Risk and protective factors of feline tooth resorption in 8115 Finnish cats

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Abstract

Tooth resorption (TR) is the most common dental disease in cats. It causes painful lesions in the teeth, the only treatment being tooth extraction. The prevalence of the TR is high in clinical studies while the estimate in the population sample is unknown. The aetiology of the disease remains unclear, but associations to old age, breed, other oral and dental diseases, viral infections and certain environmental factors have been suspected. We wanted to determine the prevalence, risk factors and heredity of feline TR in a population sample of Finnish cats. We collected health and environmental information of 8115 Finnish cats in 41 breeds through an online survey targeted for breeders and owners. The prevalence of veterinary-diagnosed TR was 3.9% in the whole data and 15% in cats diagnosed with oral or dental disease. Results indicated an increased risk by age and decreased risk by constantly available food. Periodontitis and stomatitis were more common in the TR-affected cats. The interaction between gingivitis, dental calculus, and age suggests that the predisposition of young cats to TR is associated with gingivitis, which could partially be prevented by proper dental hygiene. The observed differences between breeds highlight the genetic contribution.

Introduction

Tooth resorption (TR) is the most common dental disease in cats [1]. It is a painful disease characterised by progressive dental destruction, which eventually results in loss of teeth. Dental radiography is necessary to evaluate the overall situation [1]. Prevention of the disease is not possible since the aetiology is still unknown. The goal of treatment is to relieve the pain and discomfort caused by these lesions [2]. The main cause of destruction are odontoclasts, which are multinuclear cells that resorb mineralized tissue [3]. Odontoclasts are responsible for resorption of deciduous teeth in young animals, but their abnormal activity in permanent teeth is the cause of TR [4]. The reason for this process remains unclear, although many different theories have been proposed. Tooth resorption can include plaque accumulation, inflammation of the adjacent tissue and alveolar bone ankylosis [5]. Because the pathogenesis of tooth resorption has been unclear, many different terms have been used to describe the lesion, i.e. erosion, neck lesion, FORL (feline odontoclastic resorptive lesion). Nowadays, most used term is TR.

TR is a relatively new disease, which has become more common in the last decades [6]. Almost no resorptions could be found in feline skulls from the 1930–1950's but starting from 1960's they were increasing in number [7]. First publication about TR came out in 1955 [6]. The size and origin of the study population have had a major impact on the reported prevalence of TR in previous studies varying from 29-85% (Table 1). Most studies are based on a small clinical sample (n< 150) and no reports have been published yet in a large population sample. TR exists also in large cats, such as leopards and lions, but rarely in humans and dogs [1]. The increasing number of tooth resorption indicates a change in the environment of domestic cats [4]. For example, the factors preventing resorption in the outer surface of the teeth could have been compromised [1]. Only lesions that occur in the crown or in the cemento-enamel junction can be detected clinically [1]. However, resorption can occur at any surface of the teeth or in the root and can lead to massive destruction in the adjacent tissue.

Table 1. Prevalence of feline tooth resorption in previous studies. NK = not known

Reference	Country	Target population	Study population (n), average age (years)	Method	Prevalence (%)
Coles 1990 [13]	Australia	General anaesthesia	64, NK	Clinical	52
van Wessum et al. 1992 [7]	Netherlands	Dental procedure	432, NK	Clinical	62

van Wessum et al. 1992 [7]	United States	Dental procedure	78, NK	Clinical and radiographs	67
Lund et al. 1998 [15]	United States	General anaesthesia	145, 7.9	Clinical	48
Ingham et al. 2001 [16]	United Kingdom	Clinically healthy test animals	228, 4.9	Clinical and radiographs	29
Pettersson & Mannerfelt 2003 [17]	Sweden	Sedation	96, 6.0	Clinical and radiographs	32
DeLaurier et al. 2009 [5]	United States	Clinically and radiographically normal teeth	13, NK	Electron microscopy	85
Our study	Finland	Finnish cat population: all / cats with oral or dental disease	8115, 5.3	Questionnaire	3.9 / 15

American Veterinary Dental College has developed a classification for tooth resorption based on their radiographic appearance. In type 1 tooth resorption there is a focal radiolucent area in the tooth that appears otherwise normal with a normal periodontal ligament space. In type 2 tooth resorption, there is decreased radiopacity, which indicates that the root is being replaced with alveolar bone. In type 3 tooth resorption, there are signs of both type 1 and type 2 resorptions [8,9]. The same cat can suffer from different types of resorptions [9]. The three resorption types have been suspected to have different aetiologies [10].

Unlike the previous clinical studies, our aim was to investigate the prevalence of veterinary-diagnosed TR, its risk factors and variation between breeds in a large population sample of Finnish cats collected during 2012–2015 using an online feline health survey data [11].

Results

Prevalence

Our cat population consisted of 8115 cats in 41 breeds, of which 4290 (53%) were females. 2070 (26%) cats were diagnosed with oral or dental disease and 316 cats had veterinarian diagnosed TR. The mean age of the cat population was 5.3 years - for cats without TR 5.1 and for cats with veterinarian diagnosed TR 9.8 years. The prevalence of veterinary-diagnosed TR in our study was 3.9% (95% CI 3.5–4.3%, Table 1). The prevalence increased strongly by age, being 0.4% in 1 to <3 years old, 3.0% in 3 to <7 years old, 8.8% in 7 to <11 years old, and 11.6% in at least 11 years old cats. TR was not reported in cats under one year of age. For comparison, in subgroup of cats that had been diagnosed with oral or dental disease, the prevalence of TR was 15.2% (95% CI 13.5–16.8%, Table 1), increasing again by age 3.7%, 12.6%, 24.3% and 28.1%, respectively.

We did not find any significant difference between the TR prevalence in purebred cats and non-pedigree house cats (3.8%; CI 3.4–4.3% and 4.2% and CI 3.3–5.3%, respectively, P = 0.551, Fisher). However, in some breeds, the prevalence was much higher or lower than in the entire population or in-house cats – high in Siamese (9.9%), Abyssinian (9.3%), Oriental Shorthair (9.1%) and Cornish Rex (8.9%), and much lower than average in Turkish Van (0.4%) and Birmans (1.3%). TR was not reported in breeds of Burmilla, American Shorthair, Don Sphynx, Egyptian Mau, Kurilian Bobtail, Manx, Neva Masquerade and Seychellois. However, these breeds were present in low numbers in our dataset.

Factors associated with tooth resorption

Total of 15 factors were qualified into the final multivariable logistic regression modelling for finding out the most significant factors associated to TR. They were age, breed, gender, availability of food, gingivitis, stomatitis, periodontitis, dental calculus, tooth fracture, abnormal number of teeth, cat flu, musculoskeletal disease, digestive tract disease, respirator system disease and endocrinological disease and tumours. These 15 factors were selected out of 51 (Supplementary Table S1) factors from the feline health survey [11], which were known to be or could possibly be related to TR. Qualification by basic association tests (Fishers' exact or Kruskal-Wallis, p>0.2) suppressed the number of factors from 51 to 26 (Table 2, Supplementary Tables S2 and S3). Logistic regression modelling with confounding factors age, gender and breed - for each of the 26 variables separately - favoured 15 factors (p <0.05) (Supplementary Tables S2 - S4) to be approved into the final multivariable logistic regression modelling. Majority of the cats – 92% of cases and 78 % of controls – were neutered and thus, too small comparison groups of non-neutered cats prevented validation of the effect of neutering in obtaining TR.

Table 2. Demographics and basic association test results (breed and disease categories excluded) of cats with and without veterinarian diagnosed tooth resorption (N = 8115); number (n), percentage (%) and association with tooth resorption (only P < 0.2 shown) in Finnish cats in feline health survey 12/2012–2/2015. P-value: Fisher or Kruskal-Wallis test. CI = confidence interval. Bolded: selected for further analysis in logistic regression model with confounding factors age, gender and breed. Same cat may have had several of the oral/dental diseases or viral infections.

Variable	**Diagnosed**			**Not diagnosed**			
	n	**%**	**95% CI**	**n**	**%**	**95% CI**	**P-value**
Age	311			7631			**<0.001**
< 1 yr	0	0.0	0.0–1.2	1119	14.7	13.9–15.5	
1–2.99 yrs	8	2.6	1.3–5.0	1973	25.9	24.9–26.8	
3–6.99 yrs	76	24.4	20.0–29.5	2490	32.6	31.6–33.7	
7–10.99 yrs	115	37.0	31.8–42.5	1197	15.7	14.9–16.5	
≥11 yrs	112	36.0	30.9–41.5	852	11.2	10.5–11.9	
Gender	313			7742			**0.184**
Female	155	49.5	44.0–55.0	4135	53.4	52.3–54.5	
Male	158	50.5	45.0–56.0	3607	46.6	45.5–47.7	
Oral/dental disease							
Gingivitis	109	34.5	29.5–39.9	499	6.4	5.9–7.0	**<0.001**
Stomatitis	18	5.7	3.6–8.8	43	0.6	0.4–0.7	**<0.001**

Variable	Diagnosed			Not diagnosed			
	n	%	95% CI	n	%	95% CI	P-value
Periodontitis	36	11.4	8.3–15.4	68	0.9	0.7–1.1	**<0.001**
Dental calculus	187	59.2	53.7–64.5	1407	18.0	17.2–18.9	**<0.001**
Tooth fracture	16	5.1	3.1–8.1	90	1.2	0.9–1.4	**<0.001**
Abnormal number of teeth	12	3.8	2.2–6.5	63	0.8	0.6–1.0	**<0.001**
Viral infections							
Cat flu	20	6.3	4.1–9.6	201	2.6	2.2–3.0	**0.001**
Feline infectious peritonitis (FIP)	1	0.3	0.1–1.8	110	1.4	1.2–1.7	0.133
Diet							
Cooked meat/fish	88	27.8	23.2–33.0	1812	23.2	22.3–24.2	0.067
Availability of food	166	53.2	47.7–58.7	5287	68.9	67.9–70.0	**<0.001**
Vaccinations							
Cat flu	201	70.3	64.7–75.3	4907	74.2	73.1–75.2	0.148
Panleucopenia	239	83.6	78.8–87.4	5752	86.6	85.8–87.4	0.157
Leukaemia	28	12.8	9.0–17.9	936	20.0	18.8–21.1	0.009
Rabies	80	32.4	26.9–38.5	2649	46.0	44.7–47.3	<0.001

Multivariable logistic regression model

Seven variables remained in the final multivariable logistic regression model after model validation with backward selection and goodness of fit tests (Table 3). Based on the model, independent risk factors for veterinarian-diagnosed TR were breed, stomatitis and periodontitis whereas availability of food constantly had a significant protective effect.

Breeds and breed groups with significantly higher risk for tooth resorption in comparison to house cats were oriental group (Siamese, Balinese, Oriental, Seychellois), British, Cornish Rex, European, Norwegian Forest Cat and Ragdoll. Turkish Van had significantly lower risk for TR. Those cats, which did not have food available all the time as well as cats, which had stomatitis or periodontitis were more prone to TR than other cats.

The second order interaction was found between age, gingivitis and dental calculus. The interaction demonstrated that there was considerable variation in the risk to have TR in the groups indicated by these interaction factors (Fig 1). Gingivitis was a significant risk factor for TR in age groups of < 7 years and ≥11 years old cats, and the risk of having TR due to gingivitis was highest in the subgroup of young cats (< 7 years) having gingivitis but not dental calculus (Table 3).

Even though the P-value of the second order interaction was non-significant (0.0949) in this model, it gathered the information of the three separate significant interactions explicitly and the model achieved the best AIC and AUC values and McFadden index. The AIC was 2004. The AUC-value for the ROC-curve was 0.870 (95% CI 0.850–0.890), which makes the predictive value of the model moderate [12]. The McFadden goodness of fit index was 0.255. The goodness of fit and predictive value tests for the final model were mainly good or moderate.

Table 3. Multivariable logistic regression model of the risk factors for veterinarian diagnosed tooth resorption in Finnish cats in data collected during 12/2012–2/2015 in an internet survey. Only significant breeds are shown. B = logistic regression model coefficient, se = Standard Error, Wald = Wald test statistic, df = degrees of freedom, P = Wald's P-value, OR = odds ratio, CI = confidence interval for OR, ref = reference group. n_{cases}=308 nand $n_{controls}$=7508. P-values of the first order interactions age x gingivitis, age x dental calculus and gingivitis x dental were 0.003, 0.0003 and 0.0002, respectively.

Variable	**B**	**se**	**Wald**	**P**	**OR**	**95% CI**	**df**
Constant	-5.25	0.26	410.40	<0.001			1
Breed: House cat	ref						20
Siamese, Balinese, Oriental, Seychellois	0.72	0.25	8.25	0.004	2.05	1.26 – 3.36	1
British	0.65	0.32	4.23	0.040	1.92	1.03 – 3.58	1
Cornish Rex	1.14	0.25	20.39	<0.001	3.12	1.90 – 5.11	1
European	0.89	0.29	9.54	0.002	2.44	1.39 – 4.31	1
Norwegian Forest Cat	0.64	0.29	4.97	0.026	1.89	1.08 – 3.32	1
Ragdoll	0.66	0.32	4.27	0.039	1.93	1.03 – 3.61	1
Turkish Van	-2.28	1.02	4.98	0.026	0.10	0.01 – 0.76	1
Food available vs. no	-0.47	0.13	12.52	<0.001	0.63	0.49 – 0.81	1

Oral /dental diseases							
Stomatitis vs. no	0.98	0.36	7.28	0.007	2.65	1.31 – 5.39	1
Periodontitis vs. no	1.29	0.26	25.32	<0.001	3.63	2.20 – 6.01	1
Interaction age x gingivitis x dental calculus			4.71	0.095			
Gingivitis vs. no when:	**Age yrs**						
Dental calculus	< 7				2.55	1.34–4.83	1
No dental calculus	< 7				15.11	7.49–30.47	1
Dental calculus	7-<11				1.47	0.84–2.55	1
No dental calculus	7-<11				2.03	0.71–5.81	1
Dental calculus	≥11				2.27	1.23–4.20	1
No dental calculus	≥11				3.76	1.57–9.01	1

Figure 1. Dental calculus and gingivitis by age groups in cats with and without tooth resorption. Demonstrative bar chart of subgroup formation in the interaction between age, dental calculus and gingivitis in the multivariable logistic regression model of the risk factors for veterinarian diagnosed tooth resorption (Finnish cats in data collected during 12/2012–2/2015 in an internet survey). Blue = percentage of cats with dental in the age group. Grey = percentage of cats with no dental calculus in the age group. Horizontal black lines in blue and grey bars: proportion of gingivitis in cats with dental/without calculus under the line.

Discussion

This is the first study of TR and its associated factors in a large population sample [11]. Tooth resorption is a disease of high prevalence, unclear pathogenesis and various clinical presentations. The prevalence of veterinarian diagnosed TR in this study (3.9%) was clearly lower than in studies that have clinically evaluated the teeth, usually between 29–67%. The prevalence of TR in our restricted group of cats diagnosed with oral or dental disease (15%) is closer to that found in clinical studies. The mean age of the population was not particularly lower than in other studies and so the age of the cat population does not explain the low prevalence. The selection of the research population has a major impact on the results. If the target population consists of cats seeking for dental treatment routinely or because of dental disease, the prevalence of TR is expectedly higher than in healthy cats. The methods used in various studies to detect the TR also affect the prevalence. Most obvious lesions are found in general examination without sedation, but dental calculus can distract the examination, nor can the gum line be explored. Since examination with dental explorer instrument under anaesthesia only detects lesions in the cementoenamel junction or in the crown area, dental radiographs increase the prevalence even higher when lesions in the root area are detected.

In this study, the tooth resorption was diagnosed by the veterinarian, but those cats used as controls had not been examined for TR as in clinical studies. This explains partly the low prevalence of TR in this study. Commonly cat owners do not monitor their pets' teeth, nor have the cats regular health checks by veterinarian. For these reasons and due to the progressive nature and challenging diagnostics, TR may not have been noticed in the healthy cats. Open ended questions revealed that in most of the cats the tooth resorption had been found during routine dental calculus removal, dental radiography was used for diagnosis and most of the cats had teeth removed because of TR.

Our finding that prevalence of TR increases by age is in alignment with other studies [5,6,13,14,15,16,17,18]. Together with age, risk to have TR was also associated with gingivitis and dental calculus, leading to different odds of getting TR based on differential exposure to these factors. Gorrel's (2015) theory suggests that tooth resorption consists of at least two aetiologically different diseases: inflammatory type 1 resorptions and idiopathic type 2 resorptions [19]. Of particular interest was that gingivitis was extremely high risk to TR in young cats that did not have dental calculus. The pathophysiological logical path is that dental calculus causes gingivitis, which in turn predisposes to resorption. On the other hand, gingivitis can occur without dental calculus, and it is an interesting and anticipated finding that if young cats have gingivitis (with or without dental calculus) they also have an increased risk of resorption, which probably is inflammatory, i.e. type 1 resorption. Based on this, one might suspect that there are more inflammatory type 1 resorptions in young cats, and thus, regular tooth cleaning and dental exanimation could help young cats to avoid development of this type of TR in the early stage of life. However, the very high odds observed in young cats with no dental calculus may be an overestimation, as many of youngest healthy control cats without reported dental calculus had not undergone clinical dental examination. The owner may not have noticed dental calculus or gingivitis.

In addition to gingivitis and dental calculus, stomatitis and periodontitis were risk factors for TR in our study. Previous studies have shown a connection between inflammatory type 1 resorptions and stomatitis [8], but not all studies have found the connection [20]. It has been suspected that chronic stomatitis caused by feline calici virus has an impact on development of TR [1]. Low number of cats with stomatitis hindered us to study this connection properly. Periodontitis has been related to TR also in previous studies [4] and it has been linked especially with type 1 tooth resorption [8], but also the inflammation caused by tooth resorption has been suspected to cause periodontitis [21].

The continuous availability of food had a protective effect on TR. If there is food available all the time, the cat probably goes to eat more often. On the other hand, if the food is available only on certain times, the cat might eat faster and more eagerly, which can also affect the teeth. The effect of the availability of food has not been, to authors' knowledge, studied before. DuPont & DeBowes (2002) suspected dry food to cause mechanical trauma leading to type 2 tooth resorption and soft food, causing periodontitis, being a risk factor for type 1 resorption [8]. Scarlett et al. (1999) did not find a difference in prevalence between cats eating dry or soft food [4]. In our questionnaire we did not specifically ask if the cats ate dry or soft food, but we did not find association between TR and eating cooked meat/fish.

Our finding of gender not being in association with TR was in line with previous studies [4, 13]. In previous studies, indoor cats have been suspected to have higher risk of TR than outdoor cats [4], but some studies have not found a difference [16]. We did not find difference in outdoor habits of the cats with or without TR and could not reliably evaluate the effect of neutering and vaccinations due to uneven groups in neutering status and missing values in vaccinations. Considering other diseases, feline infectious peritonitis (FIP), cat flu (including herpes and calici virus), leukaemia virus (FeLV), immunodecifiency virus (FIV) and feline panleukopenia virus were not associated with TR in our study.

Varying results have been published considering the prevalence of TR in different breeds. Our results revealed that TR is highly associated with breed – being purebred was not a risk factor as itself, but the associations concerned certain breeds or breed groups. We found oriental group (Siamese, Balinese, Oriental, Seychellois), British, Cornish Rex, European, Norwegian Forest Cat and Ragdoll in higher risk for TR. Interestingly, the only breed having less TR than our comparison group of house cats was Turkish van. Siamese, Cornish Rex and European have been found to be predisposed to TR also before [7,11,13]. The breed predisposition might indicate a genetic component in the aetiology of the disease. Some breeds might be genetically predisposed to dental and oral diseases in general. Exposition to several dental and oral diseases at the same time in cats have been observed in our previous study [11], in which, for example Cornish Rex and the oriental group (Siamese, Balinese, Oriental, Seychellois) were predisposed to periodontitis and stomatitis at the same time. However, it seems that not all breeds that were associated with TR have the predisposition to other dental and oral diseases. In our study, European was associated with TR whereas the previous study did not find European to be predisposed to other dental diseases [11]. The causalities between dental and oral diseases are unclear, as they can occur on their own or with other oral diseases. Breeder's influence on the prevalence of tooth resorption, stomatitis and periodontitis in the breed has also been suspected [11]. This is an interesting speculation, since this can indicate heritability or similarity in environmental factors and infections. Further analysis of the genetic background of tooth resorption would require a clinical trial where the type of resorption and dental health of the controls could be determined via radiography.

Because the data were collected in a cross-sectional manner, only the effect of permanent risk factors such as breed, age and gender can be considered causal, since they have been permanently present before the disease. However, other factor found significant are potential risk or protective factors that should be verified with clinical trials or observational follow-up studies.

Conclusions

We have performed the first large scale population study of TR and identify several predisposing factors. Old age, stomatitis and periodontitis were risk factors for TR. Together with age, risk to have TR was associated with gingivitis and dental calculus, suggesting that young cats that are susceptible to tooth resorption associated with gingivitis could be helped with proper dental hygiene. In addition, keeping food available constantly was a potential protecting factor. Finally, certain breeds appeared more predisposed to TR, suggesting a genetic contribution to the aetiology of the disease.

Materials and Methods

The material for this study was part of a cross-sectional online feline health survey targeted to all Finnish cat breeders and owners. The data originated from survey responses between December 2012 to February 2015 and included 8115 cat owners' responses from the feline health survey. The cats belonged to 40 different breeds and non-pedigree house cats. We used sample size requirements for breeds as described by Vapalahti et al [11]. The sample size requirements were met in purebred cats by 13 single breeds and 6 breed groups that consisted of 18 different breeds. The questionnaire included information about the cats themselves, their environment, diseases and behaviour. The diseases were divided into various categories and each category included information whether the diagnosis was made by a veterinarian or by the owner. The content, the questionnaire and data collection methods in detail and some results of the survey have been published previously [11,21,22,23]. Our data consisted of 1) basic information of the cat: breed, registration number, day of birth, possible day of death, gender, neutering, 2) environmental factors: vaccinations, outdoor habits, diet, home environment, and 3) disease categories and specific diagnoses, of which only oral and dental diseases, autoimmune diseases and viral infections were considered. The differential diagnoses in dental and oral diseases were malocclusion, gingivitis, stomatitis, periodontitis, tooth resorption (in the survey feline odontoclastic resorptive lesion FORL), dental calculus, tooth fracture and abnormal number of teeth.

The age of the cat was determined by the date of birth and the date of response. Age was categorized into age groups: <1 year, 1 to <3 years, 3 to <7 years, 7 to <11 years, and at least 11 years. For multivariable analysis the following age groups were used: <7 years, 7 to < 11 years, and at least 11 years. The gender of the cats was coded as 'male (1) and 'female' (2) and neutering as 'yes' (1) and 'no' (0). The association of TR with other conditions was studied both at the level of disease categories and at specific diagnosis level. As an exception to other disease categories, in dental and oral disease category only the veterinarian's diagnoses were included in the study. In other disease categories, the initial options 'veterinarian's diagnosis' or 'own diagnosis' were summed up to option 'yes' (1) if either option was selected. 'Not known' responses were coded as missing. Finally, reencoding included two options: 'yes' (1) and 'no' (0). In the analysis of specific diagnoses, coding 'yes (1)' or 'no (0)' was used. The environmental questions, such as diet and vaccinations, were coded similarly.

Those cats that had been responded to have veterinarian diagnosed tooth resorption in the health survey, were determined as TR-cats. When evaluating breed associations, we used house cat as the reference group. Even though logistic regression analysis is not the primary method to be used in data based on cross-sectional study, it gives reliable results when the prevalence of the issue (here TR) is less than 5% [24] (3.9% in our study). Demographic and environmental factors of cats were examined and tabulated. The prevalence of veterinarian diagnosed tooth resorption in different breeds and age groups was calculated with cross tabulation. Cross tabulation was used also to evaluate the associations of TR with gender, other diseases and environmental factors. The 95% confidence intervals for prevalence was calculated with Epitools [25] using the Wilson method [26]. Statistical significance of associations in cross tabulation were evaluated with Fisher's exact test for two-categorical variables, Chi-square test for multicategorical and Kruskal-Wallis test for ordinal variables. After cross tabulations, variables at level $P < 0.2$ in basic tests were further analysed individually in multivariable logistic regression with confounding factors. According to literature, age, gender and breed were considered as confounding factors [27].

Multivariable logistic regression modelling was performed to find the best model with the most important risk factors. Interactions until the second order and multicollinearity between variables were tested. The model selection was performed by backward selection and goodness of fit statistics. P-value <0.05 of Wald chi-square was set to cut off value for significance. Goodness of fit of the model was evaluated with McFadden index and Akaike information criterion (AIC) and the predictive value by the area under the curve (AUC) of the receiver operating characteristic (ROC) curve. Multicollinearity between variables was estimated by Phi coefficient – the limit value for strong correlation was set at 0.5 [28]. Microsoft Office Excel 2010 was used for data editing and IBM SPSS Statistics, Version 22–24 for statistical analysis and SAS version 9.4, SAS Institute Inc., Cary, NC in final logistic regression modelling.

Ethical statement

The data in this study was collected 2012-2015 using an online feline health survey as published by Vapalahti et al.[11]. The data was collected before the onset of the GDPR regulation according to the Finnish legislation https://www.finlex.fi/fi/laki/ajantasa/1999/19990523. This survey study focused on the investigation of cats and not human participants or the cat owners, and therefore a specific ethical approval was not needed. As for the study participants (cat owners), we collected only names and addresses. Owners were informed that the participation is voluntary, confidential, and that the data is used only for scientific purposes. We received informed consents from all participants.

Additional Information

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Competing Interests

The authors have declared that no competing interests exist.

References

1. Reiter, A., Mendoza, K. Feline odontoclastic resorptive lesions – an unsolved enigma in veterinary dentistry. Vet Clin Small Anim. 2002; 32: 791-837.
2. Gorrel, C. Small Animal Dentistry. 1 st ed. China: Saunders Elsevier; 2008.
3. Okuda, A., Harvey, C. Etiopathogenesis of feline dental resorptive lesions. Vet Clin Small Anim. 1992; 22: 1385-1403.
4. Scarlett, J. M., Saidla, J., Hess, J. Risk factors for odontoclastic resorptive lesions in cats. JAAHA. 1999; 35: 188-192.
5. DeLaurier, A., Boyde, A., Jackson, B., Horton, M., Price, J. Identifying early osteoclastic resorptive lesions in feline teeth: a model for understanding the origin of multiple idiopathic root resorption. J. Periodont Res. 2009; 44: 248-257.
6. Harvey, C. Feline dental resorptive lesions. Semin Vet Med Surg. 1993; 8: 187-196.
7. van Wessum, R., Harvey, C., Hennet, P. Feline dental resorptive lesions prevalence patterns. Vet Clin Small Anim. 1992; 22: 1405-1415.
8. DuPont, G., DeBowes, L. Comparison of periodontitis and root replacement in cat teeth with resorptive lesions. J. Vet Dent. 2002; 19: 71-75.
9. DuPont, G. Radiographic evaluation and treatment of feline dental resorptive lesions. Vet Clin Small Anim. 2005; 35: 943-962.
10. Girard, N., Servet, E., Biourge, V., Hennet, P. Feline tooth resorption in a colony of 109 cats. J. Vet Dent. 2008; 25: 166-174.
11. Vapalahti, K., Virtala, A-M., Joensuu, T., Tiira, K., Tähtinen, J., Lohi, H. Health and behavioral survey of over 8000 Finnish cats. Frontiers Vet Sci. 2016; 3: 70.
12. Greiner, M., Pfeiffer, D., Smith, R. D. Principles and practical application of the receiver-operating characteristic analysis for diagnostic tests. Prev Vet Med. 2000; 45: 23–41.
13. Coles, S. The prevalence of buccal cervical root resorptions in Australian cats. J. Vet Dent. 1990; **7**: 14–16.
14. Lund, E., Bohacek, L., Dahlke, J., King, V., Kramek, B., Logan, E. Prevalence and risk factors for odontoclastic resorptive lesions in cats. JAVMA. 1998; 212: 393-395.
15. Ingham, K., Gorrel, C., Blackburn, J., Farnsworth, W. Prevalence of odontoclastic resorptive lesions in a population of clinically healthy cats. JSA. 2001; 42: 439-443.
16. Pettersson, A., Mannerfelt, T. Prevalence of dental resorptive lesions in Swedish cats. J. Vet Dent. 2003; 20: 140-142.
17. Reiter, A., Lyon, K., Nachreiner, R., Shofer, F. Evaluation of calciotropic hormones in cats with odontoclastic resorptive lesions. AJVR. 2005; 66: 1446-1452.

18. Mestrinho, L., Runhau, J., Braganca, M., Niza, M. Risk assessment of feline tooth resorption: a portuguese clinical case control study. J. Vet Dent. 2013; 30: 78-83.
19. Gorrel, C. Tooth resorption in cats: patophysiology and treatment options. JFMS. 2015; 17: 37-43.
20. Reiter, A., Lewis, J., Okuda, A. Update on the etiology of tooth resorption in domestic cats. Vet Clin Small Anim. 2005; 35: 913-942.
21. Lemmons, M. Clinical feline dental radiography. Vet Clin Small Anim. 2013; 43: 533-554.
22. Ahola, M. K., Vapalahti, K., Lohi, H. Early weaning increases aggression and stereotypic behaviour in cats. Sci Rep. 2017; **7**: 10412.
23. Salonen, M. K., Vapalahti, K., Mäki-Tanila, A., Lohi, H. Breed differences of heritable behaviour traits in cats. Sci Rep. 2019; 9: 7949.
24. Dohoo, I., Martin, W., Stryhn, H. Veterinary Epidemiologic Research. The University of Prince Edward Island, Ver Inc, Charlotteville; 2009.
25. Sergeant, ESG. Epitools epidemiological calculators. Aus Vet animal health services and Australian biosecurity cooperative research centre for emerging infectious disease. http://epitools.ausvet.com.au (2017).
26. Brown, L. D., Cat, T. T., DasGupta, A. Interval estimation for a proportion. Stat Sci. 2001; 16: 101-133.
27. Houe, H., Ersbøll, A. K., Toft, N. Introduction to Veterinary Epidemiology. Biofolia, Denmark; 2004.
28. Pett, M. A. Nonparametric Statistics for Health Care Research: Statistics for Small Samples and Unusual Distributions. Sage Publications, United States; 1997.

Author contributions

H.N., A-M.V. K.V. and H.L conceptualized and designed the experiment. H.N. made the preliminary analysis and K.V. performed the multivariable analyses. K.V. and H.N. drafted the manuscript, which was edited and contributed by H.L and A-M.V. All authors approved the final version of the manuscript.

Supporting information

Data available: Supplementary Tables S1-S4 and S5

Figure Legends

Figure 1. Dental calculus and gingivitis by age groups in cats with and without tooth resorption. Demonstrative bar chart of subgroup formation in the interaction between age, dental calculus and

gingivitis in the multivariable logistic regression model of the risk factors for veterinarian diagnosed tooth resorption (Finnish cats in data collected during 12/2012–2/2015 in an internet survey). Blue = percentage of cats with dental in the age group. Grey = percentage of cats with no dental calculus in the age group. Horizontal black lines in blue and grey bars: proportion of gingivitis in cats with dental/without calculus under the line.

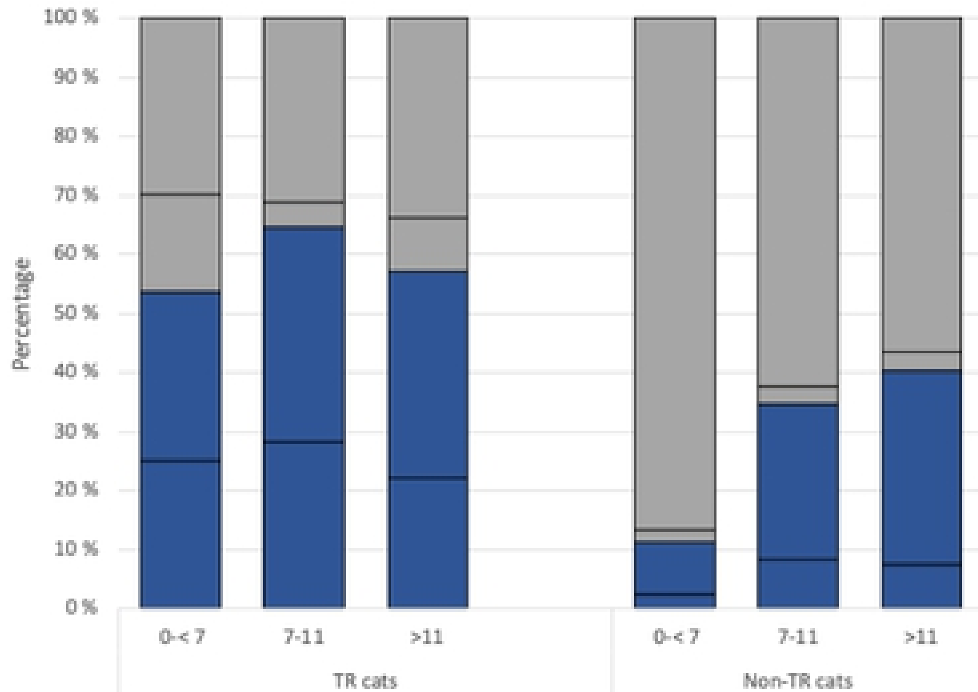
100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
Percentage
0-< 7
7-11
>11
TR cats
0-< 7
7-11
>11
Non-TR cats

Figure 1