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Radiographic, computed tomographic, gross pathological and histological findings with suspected apical infection in 32 equine maxillary cheek teeth (2012-2015)

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Summary

Background: Equine maxillary cheek teeth apical infections are a significant disorder because of frequent spread of infection to the supporting bones. The accuracy of computed tomographic imaging (CT) of this disorder has not been fully assessed.

Objectives: To compare the radiographic and CT findings in horses diagnosed with maxillary cheek teeth apical infections with pathological findings in the extracted teeth to assess the accuracy of these imaging techniques.

Study design: Observational clinical study.

Methods: Thirty-two maxillary cheek teeth (in 29 horses) diagnosed with apical infections by clinical, radiographic and principally by CT examinations, were extracted orally. The extracted teeth were subjected to further CT, gross pathological and histological examinations. Four normal teeth extracted from a cadaver served as controls.

Results: Pulpar and apical changes highly indicative of maxillary cheek teeth apical infection were present in all 32 teeth on CT, but in just 17/32 teeth (53%) radiographically. Gross pulpar/apical abnormalities and histological pulpar/periapical changes were present in 31/32 (97%) extracted teeth. On CT, one tooth contained small gas pockets in the apical aspect of one pulp and adjacent periodontal space, however no pathological changes were found following its extraction.

Main limitations: The study is descriptive and is confined to a small number of cases

Conclusion: This study showed a 97% agreement between CT diagnosis of maxillary cheek teeth apical infection and the presence of pathological changes in the extracted teeth, confirming the diagnostic accuracy of CT compared to radiography for this disorder.

Introduction

Dental apical (periapical) infections are caused by multispecies bacterial infection of one or more pulp horns that spreads to the adjacent periapical periodontal membranes as well as, to a varying degree, to adjacent alveolar bone and calcified dental tissues [1-7]. Equine apical infections can be caused by dental fractures, infundibular caries, anachoresis (blood borne infection) and descending periodontal disease [2, 8]. Regardless of aetiology, apically infected teeth usually have pathological changes to one or more pulp horns and the adjacent periapical periodontal membranes. An exception is periapical infection caused by patent maxillary cheek teeth infundibulae that usually do not have pulpar involvement [2, 9].

Because of the great length of equine maxillary cheek teeth, apical infections are a very significant disease and commonly extend to the supporting maxillary bones, especially in younger horses, causing chronic, unilateral malodorous nasal discharge or bony facial swellings and/or sinus tracts [6]. Such cases require extraction (or endodontic therapy) of affected teeth for permanent resolution of signs. However, extraction of equine cheek teeth is a major undertaking with numerous possible short and long-term complications [6, 9], hence the great reliance on imaging for the accurate diagnosis of apical infections.

Radiography is the most commonly used imaging technique for such cases, but conventional radiography has a reported sensitivity of only 50%-69% [10, 11, 12], and digital radiography of 76% - 80% [13]. Scintigraphy also has a poor sensitivity (56%) in diagnosing apical infections [11], but a better sensitivity (79%) in diagnosing dental-related sinusitis [12].

Because of the above-noted limitations of radiography, computed tomography (CT) is increasingly used to diagnose equine sinonasal and dental disorders [14, 15, 16] and for anatomical dental studies [17, 18, 19]. Henninger *et al*. [14] and Buhler *et al*. [16] noted the diagnostic advantage of CT for equine cheek teeth apical infection, with the former noting the diagnostic significance of intrapulpar gas or root fragmentation, whilst the latter noted the significance of increased volume and irregular margins of pulp horns, and heterogeneous pulp density.

The aim of this study was to compare the radiographic and CT findings in horses diagnosed with maxillary cheek teeth apical infections with the gross pathological and histological findings in the extracted teeth, to assess the accuracy of these imaging techniques for this disorder.

Materials and methods

Twenty-nine horses presented to the Hospital for Large Animal, Royal (Dick) School of Veterinary Studies (2012-2015) with chronic unilateral nasal discharge (n = 24) or maxillary swelling (n = 5) of 1-20 weeks' duration, including Thoroughbred (n = 16); Warmblood (N = 5); Irish Draught (N = 4); Cob (N = 3) and Arabian (n = 1) with a mean age of 9 years (range 3-15 years). Clinical examination, including oral endoscopy, was performed in each case, followed by radiographic and standing CT. Teeth diagnosed with apical infection on the basis of these clinical and imaging findings were orally extracted. The extracted teeth underwent further CT, gross pathological and histological examinations. Four normal maxillary cheek teeth (Triadan 07-10) extracted from a cadaver were used as controls.

Diagnostic Imaging

Four computed radiographic projections were acquired from each case (Agfa CR 25 digitiser[a]): lateral, dorsoventral, two latero30^0dorsal-lateroventral oblique projections of the affected and of the contralateral maxillary arcade (for comparison) and assessed for features of apical infection using standard criteria [13, 20].

CT images were acquired using a multislice scanner (Siemens Volume Zoom[b]) at Kv 120, mAs 100 and H70 algorithm, at 3 mm intervals, with images saved in a DICOM format. The extracted teeth were re-imaged by CT within 24 hours of extraction, at 0.5 mm intervals in a vertical position. The main emphasis on CT was assessment of the pulp horns including for the presence of gas or heterogeneity of pulp; pulpar volume and regularity of pulp horns margins; changes in periapical periodontium including presence of gas and widening; root clubbing and fragmentation and periapical alveolar bone lysis [16, 18, 19, 21]. All radiographic and CT images were independently assessed by two observers.

Gross anatomical examination

Extracted and control teeth were grossly examined and photographed before being fixed in neutral buffered formalin within 24 hours of extraction. They were later transversely sectioned with a lapidary blade into 4 equal parts, i.e. occlusal; two mid-crown and apical aspects. These 4 sections were examined and photographed on both sides before a 5 mm thick section was cut from each for histology.

Histological examination

The sectioned dental specimens were placed into Decal II[c] for 4 days and then transferred into Decal I[c] for 2-4 weeks until decalcified. Specimens were then embedded in paraffin wax and 4 µm thick sections were prepared and stained with haematoxylin and eosin.

The four histological slides of each tooth, including controls, were anonymised, and re-labelled before examination, that documented findings in pulp, dentine, periodontal ligament, peripheral cementum and infundibulum in all teeth. All enamel was lost during decalcification. Pulpar features assessed included: the presence of intra-pulpar bacteria, neutrophilic or lympho-plasmacytic infiltration, food material, tertiary dentine and pulp stones.

Results

Clinical dental findings

Oral examinations showed that 12 teeth (from 12 horses) had no clinical crown abnormalities; 9 teeth (from 9 horses) had defective or absent secondary dentine overlying one or more pulp horns and 11 teeth (from 8 horses) had fractures (10 idiopathic fractures through pulp horns and one infundibular, caries-related midline sagittal fracture). The 09s were the most commonly affected Triadan position (16/32 teeth); 08s (n = 8); 07s (n = 3); 10s (n = 3); 06s (n = 1); 11s (n = 1).

Pre-extraction CT (3 mm intervals) and post-extraction CT (0.5 mm intervals)

No apparent difference was found between pre- and post-extraction CTs in the detection of pulpar or calcified dental tissue changes (other than extraction forceps marks on the clinical crown). Iatrogenic, extraction-related periodontal changes were present post-extraction, mainly characterised by localised loss of reserve crown periodontium. The width of the periodontal space could not be assessed on post-extraction CT. The pre-extraction CT findings were further used in the study.

Radiography

The main radiographic findings included: periapical sclerosis in 12/32 teeth; apical blunting (n = 10); periapical halo (n = 3) and crown fracture (n = 6). Periapical halo is a well-defined osteolucency surrounding the apex. On the basis of these findings, a consensus was reached that radiographic changes highly indicative of apical infection were present in 17/32 (53%) teeth.

Pre-extraction CT findings

The main CT findings included: gas (areas with a density of <1000 Hounsfield units) within pulps in 32/32 teeth, increased pulpar volume (n = 16), irregular pulp horns margins (n = 13); gas within periapical tissues (n = 15), widened periodontal space (n = 8); root clubbing (n = 24), root fragmentation (n = 14); periapical halo (n = 31), periapical alveolar bone lysis (n = 11), dental fracture (n = 11) and infundibular changes (other than cemental hypoplasia) (n = 10) (Figs 1-3). A consensus was reached by both examiners that all 32 teeth had CT evidence of apical disease, in particular the presence of pulpar changes in all teeth. Largely on the basis of these CT findings, all 32 teeth were extracted. No CT changes (post-extraction imaging only) were found in the 4 control cheek teeth.

Gross pathological findings in extracted teeth

Pulp

The 11 teeth with pre-existing fractures contained pulpar changes (including discoloured pulps, food material in pulp horns and staining of adjacent dentine in sectioned teeth) in one or more pulp horns in all 11 teeth, but 10/11 teeth had one or more apparently viable pulps remaining. The 9 teeth with occlusal pulpar exposure contained pulpar changes (to apical level of the occlusally exposed pulps) in all 9 teeth, but one or more apparently viable pulps remained in 7/9 teeth. In the 12 teeth without clinical crown abnormalities, gross pulpar changes were present in 9/12 teeth, with one or more apparently viable pulps remaining in 4 of these 9 teeth. Overall, gross pulpar abnormalities were present in the pulps of 29/32 teeth, with every pulp diseased in 8 teeth and apparently viable pulps remaining in the other 24 teeth.

Dentine

Gross dentinal changes, mainly the presence of circumpulpar dentine staining and irregular dentinal-pulpar margins, were present around one or more pulp horns in 26/32 teeth. In five teeth, gross communication was present between a carious infundibulum and infected pulp horn(s).

Periodontal changes

Localised apical periodontal thickening or focal, firm, pink, soft tissue swellings were present, especially over the roots, in 26 teeth (Figs 1-3). Localised loss of periodontal membranes and discoloration of roots were present in 3 teeth (Fig 3A) and gross abscess formation was identified in one tooth (Fig 2D).

Calcified apical tissue changes

Proliferative calcified apical changes, including thickened, irregular-shaped and/or more generalised apical hypercementosis, were present in 17/32 teeth, with more destructive calcified changes including shortened roots and root destruction present in 8/32 teeth (Figs 1-3).

Infundibulae

Gross caries was identified in the infundibulae of 16 teeth, with the Triadan 09 position affected in 7 of these 16 teeth.

In summary, gross examination showed pulpar changes in 29 teeth and apical changes in 31 teeth. No grossly detectable changes were present in one tooth, or in the 4 control teeth.

Histological findings

Pulp

Histologically pulpar changes were present in 31/32 teeth, involving 112/162 pulps (mean 3.5, range 1-5 affected pulps/tooth) with every pulp diseased in 8 teeth. Histologically, 24/32 teeth were found to contain normal appearing pulp in a total of 50 pulp horns (mean 1.6, range 1-4, normal pulps/tooth). All 5 pulps in each control tooth were normal.

Histological pulpar abnormalities included what was termed "faded pulp" in 29/32 teeth. This feature was characterised by a pulp stroma that was much paler than that of normal viable pulps and which there was loss of nuclear detail in stromal fibroblasts, loss of normal vasculature and often superimposed dentinal debris at the periphery; intra-pulpar bacteria and neutrophils (n = 16); intrapulpar bacteria (n = 2); food material (n = 15) and pulp necrosis (n = 2) (Fig 5). Pulp stones (1 to 8/section) were present within pulp and secondary dentine in 20/32 infected and in 2/4 control teeth.

Of particular interest were the 3 teeth without gross pulpar changes; one histologically contained intrapulpar bacteria and neutrophils; one contained "faded pulps"; and one had no detectable pulpar abnormalities. Five further histological sections of the apical region of the latter (anatomically normal) tooth were obtained but no histological changes were identified.

Periodontal membranes

Histological periodontal abnormalities were present in 25/32 (78%) teeth, including the presence of: haemorrhage/fibrin (n = 19), bacteria/neutrophils (n = 7), plasma cells (n = 6), lymphocytes (n = 6) and, less commonly, chondroid metaplasia, micro-abscesses, periodontal thickening and granulation tissue (Fig 5).

Dentine

Histological dentinal changes were found in 22/32 (69%) teeth, including: irregular pulpar-dentinal margins (n = 15), dentinal lysis at the pulp canal periphery (n = 7) and tertiary dentine formation (n = 4) (Fig 6).

Cementum

Some roots/apices were lost during sectioning, decalcification and histological processing. In addition to the proliferative apical remodelling grossly recognised in 17 teeth (53%), histological abnormalities of apical and adjacent reserve crown peripheral cementum were found in 21/32 teeth (65.6%) and included: cemental erosion/lysis (n = 12) (Fig 4), overlying plaque/biofilm (n = 8) and cemental necrosis (n = 1).

Infundibulae

Sixteen (50%) teeth had histological infundibular changes (other than central cemental hypoplasia/occlusal caries) including the presence of plant material, bacteria, carious infundibular cementum, fibrin, haemorrhage and granulation tissue in infundibulae. The latter 3 findings indicated involvement of adjacent pulp.

Discussion

Indications for CT

Twenty teeth examined in this study had fractured crowns or occlusal pulpar exposure and it could be questioned whether advanced imaging was required to diagnose apical infection in these teeth. The presence of clinical crown ("idiopathic") fractures indicates oral cavity exposure of one or more pulp horns [1, 2], however, 72% of such fractured teeth may not develop clinical apical infection, likely due to sealing of the exposed pulp horn with tertiary dentine [22, 23, 24, 25]. The presence of occlusal pulpar exposure is usually indicative of pulpar and thus apical disease [23, 24], but some clinically normal horses have cheek teeth occlusal pulpar exposure, with dentinal bridges beneath the exposed pulp but overlying the deeper healthy pulp [24, 25, 26]. Consequently, the presence of occlusal pulpar exposure is not definitive evidence of pulpar death and apical infection.

Usefulness of radiography

As noted earlier and as recently reviewed [20, 27], radiographic diagnosis of equine cheek teeth infection has a low sensitivity, particularly in early cases, where radiographic identification of diseased teeth is frequently impossible. Interpretation of some of the radiographic changes of apical infections is subjective and differences in the interpretation of specific radiographic features can occur between examiners [1, 2, 13]. In the current study, a consensus was reached that imaging changes, sufficient to advise extraction, were present in only 53% (17/32) of infected teeth, albeit many were believed to be of short duration. Consequently, on the basis of a radiographic diagnosis, 15 teeth (47%) in this study would not have been extracted, including 14 (44%) that were later shown to have apical infection. These horses would very likely have had recurrence of clinical signs following conservative therapy such as antibiotic administration and/or sinus lavage. Later radiographic examination would likely have shown a higher proportion with definitive radiographic changes.

Usefulness of CT

Periapical infection was diagnosed by both examiners in all 32 cheek teeth by CT. In particular, the presence of pulpar changes, including intrapulpar gas and other changes in pulp density, such as those caused by the presence of food or necrotic pulp, enlarged pulp horns and irregular pulp margins were important diagnostically, along with changes to the periapical region. Many of these CT changes are not, or are only poorly, detectable radiographically. These CT findings were a significant basis for extraction of the 15 infected cheek teeth that did not have definitive radiographic evidence of apical infection and also the sole reason for extracting the apparently healthy tooth.

The pathology of equine apical infections

Apically infected cheek teeth can grossly present with the presence of: thickening, granuloma formation or even loss of the apical periodontal membranes; proliferative (hypercementosis) to destructive (shortening of roots – "clubbing") remodeling of the dental apex or even necrotic apical changes. Affected pulp horn(s) can contain discolored, necrotic or absent pulp or food debris, with possible staining of the adjacent dentine [1, 2, 3, 6, 9, 25, 26]. Histologically, affected pulp may be oedematous, with inflammatory cell and bacterial infiltration with necrosis and/or destruction of dentine surrounding infected pulps [1, 2, 3, 4, 26].

Apical pathological findings in the current study

Gross, but often localised, apical changes were present in 30/32 (94%) extracted teeth, including thickened periapical periodontal membranes or focal, granulation tissue swellings, especially over the roots, in 81% of teeth; and proliferative and destructive cemental remodelling of the roots and adjacent apex in 78% (Figs 1-3). Histological periodontal or calcified apical changes were identified in 91% of teeth, although some periodontal changes, such as the presence of haemorrhage and fibrin, were likely related to the extraction procedure. Variation between gross and histological apical findings could be explained by the loss and disintegration of some more lytic roots/apices during tooth sectioning, decalcification and histological processing.

Pulpar pathological findings

Gross pulpar changes were present in 91% of teeth, including: intra-pulpar food, discoloured or necrotic pulp horns and stained adjacent dentine. There was histological evidence of pulpar disease in 97% of teeth (all teeth had shown pulpar changes on CT). Histological, pulpar changes included the presence of avascular pulp with pallor of the stroma; bacterial and neutrophil infiltration; and/or the presence of food in pulp horns. Pulp stones were histologically found in 66% of diseased and 50% of control teeth and were considered a normal finding [28].

Dentinal changes

In the current study, dentine was grossly abnormal in 81% of teeth but histologically abnormal in just 64% of teeth. Changes included the presence of irregular margins, dentinal lysis, dentinal degeneration, tertiary dentine and intra-dentinal abscess formation (Fig 6). This difference is speculated to be due to localised areas of dentinal damage recognised on gross examination not being captured in the histological sections and/or disintegrating during processing. Significant dentinal disease can make affected pulp horns appear larger, with or without irregular margins, as noted on CT in 17/32 teeth (12 with both of these changes).

Although sometimes termed as apical abscesses (which indicates the accumulation of pus) only 4/32 teeth (13%) could be grossly classified as such (one apex contained pus and 3 apices had localised, necrotic changes). However, with spread of infection to the adjacent maxillary bone or sinuses, as occurred in these cases, a marked purulent infection of these other structures then ensued. Surprisingly, 24/32 teeth (75%) still had one or more histologically normal pulps remaining, further demonstrating the localisation of infection in affected teeth. Overall, the changes in most extracted teeth were indicative of a chronic, low-grade infection. It is likely that the current early recognition and referral of these cases for advanced imaging could explain the lower grade changes found in these teeth than previously reported [1, 28]

One tooth (207) that lay in an adjacent alveolus to a tooth (208) with gross and histological changes of apical infection, showed gas in the apical aspect of its pulp and in the adjacent periodontal space on CT. However gross and histological examinations did not detect any abnormalities of this tooth, or of the attached periodontal membranes. The reason for this discrepancy between CT and pathological findings is unclear. It is unlikely that free gas, usually indicative of gas-producing bacteria, could be present in a healthy pulp. The possibilities include that the apparent presence of pulpar and periapical gas in this tooth on CT was artefactual, and possibly related to an immediately adjacent apically infected tooth that also contained pulpar gas. It is also possible that localised pathological pulpar changes were present, that were not detected using the current sampling technique, or that pathological changes were confined to the apical periodontium that remained attached to the alveolus during extraction or was lost during processing. Following extraction of these 2 teeth, the clinical signs permanently resolved in this horse.

Infundibular lesions

Interpreting the significance of infundibular changes in equine cheek teeth on clinical, imaging or pathological examinations is very problematic. Imaging [20, 21] and pathological [29, 30] studies have shown that up to 90% of infundibulae are incompletely filled with normal cementum. Extension of infundibular caries has been reported to cause 16% [2] and 27% [9] of maxillary cheek teeth apical infections although another CT study found no relationship between infundibular and apical abnormalities [23]. Hypoplastic or carious infundibular lesions can look dramatic on imaging, gross and histological examinations, but if the enamel "cup" of the infundibulum remains intact, none of these lesions can cause endodontic and thus apical infection. However, in some cases extension of infundibular caries through infundibular enamel defects can cause endodontic and apical infection [1, 2, 20, 21, 9] as was found in five of the current 32 teeth.

Limitations and Conclusions

The study is limited to a small number of animals and its descriptive nature. Nevertheless pathological examination of the extracted teeth in this group of animals confirmed the advantage of CT over radiography in the diagnosis of early equine maxillary cheek teeth apical infections.

Authors' declaration of interests

No competing interest have been declared.

Ethical animal research

This study was approved by the Ethical Committee of the University of Edinburgh. Owners of horses with apical infection and one control horse subjected to post mortem examination for unrelated reasons gave permission for use of images and tissues for research.

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Authorship

All authors contributed and accepted full responsibility for the study design.

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Figure legends

Fig 1: Tooth 2

A: Apex post-extraction, showing abnormal, thickened periodontium attached to one blunt root tip and much periodontal loss.

B: Transverse CT image of its rostral aspect showing; widened perialveolar space (arrow), blunting and shortening of roots and fluid filled right ventral conchal sinus (VCS) (*) and rostral maxillary sinus (RMS) (+).

C: Transverse CT image of its caudal aspect showing intrapulpar gas (arrow)

R: Right, L: Left.

Tooth 4

D: Apex post-extraction, showing shortened roots, generalised hypercementosis and thickened periodontal remnants.

E: Transverse CT image of its rostral aspect showing enlarged perialveolar space, blunting of root with hypercementosis (arrow head), and bilateral fluid filled RMS (+) (horse has intercurrent contralateral sinus disease).

F: Transverse CT image of its caudal aspect showing distorted apex, intrapulpar gas (arrow) and a round cemental structure ("pearl") in periodontium.

R: Right, L: Left

Fig 2: Tooth 15

A: Apex post-extraction, showing a swollen pulp (arrow) protruding through a thickened, short, caudo-buccal root with thickened remnants of apical periodontal membranes.

B: Transverse CT image of its rostral aspect showing an enlarged perialveolar space, blunting of root and intrapulpar gas (arrow).

C: Transverse CT image of its caudal aspect with intrapulpar gas.

R: Right, L: Left

Tooth 27

D: Apex post-extraction, showing inspissated exudate lying in a lytic palatal root that fractured during extraction.

E: Transverse CT image of its rostral aspect showing; enlarged perialveolar space, blunting of buccal root, perialveolar gas (arrow) and a fluid filled RMS (+).

F: Transverse CT image of its caudal aspect showing much perialveolar gas (arrow) and a fluid filled RMS (+).

R: Right, L: Left

Fig 3: Tooth 6

A: Apex post-extraction, showing chronically infected apex with focal, brown discoloration of roots. Periodontium is lost on crown and thickened over apex.

B: Transverse CT image of its rostral aspect showing widened perialveolar space, blunting of the gas-filled buccal root (arrow), and fluid filled VCS (*) and RMS (+).

C: Transverse CT image of its caudal aspect showing intrapulpar gas (arrow)

R: Right, L: Left

Tooth 5

D: Apex post-extraction showing widened apex, apical granuloma (arrow) and thickened apical periodontal membranes.

E: Transverse CT image of its rostral aspect showing an enlarged perialveolar space (arrow), blunt roots and abnormal apical architecture.

F: Transverse CT image of its caudal aspect showing intrapulpar gas (arrow).

Fig 4: Tooth 10

A: Transverse CT image showing an enlarged perialveolar space, gas within the common pulp, widened periapical region (black arrows); maxillary bone lysis (white arrow), and a blunt, shortened palatal root.

A1: Gross transverse section just above the apex showing an enlarged, discolored common pulp.

A2: Transverse CT section of tooth corresponding to the gross section A1.

B: Histological image just above the apex showing reactive peripheral cementum deposition and subsequent lysis (C and D) at the level of the common pulp cavity.

R: Right, L: Left

Fig 5: Tooth 8

A: Transverse CT image of its rostral aspect showing an enlarged perialveolar space, fragmented root (arrow) and maxillary bone thickening.

B: Transverse CT image of its caudal aspect showing intrapulpar gas (arrow).

C: Histological image of apex. Yellow box: Chronic suppurative focus indicative of chronic abscessation with granulation tissue; cemental erosion and loss of viable pulp (E). E1 (higher power) shows many neutrophils and a few bacteria.

Green box: Pulp cavity containing small area of suppurative inflammation and no viable pulp.

Red circle: Granulation tissue and fibrosis with fragment of embedded cementum (*). Within the granulation tissue there is an infolding of periodontium surrounded by lymphocytes and plasma cells and peripheral cemental erosion where the granulation tissue extends into cementum (arrow) (D)

R: Right, L: Left

Fig 6: Tooth 18

A: Transverse CT image showing enlarged perialveolar space; intrapulpar gas (arrow) and an extensive soft tissue facial swelling (*).

B: Histological image of apex

Red box: Well demarcated area of severe dentinal lysis. The resultant cavity is filled with granulation tissue, blood and small numbers of lymphocytes and macrophages.

Blue box: Pulp necrosis with granular material and some necrotic cell debris. Tertiary dentine (*), which is partly degenerate and pulp stones are also visible (+)

R: Right, L: Left

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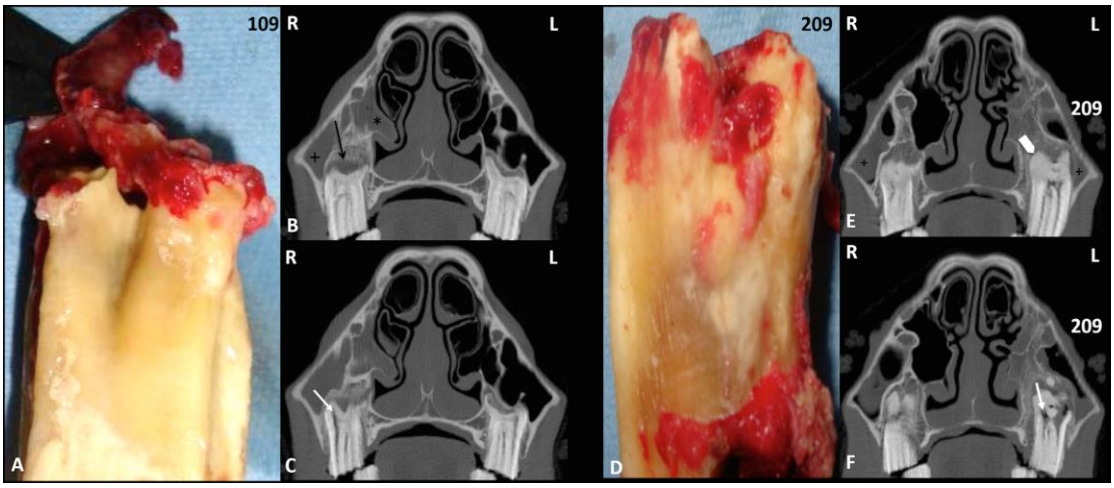

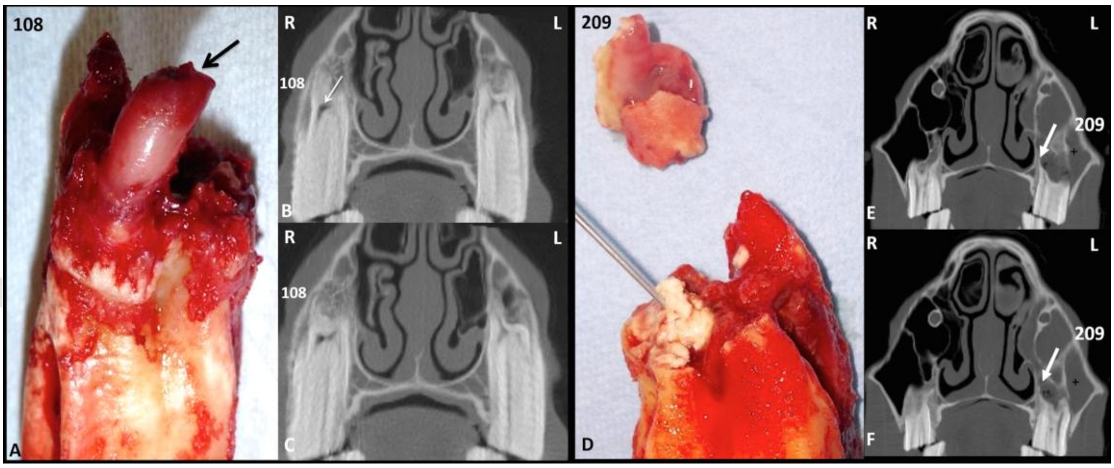

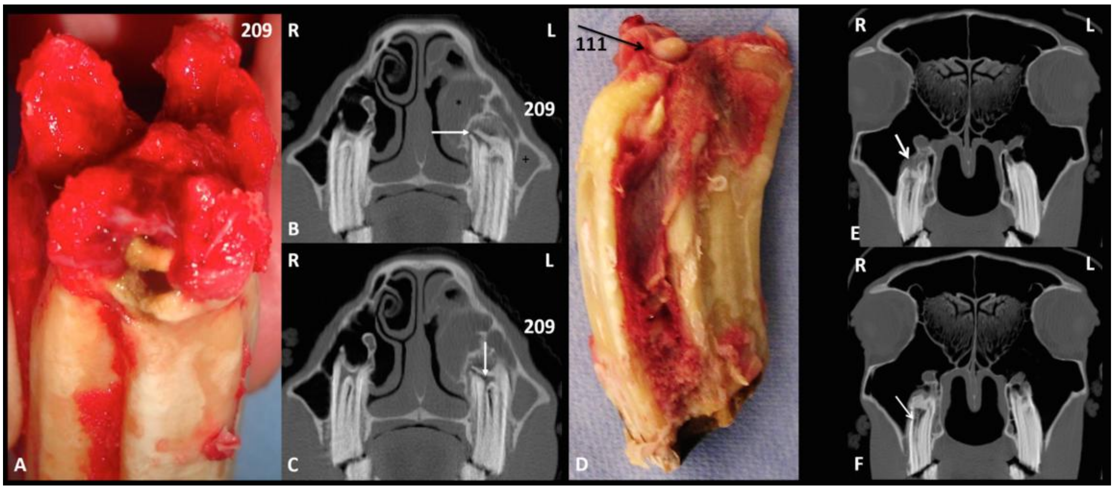
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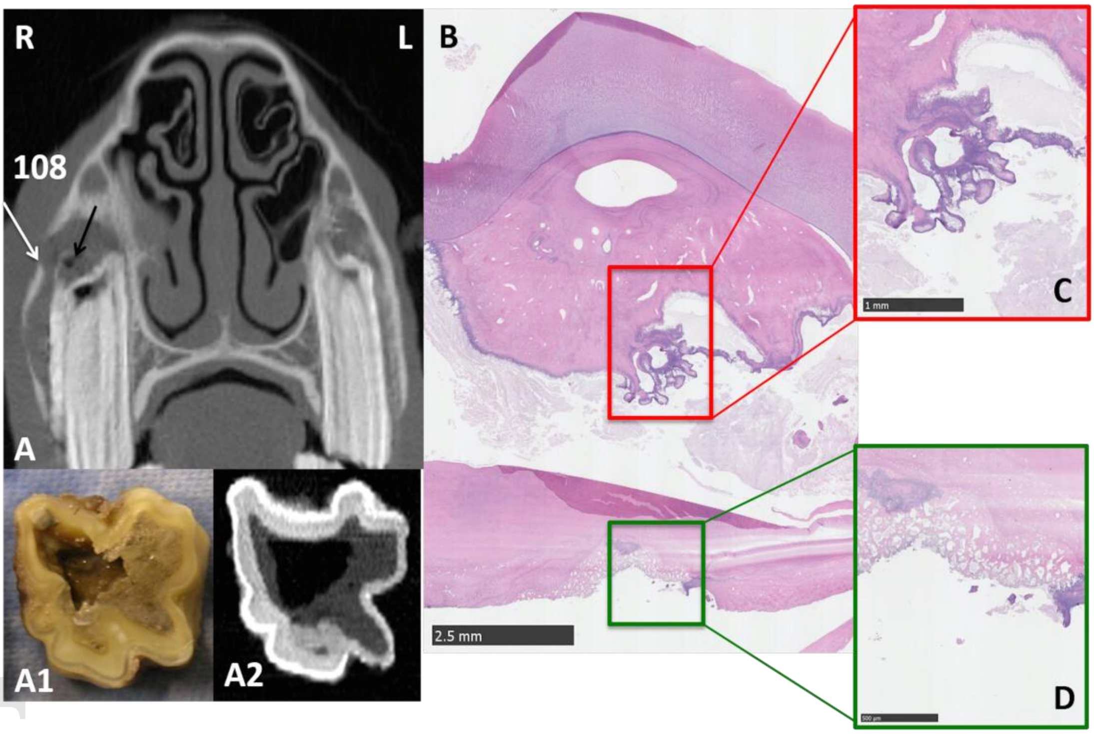
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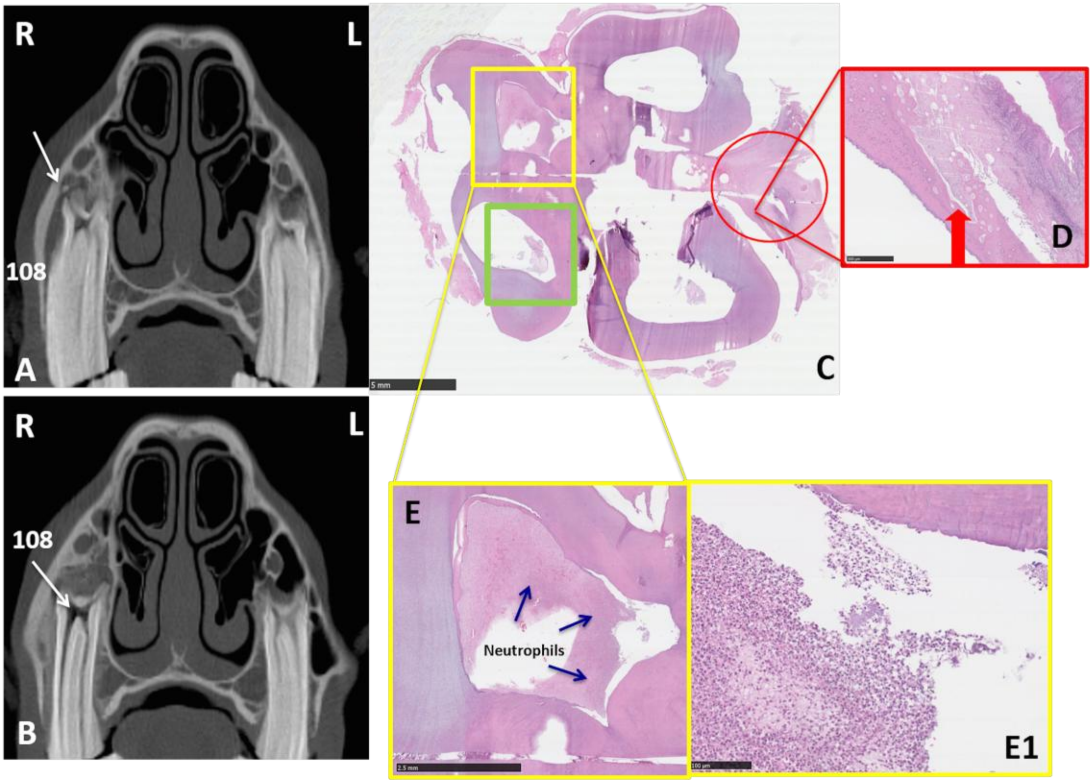
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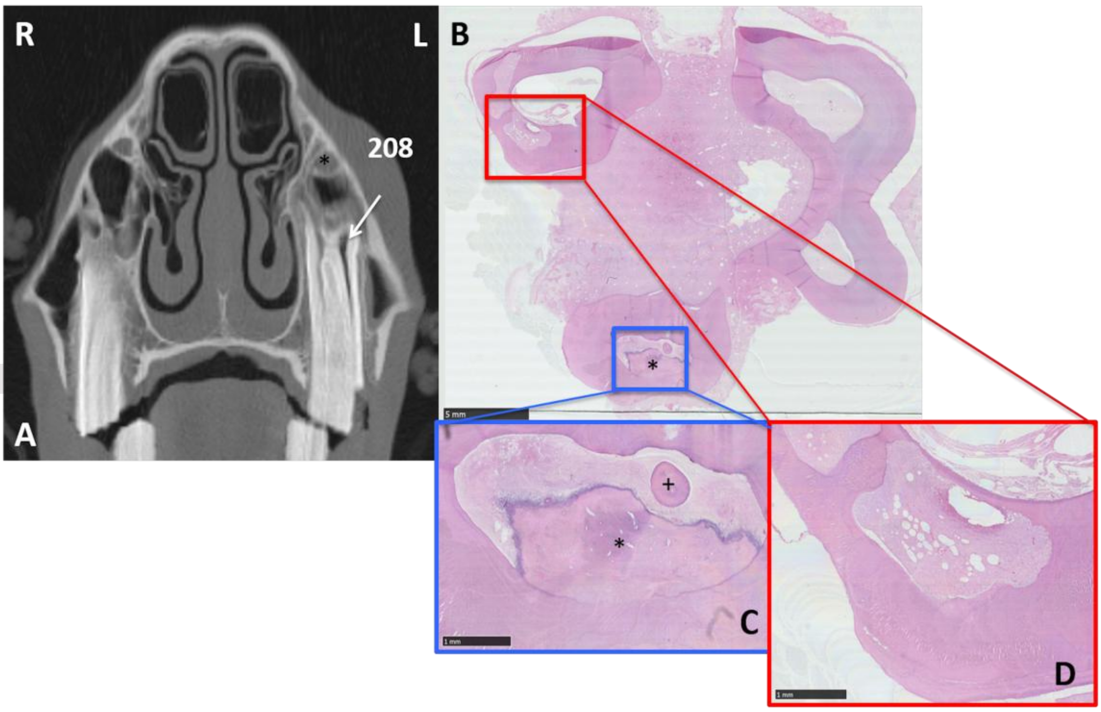
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