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ORIGINAL PAPER

Dental morphology and pathology in the Scandinavian red fox (*Vulpes vulpes*)

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Abstract

The aims of this study were to investigate dental anomalies, variations and pathology in the red fox (*Vulpes vulpes)* in Sweden. Heads from 55 free-ranging red foxes, all obtained through legal hunt, from the south and western parts of Sweden, were examined macroscopically and radiographically for dental anomalies, variations, and pathology. Seventeen foxes which correspond to 31% of the specimens had an incomplete dentition. In total, 43 teeth were missing leaving 2267 out of 2310 teeth for examination. The three most common macroscopic findings in the 2267 teeth were: attrition/abrasion (n = 149, 6.5%), uncomplicated crown fractures (n = 130, 5.7%) and localized enamel defects (n = 49, 2.2%). The three most common radiographic findings were radicular developmental grooves (n = 313, 13.8%), periapical radiolucency (n = 134, 5.9%) and dilaceration (n = 52, 2.3%). Malocclusions were found in four foxes (7.3%). No deciduous teeth or mixed dentition were observed. Radicular developmental grooves and dilacerations in tooth roots were common findings in the examined foxes. Radicular developmental grooves are to be considered as normal features and dilaceration as a variation of tooth morphology rather than anomalies. As in many other carnivores, dental trauma was a common finding. Attrition, abrasion, uncomplicated and complicated crown fractures, and their consequences, may have adverse implications on the red fox in Sweden´s ability to hunt, and its quality of life.

Keywords Abrasion · Attrition · Dental radiography · Dental fracture · Dental trauma · Radicular developmental groove

Background

The red fox (*Vulpes vulpes*), a member of the Canidae family, is one of the most common and well-known species of the genus Vulpes. It is widely distributed across the entire northern hemisphere from the Arctic Circle to North Africa, from Central America to the Asiatic steppes and although not indigenous, even in Australia (Lariviére and Pasitschniak-Arts 1996).

In Sweden, the species is spread throughout the entire country. According to the Swedish Hunting Association, the population of red foxes in Sweden (2023) was estimated at about 150.000 individuals (Svenska Jägarförbundet 2012).

Wide individual and geographical variations in size exist. Body-mass varies between 3–14 kg even if a weight of 5–8 kg is more common. Males are on average larger than females. The average lifespan for Swedish free ranging foxes is 8–10 years (Lariviére and Pasitschniak-Arts 1996; Svenska Jägarförbundet 2012).

The red fox has a diphyodont dentition, with 28 primary teeth and 42 permanent teeth (Lariviére S, Pasitschniak-Arts 1996). As in domestic dogs, the dental formula for permanent teeth includes incisor (I), canine (C), premolar (P) and molar (M) teeth (I 3/3, C 1/1, P 4/4, M 2/3). The maxillary fourth premolar and the mandibular first molar teeth represent the carnassial teeth. Compared to teeth in domestic dogs, fox teeth are pointed and slender (Lariviére and Pasitschniak-Arts 1996; Svenska Jägarförbundet 2012).

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In the red fox, like in other brachydont species, teeth with a wide pulp cavity, incomplete development of the tooth roots and open root apices indicate a juvenile individual. Closure of the root apices and a gradual decrease in pulp cavity volume reflects the aging process of the individual from young adult, adult to old (Morgan and Miyabayashi 1991; Reiter and Gracis 2018).

There is limited literature regarding dental pathology in the red fox in Sweden. However, studies characterizing dental anomalies, variations, and pathology in foxes from other countries, for example the United States, Poland, Finland, Czech Republic, Netherlands, France, and Lithuania, have been published (Gisburne and Feldhamer 2005; Atchley et al. 2023; Evenhuis et al. 2018; Szuma 1999, 2002; Rantanen and Pulliainen 1970; Nentvichová and Andéra 2008; Van Bree and Sinkeldam 1969; Jurgelénas et al. 2020). Most of these studies focused on tooth number variations, dental morphology and dental anomalies while only a few studies included acquired dental pathology (Atchley et al. 2023; Evenhuis et al. 2018; Rantanen and Pulliainen 1970; Jurgelénas et al. 2020). Only three of these studies performed dental radiography, but only on selected skulls, as part of the examination to confirm or exclude pathology (Gisburne and Feldhamer 2005; Rantanen and Pulliainen 1970; Jurgelénas et al. 2020).

The aims of this study were to characterize different types of dental anomalies, variations, and pathology in the free-ranging red fox in Sweden.

Methods

Heads from 55 free-ranging red foxes, (*Vulpes vulpes*), acquired through legal hunt, from southern and western parts of Sweden were included in this study. All foxes were killed by gunshot but no injuries to the dentition were obtained. Eighteen of the heads were donated from one local hunter, collected for approximately two years. The remaining heads were provided by Accesia AB, an education center for veterinary dentistry, with institutional approval and contract, purchasing fox heads from local hunters. Frozen, defrosted, unprepared heads with specimen number, were examined macroscopically and radiographically for congenital, developmental, and acquired dental anomalies using previously determined criteria (Table 1). All teeth were assessed radiographically for the same anomalies (Table 1). The macroscopic and radiographic examinations were performed by author KA. Assessments of the obtained radiographs were performed by authors KA and DB in agreement. A complete set of intraoral radiographs were obtained for each skull using the recommended views, position, and techniques (Tsugawa AJ and Verstraete FJM 2000; DuPont GA and DeBowes LJ 2009). An indirect digital imaging system was used with size 2, 3 and size 4 photostimulable phosphor plates. (Gendex Expert DC, Gendex Dental Systems, Hatfield, Pa. and Scan X Duo, Air Techniques, Melville, NY). Photographs documented most of the anomalies. Definitions and criteria used in the study are described in detail in Table 1**.**

Based on pulp cavity width and apical root closure on radiographs, the foxes were divided into three groups: juvenile, young adult, and adult. The juvenile group consisted of individuals with an open apex in at least one of the canine teeth and with wide pulp cavities in the remaining dentition, as expected in a juvenile individual. The ratios of the pulp cavity width to the root width at the cementoenamel junction in the maxillary canine teeth were measured and the percentage of the root occupied by the cavity was calculated. The young adult group consisted of individuals with a pulp cavity to tooth root ratio > 10%. The adult group consisted of individuals with a pulp cavity to tooth root ratio approximately 10% or less.

The affected number of teeth were recorded per category and per fox. The affected number of incisor, canine, premolar, and molar teeth were also recorded for every category and per fox. For documentation, compilation and preparation of the results, Excel software was used. No further statistical analysis was performed because of the limited number of specimens. The distribution (number of teeth affected) of abnormal findings in maxillary and mandibular teeth is listed in Table 2.

Results

The study population included 4 females, 3 males and 48 individuals of unknown sex. In total 14.5% (n = 8) of the foxes, or 1% (n = 23) of 2267 evaluated teeth, had open apices, and were defined as juvenile. All teeth affected with open apices were canine teeth. Twenty-five foxes were considered young adults, and 22 foxes were considered adult. Heads with deciduous teeth or mixed dentition were not present. No signs of traumatic damage to the dentition in connection with euthanasia were observed. In total, 51.6% (n = 1170) of the examined teeth presented some sort of variation. Of these, congenital or developmental (including radicular developmental grooves) variations and anomalies presented in 42.5% (n = 497) of the teeth and 57.5% (n = 673) of the teeth were presented with acquired anomalies.

Absence of teeth

The total number of teeth available for examination was 2267 out of a potential of 2310, which equals 98%. In total 17 (30.9%) of the foxes had one or more absent tooth. In total, 43 teeth were absent. Congenital tooth absence accounted

Table 1 Congenital, developmental and acquired abnormalities noted and inclusion criteria

Observation	*Criteria/Definition*
Tooth absent-presumably acquired	Tooth absent, alveolus or remnant alveolus visible macroscopically or on radiograph, alveolar bone shows pathological signs. Occasionally root remnant visible
Tooth absent-presumably congenital	Tooth and alveolus absent, smooth morphologically normal bone present at site. Congenital refers to the existence at or before birth
Tooth absent-presumably developmental	Tooth absent, visible tooth embedded or impacted in the alveolar bone
Malformed tooth	Any form of the crown different from the established form, like microdontia, macrodontia, germination or supernumerary cusps
Microdontia	A tooth that appears smaller than a normal tooth
Macrodontia	A tooth that appears larger than a normal tooth
Gemination	A toothgerms attempt to split. A tooth with two crowns and a single root and rootcanal
Attrition/Abrasion	Tooth with mild wear without tertiary dentin formation, or tooth with severe wear and tertiary formation or exposed pulp
Enamel infraction	Incomplete fractures, micro cracks in the enamel without loss of tooth substance
Enamel fracture	Fracture with loss of crown substance confined to the enamel
Uncomplicated crown fracture (UCF)	Fracture involving the enamel and dentin without exposing the pulp
Complicated crown fracture (CCF)	Fracture involving the enamel and dentin with pulp exposure
Complicated crown root fracture	Fracture involving enamel, dentin, and cementum with pulp exposure
Root fracture	Fracture affecting cementum, dentin, and the pulp
Enamel defect/hypoplasia	Irregular pitting or a band-shaped absence or thinning of enamel consisting with the clinical signs of enamel hypoplasia
Maloccolusion	An occlusion where the mandible was shorter (mandibular retrognathic bite), longer (mandibular prognathic bite) or asymmetric (wry bite), in relation to the maxilla. Jaw lengths resulting in an occlusion of the maxillary and mandibular incisors, cusp to cusp (level bite)
Retained root	Presence of a tooth root in the alveolus, intact or under resorption but clearly visible
Supernumerary root	Increased number of roots from normal
Impacted tooth	Visible tooth still in the alveolar bone unable to erupt because of interference with other teeth or bone (physical barrier)
Embedded tooth	Visible tooth still in the alveolar bone unable to erupt because of lack of eruptive force
Periapical radiolucency	A radiolucent area extending at least 3 mm apical or circumferential around a tooth root apex
Root resorption	Affecting the tooth root. External replacement resorption (loss of dental tissue replaced by bone) or external inflammatory resorption secondary to inflammatory conditions, endo-perio lesions
Radicular groove	Double root shadow caused by radicular developmental groove
Dilaceration	A pronounced curved root apex, compared with the normal tooth root appearance
Horizontal bone loss	Bone loss resulting in alveolar margin being situated below the cemento-enamel junction of the tooth, identified in a radiograph
Vertical bone loss	Bone loss perpendicular to the alveolar margin, following the tooth root, identified in a radiograph
Furcation lesion	Bone loss in the furcation area in two or multi rooted teeth identified in a radiograph

for 39.5% (n = 17) of teeth, developmental tooth absence for 2.3% (n = 1) and acquired tooth absence for 58.1% (n = 25) of the absent teeth. The most commonly congenitally absent tooth was the third mandibular molar tooth, 41% (n = 7), and the first maxillary premolar tooth, 17.6% (n = 3) (Fig. 1). The number of teeth congenitally absent were almost the same in the adult and the young adult group (8 and 9 respectively out of 43 teeth).

Twenty-five teeth were presumed lost due to trauma, representing 1.1% of 2267 examined teeth. The most common teeth to be traumatically absent were the incisor teeth, 32% (n = 8), followed by the first mandibular premolar teeth, 28% (n = 7). Acquired tooth absence was much more common in the adult group (21 teeth out of 43) compared to the young adult and juvenile group (3 respectively 1 out of 43 teeth). In one specimen the left mandibular third molar tooth was absent macroscopically, but was identified on the radiograph, impacted under the second mandibular molar. This was the only developmentally absent tooth, found in a young adult fox. No supernumerary teeth were present.

Dental morphology and malformation

Radicular developmental grooves affecting tooth roots were identified in 13.8% (n = 313) of the evaluated teeth, 9.2% (n = 209) in the mandible and 4.6% (n = 104) in the maxilla

Table 2 The distribution of affected teeth in the maxilla and mandible

Maxilla

Category of anomaly	I^1	I^2	I^3	C^1	P^1	P^2	P^3	P^4	M^1	M^2
Tooth absent	2	3		2	4	1	1	1	1	1
Attrition/abrasion	16	9	7	12	3	6	8	6		
Enamel fracture	1	2	5	2		2	2			
Uncomplicated crown facture	4	8	14	10	14	8	8			
Complicated crown fracture		1	1	9			1	2		
Enamel defect	4	2	3	12	3	1		1		
Staining	18	4	1	4		2	1		6	13
Malformed tooth			2			2				
Supenumerous cusp										
Radicular groove						47	49	8		
Dilaceration						27	2			
Periapical radiolucency	1		1	19			1	2		
Tooth resorption	1			22	1	2	2			
Horizontal bone loss					5	6				
Vertical bone loss				1	3		1			
Retained tooth root	2	2		2	1			1		

Mandible

Category of anomaly	I_1	I_2	I_3	C_1	P_1	P_2	P_3	P_4	M_1	M_2	M_3
Tooth absent	2	1	2		9	3				1	9
Attrition/abrasion	12	15	13	6	5	7	5	8	7	3	1
Enamel fracture			1	1	1	2	3	4		1	
Uncomplicated crown facture		1	4	10	25	14	2	6	2		
Complicated crown fracture				4		2				1	
Enamel defect				14	1	3	2	2	1		
Staining	7	4	3	2					1	5	2
Malformed tooth						2		1			3
Supenumerous cusp							2	11			
Radicular groove						29	27	41	83	29	
Dilaceration					3	1			8	10	1
Periapical radiolucency				24			1		1	3	
Tooth resorption				16				1	1		
Horizontal bone loss	10	12	12		2	4	5	7	6	6	2
Vertical bone loss	14					2	4	3			
Retained tooth root	1	1	2	1	6	3	1			1	

(Table 2 and Fig. 2). The most common teeth identified with radicular developmental grooves in the mandible were the first molar teeth, followed by the second and fourth premolar teeth. In the maxilla, the second, third and fourth premolar teeth were the most common identified. Dilaceration of tooth roots affected 2.3% (n = 52) of the evaluated teeth, 29 in the maxilla and 23 in the mandible (Fig. 3). The most common teeth identified in the maxilla were the second premolar teeth (27 out of 29). In the mandible the first and second molar teeth were most identified with root dilaceration.

Only 1% (n = 23) of 2267 evaluated teeth presented with an abnormal crown morphology. Supernumerary cusps were identified in 0.6% (n = 13) of evaluated teeth. The most common tooth to be identified with this anomaly was the mandibular fourth premolar tooth 0.5% (n = 11), followed by mandibular third premolar tooth 0.1% (n = 2). Microdontia was identified in two heads, bilateral in one and unilateral in the other. In total, 0.1% (n = 3) of the evaluated teeth, all mandibular third molar teeth, had an abnormal small size of the crown (Fig. 4a). Macrodontia was identified in one head. In this head the crown of the right and left second mandibular premolar tooth, were larger than normal and rotated because of lack of space (Fig. 4b). Gemination was present in 0.1% (n = 3) of evaluated teeth in two of the heads.

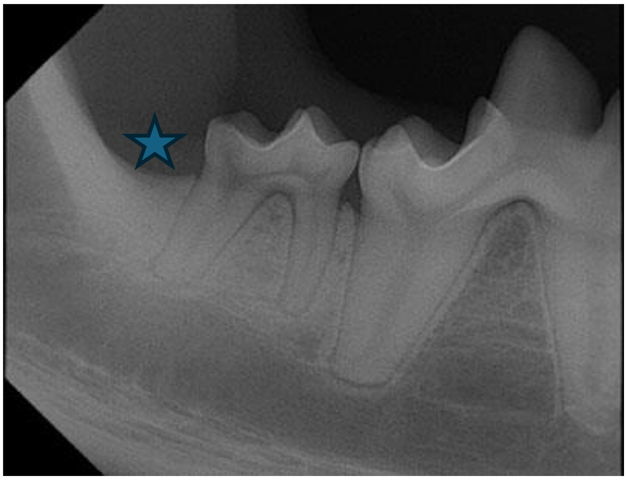

Fig. 1 Absent tooth. The right mandibular third molar tooth congenitally absent (blue star)

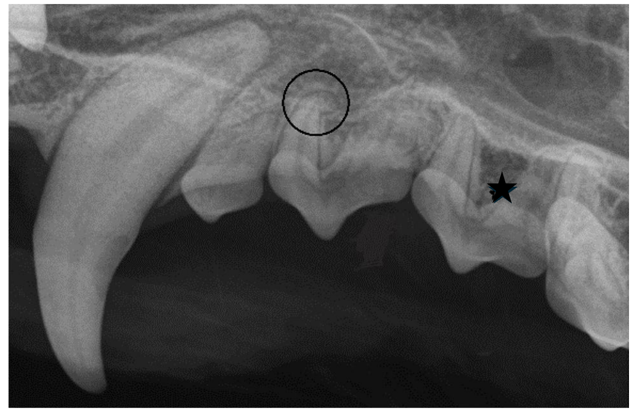

Fig. 3 Dilaceration and radicular developmental groove. Dilaceration in the mesial root of the left maxillary second premolar tooth (black circle) and radicular developmental groove in the left maxillary third premolar tooth (black star) in the same fox

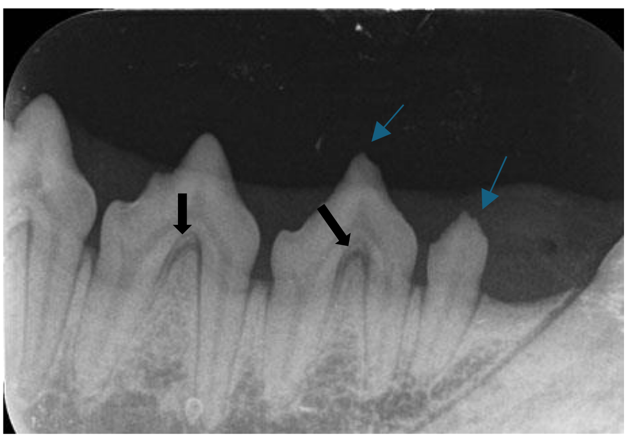

Fig. 2 Radicular developmental grooves and uncomplicated crown fractures. Radicular developmental grooves in the right mandibular second and third premolar teeth (black arrows) and uncomplicated crown fractures in the right mandibular first and second premolar teeth (thin blue arrows) in the same fox

The right and the left second maxillary premolar teeth were affected in one head (Fig. 4c) and the left third incisor in the other.

One head presented with a right mandibular fourth premolar tooth with pronounced cusps and four roots (Fig. 4d). The left third maxillary incisor tooth in one head had an abnormal, curved shape of the tooth crown.

Number of roots

Abnormal number of roots affected in total 0.3% (n = 7) of 2267 evaluated teeth. Three maxillary first premolar teeth presented with an extra root, bilateral in one head and unilateral in the other. Similarly, three first mandibular premolar teeth with a supernumerary root were identified in two specimens. Unilateral in one head and bilateral in the other. In one specimen, the right fourth mandibular premolar tooth had four roots instead of two. The same tooth also showed a pronounced abnormal crown morphology as mentioned above.

Enamel defects

Localized enamel defects were found in 1.9% (n = 44) of evaluated teeth. The most common affected teeth were the canine teeth, 12 in the maxilla and 14 in the mandible. In one skull the left maxillary fourth premolar tooth had a severe enamel defect affecting the crown, resulting in an abnormal form and a crown fracture.

Attrition/Abrasion

Twenty-five percent (n = 14) of the heads, or 6.6% (n = 149) of evaluated teeth was affected by attrition/abrasion. Eight of the heads presented with more than 10 affected teeth. The most common affected teeth were the incisor teeth (maxillary and mandibular) which accounted for 48.3% (n = 72) of teeth with attrition/abrasion, followed by premolar teeth 32.2% (n = 48), canine teeth 12% (n = 18) and molar teeth 7.4% (n = 11) respectively. Most of the heads with attrition/abrasion were found in adult foxes (12 out of 14 heads, 86%). Only one head each in the young adult and the juvenile group were presented with attrition/abrasion constituting 7% each of the heads with this anomaly.

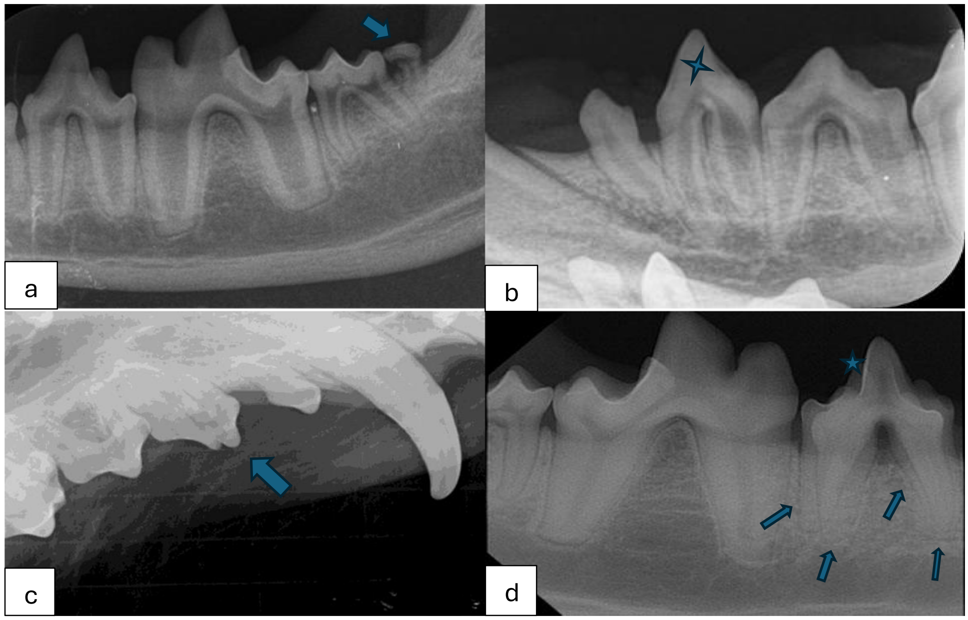

Fig. 4 **a**-**d** Abnormal tooth morphology. **a**. Microdontia in the left mandibular third molar tooth (blue arrow), **b**. Macrodontia in the left mandibular second premolar tooth (blue star), **c**. Gemination in the right maxillary second premolar tooth (blue arrow), **d**. Supernumerous roots (4 blue arrows) and abnormal shape of the tooth crown in the right mandibular fourth premolar tooth (blue star)

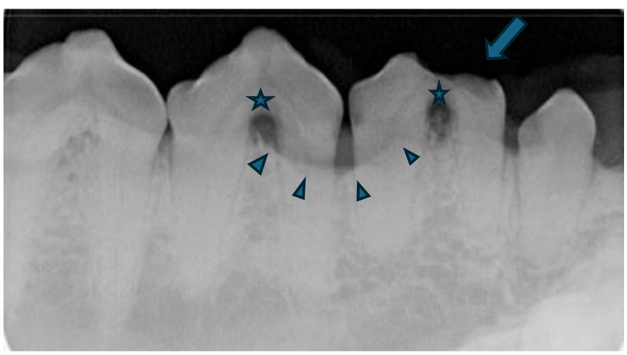

Fig. 5 Complicated crown fracture, horizontal bone loss and furcation lesions. Complicated crownfracture in the right mandibular second permolar tooth (blue arrow) together with horizontal bone loss and furcation exposure in the same tooth, and in the right mandibular third premolar tooth (blue arrowheads and blue stars)

Dental fractures

In 80% (n =44) of the heads or 8.7% (n =197) of evaluated teeth, some type of dental fracture including enamel infractions, enamel fractures, uncomplicated crown fractures, complicated crown fractures, complicated crown root fractures and root fractures was present (Fig. 2 and Fig. 5). The most common fracture type was uncomplicated crown fracture which was almost equally common in the adult (20 heads), as in the young adult group (18 heads). Complicated crow fractures and enamel fractures were more common in the adult group (10 and 13 heads respectively) compared with the young adult group (0 and 6 heads respectively). In the juvenile group one enamel infraction, one uncomplicated crown fracture and one complicated crown fracture were present. Fractures were most often seen in incisor, canine, and premolar teeth and more seldom in the molar teeth. Further, 21(38.1%) of the heads had more than one type of dental fracture. Twenty-one retained tooth roots were presented in 9 (16%) of the heads.

Endodontic disease

Endodontic disease was assessed using dental radiography. In total 2.4% (n =54) of evaluated teeth were affected by periapical radiolucency, 24 teeth in the maxilla and 30 teeth in the mandible.

Periodontitis

Thirty-six percent of the heads had alveolar bone changes consistent with periodontitis. In 3.4% (n =77) of 2267 teeth evaluated horizontal bone loss was present (Fig. 5). The most common affected teeth were the mandibular incisor teeth accounting for 44.1% (n =34) of affected teeth. Vertical bone loss was less common than horizontal bone loss. In total 28 teeth were identified. Five teeth located in the maxilla, 23 in the mandible. Furcation exposure was noted in one head (Figs. 5, 6 and 7).

Other findings

Malocclusion was found in 7.4% (n =4) of the heads, two level bites and two mandibular prognathic bites were present. The heads with level bite, had worn maxillary and mandibular incisors. All the other heads, 92.7% (n =51) had a normal occlusion, scissor bite.

Incorrect positioning of teeth was found in 5.4% (n =3) of the skulls. One head presented with rotation of the right and

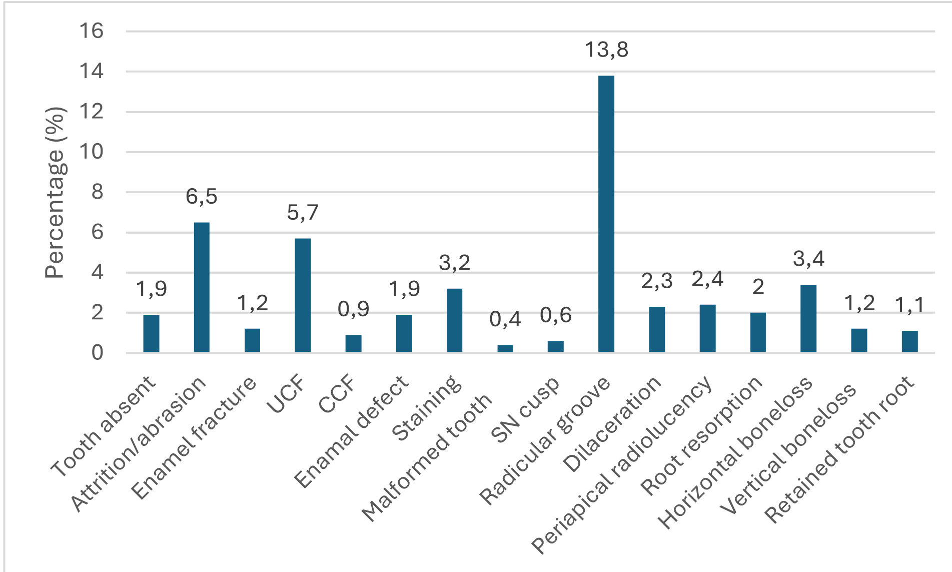

Fig. 6 Percentage of examined teeth (n = 2267) affected by dental anomalies, variations and pathology in the Swedish red fox. UCF denotes uncomplicated crown fracture, CCF denotes complicated crown fracture, SN denotes supernumerary cusps

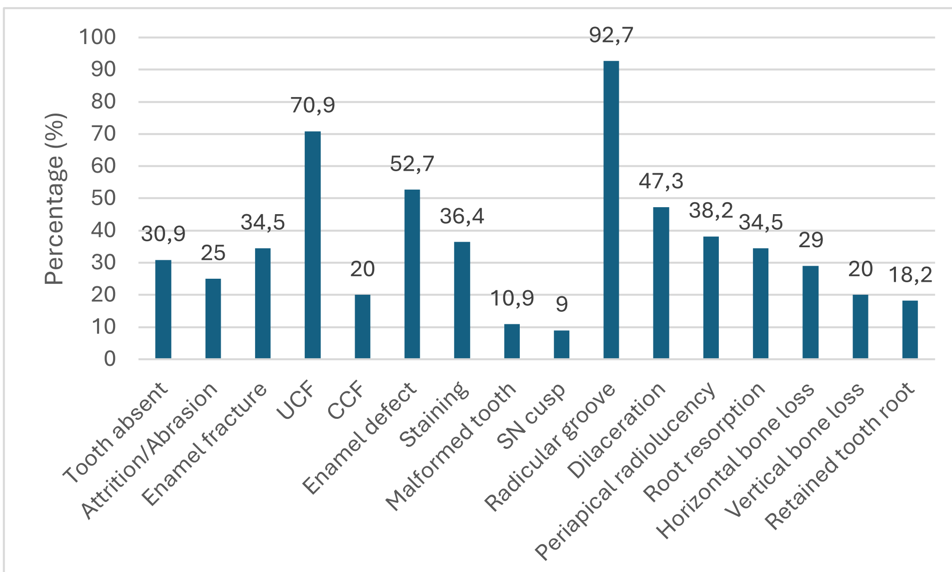

Fig. 7 Percentage of foxes (n = 55) affected by dental anomalies, variations and pathology in the Swedish red fox. UCF denotes uncomplicated crown fracture, CCF denotes complicated crown fracture, SN denotes supernumerary cusps

left second mandibular premolar tooth (the same individual which presented with macrodontia). One head presented with rotation of the right second maxillary premolar tooth and one head with rotation of the right and left maxillary third premolar tooth.

Staining was seen in 36.4% of the heads. Maxillary and mandibular incisors were the most common teeth affected together with the second maxillary molar tooth.

Root resorption was seen in 2% (n = 46) of evaluated teeth, 28 teeth in the maxilla and 18 teeth in the mandible.

Discussion

This study is the first study since 1963 to describe dental anomalies, variations, and pathology in the red fox in Sweden. It shows that deviations are common, both to regard as normal variation and pathologic conditions potentially causing pain and suffering for the animal.

In addition, our study is the first using oral radiography to explore the dentition of free ranging red foxes in

Sweden. Studies based on cadaver examination and radiology enables increased detection of oral pathology compared to ocular evaluation of dry skull specimens.

Absence of teeth

In this study tooth absence was a common finding, as 17 out of 55 (30.9%) foxes were missing one or more teeth. The number of congenitally absent teeth in our study were almost the same in the adult group as in the young adult group (8 and 9 teeth respectively). In young animals, congenital tooth absence is supposedly more common than acquired tooth absence. Acquired tooth absence is more likely to be observed in older animals which was found in our study, where 21 teeth were lost in the adult group, compared to 3 in the young adult group and 1 in the juvenile group, which confirms this assumption.

Previous studies have shown a prevalence of tooth absence between 7.2% and 16.5% in the red fox (Gisburne and Feldhamer 2005; Szuma 1999; Jurgelénas et al. 2020), while a prevalence of 19.8% was found in the grey fox (Gisburne and Feldhamer 2005). Reason for tooth absence was not included. The most common teeth to be absent were the mandibular third molar and the first maxillary premolar teeth.

Genetic variation between species can explain different prevalences of congenital tooth absence (Szuma 1999, 2002; World Health Organization (WHO) 2024). The grey fox is smaller than the red fox, and relative jaw and muzzle length may have some influence on tooth absence. Reduction in relative jaw and muzzle length can lead to crowding and rotation of teeth and in the end a selection for individuals missing the third mandibular molar and the first maxillary premolar tooth, teeth with weak genetic control and little significance in feeding (Gisburne and Feldhamer 2005; Szuma 1999, 2002; World Health Organization (WHO) 2024).

The fact that few other studies included acquired tooth loss may contribute to a higher prevalence of tooth absence in our study. Looking specifically at the frequency of tooth absence of the third mandibular molar tooth supposedly congenitally missing, a more concordant result between our study and other studies was evident (Szuma 1999; Rantanen and Pulliainen 1970; Nentvichová and Andéra 2008; Jurgelénaset et al. 2020).

The most common teeth to be missing due to trauma in our study were the incisors and the mandibular first premolar teeth, followed by maxillary canines. Our result corresponded well with the result in a study from North America of the Grey fox (*Urocyon cinereoargenteus*) (1.1% compared to 0,8%) even though radiographic examination was not included in that study (Evenhuis et al. 2018).

Tooth morphology

Tooth crowns are generally slender and more pointed in the red fox than in domesticated dogs. Studies of red foxes have shown that tooth morphology differ geographically (Szuma 2007, 2008). This biologic variation is caused either by genetic differences; genotypic variation (mutations), or by the effect of environmental factors (climate, food supply, other predators etc.) on the expression of the genetic potentials; phenotypic variation (Szuma 2008). Further, gender differences in tooth morphology also occur, called sexual dimorphism (Szuma 2008). The term anomaly characterizes abnormality, deviation from or divergence from the established norm (Nentvichová and Andéra 2008). The same feature may be considered an anomaly by some and an expression of natural variation by others.

Radicular developmental grooves are normal features in carnivores and are previously described in the red fox (Mitteilung 1955). The prevalence is, however, not well studied as most studies do not include dental radiography and to the author´s knowledge it has not been reported earlier. Domesticated dogs have radicular developmental grooves, most prominent in the mesial root of the mandibular first molar tooth (Reiter and Gracis 2018; Tsugawa and Verstraete 2000; DuPont and DeBowes 2009). In our study radicular developmental grooves were seen in almost all (92.7%) of the heads. The fact that dental radiography was performed of all heads may explain the high detection rate of radicular developmental grooves, not only in the first mandibular molar tooth. The frequent appearance of these developmental grooves in the red fox in Sweden may be considered as normal feature rather than an anomaly.

Another finding was root morphotype dilaceration. Dilaceration was more often present in the maxilla rather than in the mandible. No other study has investigated the prevalence of dilaceration in the red fox, however other root morphotype like fused roots are mentioned in one study (Nentvichová and Andéra 2008).

One further finding was supernumerary roots. The cause of supernumerary roots is not fully understood (Pavlica et al. 2001). Trauma or infection during odontogenesis and root formation may be a possible explanation for supernumerary roots (Bittegeko et al.1995). In the domestic dog the most common teeth to have supernumerary roots are the second and third maxillary and mandibular premolars (Pavlica et al. 2001).

In our study supernumerary roots were found in 9% of the heads, primarily in the maxillary and mandibular first premolar teeth. Another study reported a prevalence of 5.7%, not only the first premolar teeth but also the first maxillary molar teeth (Nentvichová and Andéra 2008). In Poland, the frequency of teeth with supernumerary roots were 2% and the most common tooth to be affected was the third maxillary premolar tooth (Szuma 1999). In two different studies from North America the prevalence of supernumerary roots was 2.3% in the red fox and 10.7% in the grey fox, the latter which corresponds well with the result in our study (Atchley et al. 2023; Evenhuis et al. 2018). In dogs both genetic and environmental factors are supposed to play a role in the development of supernumerary roots (Pavlica et al. 2001). Presumably the same applies to foxes and may explain the differences in results between studies.

Anomalies in the crown are unusual and have not always been included in other studies. In our study malformed tooth crowns, like microdontia, macrodontia, gemination and supernumerary cusps were identified in 27.2% of the heads but only1% of examined teeth. In two studies 0.8% respective 1.6% of the skulls were presented with malformed crowns (Szuma 1999; Atchleyet al. 2023). In one study from Poland 18.4% of the examined skulls had deviations from the typical shape of the tooth. The deviations were reported as a change of the crown outline, faulty formation of the occlusal surface, additional and incorrect structures, and reduction in tooth shape and not specified as microdontia, gemination etc. (Szuma 1999, 2002, 2007, 2008). Variations and details in classification of crown morphology differ between studies making comparisons difficult and may partly explain differences in results between studies. Besides inclusion criteria and a subjective classification, genetic variations between populations in different regions of the world presumably explain the different prevalence of malformations/variations in crown and root-morphology.

Enamel defects

Enamel defects can be generalized or localized. Trauma, infection or radiation can cause localized defects (few teeth) while different deficiency states, genetic or viral diseases, chemicals or drugs tend to cause generalized defects (multiple teeth) (Fulton et al. 2014; Jälevik and Norén, 2009). Localized enamel defects were found in 52.7% of the heads in our study and in 1,9% of teeth examined although histologic examination was not performed. The most affected teeth were the maxillary and mandibular canines followed by mandibular premolars and maxillary incisors. In another study 6.9% of the skulls presented with enamel defects most frequently in the canine teeth, like in our study (Atchley et al. 2023). The reason for higher prevalence of enamel defects in our study compared to others is unclear. Trauma is the most probable cause of the localized enamel defects seen in our study. The fact that staining was a common finding in our study may be explained by postmortem changes and discolorations because of frozen-thawed heads.

Attrition/abrasion

Dental wear commonly occurs in free-ranging carnivores. In our study, in total 149 teeth (6.5% of examined teeth, 25% of the heads) were affected by attrition or abrasion. One earlier study reported a prevalence of 3,5% attrition/abrasion in the skulls another 1% of examined teeth (Jurgelénas et al. 2020; Evenhuis et al. 2018), which is considerably lower than in our study. In contrast, one study reported so-called stage 1 attrition/abrasion in 94% of the specimens, however, as stages of attrition were not specified in our study, comparison is difficult (Atchley et al. 2023). Further, in another study, most of the grey foxes (85.6%) exhibited some degree of attrition and abrasion, affecting 47.1% of the teeth present for examination (Evenhuis et al. 2018). The fourth premolar teeth and the first and second molar teeth in all quadrants were the most affected teeth, unlike in our study, where the upper and lower incisors and the upper canines were the most affected teeth. The difference in abrasion pattern may indicate a different dietary habit, suggesting that the grey fox ingests a higher proportion of plant material (Gomez Ortiz et al. 2015). Age of the animal is also a significant factor to consider when assessing attrition and abrasion. The older the specimen, the more likely it is to find attrition and abrasion.

Dental fractures

Diet, age, competition for resources and the size of the prey for different species, may affect the type of dental fracture and most affected teeth in the oral cavity (Van Valkenburgh 1988, 2009). In our study 80% of the heads, or 8.7% of examined teeth, presented with some type of dental fracture. The rostral and exposed position of the canine and incisor teeth and their role in defense and hunting may contribute to these teeth´s susceptibility for fracturing. Dental fractures were noted in 78.4% of heads and 15.4% of teeth examined in the grey fox from California, USA, although radiography was not included in this study (Evenhuis et al. 2018). This is consistent with our results, except that the prevalence of enamel fractures was higher in our study. As in our study, the canine teeth were the most frequently affected teeth. Another recent study of the red fox, although not including radiography, reported tooth fractures in 51% of the skulls or 3,1% of examined teeth (Atchley et al. 2023). Root fractures with visible root remnants were most common, especially in the incisors, followed by complicated crown fracturs and complicated crown root fractures.

One study of 36 different species of carnivores, but also 5 different Pleistocene species, clearly stated that extant bone eaters like the spotted hyena (*Coruta coruta*) and the grey wolf (*Canis lupus*) as well as extinct meat eaters, have significantly higher prevalence of dental fractures (29–40%) compared to other carnivores and canids (Van Valkenburgh

2009, 1988). In the study the red fox (*Lupus lupus*) had an average dental fracture prevalence of 5,8%. Dry museum specimen was used in this study and no radiography was performed. Only severely fractured or worn teeth were included in the study, no uncomplicated crown fractures or root fractures, which likely contribute to the lower prevalence of fractured teeth compared to our study.

Periapical radiolucency, indicating endodontic disease, was present in 38.2% of the foxes and often seen together with root resorption. In our study endodontic disease was noted primarily together with complicated crown fractures which were present in 20% of the foxes. Other trauma like uncomplicated crown fractures, attrition/abrasion, as well as periodontal disease can cause endodontic disease and may explain the presence of periapical radiolucency seen in teeth without complicated crown fractures. Endodontic disease can be highly painful, implying that a considerable number of foxes may experience oral pain (Reiter and Gracis 2018).

Periodontitis

Horizontal and vertical bone loss are indications of periodontitis (Tsugawa et al. 2003). In our study 29% of the foxes showed localized horizontal bone loss and 20% showed vertical bone loss. No classification of the periodontal disease into different stages was performed in our study (Reiter and Gracis 2018). The most affected teeth, especially with horizontal bone loss, were the mandibular third and fourth premolars and the mandibular molar teeth. This aligns well with the study of grey foxes, where about half of the specimens displayed some degree of bony changes consistent with periodontitis (Gisburne and Feldhamer 2005). Like in our study, premolar teeth were most affected. Early onset and high prevalence of periodontitis is described in other canids such as the domestic dog (Kortegaard et al. 2008).

Methodological considerations

Prevalence of absent teeth are frequently included in studies on dental variations and anomalies in wild animals (Gisburne and Feldhamer 2005; Atchley et al. 2023; Evenhuis et al. 2018; Szuma 1999; Rantanen and Pulliainen 1970; Nentvichová and Andéra 2008; Jurgelénas et al. 2020). Museum specimens are commonly used when analyzing oral and dental anomalies and pathology (Gisburne and Feldhamer 2005; Atchley et al. 2023; Evenhuis et al. 2018; Szuma 1999; Nentvichová and Andéra 2008; Van Bree and Sinkeldam 1969; Jurgelénas et al. 2020; van Valkenburgh 2009). In a dry museum specimen, true congenital tooth absence has been described as presenting with a flat and straight bony ridge, in contrast to traumatic tooth loss where a scar like, small elevation or pocket at the original location of the tooth may be seen. Identification of missing teeth in museum specimens usually rely solely on macroscopic findings while dental radiography is seldom used. Hence it can be difficult to determine if a tooth is missing congenitally or as consequence of trauma. The criteria for tooth absence are conclusive for assessment of the result and the possibility to compare results between studies.

Dental radiography is thus crucial in identification of tooth absence. Tooth root remnants and a visible alveolus are signs that confirm acquired tooth absence. Morphologic normal bone together with absence of alveolus and tooth at the site is characteristic of a congenital tooth absence, however, if an old individual has lost a tooth early in life, the bone will show a similar appearance as with congenital tooth absence making it difficult to determine the etiology behind tooth absence in elderly animals (Bouwmeister et al.1989). Hereby**,** age becomes another factor influencing the determination of the etiology behind missing teeth and may implicate a negligible risk of misjudgment in our study.

The composition and the ratio between young and old individuals in a study group must be considered when comparing results of different studies. Age can be estimated in various ways, e.g. based on tooth eruption and the development of the cranial sutures or examination of the cementum annuli (Harris 1978; Wood 1958; Matson´s Laboratory 2024). In our study the width of the pulp cavity was used to estimate the age of the foxes (Morgan and Miyabayashi 1991). Similar to our study, many studies divided their study population into groups based on age: adult or young adult (Gisburne and Feldhamer 2005; Atchley et al. 2023; Evenhuis et al. 2018; Jurgelénas et al. 2020). With respect to age, our study population was comparable to these studies provided that our juvenile group was counted as young adults. Foxes with deciduous teeth were excluded in all studies.

One limitation of this study was the relatively low number of examined specimens. Further, all specimens were collected from a limited geographic area of Sweden. Further studies on a larger population of foxes with known sex, more exact age determination and from different regions of Sweden would give an even more accurate depiction of the dental anomalies, variations and pathology existing in the red fox in Sweden.

Conclusions

In contrast to many previous studies, the present study included dental radiography of all teeth and was thus able to identify acquired dental anomalies**.** In our study congenital and developmental anomalies were presented in 20,2% of examined teeth, in 36,4% of the foxes. This may be compared to 26,1% of examined teeth, in 87% of foxes, having an anomaly of acquired origin. Dental fractures were very common and 80% of the heads showed some kind of dental fracture.

Radicular developmental grooves, dilacerations and super numerous cusps were among the most conspicuous and interesting findings in this study. Radicular developmental grooves are to be considered as normal features and dilaceration and supernumerary cusps as a variation of tooth morphology rather than anomalies. Acquired pathological anomalies such as dental fractures, attrition, and abrasion, and associated endodontic disease, were also common findings. Contrary to radicular developmental grooves, dilacerations and supernumerary cusps, acquired anomalies and pathology may potentially adversely influence the red fox in Sweden`s quality of life.

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Authors' contributions DB and KA developed the research concept and study design; The macroscopic and radiographic examinations were performed by KA. Assessments of the macroscopic findings and radiographic examination were done by KA and DB in agreement. Compilation of the results was done by KA. KA wrote the original draft of the manuscript. Review and editing by KBE and AP. All authors read and approved the final manuscript.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

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