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Dental Pathology of the Iberian Lynx (*Lynx pardinus*), Part I: Congenital, Developmental, and Traumatic Abnormalities

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Abstract

The Iberian lynx is an endangered felid that has been subject to an intensive ongoing conservation program in an attempt to save it from extinction. Identification of dental pathologies could play an important role in the survival of this endangered species. The objective of this study is to evaluate the dental pathologies (congenital, developmental, and traumatic abnormalities) of this species of felid. Skulls of 88 adult specimens of the Iberian lynx (*Lynx pardinus*) from the Doñana Biological Station [Estación Biológica de Doñana-Consejo Superior de Investigaciones Científicas] (EBD-CSIC), Seville, Spain, were examined macroscopically, and full-mouth dental radiographs of all specimens were performed. Presence, absence, form of teeth, number of roots, supernumerary teeth, and persistent deciduous teeth were evaluated. The presence of attrition/abrasion, tooth fractures, enamel hypoplasia/hypomineralization, endodontic disease, intrinsically stained teeth, and other traumatic findings were also evaluated. Abnormal grooves and dilacerations were the most common abnormalities seen in the roots of teeth. Two hundred and fifteen fractured teeth (11.3% of evaluated teeth) were detected, and mainly complicated fractures were noted in maxillary canine teeth (24.2% of fractured teeth) and mandibular canine teeth (16.7% of fractured teeth). Endodontic disease was present in 3.9% of the teeth examined. Intrinsic tooth staining was assessed in 8.5% of evaluated teeth. Of all teeth examined, 831 teeth (43.7% of evaluated teeth) exhibited some type of attrition/abrasion. Our study concluded that there is a high prevalence of dental fractures and attrition/abrasion with associated endodontic disease that could lead to impaired hunting ability as well as a threat to overall health and subsequent survival of this endangered species.

Keywords

Iberian lynx, dentistry, congenital, developmental, attrition, abrasion, tooth fractures, endodontic disease

Introduction

The Iberian lynx, *Lynx pardinus* (Temminck, 1824), order Carnivora, family Felidae, is an endangered felid that has been subject to an intensive ongoing conservation program in an attempt to save it from extinction. After 1960, there was a decline and pronounced range contraction, officially becoming a critically endangered feline from 2002 to 2008. During the period between 2002 and 2012, the population size increased, thanks to conservation actions.[1] In 2015, the population size of the Iberian lynx was 406 individuals (including 120 reproductive females) restricted to the Iberian Peninsula in 3 autonomous communities in Spain (Extremadura, Castilla la Mancha, and Andalusia) and Portugal.[2]

L pardinus was first described in the 19th century based on external morphology, corporal measurements, and area of distribution,[3] and a wide review of the biometric and morphologic features of the skull have since been updated.[4,5] Other physical characteristics have also been updated.[5] Size of males and females is not significantly different in "juveniles" (up to 1 year of age) and "young adults" (up to 2 years of age). There is a marked sexual dimorphism within the species in adulthood. Male Iberian lynx reach 97.0 cm in length and a height of 51.1 cm at the shoulders (9% smaller in the bobcat, *Lynx rufus*), with males weighing up to 14.5 kg. Females can reach 91.4 cm in length, a height of 47.0 cm at the shoulders, and can weigh up to 9.9 kg.[5] There are 3 different main patterns in their pelt design.[5] Their breeding range in the wild is restricted to the Iberian Peninsula in 5 regions: Doñana, Sierra Morena, Montes

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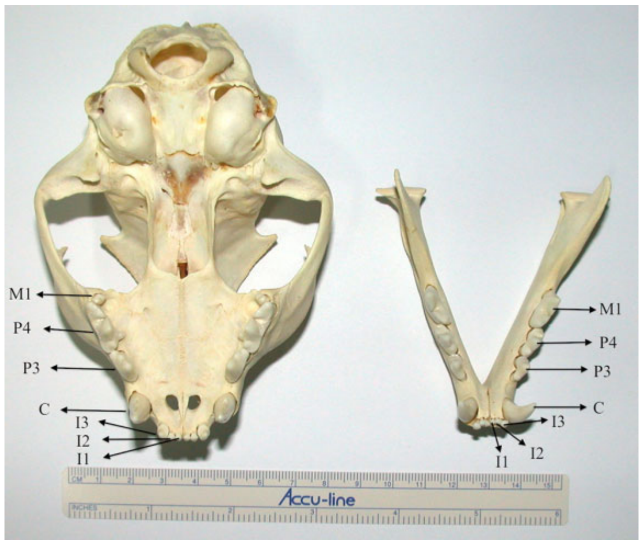

Figure 1. The dentition of a young adult male Iberian lynx (*Lynx pardina*).

de Toledo y Valle de Matachel (Spain), and Vale do Duadiana (Portugal).[2]

The Iberian lynx has an average life span of 8 years but can live up to 12 years in the wild or even up to 20 years in captivity. Studies indicate that these animals are strict feeding specialists, where the European rabbit (*Oryctolagus cuniculus*) comprises the majority of its diet, with deer (fawns), native ducks, and small mammals very exceptionally part of its diet.[6,7] In fact, the widespread decrease in rabbit abundance in the Iberian Peninsula due to changes in land use and long-term effect of viral diseases such as myxomatosis and rabbit hemorrhagic disease over the past century are considered as main causes for the Iberian lynx's endangered status.[8] Many efforts and studies have been developed to improve wild rabbit status to reinforce the prospects for Iberian lynx conservation.[9,10]

Thanks to the Iberlince LIFE Project, many efforts have also been made to prevent causes of nonnatural mortality in the Iberian lynx (trapping, shooting, and road casualties).[11] These efforts have resulted in increasing numbers of individuals in the past decade.

With regard to feeding behavior, the Iberian lynx is mostly a solitary predator.[7,12] Its hunting techniques are based on 2 modalities, active stalking and waiting, and killing small prey such as wild rabbits with a lateral or lateroventral bite in the nape, causing fracture of the spinal cord and/or the base of the cranium.[7] When the Iberian lynx captures its prey, it normally transports the kill more than 1 km if small prey, until it finds a safe place to eat.[7] Limited or nonfunctional dentition to hunt and kill prey can contribute to morbidity and mortality of the species.[13]

The adult Iberian lynx has 28 teeth (Figure 1). The dental formula is I3/3, C1/1, P2/2, M1/1 = 28.[14,15] The absence of the second premolar tooth has been interpreted as indicating a tendency toward reduced dentition in the cat as in the case of the *L pardinus*.[13,16] This fact can also be observed in other wild felines such as the caracal (*Felis caracal*), leopard cat (*Felis bengalensis*), and lynx (*Lynx lynx* and *L rufus*).[16-18] The dental morphology of the Iberian lynx is similar to that of other felines. In one study, 3 different morphological types of the mandibular first molar tooth were detected. In 83% of the cases, the form corresponded to the typical molar of this species with a poorly developed cingulum and no metaconid (the more distal of the lingual cusps of the mammalian molar tooth), and the other morphological types have either a small inflection in the enamel at the site where the metaconid would be or a patent metaconid on the cingulum.[4]

The deciduous dental formula is I3/3, C1/1, P2/2.[15] The dental morphology of the deciduous teeth in the Iberian lynx is also similar to that in other felines. The eruption sequence for deciduous dentition is different from what has been reported in other felines, in which incisors appear first, followed by canines and premolars.[19] The deciduous teeth in the Iberian lynx are succeeded by the permanent canines that begin erupting before the permanent incisors,[19] followed immediately by eruption of the maxillary fourth premolar and first molar teeth and mandibular first molar teeth. The next deciduous teeth to exfoliate are the deciduous maxillary and mandibular fourth premolars, followed by the deciduous maxillary and mandibular third premolar teeth.[15] Maxillary and mandibular incisors erupt simultaneously, but as with molars, the mandibular dentition starts to erupt 1 tooth delayed in relation to the maxillary series. Maxillary and mandibular canines are the last teeth to complete eruption.[15]

Estimation of the age of carnivores postmortem is primarily based on gross examination of the teeth, radiography, and more specifically by cementum annuli analysis,[20] which has been used as another age estimation technique.[21,22] There are numerous recent studies, where counting cementum annuli to age an animal has been performed in wild felines.[21-24] There is a specific study for age determination of *L pardinus* using radiography, the root canal of an extracted mandibular canine at its maximum width, and by cementum annuli enumeration of the maxillary third incisor and mandibular canines. This study concluded that closure of the apical foramen occurs at 12 to 18 months of age, and the formation of the first complete cementum annuli starts around 18 months of age. Another important finding is that in lynx 10 to 12 months of age, the root canal accounted for 73.3% of the canine width, while at 18 months old this percentage was 21%, decreasing with age.[25]

There is little information documenting the dental pathology of wild felids. Dental lesions are common in the family Felidae and can be a significant source of morbidity and mortality.[18,26] Recently, studies in the lynx have provided detailed information regarding their dental pathology, hypothesizing that dental lesions in wild felines may be similar to those found in domestic and feral cats.[16,27]

The aim of this study was to provide detailed information regarding the congenital, developmental, and traumatic dental abnormalities of the endangered Iberian lynx (*L pardinus*) and compare them with results of simultaneous studies developed recently in *Lynx rufus californicus*.[13] The study of periodontal disease, tooth resorption, and oral neoplasia in the Iberian lynx

Table 1. Congenital, Developmental, and Dental Acquired Abnormalities and Inclusion Criteria.

Observation	Inclusion Criteria
Tooth artifactually absent	Jaw fragment missing or tooth absent, but a well-defined, sharp-edged, normally shaped, empty alveolus present; no pathological signs in the alveolar bone; tooth presumed lost during preparation or postmortem manipulation of the skull.
Tooth absent (presumably acquired)	Tooth absent; alveolus or remnant alveolus visible; alveolar bone shows pathological signs (ie, rounding of the alveolar margin, shallow alveolus, periosteal reaction on alveolar bone, increased vascular foramina).
Tooth absent (presumably congenital)	Tooth and alveolus absent; smooth, morphologically normal bone present at the site; no evidence of acquired tooth loss of adjacent teeth.
Malformed tooth	Presence of an abnormally shaped crown or roots or both.
Number of roots	One, two, or three roots.
Supernumerary tooth	Presence of a supernumerary tooth adjacent to an expected tooth (or alveolus).
Persistent deciduous tooth	A persistent deciduous tooth adjacent to an erupted or unerupted permanent tooth.
Supernumerary roots	Increased number of roots.
Supernumerary tooth	Presence of a supernumerary tooth adjacent to the normal tooth; presence of a "peg tooth."
Persistent deciduous tooth	A persistent deciduous tooth adjacent to a fully erupted tooth.
Enamel hypoplasia	Irregular pitting or a band-shaped absence or thinning of the enamel, consistent with the clinical signs of enamel hypoplasia.
Attrition/abrasion type 1	Mild rounding or flattening of the cusp tip; mild-to-moderate exposure to dentin, without tertiary dentin formation.
Attrition/abrasion type 2	Moderate-to-severe rounding or flattening of the cusp tip with severe exposure to dentin, with tertiary dentin formation, without pulp exposure.
Attrition/abrasion type 3	Severe rounding or flattening of the cusp tip, with severe exposure to dentin with pulp exposure.
Enamel infraction	Incomplete fracture (crack) of the enamel without loss of tooth substance.
Enamel fracture	Fracture with loss of crown substance confined to the enamel.
Uncomplicated crown fracture	Fracture of the crown that does not expose the pulp.
Complicated crown fracture	Fracture of the crown that exposes the pulp.
Uncomplicated crown-root fracture	Fracture of the crown and root that does not expose the pulp.
Complicated crown-root fracture	Fracture of the crown and root that exposes the pulp.
Root fracture	Fracture involving the root.
Endodontic disease	Periapical lesion (with external inflammatory root resorption or not) and/or a pulp cavity that failed to narrow.
Discoloration	Partial or total discoloration of the crown; presence of "pink teeth" syndrome.

(*L pardinus*) will be discussed by the authors in a separate article. Results of our study can open new pathways of conservation programs in wild and captive Iberian lynx in an attempt to save it from extinction.

Material and Methods

Macroscopic examination of 88 skull specimens from the Doñana Biological Station (EBD-CSIC), Seville, Spain, was undertaken. Collections of skulls were obtained from carcass recovery and donations from the public and other institutions, from 1954 to 2013.

Each skull had been previously labeled with a unique catalog number (EBD), collection date, collection location, age, sex, and cause of death of the animal (if known). Each skull specimen was categorized as "young adult" (up to 18 months of age), "adult" (range from 18 months to 4 years of age), and "senior adult" (more than 4 years of age). Age status of the skulls was determined based on known age of death and the stage of development of the teeth evaluated through dental radiography. "Juveniles" (with presence of deciduous or mixed dentition) were previously excluded from the study.

The teeth and surrounding bony tissues were inspected with an explorer and a probe[a] according to predefined criteria (Table 1) utilized in similar previous studies[13,18,26,28] and modified and adapted to the present study. In order to confirm and classify certain lesions, full-mouth dental radiographs were obtained.

The prevalence of dental lesions was compared between skulls from animals of different ages and sex. The SAS software, version 9.4,[b] was used for logistic regression analyses. Significance was calculated using the Pearson χ^2 test and the Wilcoxon (rank-sum) test. $P < .05$ was considered significant.

As in a very recent and simultaneous study performed in the Bobcat (*L rufus californicus*),[13] the presence or absence (congenital, acquired, or artifactual) of all teeth was recorded. The number of teeth present was used to calculate the prevalence of different types of attrition/abrasion, fractures, and endodontic disease. Teeth and number of roots were assessed through macroscopic and radiographic examination. The presence of any supernumerary teeth, persistent deciduous teeth, and signs of staining due to enamel hypoplasia/hypomineralization was also recorded. The teeth were examined for signs of attrition and/or abrasion, including its severity (mild, moderate, and

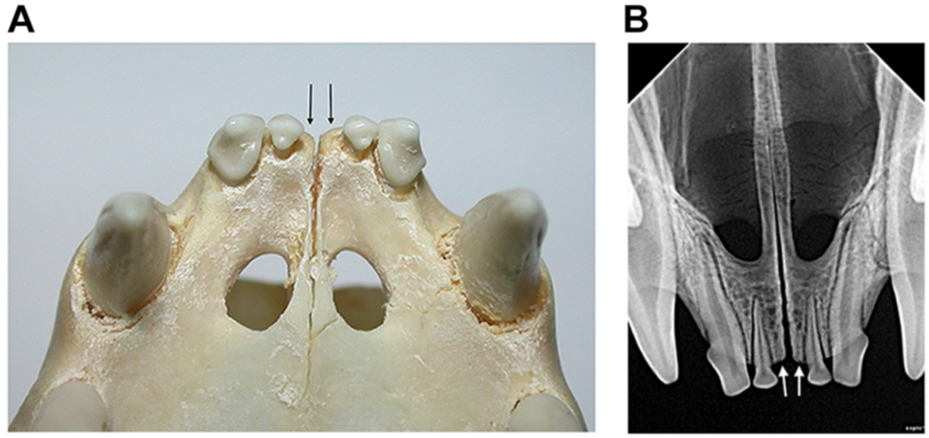

Figure 2. A, Gross appearance of congenitally absent maxillary first incisor teeth (arrows) in a young adult female Iberian lynx skull. B, Radiographic appearance of congenitally absent maxillary first incisor teeth (arrows) in a young adult female Iberian lynx skull.

severe flattening of the tooth cusp, which can include exposed dentin, presence of tertiary dentin, or pulp exposure). Tooth fractures were classified according to predefined criteria established by the American Veterinary Dental College.[29] Complicated tooth fractures were examined during the radiographic examination for additional indications of endodontic disease. Discoloration and other findings (relevant traumatic findings and malocclusion) were also noted.

The second part of the study included obtaining full-mouth intraoral dental radiographs of the skulls in order to confirm and classify detected lesions and assess the importance of the diagnostic value of full-mouth radiography in this species. Radiographs were obtained using a portable handheld dental X-ray unit,[c] size 2 intraoral direct digital sensor,[d] and a veterinary diagnostic imaging software.[e] Radiographic views were obtained following the small animal radiographic set technique description of the American Veterinary Dental College,[30] resulting in 10 maxillary and mandibular radiographic views. Accessory modified views were obtained for adequate and accurate assessment of areas of special interest. Once the radiographs were obtained, each radiograph was evaluated independently and then compared to the findings of the gross examination. Findings of the macroscopic and radiographic examinations were documented.

Results

Of the 88 skull specimens evaluated, 48.9% were from male Iberian lynx, 33.0% were from female Iberian lynx, and 18.1% were from animals with an unknown gender.

Senior adult Iberian lynx skull specimens comprised 55.7% of the skulls examined, adult Iberian lynx skull specimens comprised 20.4% of the skulls examined, while young adult Iberian lynx skull specimens comprised 23.9% of the skulls examined.

Presence of Teeth

The total number of teeth available for examination was 1903 (77.3%) out of a potential total of 2464 teeth. Artifactual tooth absence accounted for 81.1% of missing teeth, presumed lost during preparation or postmortem manipulation of the skulls. Teeth lost through acquired means accounted for 18.5% of missing teeth, presumed lost due to pathology. Congenitally absent teeth only accounted for 0.4% of missing teeth; only 2 congenitally absent maxillary first incisor teeth were identified in 1 individual skull specimen (Figure 2).

The mandibular incisor teeth (57.7%) and maxillary incisor teeth (28.8%) accounted for a majority of teeth lost through acquired means. Senior adult Iberian lynx specimens had more acquired tooth loss than the group of young adult and adult specimens ($P < .0001$). There were no significant differences between the sex groups.

Tooth Form

Abnormal tooth anatomy was considered to be any irregular structure or formation of the crown of the tooth, root, or both.[13]

Abnormal grooves on the root affected 80 teeth (4.2% of evaluated teeth): 65 of these were the mandibular first molar teeth (Figure 3), 13 of these were the maxillary third premolar teeth (Figure 4), and 2 of these were the mandibular fourth premolar teeth of one skull specimen. Dilaceration of tooth roots affected 56 teeth (2.9% of evaluated teeth): 44 of these were the mandibular third premolar teeth, 10 of these were the mandibular fourth premolar teeth (Figure 5), and 2 of these were the maxillary third premolar teeth of 1 skull specimen. Other less common anatomic abnormalities were found: 9 teeth with an abnormal shape of the distal root of the maxillary third premolar teeth, and fused roots of the right mandibular fourth premolar tooth of one skull specimen were detected (Figure 6).

Figure 3. Radiograph of groove on the mesial surface of the distal root of the left mandibular first molar tooth in an adult female Iberian lynx skull (arrow).

Figure 4. Radiograph of groove on the distal root of the left maxillary third premolar tooth in a senior adult female Iberian lynx skull (arrow).

Number of Roots

Abnormal number of roots affected 76 teeth (4.0% of evaluated teeth): 38 of these were maxillary first molar teeth (Figure 7), 20 of these were maxillary third premolar teeth (Figure 7), and 18 of these were mandibular first molar teeth (Figure 8). This aberration of the mandibular first molar tooth was found to be bilateral in 1 lynx.

Supernumerary Teeth

Only 1 supernumerary tooth was detected during macroscopic and radiographic examination (1.1% of skulls specimens). This supernumerary tooth was located on the mesiolingual aspect of the right mandibular third molar tooth (Figure 9). A complicated crown-root fracture was noted in the supernumerary tooth that was not included in the section of tooth fractures of this study.

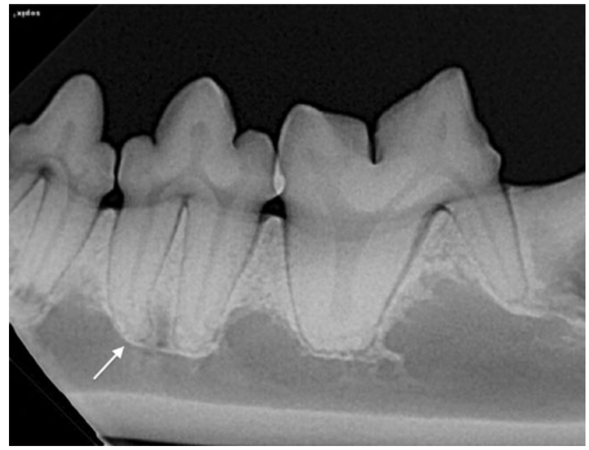

Figure 5. Radiograph of dilacerations of the mesial root of the left mandibular fourth premolar tooth (arrow) in a senior adult male Iberian lynx skull.

Persistent Deciduous Teeth

No persistent deciduous teeth were detected during macroscopic and radiographic examination in any of the skull specimens examined.

Enamel Hypoplasia/Hypomineralization

Enamel hypoplasia/ hypomineralization was found to affect 8 teeth (0.42% of evaluated teeth) in 5 skulls specimens (5.7% of the individuals); 5 of these were mandibular canine teeth (Figure 10), 2 of these were mandibular first molar teeth, and 1 was mandibular fourth premolar tooth.

Attrition/Abrasion

A majority (90.9%) of the specimens examined had at least 1 tooth affected by attrition/abrasion. Of the teeth examined, 831 teeth (43.7% of evaluated teeth) exhibited attrition/abrasion; 27.4% exhibited attrition/abrasion type 1 (mild rounding or flattening of the cusp tip with mild-to-moderate exposure to dentin; Figure 11); 14.2% exhibited attrition/abrasion type 2 (moderate-to-severe rounding or flattening of the cusp tip with severe exposure to dentin and tertiary dentin formation without pulp exposure; Figure 12); and 2.1% exhibited attrition/abrasion type 3 (severe rounding or flattening of the cusp tip, with severe exposure to dentin with pulp exposure; Figure 13).

Of the teeth examined that exhibited attrition/abrasion type 1, the mandibular premolar and molar teeth accounted for 29.4% of teeth with attrition/abrasion, the maxillary premolar and molar teeth accounted for 25.7% of teeth with attrition/abrasion, the maxillary canine teeth accounted for 13.1% of teeth with attrition/abrasion, and the mandibular canine teeth

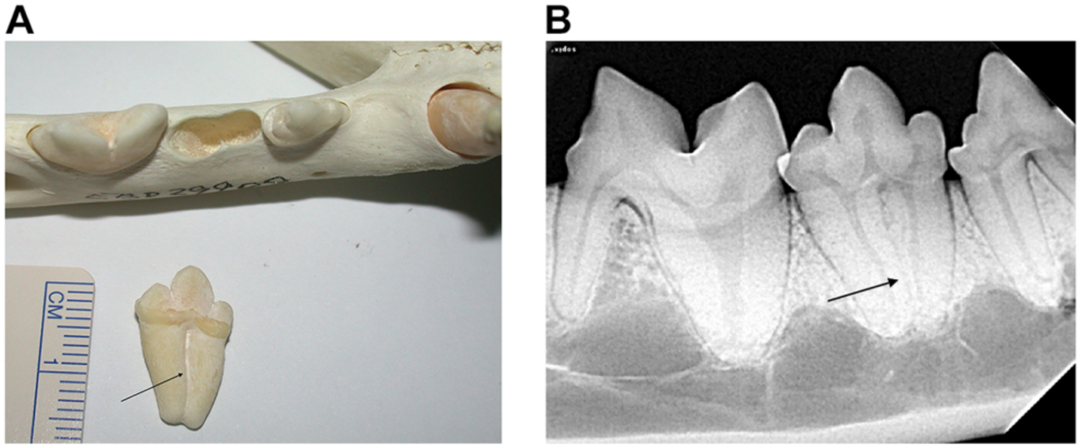

Figure 6. A, Gross appearance of fused roots (arrow) of the right mandibular fourth premolar tooth in an adult male Iberian lynx skull. B, Radiographic appearance of fused roots (arrow) of the right mandibular fourth premolar tooth in an adult male Iberian lynx skull.

Figure 7. Radiograph of the left maxillary third premolar tooth (arrow) and maxillary first molar tooth (asterisk) both with an extra root in a young adult female Iberian lynx skull.

accounted for 11.9% of teeth with attrition/abrasion. In attrition/abrasion type 2, the mandibular premolar and molar teeth accounted for 26.3% of teeth with attrition/abrasion, the maxillary premolar and molar teeth accounted for 18.9% of teeth with attrition/abrasion, the maxillary canine teeth accounted for 16.3% of teeth with attrition/abrasion, and the mandibular canine teeth accounted for 13.7% of teeth with attrition/abrasion. In attrition/abrasion type 3, the maxillary canine teeth accounted for 37.5% of teeth with attrition/abrasion, and the mandibular canine teeth accounted for 27.5% of teeth with attrition/abrasion.

Senior adult Iberian lynx specimens had more attrition/abrasion than the group of young adult and adult specimens ($P < .0001$). Female Iberian lynx was found to have more teeth with attrition/abrasion than males, but these results were not significant.

Tooth Fractures

The total number of fractured teeth was 215 (11.3% of teeth), and the prevalence of specimens with any fracture type was found to be 68.2%.

Complicated crown and complicated crown-root fractures accounted for 6.3% of the teeth examined. Complicated crown and complicated crown-root fractures accounted for 55.3% of the fractured teeth examined, 43.7% of those fracture types were detected on maxillary canine teeth, and 30.3% on mandibular canine teeth, respectively.

Enamel infraction (Figure 14) accounted for 16 (7.4%) fractured teeth. Enamel fractures (Figure 15) accounted for 20 (9.3%) fractured teeth. Uncomplicated crown fractures accounted for 14 (6.5%) fractured teeth. Uncomplicated crown-root fractures accounted for 4 (1.9%) fractured teeth (Figure 16). Complicated crown fractures (Figure 17) accounted for 77 (35.8%) fractured teeth. Complicated crown-root fractures (Figure 18) accounted for 42 (19.5%) fractured teeth. Root fractures accounted for 42 (19.5%) fractured teeth, with the maxillary and mandibular incisor teeth (97.6%) being the most commonly affected. The most common fracture types were complicated crown fractures, followed by complicated crown-root fractures.

Senior adult Iberian lynx specimens were more likely to have fractures than the group of young adult and adult specimens ($P < .0001$). There were no significant differences between sex groups. Senior adult Iberian lynx specimens had more complicated tooth fractures than the group of young adult and adult specimens ($P < .0001$). Female Iberian lynx had more complicated tooth fractures than males, but there were no significant differences.

Endodontic Disease

Endodontic disease (Figure 19) was assessed via dental radiography and recognized by the presence of a complicated crown

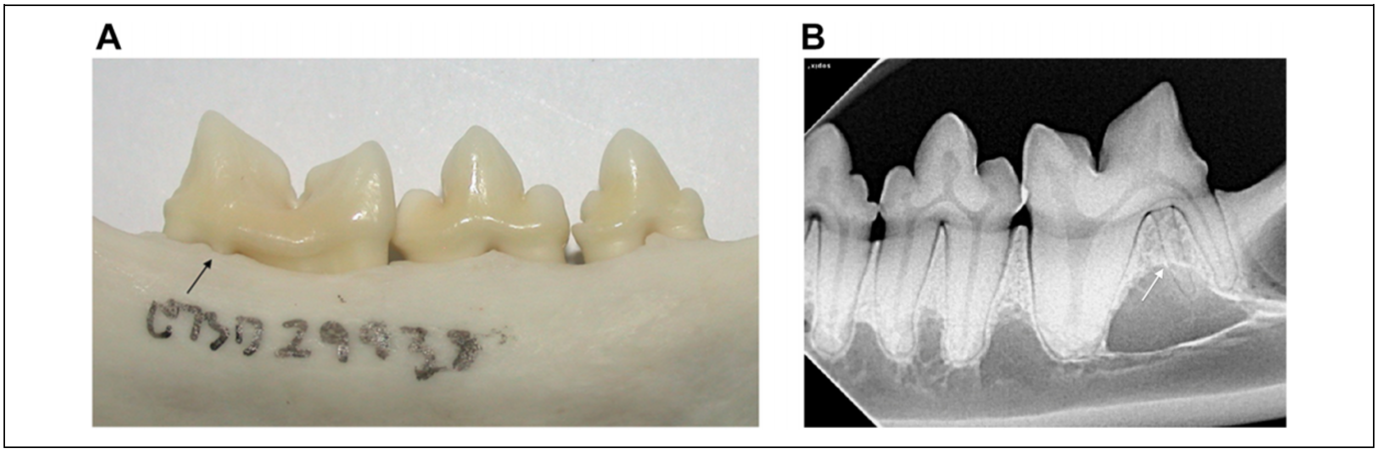

Figure 8. A, B, Gross appearance of the left mandibular first molar tooth (lingual view) in a senior adult female Iberian lynx skull with a supernumerary root (arrow). B, Radiographic appearance of the left mandibular first molar tooth in a senior adult female Iberian lynx skull with a supernumerary root.

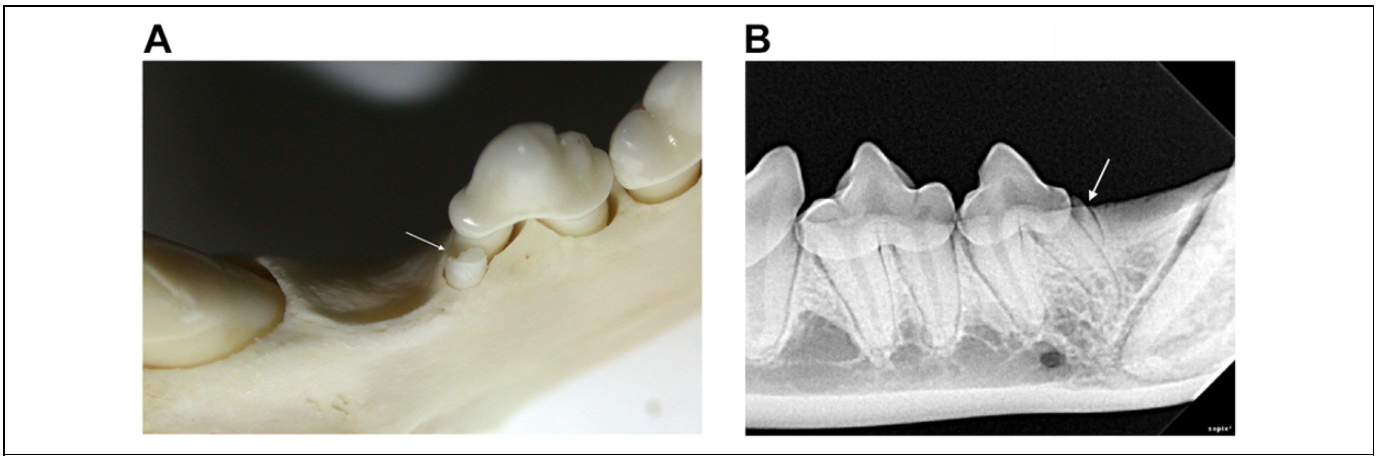

Figure 9. A, Gross appearance of supernumerary tooth (arrow) located on the mesiolingual aspect of the right mandibular third premolar tooth (lingual view). Note the complicated crown-root fracture of the supernumerary tooth. B, Radiograph of the supernumerary tooth (arrow) located on the mesiolingual aspect of the right mandibular third premolar tooth. Note the complicated crown-root fracture of the supernumerary tooth.

Figure 10. Gross appearance of enamel hypoplasia/hypomineralization of the left mandibular canine tooth in a young adult male Iberian lynx skull (arrow).

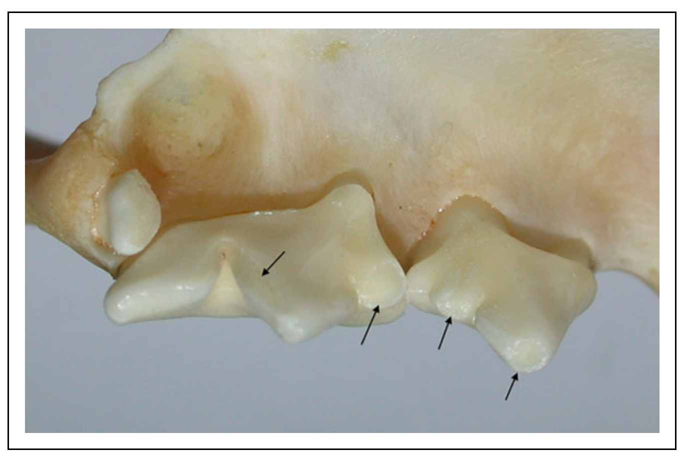

Figure 11. Gross appearance of type 1 attrition/abrasion of the left maxillary third and fourth premolar teeth in a senior adult female Iberian lynx skull (arrows).

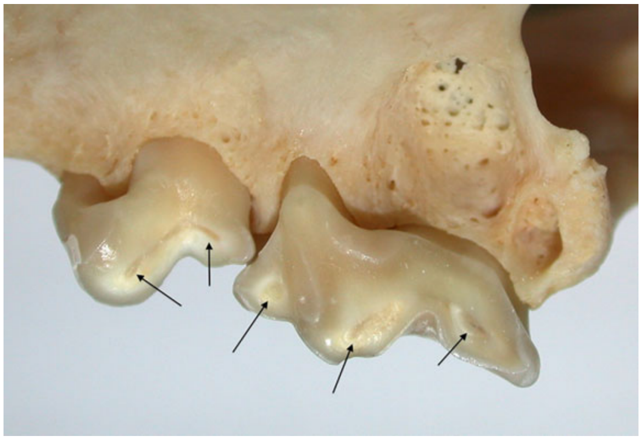

Figure 12. Gross appearance of type 2 attrition/abrasion of the right maxillary third and fourth premolar teeth in a senior adult female Iberian lynx skull (arrows).

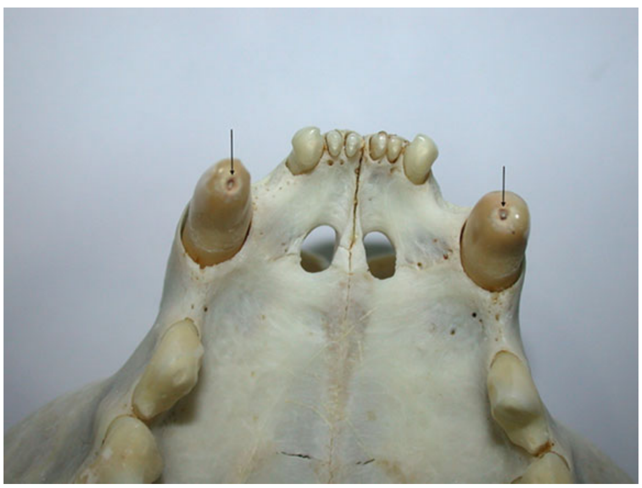

Figure 13. Gross appearance of type 3 attrition/abrasion of the right and left maxillary canine teeth in a senior adult female Iberian lynx skull (arrows).

fracture, complicated crown-root fracture (a total of 119 teeth, of which 73.9% were canine teeth), and attrition/abrasion type 3 (a total of 40 teeth) with resulting periapical lesions (including external inflammatory root resorption or not) and/or a root canal system that fails to mature resulting in a wider root canal.

Periapical lesions were subsequently diagnosed in 74 teeth (3.9% of teeth examined). Teeth diagnosed with periapical lesions were found in 35.2% of specimens.

The most commonly affected teeth were the maxillary and mandibular canine teeth, comprising 69.2% of teeth with periapical lesions (Figure 20).

Senior adult Iberian lynx specimens were more likely to have periapical lesions than the group of young adult and adult specimens ($P < .0001$). There were no significant differences in prevalence and number of teeth affected between sex groups.

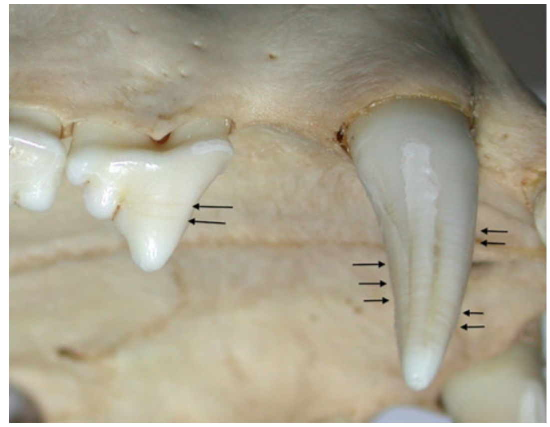

Figure 14. Gross appearance of enamel infraction of the right maxillary canine and third premolar teeth in a young adult unknown sex Iberian lynx skull (arrows).

Figure 15. Gross appearance of enamel fracture of the right maxillary canine tooth in a young adult male Iberian lynx skull (arrows).

In addition to periapical lesions resulting from complicated tooth fractures, radiographs were analyzed for the presence of a root canal system that fails to mature. This additional radiographic feature of endodontic disease was present in 41 teeth (2.2% of teeth examined, 34.4% of affected teeth from complicated tooth fractures), where 34 teeth were maxillary and mandibular canine teeth.

Intrinsically Stained Teeth

Intrinsic discoloration occurs following a change to the structural composition or thickness of the dental hard tissues. A color scale from gray, orange, to brown (partially or totality affecting the crown) was assessed in 162 teeth (8.5% of evaluated teeth); 118 of these teeth (72.8% of affected teeth) were maxillary and mandibular canine teeth of which, 65 teeth (55.9%) were discolored canine teeth affected from complicated tooth fractures (Figure 21). Of these teeth, 6 were maxillary fourth premolar teeth, 2 of these teeth were maxillary first

Figure 16. Gross appearance of uncomplicated crown-root fracture (lingual view) of the right mandibular first molar tooth in a senior adult unknown sex Iberian lynx skull (arrows).

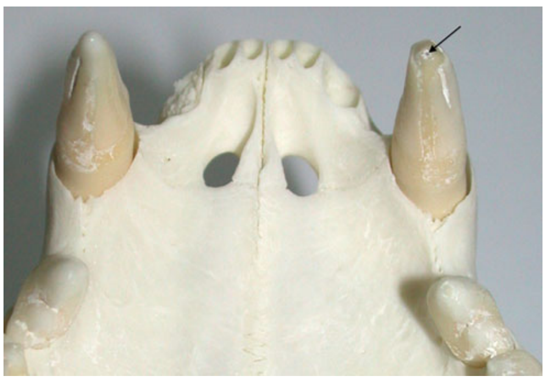

Figure 17. Gross appearance of complicated crown fracture of the left maxillary canine tooth in an adult male Iberian lynx skull (arrow).

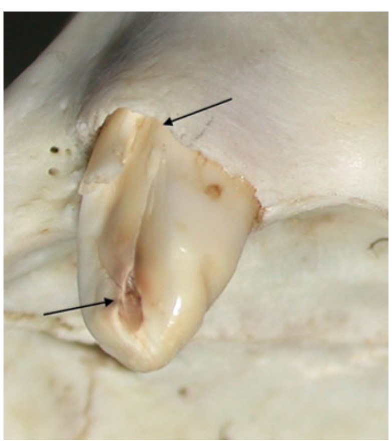

Figure 18. Gross appearance of complicated crown-root fracture of the left maxillary canine tooth in a senior adult male Iberian lynx skull (arrow).

molar teeth (Figure 22), 7 of these teeth were mandibular third premolar, 11 of these teeth were mandibular fourth premolar teeth, and 8 of these teeth were mandibular first molar teeth. This discoloration also affected 2 maxillary incisor teeth and

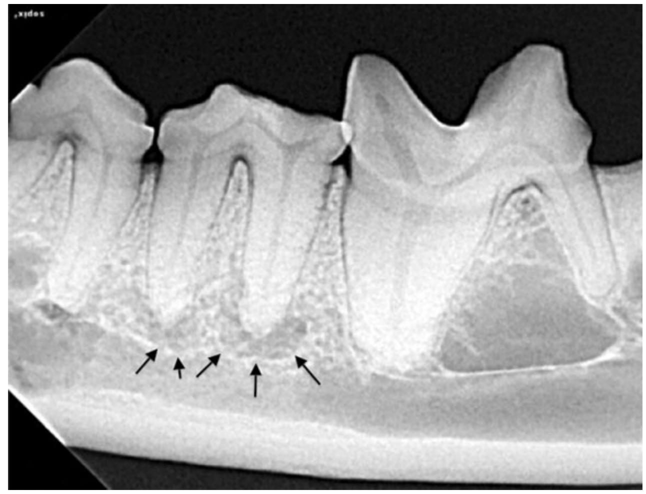

Figure 19. Radiograph of the left mandibular fourth premolar tooth of a senior adult female Iberian lynx skull with endodontic disease (arrows) due to a complicated crown-root fracture.

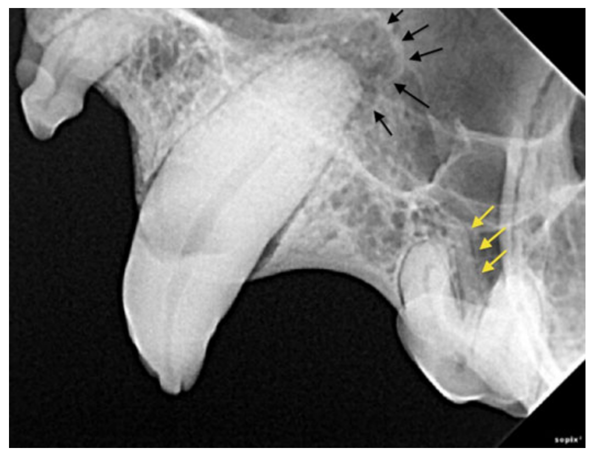

Figure 20. Radiograph of left maxillary canine tooth of a senior adult female Iberian lynx skull with endodontic disease (black arrows) as a result of a complicated crown fracture. Note an extra root on the left maxillary third premolar tooth (yellow arrows).

9 mandibular incisor teeth (Figure 23). In all, 70.5% of the discolored premolars, molars, and incisors of the specimens examined had 1 type of attrition/abrasion. One skull specimen had a "pink" discoloration of the teeth, corresponding to the "postmortem pink teeth" syndrome. Senior adult Iberian lynx specimens were more likely to have intrinsically stained teeth than the group of young adult and adult specimens ($P < .0001$). Male Iberian lynx had more intrinsically stained teeth than females, but there were no significant differences between the 2 groups.

Other Findings

One adult female specimen showed damage to the maxillary canine teeth and right mandibular canine tooth due to electric

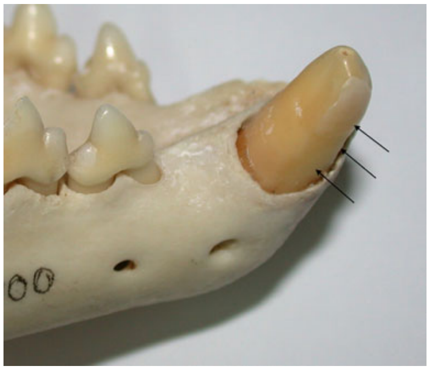

Figure 21. Gross appearance of intrinsic discoloration (arrow) of a complicated crown fracture of the right mandibular canine tooth, affected by abrasion, in a senior adult male Iberian lynx skull.

Figure 22. Gross appearance of intrinsic discoloration (arrows) of the left maxillary first molar tooth in a senior adult unknown sex Iberian lynx skull.

Figure 23. Gross appearance of intrinsic discoloration (arrow) of the right mandibular second incisor tooth in a young adult male Iberian lynx skull. Note the enamel hypoplasia of the right mandibular canine tooth (asterisk).

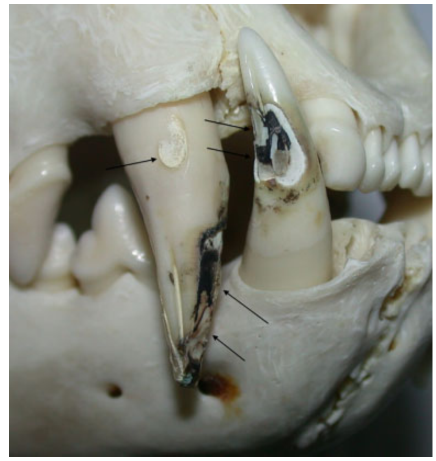

Figure 24. Gross appearance of staining in right maxillary and mandibular canine teeth due to electric burn trauma (arrows) in an adult female Iberian lynx skull.

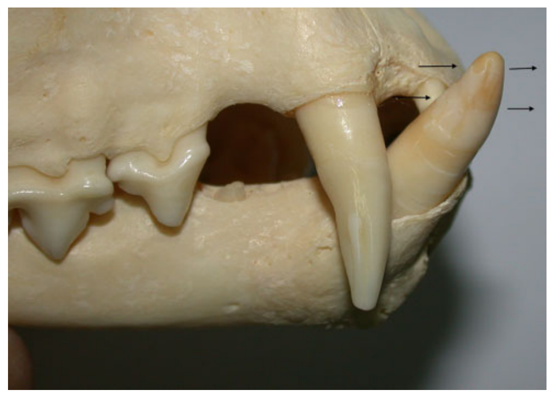

Figure 25. Gross appearance of a mesioverted right mandibular canine tooth in a senior unknown sex female Iberian lynx skull.

cord bite trauma (Figure 24). One senior adult specimen had a mesioverted right mandibular canine tooth, presumably as a result of a congenital etiology or due to trauma (Figure 25). One healed bony lesion of a mandibular fracture in the right mandibular canine tooth (absent) area was diagnosed in one senior adult female specimen. During our study, of the teeth examined, 43 teeth (2.3% of evaluated teeth) exhibited some type of artifactual damage/lesions due to studies performed in the past.

Discussion

The Doñana Biological Station (EBD-CSIC) has the most unique collection of Iberian lynx (*L pardinus*) skull specimens in the world. The collection dates of the skulls ranged from 1954 to 2015 and were obtained from carcass recovery, individual and public collections, and other wildlife care and government institutions. Wide and valuable information was available from most of the skull specimens examined.

It is important to take into consideration that the number of skull specimens in this study (n = 88) represents 21.7% of the adult population size of the Iberian lynx in the Iberian Peninsula in 2015. These data imply that even small percentages in obtained results may provide relevant and useful information. Every single effort to prevent or treat dental pathologies in this species would have decisive effects in the ongoing conservation efforts in this endangered species.

The majority of missing teeth was lost through artifactual means, and only 18.5% of missing teeth were caused by acquired means. The most common teeth lost in both categories were the maxillary and mandibular incisor teeth. Acquired tooth loss was more prevalent in senior adult Iberian lynx than in the group of young adult and adult. Congenital absent teeth were rare throughout this study (0.11% of studied teeth), detected in only 2 maxillary first incisors in the same skull specimen (1.1% of examined skulls). In 1 study of *L lynx*, congenitally absent maxillary incisors were also recorded in 5.2% of examined skulls.[31] In the study of dental pathology in the California bobcat *L rufus carlifornicus*,[13] results of missing teeth were similar, with the exception that a higher prevalence of congenital findings was detected (0.22% of studied teeth).

Abnormal tooth morphology was occasionally found (7.7% of teeth). The most common morphological abnormality was an abnormal groove on the root that affected 80 teeth (4.2% of evaluated teeth). This was most notable in the mandibular first molar teeth (81.3% of affected teeth with an abnormal groove). Dilacerations of a tooth root were noticed in 2.9% of teeth examined. Other less common form abnormalities were an abnormal shape of the distal root of the maxillary third premolar teeth, and one skull specimen with fused roots of the right mandibular fourth premolar tooth. In the study of dental pathology in the California bobcat, only 40 teeth (0.5% of teeth) were found to have an abnormal form, and the most common morphological abnormalities were large crowns of the maxillary first molar tooth and bigemination of the mandibular incisor teeth.[13] In this study, abnormal tooth morphology was detected on the crown and was also detected in the roots by radiographic assessment. In our case, evaluation for the existence of large maxillary first molar crowns was not possible because they were absent or because they were affected by attrition/abrasion.

Abnormal number of roots (more roots than expected in all cases) affected 76 teeth (4.0% of evaluated teeth), and the most common teeth affected were the maxillary first molar teeth, maxillary third premolar teeth, and mandibular first molar teeth. The prevalence of abnormal number of roots is considerably higher than in the study of the California bobcat, where only 0.9% of teeth were affected.[13] In 1 study in Eurasian lynx (*L lynx*), the prevalence was considerably higher compared to our study, where 31.9% of teeth had increased number of roots, with the maxillary first molar teeth, maxillary third premolar teeth, and mandibular first molar teeth being affected.[27]

In our study, the fact that the teeth affected by an abnormal groove on the roots coincides with teeth affected by an abnormal number of roots could be explained as course of evolution of this species. One supernumerary tooth was detected during macroscopic and radiographic examination in our study (1.1% of skulls specimens), located on the mesiolingual aspect of the right mandibular third molar tooth. This has not been described in the lynx in the previous literature. Supernumerary teeth were not detected on the distal area of mandibular first molar teeth ("M2") nor rostral to maxillary third premolar teeth ("P2") as has been recorded in other studies in *L lynx*.[23,27,31]

No persistent deciduous teeth were detected during macroscopic or radiographic examination of any of the skull specimens examined. At Iberian Lynx Breeding Centers, this feature has been detected in live young animals. Future studies of dental pathology in "juvenile" Iberian lynx should be developed to assess its prevalence.

Enamel hypoplasia/hypomineralization results from disruption of the normal enamel development and is the most common acquired cause of disease to 1 or multiple unerupted teeth in the same traumatized area.[32] Enamel hypoplasia/hypomineralization affected 8 teeth (0.42% of evaluated teeth), 5 of these teeth were mandibular canine teeth, and it was recorded in 5 skulls (5.7% of the individuals). No generalized enamel hypoplasia/ hypomineralization was recorded in our study.

Attrition refers to wear of the teeth caused by contact of a tooth with another tooth. Abrasion is defined as tooth wear caused by contact of a tooth with a nondental object.[33] Attrition and abrasion were grouped for the purposes of this study as in similar ones due to the fact that assigning either process to a tooth would be speculative.[13] On the other hand, to determine the severity of attrition/abrasion has a vital relevance, especially in those cases where pulp exposure occurs. For this reason, affected teeth were included in 3 different types of attrition/abrasion, including its severity (mild, moderate, and severe flattening of the tooth cusp, which can include exposed dentin, presence of tertiary dentin, or pulp exposure).

Attrition/abrasion has a high prevalence in the Iberian lynx, where 90.9% of the specimens examined had at least 1 tooth affected by attrition/abrasion as in similar studies in *L rufus californicus*.[13] In our study, 831 teeth (43.7% of evaluated teeth) exhibited attrition/abrasion; 27.4% exhibited attrition/abrasion type 1 (mild rounding or flattening of the cusp tip with mild-to-moderate exposure to dentine); 14.2% exhibited attrition/abrasion type 2 (moderate-to-severe rounding or flattening of the cusp tip with severe exposure to dentin and tertiary dentin formation, without pulp exposure); and 2.1% exhibited attrition/abrasion type 3 (severe rounding or flattening of the cusp tip, with severe exposure to dentin with pulp exposure). Of the teeth examined that exhibited attrition/abrasion type 1, the mandibular premolars and molar teeth accounted for 29.4% of teeth with attrition/abrasion, the maxillary premolars and molar teeth accounted for 25.7% of teeth with attrition/abrasion, the maxillary canine teeth accounted for 13.1%, and the mandibular canine teeth accounted for 11.9% of teeth with attrition/abrasion. In attrition/abrasion type 2, the mandibular premolars and molar teeth accounted for 26.3% of teeth with attrition/abrasion, the maxillary premolars and molar teeth accounted for 18.9% of teeth with attrition/

abrasion, the maxillary canine teeth accounted for 16.3%, and the mandibular canine teeth accounted for 13.7% of teeth with attrition/abrasion. In attrition/abrasion type 3, high prevalence was found in the maxillary canine teeth (37.5%) and the mandibular canine teeth (27.5%) of teeth with attrition/abrasion type 3. This last fact implies that pulp exposure in canine teeth due to attrition/abrasion has to be taken into consideration for potential endodontic disease.

Tooth fractures were the second most common dental lesion seen in this study of congenital, developmental, and traumatic abnormalities in *L pardinus*, affecting 68.2% of specimens and 11.3% of teeth. In a study of the California bobcat, dental fractures were noted at a lower rate in the population (affecting 50.9% of specimens and 7.7% of teeth)[13] compared to a study of feral cats (affecting 54.8% of specimens and 7.0% of teeth).[18] One hypothesis that could justify this finding could be related to Iberian lynx feeding behavior (including its strict feeding diet based on wild rabbit) and hunting techniques. Complicated fractures accounted for 6.3% of the teeth examined (compared with 3.6% of teeth examined in California bobcat[13]) that represent 55.3% of the fractured teeth examined (43.7% of those fracture types were detected on maxillary canines and 30.3% on mandibular canines). In the Iberian lynx and feral cats, the 2 most common types of tooth fractures were the complicated fractures and root fractures,[18] which differ from California bobcat in that the 2 most common types of tooth fractures were enamel fractures and uncomplicated crown fractures.[18]

Endodontic disease was assessed via dental radiography and recognized by the presence of a complicated crown fracture, complicated crown-root fracture, and attrition/abrasion type 3 with resulting periapical lesion (including external inflammatory root resorption or not) and/or a root canal system that fails to mature. Pulp exposure in complicated fractures will always result in endodontic disease. Extension of endodontic disease into the periapical tissues will cause apical periodontitis or granuloma or abscess formation.[34] Periapical rarefaction is seen radiographically and is a lucency of the periapical bone, caused by loss of mineralization of the alveolar bone.[13,35] Additional signs of endodontic disease included having a pulp chamber and root canal system that fails to mature, resulting in a wider root canal than the mature tooth. Contralateral teeth were compared by assessing the width of the root canal. A tooth with a root canal that is wider than its counterpart is assumed to have stopped maturation due to pulp death.[13] Periapical lesions were diagnosed in 3.9% of teeth examined and 35.2% of the skull specimens. The most commonly affected teeth were the mandibular and maxillary canine teeth, comprising 69.2% of teeth with periapical lesions. The presence of root canal system that fails to mature was present in 2.2% of teeth examined, where 82.9% of affected teeth were mandibular and maxillary canine teeth. As in the study of the California bobcat,[13] the most common teeth affected by periapical lesions were the mandibular and maxillary canine teeth.

Endodontic disease may result in crown discoloration (pink, red, purple, gray, or brown), which can be interpreted as indicative of pulp necrosis[34] and possible secondary infection.[32] In conclusion, obtaining dental radiographs of the affected teeth is mandatory. Intrinsically stained teeth (gray, orange, or brown) was assessed in 8.5% of evaluated teeth, and 72.8% of affected teeth were maxillary and mandibular canine teeth (55.9% affected from complicated tooth fractures). This discoloration also affected premolars, molars, and incisors, where 70.5% of the affected teeth had 1 type of attrition/abrasion. One skull specimen had a "pink" discoloration in all teeth, corresponding to "postmortem pink teeth staining." The pink coloration of dentin is caused by the increased intracranial blood pressure, leading to hemorrhage in the pulp chamber, while the enamel is not affected. This phenomenon is more frequently associated with asphyxia in humans, but etiology in still unclear.[36,37]

Other findings with traumatic and/or congenital etiology were detected in 3 specimens. One adult female specimen had stained maxillary canine teeth and right mandibular canine tooth due to electric burn trauma as a result of human intervention in this natural habitat; in the opinion of this author, this feature should be taken into consideration in conservation programs of the species. One senior adult specimen had a mesioverted right mandibular canine tooth (class I malocclusion), presumably by congenital etiology or due to trauma. One spontaneous healed bony lesion of a mandibular fracture in the right mandibular canine tooth (absent) area was diagnosed in 1 senior adult female specimen.

During our study, 2.3% of evaluated teeth exhibited some type of artifactual damage or lesions presumably due to studies developed in the past. This emphasizes the importance of careful handling of irreplaceable specimens.

In conclusion, the Iberian lynx exhibits a wide range of congenital, developmental, and traumatic abnormalities. Prevalence of congenital and developmental abnormalities is low, but high prevalence of traumatic abnormalities including attrition/abrasion and tooth fractures (including endodontic disease) was found. International conservation programs should take into consideration these features and develop actions to specifically prevent and treat traumatic dental pathologies in the Iberian lynx. It should also be taken into consideration that acquired lesions affected senior adult Iberian lynx (older than 4 years) more frequently than the group of young adults and adults. As a result, lynx that suffer from severe primary dental disease probably suffer from reduced hunting capabilities, affecting the health and survival of this endangered species. Future study of periodontal status, prevalence of tooth resorption, and oral tumors is warranted.

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Materials

a. Color-Coded Expro 23/CP-11, XP23/116; Hu-Friedy Mfg Co, Chicago, Illinois.
b. SAS software, version 9.4; SAS Institute Inc, Chicago, Illinois.
c. Nomad Handheld X-Ray System; Aribex, Inc, Orem, Utah.
d. Sopix SD sensor size 2, Satelec—Acteon, Acteon Medico-Dental Iberica, Sentmenat, Barcelone, Spain.
e. Sopro Imaging VET 2.10, Satelec—Acteon, Acteon Medico-Dental Iberica.

Declaration of Conflicting Interests

The author(s) declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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References

1. Rodríguez A, Calzada J. *Lynx pardinus*. The IUCN red list of threatened species. 2015. doi:10.2305/IUCN.UK.2015-2.RLTS.T12520A50655794.en. Downloaded on August 12, 2016.
2. Simón MA. Life+ Iberlince website. Recuperación de la distribución histórica del Lince ibérico (*Lynx pardinus*) en España y Portugal. (LIFE10NAT/ES/570). Censo de las poblaciones ibéricas de lince ibérico, año 2017 [Spanish]. http://www.iberlince.eu/images/docs/3_InformesLIFE/Informe_Censo_2017.pdf. Accessed July 31, 2018.
3. Temminck CJ. Monographies de Mammalogie, ou description de quelques genres de Mammiferes, dont les espéces ont étè observées dans les differens Musées de l'Europe. In: D'Ocagne G. Dufour, eds. Paris; 1827.
4. García-Perea R, Gisbert J, Fernando P. Review of the biometrical and morphological features of the skull of the Iberian lynx, *Lynx pardina* (Temminck,1824). *Säugetierkundl Mittl*. 1985;32: 249-259.
5. Beltrán JF, Delibes M. Physical characteristics of Iberian lynxes (*Lynx pardinus*) from Doñana, southwestern Spain. *J Mammal*. 1993;74(4):852-862.
6. Ferreras P, Rodríguez A, Palomares F, et al. Iberian lynx: the difficult recovery of a critically endangered cat. In: Macdonald DW, Loveridge AJ, eds. *Biology and Conservation of Wild Felids*. Oxford, England: Oxford University Press; 2010:507-520.
7. Delibes M. *El Lince Ibérico: ecología y Comportamiento Alimenticio en el Coto de Doñana, Huelva. Doñana Acta Vertebr. 7*. Madrid, Spain: Consejo Superior de Investigaciones Científicas [Spanish]; 1980:1e128.
8. Sarmento P, Cruz J, Paula A, et al. Occupancy, colonization and extinction patterns of rabbit populations – implications for Iberian lynx conservation. *Eur J Wildl Res*. 2012;58(3):523-533.
9. Ferreira C, Célio P. Influence of habitat management on the abundance and diet of wild rabbit (*Oryctolagus cuniculus algirus*) populations in Mediterranean ecosystems. *Eur J Wildl Res*. 2009;55(5):487-496.
10. Ferreira C, Delibes-Mateos M. Wild rabbit management in the Iberian Peninsula: state of the art and future perspectives for Iberian lynx conservation. *Biol Pract*. 2010;6(3):48-66.
11. Rodrıguez A, Delibes M. Patterns and causes of non-natural mortality in the Iberian lynx during a 40-year period of range contraction. *Biol Conserv*. 2004;118(2):151-161.
12. Rodríguez-Hidalgo A, Lloveras L, Moreno-García M, et al. Feeding behaviour and taphonomic characterization of non-ingested rabbit remains produced by the Iberian lynx (*Lynx pardinus*). *J Archaeol Sci*. 2013;40(7):3031-3045.
13. Aghashani A, Kim AS, Kass PH, Verstraete FJM. Dental pathology of the California bobcat (*Lynx rufus californicus*). *J Comp Path*. 2016;154(4):329-340.
14. Cabrera A. *Fauna Ibérica: Mamíferos*. Madrid, Spain: Museo de ciencias naturales [Spanish]; 1914:207.
15. García Perea R. Patterns of postnatal development in skulls of lynxes, genus *Lynx* (Mammalia: Carnivora). *Int J Morphol*. 1996;229(3):241-254.
16. Lüps P. Vergleichende untersuchung am zwiten oberen vorbackenzahn P^2 der hauskatze felis silvestris f catus. *Z Siiugetierkund* [German]. 1980;45:245-249.
17. Skinner JD, Smithers RHN. *The Mammals of the Southern African Subregion*. 2nd ed. Pretoria, South Africa: University of Pretoria; 1990:391-423.
18. Verstraete FJM, Van Aarde RJ, Nieuwoudt BA, et al. The dental pathology of feral cats on Marion Island, part I: congenital, developmental and traumatic abnormalities. *J Comp Path*. 1996; 115(3):265-282.
19. Yerga J, Calzada J, Manteca X, et al. Early development and growth in captive-born Iberian lynx (*Lynx pardinus*). *Zoo Biol*. 2014;33(5):381-387.
20. Matson GM. *Workbook for Cementum Analysis*. Milltown, Montana: Matson's Laboratory; 1981.
21. Thome H, Geiger G. Vergleich zweier methoden der altersbeurteilung an zahnen altersbekannter wildlebender fleischfresser. *Anat Histol Embryol* [German]. 1997;26(2):81-84.
22. Hiller TL, Tyre AJ. Comparison of two age-estimation techniques for cougars. *Northwestern Nat*. 2014;95(2):77-82.
23. Garcia-Perea R, Baquero RA. Age estimation in Iberian wildcats *Felis silvestris*, by canine tooth sections. *Acta Theriol*. 1999; 44(3):321-327.
24. Danner RM, Farmer C, Hess SC, et al. Survival of feral cats, *Felis catus* (Carnivora: Felidae), on Mauna Kea, Hawai'i, based on tooth cementum lines. *Pac Sci*. 2010;64(3):381-389.
25. Zapata SC, Garcia Perea R, Beltrán JF, et al. Age determination of Iberian lynx (*Lynx pardinus*) using canine radiograph and cementum annuli enumeration. *Z Säugetierkund*. 1997;62(1997):119-123.
26. Verstraete FJM, Van Aarde RJ, Nieuwoudt BA, et al. The dental pathology of feral cats on Marion Island. Part II: periodontitis, external odontoclastic resorption lesions and mandibular thickening. *J Comp Path*. 1996;115(3):283-297.
27. Pettersson A. Tooth resorption in the Swedish Eurasian lynx (*Lynx lynx*). *J Vet Dent*. 2010;27(4):222-226.

28. Winer JN, Liong SM, Verstraete FJM. The dental pathology of southern sea otters (*Enhydra lutris nereis*). *J Comp Path*. 2013; 149(2-3):346-355.
29. American Veterinary Dental College AVDC nomenclature. 2016. http://www.avdc.org/Nomenclature/Nomen-Teeth.html#fracture. Accessed August 14, 2016.
30. American Veterinary Dental College AVDC. 2010. Small animal radiographic set technique description. http://www.avdc.org/Rad_tech_description.pdf. Accessed August 14, 2016.
31. Gomercic T, Guzvica G, Guzvica MD, et al. Variation in teeth number, teeth and skull disorders in Eurasian lynx, *Lynx lynx* from Croatia. *Folia Zool*. 2009;58(1):57-65.
32. Niemiec BA. Oral pathology. *Top Compan Anim Med*. 2008; 23(2):59-71.
33. American Veterinary Dental College AVDC nomenclature. 2016. http://www.avdc.org/Nomenclature/Nomen-Teeth.html. Accessed July 31, 2018.
34. Reiter AM. Dental and oral diseases. In: Little SE, ed. *The Cat: Clinical Medicine and Management*. St. Louis, MO: Saunders; 2012.
35. Lemmons M. Clinical feline dental radiography. *Vet Clin North Am Small Anim Pract*. 2013;43(3):533-554.
36. Manoilescu I, Ion A, Loan BG. Post-mortem changes in teeth-forensic issues. *Int J Paediatr Dent*. 2015;5(4):249-252.
37. Labajo G. Postmorten pink-teeth: un curioso fenomeno. *Rev Escuela Med Legal* [Spanish]. 2006;1(2006).