Feline tooth resorption findings from a questionnaire survey on 8115 Finnish cats and a case-control study for a more defined population drawn from the survey

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Abstract

Tooth resorption (TR) is one of the most common dental diseases in cats. It is a painful disease characterised by progressive dental destruction, which eventually results in loss of teeth. The aetiology of the disease remains unclear, but associations with old age, breed, other oral and dental diseases, and certain environmental factors have been suspected. We collected health and environmental information of 8115 Finnish cats from 41 breeds through an online survey for cat owners to study TR in Finland with an observational study. The frequency of TR that the owner reported as veterinarian-diagnosed was 3.9% in the entire data (316/8115) and 15% in cats that the owner reported as having veterinarian-diagnosed oral or dental disease (316/2070). We determined the risk factors and breed variation of feline TR by logistic regression with the entire data and a case-control study in a more defined population drawn from the entire data. In the entire data, we defined those cats that the owners had reported as being diagnosed with TR by a veterinarian as TR-cats and compared them to all other cats. In the case-control study, we included only cats with owner-reported veterinarian-diagnosed oral and dental diseases. We defined cats with TR-diagnosis made under sedation as TR-cases. Other veterinarian-diagnosed TR-cats were excluded. Cats with other oral and dental diseases were used as controls. The model with the entire population included 308 TR-cats compared with 7508 cats, and the case-control study included 198 TR-cats and 1683 controls. Although the diagnoses were reportedly made by a veterinarian, the owner answered the survey and might have understood, remembered, or interpreted the diagnoses in a way that could affect the results. The results indicated an increasing risk of TR with age. Dental calculus, gingivitis, and periodontitis were potential risk factors for TR. These findings and the interaction between dental calculus and gingivitis suggest that inflammatory changes caused by dental calculus increase the risk of TR. Keeping food available constantly was a potential protective factor. We found that Cornish Rex, European, and Ragdoll breeds were at higher risk for TR. The observed differences between breeds highlight a genetic contribution.

Keywords: cat, feline, tooth resorption, FORL, dental, oral disease

Introduction

Tooth resorption (TR) is one of the most common dental diseases in cats. It is a painful disease characterised by progressive dental destruction, which eventually results in loss of teeth. Dental radiography is required to evaluate the overall situation (Reiter and Mendoza, 2002). Prevention of TR is not possible as the aetiology is still unknown. The goal of treatment is to relieve pain and discomfort caused by these lesions (Gorrel, 2008). The leading cause of destruction is odontoclasts, multinuclear cells that resorb mineralised tissue (Okuda and Harvey, 1992). Odontoclasts are responsible for the resorption of deciduous teeth in young animals, but their abnormal activity in permanent teeth is the cause of TR (Scarlett et al., 1999). 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 (DeLaurier et al., 2009). As the pathogenesis of tooth resorption is unclear, many different terms have been used to describe the lesion, i.e., erosion, neck lesion, and feline odontoclastic resorptive lesion (FORL). The most common term currently used is TR.

Increasing age increases the risk of TR (Coles, 1990; Harvey, 1993; Lund et al., 1998; Ingham et al., 2001; Pettersson and Mannerfelt, 2003; Reiter et al., 2005b; DeLaurier et al., 2009; Mestrinho et al., 2013). Scarlett et al. (1999) reported that cats with previous dental disease (gingivitis, calculus, or periodontal disease) had four to five times higher odds for resorptive lesions than those without the previous dental disease. An association of gingivitis with TR lesions has also been found in some studies (Harvey, 1993; Mestrinho et al., 2013) but not in others (Ingham et al., 2001; Gorrel and Larsson, 2002). However, the methods of Gorrel and Larsson (2002) differed from others as they examined individual teeth histologically. Periodontitis is associated with inflammatory tooth resorption (DuPont and DeBowes, 2002). However, inflammation associated with tooth resorption can cause inflammatory resorption of the surrounding alveolar bone and increase the risk of decreased alveolar bone height (Lemmons, 2013). Farcas et al. (2014) did not find TR more in cats with chronic gingivostomatitis.

The size and origin of the study population and study methods have a major impact on the reported prevalence of TR in previous studies, which range from 29-85% (Table 1). Most studies are based on a small clinical sample (n< 150), and no reports have been published on a large population sample. Studies with the largest sample size are van Wessum (1992) with 432 cats and 62% prevalence, Lommer and Verstraete (2000) with 265 cats and 60.8% prevalence, and Ingham et al. (2001) with 228 cats and 29% prevalence.

Table 1. Prevalence of feline tooth resorption in previous studies.

Reference	Country	Target population	Study population (n), average age (years)	Method	Prevalence (%)
Coles 1990	Australia	General anaesthesia	64, NK	Clinical	52
van Wessum et al. 1992	Netherlands	Dental procedure	432, NK	Clinical	62
van Wessum et al. 1992	United States	Dental procedure	78, NK	Clinical and radiographs	67
Lund et al. 1998	United States	General anaesthesia	145, 7.9	Clinical	48
Ingham et al. 2001	United Kingdom	Clinically healthy test animals	228, 4.9	Clinical and radiographs	29
Lommer and Verstraete 2000	United States	Dental procedure	265, NK	Radiographs	60.8
Pettersson and Mannerfelt 2003	Sweden	Sedation	96, 6.0	Clinical and radiographs	32
DeLaurier et	United	Clinically and	13, NK	Electron	85

al. 2009	States	radiographically normal teeth		microscopy	
Whyte et al. 2020	Spain	Clinical signs of dental disease	59, 8.0 (median)	Clinical and radiographs	66.1

NK = not known

Our first objective was to investigate the frequency of cats that the owner reported as having TR diagnosed by a veterinarian with an extensive population survey. The second objective was to study the risk factors for TR in the entire population and, with a case-control study, in a more defined population of cats with TR-diagnosis made under sedation by a veterinarian compared with cats with other veterinarian-diagnosed oral or dental diseases. We did not specify any hypotheses, but we wanted to explore the possibilities to study this kind of disease with a big observational data.

Materials and Methods

The material for this study was part of a cross-sectional online feline health survey targeted at all Finnish cat owners. The data originated from survey responses between December 2012 and February 2015 and included responses for 8115 cats 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. (2016). The sample size requirements were met in purebred cats by 13 single breeds and six breed groups that consisted of 18 different breeds. There was no random sampling involved since owners themselves selected participation.

The questionnaire included cat-level information about the cats themselves, their environment, diseases, and behaviour. The diseases were divided into various categories, and each category included information on whether the diagnosis was made by a veterinarian or by the owner. The diseases or conditions that the owner reported as being diagnosed by a veterinarian are referred to veterinarian-diagnosed. The content, the questionnaire, and data collection methods in detail and some results of the survey have been published previously by Vapalahti et al. (2016), Ahola et al. (2017) and Salonen et al. (2019). Our data consisted of basic information on the cat (breed, registration number, day of birth, possible day of death, gender, neutering), environmental factors (vaccinations, outdoor habits, diet, home environment), and disease categories and specific diagnoses. The specific diagnoses were considered only in oral and dental diseases, autoimmune diseases, and viral infections. The differential diagnoses in dental and oral diseases were malocclusion, gingivitis, stomatitis, periodontitis, tooth resorption (in the survey as feline odontoclastic resorptive lesion [FORL]), dental calculus, tooth fracture, and an abnormal number of teeth.

The age of the cat was the difference between the date of birth and the date of response. Age was categorised into the following 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 at the level of disease categories and specific diagnosis level. As an exception to other disease categories, in the 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 the option 'yes' (1) if either option was selected. 'Not known' responses were coded as missing. Finally, re-encoding included the 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 with a veterinarian-diagnosed TR, as reported by the owner in the health survey, were considered TR-cats and are referred to as veterinarian-diagnosed TR-cats. Demographic and environmental factors of cats were examined and tabulated. The frequency of veterinarian-diagnosed TR in different breeds and age groups was calculated with cross-tabulation. Cross tabulation was also used to evaluate the associations of TR with gender, other diseases, and environmental factors. The 95% confidence intervals (CI) for prevalence were calculated with Epitools (Sergeant, 2017) using the Wilson method (Brown et al., 2001). Statistical significance of associations in cross-tabulation was evaluated with Fisher's exact test for two-categorical variables, Chi-square test for multicategorical variables, and Kruskal-Wallis test for ordinal variables. After cross-tabulations, variables at level $P<0.2$ in basic tests were further analysed individually in preliminary logistic regressions with confounding factors. According to the literature, age, gender, and breed were considered confounding factors (Houe et al., 2004). Variables with P-value <0.05 (Wald chi-square) were qualified for the multivariable logistic regression modelling for TR's most important risk factors. For modeling, variables with uneven groups or multiple missing values were excluded if the reliable analysis was compromised.

Modelling was first performed with the entire population, and we compared all cats with veterinarian-diagnosed TR with all the cats without TR based on the survey. Secondly, to minimise the dispersion and selection bias of the multivariable model, we further defined a more specified population for a case-control study. In this second multivariable modelling, TR-cases were veterinarian-diagnosed TR-cats that the owner mentioned as being sedated during the veterinarian's examination (clarified in the open-ended question field). These cats are referred to as under sedation diagnosed TR-cats. Other veterinarian-diagnosed TR-cats were excluded. We used cats with other veterinarian-diagnosed oral or dental disease as controls. Instead of using breed as an organisational level variable, we used it as an independent variable since we were interested in its association with TR. When evaluating breed associations, we used house cats as the reference group.

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. The goodness of fit of the model was evaluated with deviance and Pearson goodness-of-fit statistics, 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 (Pett, 1997). Microsoft Office Excel 2010 was used for data editing, IBM SPSS Statistics, version 22-24, Chicago, USA for statistical analysis, and SAS version 9.4, SAS Institute Inc., Cary, NC for final logistic regression modelling.

Results

Frequency of tooth resorption

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

We did not find any significant difference between TR frequency in purebred cats and non-pedigree house cats (3.8%, 95% CI 3.4–4.3 and 4.2%, 95% CI 3.3–5.3, respectively; P=0.551, Fisher). However, in some breeds, the frequency was much higher or lower than in the entire population or in house cats. High TR frequency was observed in Siamese (9.9%), Abyssinian

(9.3%), Oriental Shorthair (9.1%) and Cornish Rex (8.9%) but was considerably 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.

Based on open-ended question field, the diagnosis of TR was made under sedation in 202 of 316 veterinarian-diagnosed TR-cats (64%). Of these, 169 cats had teeth extractions due to TR (84%).

Factors associated with tooth resorption

From the feline health survey (Vapalahti et al., 2016), a total of 51 factors (Supplementary Table S1) were examined that were known to be or could 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 16 factors (P <0.05) (Supplementary Tables S2 - S4) to be approved into the multivariable logistic regression modelling. These 16 factors were age, breed, gender, food availability, gingivitis, stomatitis, periodontitis, dental calculus, tooth fracture, an abnormal number of teeth, cat flu, musculoskeletal disease, digestive tract disease, respiratory system disease, endocrinological disease, and tumours. Most of the cats were neutered and thus the size of 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 and association with tooth resorption (only P < 0.2 shown).

Variable	**Diagnosed**			**Not diagnosed**			
	N	**%**	**95% CI**	**N**	**%**	**95% CI**	**P-value**
Age, years	311			7631			**<0.001**
< 1	0	0.0	0.0–1.2	1119	14.7	13.9–15.5	

Variable	**Diagnosed**			**Not diagnosed**			
	N	**%**	**95% CI**	**N**	**%**	**95% CI**	**P-value**
1 to <3	8	2.6	1.3–5.0	1973	25.9	24.9–26.8	
3 to <7	76	24.4	20.0–29.5	2490	32.6	31.6–33.7	
7 to <11	115	37.0	31.8–42.5	1197	15.7	14.9–16.5	
≥11	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**
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**

P-value: Fisher or Kruskal-Wallis test. CI = confidence interval. Bolded: selected for further analysis in a logistic regression model with confounding factors age, gender, and breed. The same cat may have had several oral or dental diseases or viral infections.

Multivariable logistic regression model

The model with the entire population included 308 TR-cats compared with 7508 cats, and the case-control study included 198 TR-cats and 1683 controls. The model with the defined population was chosen as the final model because of less dispersion and selection bias. The model with the entire population is shown in Supplementary Table S6. Six 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 age, breed, and periodontitis whereas constant food availability had a significant protective effect.

Breeds with a significantly higher risk for tooth resorption than house cats were Cornish Rex, European, and Ragdoll. Turkish Van and Devon Rex had no TR in the final model.

A significant interaction was found between gingivitis and dental calculus. The interaction demonstrated that gingivitis was a risk factor for TR in the group of cats with dental calculus, whereas the absence of dental calculus seemed to protect cats from TR even if they had gingivitis (Table 3).

The model achieved the best AIC and AUC-values and McFadden index. Deviance and Pearson goodness-of-fit statistics were 0.283 and 0.079, respectively. The AUC-value for the ROC-curve was 0.771 (95% CI 0.738–0.804), which makes the predictive value of the model moderate (Greiner et al., 2000). McFadden's goodness-of-fit index was 0.14. The goodness of fit and predictive value tests for the final model were mainly good or moderate.

The model from the entire study population suggested parallel results, except that stomatitis and more interactions and breeds appeared to be risk factors. However, there was high dispersion (Deviance=0.08 and Pearson≤0.001) in this model. A larger population might lead to higher bias, especially regarding owner-evaluated information about dental diseases in the comparison group.

Table 3. Multivariable logistic regression model of the risk factors for reportedly under sedation diagnosed tooth resorption.

Variable	**B**	**Se**	**Wald**	**P**	**OR**	**95% CI**	**df**
Constant	-1.93	0.27	49.22	<0.001			1
Age: <7	Ref						2
7-<11	1.17	0.20	34.05	<0.001	3.23	2.18 – 4.79	1
≥11	1.33	0.22	36.92	<0.001	3.76	2.45 – 5.77	1
Breed: House cat	Ref						20
Cornish Rex	0.83	0.32	6.81	0.009	2.30	1.23 – 4.28	1
European	1.03	0.35	8.50	0.004	2.79	1.40 – 5.55	1
Ragdoll	0.97	0.38	6.41	0.011	2.65	1.25 – 5.62	1
Food available vs no	-0.40	0.17	5.71	0.017	0.67	0.48 – 0.93	1

Oral /dental diseases							
Periodontitis vs no	0.60	0.28	4.45	0.035	1.82	1.04 – 3.18	1
Interaction gingivitis x dental calculus	1.90	0.36	27.15	<.0001			
Gingivitis vs no when no dental calculus					0.38	0.21 – 0.68	1
Gingivitis vs no when dental calculus					2.51	1.68– 3.76	1

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}=198 and $n_{controls}$=1683.

Discussion

This is the first study of TR and its associated factors in a large population sample. We identified several predisposing factors, such as dental calculus, gingivitis, and periodontitis, and demonstrate increased risk with age. Food availability was found as a protective factor. Breed-specificity was also observed, suggesting a genetic contribution to the aetiology of the disease.

Our study was not a prevalence study for TR, since not all cats were examined for TR with radiography as in clinical studies. Additionally, we did not have random sampling from the target population. The frequency of veterinarian-diagnosed TR in this study was low (3.9%), but the frequency of TR in the group of cats with veterinarian-diagnosed oral or dental disease (15%) is closer to that found in clinical studies. As the definitive diagnosis of TR requires clinical examination and dental radiographs under sedation, a cross-sectional questionnaire study is expected to reveal a low frequency. In contrast, clinical studies of cats seeking dental treatment describe the frequency of TR in the chosen study population rather than the prevalence in the entire cat population. When comparing the model of the entire population (cats with veterinarian-diagnosed TR compared to all cats without TR based on the survey) with the defined model (cats with under sedation diagnosed TR compared with cats with other veterinarian-diagnosed oral or dental diseases), the results of the models remained somewhat similar. Some differences concerning interactions and significant breed associations were found. We did not specifically ask about dental radiographs, which is a limitation of this study. Both models might have also included cats with TR as controls, as the controls were not shown to be healthy with dental radiography. Therefore, our associations may be underestimations. Although the diagnoses were reportedly made by a veterinarian, the owner answered the survey. The owners might have understood, remembered, or interpreted the diagnoses in a way that could affect the results.

The prevalence of TR in studies that have clinically evaluated the teeth is usually between 29-67% (Table 1). The age and selection of the research population have a major impact on prevalence. If the target population consists of cats seeking dental treatment routinely or because of dental disease, the prevalence of TR is expected to be higher than in healthy cats. The methods used to detect TR lesions also affect prevalence. The most obvious lesions are found in the general examination without sedation, but examination with a dental probe under anaesthesia is required for most lesions. Only lesions in the cementoenamel junction or the crown area can be detected clinically. Use of dental radiographs increases the prevalence even further when lesions in the root area are detected.

Varying results have been published regarding the frequency of TR in different breeds. Our results revealed that TR is highly associated with the breed. While being purebred was not a risk factor in itself, some associations were observed with certain breeds. We found that Cornish Rex, European, and Ragdoll are at a higher risk for TR in the final multivariable model. In a recent study, Mestrinho et al. (2018) found a higher frequency of TR in Persian and Exotic cats. 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. Exposure to several dental and oral diseases at the same time in cats was observed in our previous study (Vapalahti et al., 2016), in which, 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 associated with TR have a predisposition to other dental and oral diseases. In our study, European was associated with TR, whereas the previous study did not find Europeans predisposed to other dental diseases (Vapalahti et al., 2016). The causalities between dental and oral diseases are unclear, as they can occur on their own or with other oral diseases. 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 and genetic analyses.

We found several oral and dental diseases that are associated with TR. The found interaction between gingivitis and dental calculus revealed that gingivitis is a risk factor for TR in the group of cats with dental calculus. The absence of dental calculus seemed to protect cats from TR even if they had gingivitis. Gorrel's (2015) theory suggests that tooth resorption consists of at least the following two aetiologically different diseases: inflammatory type 1 resorptions and idiopathic type 2 resorption. Tooth resorption lesions often include inflammation of the adjacent gingiva (Reiter et al., 2005a), making it difficult to assess causation between TR and gingivitis. Bacteria in dental plaque may initiate inflammatory resorption (Booij-Vrieling et al., 2010). Dental calculus causes gingivitis in cats, as reported by Thengchaisri et al. (2017). Our findings might suggest that dental calculus causing gingivitis increases the risk of TR.

In addition to gingivitis and dental calculus, periodontitis was a risk factor for TR in our study. Periodontitis is related to TR (Scarlett et al., 1999) and is linked in particular with type 1 tooth resorption (DuPont and DeBowes, 2002). In contrast, inflammation caused by tooth resorption is suspected to cause periodontal lesions (Lemmons, 2013). In a recent study by Whyte et al. (2020), no relationship between TR and periodontitis was found. Although periodontitis would most likely be associated with inflammatory type 1 resorption, the type of TR was not determined in our study.

Stomatitis was not associated with TR in our final multivariable model. However, the low number of cats with stomatitis prevented us from studying this connection properly. Although DuPont and DeBowes (2002) found a connection between inflammatory type 1 resorptions and stomatitis, Reiter et al. (2005a) did not find a relationship. It was previously suspected that chronic stomatitis caused by the feline calici virus (FCV) impacts development of TR (Reiter and Mendoza, 2002). However, Thomas et al. (2017) recently found that FVC was associated with feline chronic gingivostomatitis, but not with TR.

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

Our findings that the frequency of TR increases with age (Coles, 1990; Harvey, 1993; Lund et al., 1998; Ingham et al., 2001; Pettersson and Mannerfelt, 2003; Reiter et al., 2005b; DeLaurier et al., 2009; Mestrinho et al., 2013) and gender not being associated with TR are consistent with previous studies (Scarlett et al., 1999; Coles, 1990). Scarlett et al. (1999) suspected that indoor cats have a higher risk of TR than outdoor cats, but Pettersson and Mannerfelt (2003) did not find a difference. We did not find a difference in the outdoor habits of cats with or without TR. We 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 calicivirus), leukaemia virus (FeLV), immunodeficiency virus (FIV), and feline panleukopenia virus were not associated with TR in our study.

Due to the cross-sectional data collection, only the effect of permanent risk factors such as breed, age, and gender can be considered causal since they were permanently present before the disease. However, other significant factors that are potential risk or protective factors should be verified with clinical trials or observational follow-up studies.

Conclusions

In the first large-scale population survey, the frequency of TR was considerably lower than in studies that have clinically evaluated the teeth. We identified several predisposing factors – dental calculus, gingivitis, and periodontitis. These findings suggest that inflammatory changes caused by dental calculus might increase the risk of TR. In addition, risk of TR increased with age, but keeping food available constantly was a potential protective factor. Finally, certain breeds appeared more susceptible to TR, suggesting a genetic contribution to the aetiology of the disease.

Ethical statement

The data in this study were collected 2012-2015 using an online feline health survey published by Vapalahti et al. (2016). The data were collected before the onset of the GDPR according to the Finnish legislation https://www.finlex.fi/fi/laki/ajantasa/1999/19990523. This survey study focused on investigating cats and not human participants or the cat owners, and therefore a specific ethical approval was not needed. We collected only the names and addresses of the study participants (cat owners). Owners were informed that participation is voluntary, confidential and that the data are used only for scientific purposes. We received informed consent from all participants.

Additional Information

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Competing Interests

The authors have declared that no competing interests exist.

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Author contributions

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

Supporting information

Data available: Supplementary Tables S1-S4, S5 and S6.