study was higher than previous UK estimates of 12.2%[5] and 10.9%.[6] However, it is possible that the secondary use of historical clinical records in the current study may still underestimate the true scale of dental disease because the stoical nature of rabbits as a species may prevent attending veterinary surgeons from formally diagnosing many true cases, or veterinary surgeons may have failed to record their findings in the clinical records. Additionally, dental disease may have been missed in rabbits whose owners sought veterinary care on different issues. Sharp vertical points on the lingual edges of cheek teeth are formed by physiological enamel ridges and play an important role in the mastication of abrasive material.[12,46] Misclassification as dental cases could have resulted when veterinary surgeons mistook these physiological vertical points, which should not be taken as evidence of dental disease, as lingually pointing spurs, which should be taken as evidence of dental disease. The prevalence of 15.36% suggests that approximately 153,600 of the estimated 1 million companion rabbits in the UK may suffer from dental disease each year.[47] The increasing popularity of rabbits as companion animals between 2013 and 2019 further suggests that the absolute welfare burden from dental disease is both huge and growing at a rabbit population level.[48,49]

The difference between the 8.20% incidence risk for new cases of dental disease in rabbits in 2019 and the 15.36% prevalence suggests that up to 7.16% of rabbits may live with dental disease for over 1 year. Disorders with a long duration are considered to have a greater health-related welfare impact resulting from longer periods of pain.[50,51] Given the high frequency and lengthy disease duration evidenced in the current study, dental disease should be considered a high welfare concern for rabbits and to warrant prioritisation of often limited rabbit-focused funding for future research, public awareness campaigns and supporting dental care recommendations.[51–53]

Conformational risk factors for dental disease

The current findings did not provide evidence to support increased odds of dental disease in lop-eared breeds compared with erect-eared breeds. This contrasts with previous research reporting lop-eared conformation as a risk factor, although that work was limited by low statistical power and generalisability from a study size of just 30 rabbits sampled from a single rescue centre.[15,54] The lop-eared

TABLE 2 One-year period prevalence and 2019 incidence risk of dental disease in 161,979 rabbits under primary veterinary care in 2019 in the VetCompass programme in the UK

Rabbit characteristic	Category	Annual prevalence of dental disease			Annual incidence of dental disease		
		All tooth types	Incisor	Cheek teeth	All tooth types	Incisor	Cheek teeth
All rabbits (*n*)	All rabbits (161,979)	2219, 15.36% (14.78–15.96)	454, 3.14% (2.87–3.44)	1982, 13.72% (13.17–14.29)	1185, 8.20% (7.77–8.66)	238, 1.65% (1.45–1.87)	1020, 7.06% (6.65–7.49)
Ear type (*n*)	Erect (35,992)	567, 17.66% (16.38–19.02)	139, 4.33% (3.68–5.09)	502, 15.63% (14.42–16.93)	300, 9.34% (8.39–10.40)	78, 2.43% (1.95–3.02)	253, 7.88% (7.00–8.86)
	Lop (47,814)	762, 17.87% (16.75–19.04)	149, 3.49% (2.93–4.09)	687, 16.12% (15.04–17.24)	394, 9.24% (8.41–10.14)	70, 1.64% (1.30–2.07)	345, 8.09% (7.31–8.95)
	Uncategorised (78,173)	890, 12.76% (12.00–13.57)	166, 2.38% (2.05–2.77)	793, 11.37% (10.65–12.14)	491, 7.04% (6.46–7.67)	90, 1.29% (1.05–1.58)	424, 6.08% (5.54–6.67)
Skull shape (*n*)	Normocephalic (18,016)	267, 16.61% (14.87–18.51)	50, 3.11% (2.37–4.08)	244, 15.18% (13.51–17.02)	138, 8.59% (7.31–10.06)	28, 1.74% (1.21–2.51)	120, 7.47% (6.28–8.86)
	Brachycephalic (70,662)	1121, 17.79% (16.86–18.75)	251, 3.98% (3.53–4.49)	996, 15.80% (14.92–16.72)	590, 9.36% (8.67–10.10)	129, 2.05% (1.73–2.43)	507, 8.04% (7.40–8.74)
	Uncategorised (73,301)	831, 13.18% (12.37–14.04)	153, 2.43% (2.08–2.84)	742, 11.77% (11.00–12.59)	457, 7.25% (6.64–7.92)	81, 1.29% (1.04–1.59)	395, 6.27% (5.70–6.89)

Note: Some rabbits had dental disease affecting both the incisors and the cheek teeth. Data are presented as *n*, % (95% confidence interval).

conformation does not feature in wild rabbits and was selected from a genetic mutation causing a deficiency of continuous cartilage at the base of the pinna, resulting in pinnal folding.[55–58] Dogs with a pendulous ear carriage, phenotypically similar to lop-eared conformation in rabbits, have been reported with higher odds of otitis externa than upright pinnae,[6] and preliminary work suggests that a similar association may also exist in rabbits.[15,59,60] However, the degree of association between the lop-eared conformation and predisposition to dental disease may be complicated by the common co-existence of abnormal skull shapes across many different breeds. Cephalometric comparison between domestic and wild rabbits with erect ears found domestic rabbits had comparatively shorter and more quadratic skull shapes than wild rabbits,[14,61] and that small or dwarf erect-eared breed domestic rabbits showed no craniofacial morphometry differences in medium and large breeds.[62] However, no studies have compared skull shapes of erect-eared and lop-eared rabbits since Darwin's recognition that skulls of lop-eared rabbits had differing shapes to those of erect-eared domestic and wild rabbits in 1868; he also noted that dental changes were proportional to the size of these skulls.[63] It is possible that the lop-eared conformation only affects the cartilaginous structures of the ear and has no effect on jaw structure or dentition, but it is also possible that some limited effects may be masked by other stronger effects such as the environmental factors discussed above (e.g., Refs. 22, 28–30).

The current study also failed to support higher odds of dental disease in brachycephalic compared with normocephalic rabbits. This finding conflicts with previous results reporting 3.19 times higher odds of dental disease in short-faced rabbits, although that work was limited by incomplete explanation on how brachycephaly was defined, so there was potential for skull shape misclassification.[20] However, some cross-species evidence does support a higher frequency of dental problems in brachycephalic animals. Cats and dogs with brachycephaly are reported with a higher prevalence of dental issues related to overcrowding and rotation of teeth, often in considerably smaller jaws than their wild-type precursors.[64–67] The presence of a large diastema (space between the incisors and premolars) in the rabbit mouth could somewhat mitigate canine and feline issues because there may still be adequate space for correct occlusion of cheek teeth without tooth rotation or crowding despite shortened jaw lengths in brachycephalic rabbits. It is similarly possible that the skull shapes of companion rabbits are almost universally so different from skull shapes in wild rabbits that high numbers of companion rabbits will develop dental issues during their lifetime, irrespective of the degree of brachycephaly in their skull shape.[14]

Although the present study did not support the hypotheses that lop-eared and brachycephalic rabbits are predisposed to dental issues, it should be noted that the absence of evidence for ear type and skull

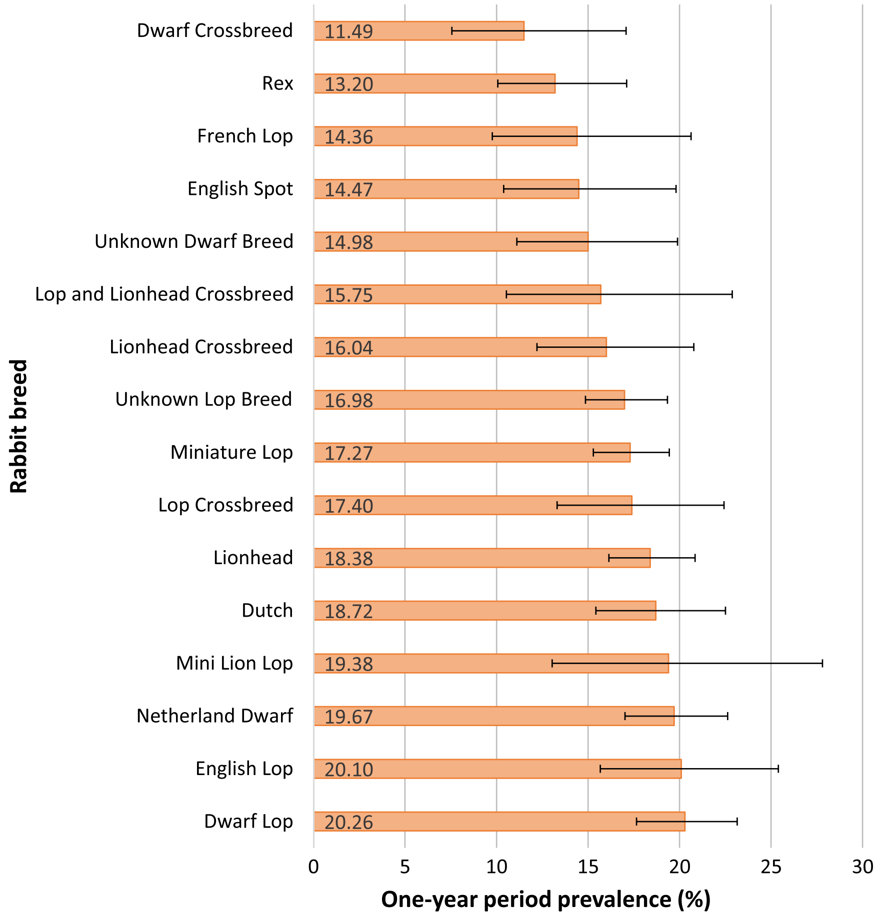

FIGURE 2 Breed related 1-year period prevalence of dental disease in rabbits under primary veterinary care in the UK VetCompass programme in 2019. Error bars represent 95% confidence intervals. Breed groups were included if there were over 20 individuals in the dental disease cases. Unknown breeds have been removed. Breed names were reported by the veterinary surgeon entering the data

shape as risk factors for dental disease in this single study alone does not confirm an absence of an effect,[68] so further confirmatory work is needed.[69] Rabbit conformations in this study were inferred from the breed names reported by the veterinarians, but it is possible that the breed identity was not always accurate. However, the reported names could be expected to have indicated that the rabbits resembled the named breed, so the conformational data deduced from these names are likely to have been appropriate for most rabbits. For example, if a rabbit was reported as a Dwarf Lop, when in fact it was a crossbreed, it is likely that the veterinarian and/or owner believed it was a Dwarf Lop because it had lop ears and a small adult body size, so classifying it as having these conformations would still be correct. It is also noteworthy that the current results relate to only one disorder, so it is still possible that these exaggerated conformations are associated with one or more other health issues, as identified in dogs (e.g., Ref. 70).

The current study did not show evidence that dwarf rabbits had higher odds of dental disease compared to 'standard' sized rabbits. This does not support Crossley's theory that dwarf breeds have a genetic predisposition to acquired dental disease.[13] In dogs, smaller breeds are reported with higher odds of diagnosis with periodontal disease than larger breeds, potentially due to overcrowding and rotation from incompatible tooth sizes in a smaller dental arch.[35,67,71,72] However, this increased risk could result from greater difficulties in brushing smaller dogs' teeth,[73] and the continuously growing nature of rabbit teeth means that brushing is unnecessary. The failure of the current study to identify differences in dental disease odds could mean that dwarfism in rabbits is genuinely not a risk factor, or it could reflect misclassification from issues around defining what is a dwarf rabbit. Rabbits weighing under 1 kg are generally considered to be 'true dwarves' and to have grossly different morphologic features compared to standard-sized rabbits.[21] However, in the general companion animal population, many breeds and individual rabbits recorded as dwarf are greater than 1 kg and are often morphologically similar to standard domestic rabbits other than their overall reduction in body size, which may explain why rabbits labelled as dwarf in the current study were not predisposed to dental issues.[21]

In contrast to dwarfism per se, lower median adult bodyweight was associated with higher odds of dental disease in the current study. However, the presence of dental disease leading to pain and gastrointestinal clinical signs may have resulted in weight loss, so the direction of any causality here is unclear. As prey animals, rabbits hide signs of illness to avoid predation, so owners may not have noticed these issues early during the clinical course and may only have sought veterinary care when dental disease was severe and weight loss had progressed.[74,75] Rabbits with dental disease should therefore have bodyweight closely monitored and assisted feeding implemented if necessary to redress any weight loss.

TABLE 3 Final ear type-focused multivariable logistic regression model for risk factors associated with rabbit dental disease in 2219 cases and 117,890 non-cases under primary veterinary care in the VetCompass programme in the UK in 2019

Variable	Category	Odds ratio	95% confidence interval	Category *p*-value	Variable *p*-value
Ear type	Erect	Base			<0.001
	Lop	1.12	0.99–1.26	0.068	
	Uncategorised	0.88	0.78–0.99	0.029[a]	
Sex	Female	Base			<0.001
	Male	1.23	1.12–1.35	<0.001[a]	
Neuter status	Entire	Base			<0.001
	Neutered	1.38	1.25–1.52	<0.001[a]	
Median adult bodyweight (kg)	≤1.49	Base			<0.001
	1.50–1.99	0.93	0.78–1.12	0.458	
	2.00–2.49	0.82	0.69–0.98	0.032[a]	
	2.50–2.99	0.75	0.62–0.90	0.002[a]	
	3.00–3.49	0.69	0.55–0.86	0.001[a]	
	≥3.50	0.63	0.49–0.81	<0.001[a]	
	Uncategorised	0.20	0.16–0.25	<0.001[a]	
Age (years)	<1.00	Base			<0.001
	1.00–1.99	1.65	1.31–2.09	<0.001[a]	
	2.00–2.99	2.73	2.15–3.46	<0.001[a]	
	3.00–4.99	4.49	3.58–5.64	<0.001[a]	
	≥5.00	7.58	6.07–9.45	<0.001[a]	
	Uncategorised	2.73	1.95–3.85	<0.001[a]	

[a]Significant category *p*-value.

Other risk factors for dental disease

Neutered rabbits had 1.38 times the odds of dental disease than entire rabbits, similar to the association noted in dogs.[35] Rather than a true link between neutering and dental disease, this association may reflect a clinical care bias whereby owners of neutered rabbits may have a stronger human–animal bond and therefore be more likely to present their rabbit for regular veterinary examinations, where subtle or early signs of dental disease could be detected.[76,77] Additionally, male rabbits had 1.23 times higher odds of dental disease than female rabbits in the current study, supporting previous evidence of a strong male predisposition to dental disease in rabbits.[6,20,25]

The odds of dental disease rose with ageing in the current study, in line with several previous reports.[2,3,6,20,22,25] In human beings, typical ageing processes have been linked with oral changes, such as reduced salivary flow, reduced masticatory function and delayed wound healing in oral mucosa, some of which may also occur in rabbits despite their aradicular hypsodont teeth.[78] Older rabbits may also develop temporomandibular joint arthritis, as seen in mice,[79] resulting in jaw pain during eating and leading to a preference for softer, less abrasive foods that wear teeth down more slowly. Conversely, part of the ageing effects identified in the current study could reflect clinical care bias if older rabbits are more likely to get unwell, as seen in ageing human beings,[80] and therefore, be presented for veterinary care, resulting in detection bias from more opportunities to detect dental problems in this group compared to younger rabbits.

Despite the lack of evidence in the current results for associations between lop ears and brachycephaly as conformational risk factors for dental disease, the high frequency of dental disease across all types of companion rabbits suggests a complex multifactorial aetiology of dental disease in companion rabbits, with one or more shared risk factors across all companion rabbit types. While some risk differences for dental disease were found here between reported rabbit breeds, such breed differences require confirmation in future studies with more definitive verification of breed status. It may be that husbandry-related factors, which could not be assessed in the current study but may be constant across all breeds, carry much more impact on dental disease risk than breed-specific conformational characteristics. Previous literature has highlighted that diet and housing play key roles in the development of dental disease because differing food abrasiveness and calcium and vitamin D concentrations alter the formation of the growing teeth.[10,13,30,31,81] A retrospective study of clinical records from 1420 domestic rabbits in Chile reported feeding hay (OR: 0.32) and being housed free range rather than in a cage or hutch (OR: 0.57) as strongly protective factors for the development of dental disease.[25] Similarly, rabbits kept indoors and only eating ‘soft fibre’ were 18.42% more likely to develop dental issues than those kept outdoors and fed ‘hard fibre’,[22] and rabbits with

TABLE 4 Results for risk factors that directly replaced the ear type variable in the final multivariable logistic regression model that also accounted for sex, neuter status, age and bodyweight

Variable	Category	Odds ratio	95% confidence interval	Category *p*-value	Variable *p*-value
Skull shape	Normocephalic	Base			<0.001
	Brachycephalic	1.13	0.97–1.31	0.112	
	Uncategorised	0.94	0.81–1.09	0.381	
Body size	Standard	Base			0.004
	Dwarf	1.14	0.99–1.31	0.061	
	Giant	1.09	0.85–1.40	0.512	
	Uncategorised	0.94	0.83–1.07	0.321	
Fur length	Shorthair	Base			<0.001
	Semi-longhair	0.98	0.84–1.13	0.751	
	Longhair	1.40	0.65–3.01	0.396	
	Uncategorised	0.84	0.76–0.92	<0.001[a]	
Fur type	Standard	Base			<0.001
	Angora	1.43	0.77–2.66	0.258	
	Lionhead	0.95	0.82–1.11	0.535	
	Rex	0.68	0.50–0.91	0.009[a]	
	Others	1.91	0.83–4.40	0.129	
	Uncategorised	0.82	0.74–0.90	<0.001[a]	
Albinism presence	Not albino	Base			<0.001
	Albino	0.63	0.20–2.00	0.435	
	Uncategorised	0.84	0.76–0.92	<0.001[a]	
BRC recognition status	Not recognised	Base			<0.001
	Recognised	1.19	1.09–1.31	<0.001[a]	
Purebred status	Non-purebred	Base			<0.001
	Purebred	1.20	1.09–1.31	<0.001[a]	
Breed name	Miniature Lop	Base			<0.001
	Unknown Lop Breed	0.94	0.76–1.17	0.584	
	Lionhead	1.06	0.87–1.31	0.554	
	Dwarf Lop	1.20	0.97–1.48	0.102	
	Netherland Dwarf	1.06	0.84–1.33	0.647	
	Dutch	1.00	0.76–1.31	0.985	
	English Lop	1.18	0.85–1.63	0.324	
	Lionhead Crossbreed	0.86	0.61–1.20	0.374	
	Lop Crossbreed	0.99	0.71–1.38	0.950	
	Rex	0.69	0.49–0.96	0.030[a]	
	Unknown Dwarf Breed	0.86	0.61–1.23	0.416	
	English Spot	0.77	0.51–1.16	0.216	
	French Lop	0.86	0.55–1.36	0.523	
	Mini Lion Lop	1.06	0.63–1.77	0.840	
	Lop and Lionhead Crossbreed	0.84	0.52–1.36	0.485	
	Dwarf Crossbreed	0.64	0.40–1.02	0.058	
	Other breeds	1.01	0.79–1.28	0.951	
	Uncategorised	0.84	0.72–0.98	0.028[a]	

Note: These results show risk factor association with rabbit dental disease in 2219 cases and 117,890 non-cases under primary veterinary care in the VetCompass programme in the UK in 2019.
Abbreviation: BRC, British Rabbit Council.
[a]Significant category *p*-value.

dental disease housed indoors had lower blood calcium concentrations than rabbits housed outside without dental disease.[29] Unfortunately, the free-text veterinary clinical data used in the current study did not provide sufficient information on housing or diet for their consideration in the current analyses. Future work could employ a husbandry questionnaire for owners to assess diet and time spent outside alongside the veterinary dental examinations.

The current study had some limitations. The validity of the data in the clinical records relied on accurate diagnosis of dental disease and reporting of breed and signalment by the veterinary teams and owners. Breed information was incomplete for many rabbits that were recorded as just 'unknown breed' or 'domestic rabbit'. Although the multivariable modelling accounts for demographic variables available to the current study, other factors such as diet, housing and insurance status were not accounted for. Insured dogs are reported with significantly higher odds of multiple diseases, suggesting high levels of diagnostic bias,[35,70,82] and a similar effect may exist for insured rabbits. Data were on the body condition score of rabbits were not available in the current study, so the presence or levels of obesity could not be considered in the analysis.

CONCLUSION

Dental disease was found to be very common across all types of companion rabbits in the UK, representing a major welfare concern. The current results did not support higher odds of dental disease in lop-eared or brachycephalic rabbits compared with their erect-eared or normocephalic counterparts, raising the possibility that pervasive conformational and husbandry changes linked to being a companion rabbit per se carry the greatest risk effect for dental disease in rabbits. If there are specific genetic predispositions to dental disease in rabbits, these are likely to be complex. These findings may aid veterinary professionals in recognising affected rabbits earlier and initiating earlier treatment to reduce pain and suffering. Full dental examination should be prioritised in companion rabbits that are male, older or present with a lower bodyweight than expected.

AUTHOR CONTRIBUTIONS

Dan G. O'Neill, Charlotte C. Burn, Joanna Hedley and Dave C. Brodbelt assisted with study design, model building, analysis and interpretation. Maria A. Jackson, Dan G. O'Neill and Dave C. Brodbelt were involved in the acquisition and extraction of data. Maria A. Jackson carried out the analysis and initial manuscript creation, with significant revision contributions from all co-authors.

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CONFLICT OF INTEREST STATEMENT

The authors declare they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Figshare at https://doi.org/10.6084/m9.figshare.25125773.v1 (reference number 25125773).

ETHICS STATEMENT

Ethical approval was granted by the Royal Veterinary College Social Science Research Ethical Review Board (reference number: SR2018-1652).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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