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Dental Health in Roman Dogs: A Pilot Study Using Standardized Examination Methods

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Dental health in Roman dogs: A pilot study using standardized examination methods

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ABSTRACT

Objective: To utilize standardized clinical veterinary methods to analyze dental health in a series of Roman dog maxillae and mandibles and to compare results to modern clinical data.
Materials: 28 skulls of juvenile and adult dogs from three archaeological sites in Switzerland and Germany dating to the Roman period.
Methods: Standardized examination was carried out, which included metric radiographic assessment to diagnose oral pathology and estimate age at death. In one case, CT analysis was undertaken.
Results: The estimated average age at death was between three and four years old. Tooth fracture, periodontal disease, the presence of non-vital teeth, and brachycephalic skull form were found in the sample. Tooth resorption was unexpectedly noted.
Conclusion: The study provides valuable insights into the dental health of dogs in the Roman era. Compared to modern dogs, Roman dogs examined in this study appear to have a shorter lifespan but display a high rate of pathological dental disease, while disease patterns were very similar to those of modern dogs. Dogs with pronounced brachycephalic features were found.
Significance: This pilot study is the first to use standardized clinical examination and recording techniques to assess dental health in dogs from archaeological contexts. It provides insight into the dental health of Roman era dogs and offers data upon which cross-populational studies can be initiated.
Limitations: The sample size and geographic location of the archaeological sites were limited.
Suggestions for further research: Subsequent standardized studies, preferably in as many different Roman Empire regions as possible, are recommended.

1. Introduction

Teeth recovered from archeological sites can provide valuable insights into the health and diseases of animals living in the past. This study aims to assess the presence of dental pathologies in dogs recovered from Roman era sites and to assess whether dental conditions noted in Roman dogs differed from those recognized in dogs within modern clinical veterinary settings. In particular, the presence of common pathological findings in modern dogs – periodontal disease, fractured teeth, persistent deciduous teeth, enamel hypoplasia, and missing teeth (Niemiec, 2008a) – were the foci of analysis.

To date, there are few paleopathological investigations focusing on the dental health of ancient dogs that use modern recording criteria. Although some studies have described a selection of oral diseases (see, for instance, Baker and Brothwell, 1980; MacKinnon and Belanger, 2006; Bartosiewicz, 2013; Bellis, 2020), the methods of evaluation are not comparable to clinical studies, nor do they allow cross-population comparisons. Of note, however, are studies by Losey et al. (2014), who examined the frequency of trauma, ante-mortem tooth loss, and enamel hypoplasia in wolves and dogs living between 1882 and 1984 in small communities in far-north latitude environments in order to evaluate the influence that coexistence with humans had on dental diseases, Tourigny et al. (2016), who created an osteobiography of a 19th-Century dog from Toronto, Canada, and Binois et al. (2013), who described a near-complete skeleton with many injuries in various stages of healing. Although these studies provide insight into the health of dogs

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(and wolves) in the past, the criteria used for diagnosing and reporting pathological conditions differ substantially from those used in modern clinical studies. This limits the use of these studies for intra and inter-populational comparisons and renders comparison with clinical data almost impossible. Hence, this study applies clinical standards set by the Global Dental Guidelines of the World Small Animal Veterinary Association (WSAVA) (https://wsava.org/global-guidelines/global-dental-guidelines/), a comprehensive work on oral pathologies in dogs and cats (Niemiec et al., 2020), in order to provide a foundation for zooarchaeological analysis.

The goal of this pilot study is to explore the dental health of Roman dogs using standardized and reproducible methods and to offer insights into the past by comparing the results to modern clinical data.

2. Materials

For this pilot study, 28 skulls recovered from archaeological sites dated to the Roman era excavated by the Universities of Basel and Cologne were analyzed. Two of the sites are located in Switzerland – Augusta Raurica (modern Augst/Kaiseraugst) and the closely situated military camp of Vindonissa (today Windisch). Another site came from the surrounding area of the Colonia Claudia Ara Agrippinensium (CCAA) (modern Cologne) in Germany (Fig. 1). The skulls are dated between 70 — 400 CE., with most of the skeletal remains dating to the middle of the 3rd century CE (Table 1). The preservation of the archaeological material varied considerably, with some remains consisting of complete skulls and others only fragmentary parts of the upper or lower jaw.

2.1. Archaeological contexts of the dog skulls from Augusta Raurica and Vindonissa (Switzerland)

Augusta Raurica was a Roman metropolis on the river Rhine in the province *Germania superior,* located on the border between Switzerland and Germany. Twenty out of the 28 dog skulls discussed in this paper originate from two wells, which were filled with numerous carcasses belonging to various animal species, as well as human remains and construction rubble, ceramics, and coin molds, dated to the second half of the third century CE (Schmid et al., 2011; Mráz, 2018). Augusta Raurica experienced political and economic crisis around 250 CE due to the fear of war caused by the shift of the imperial border to the Rhine, the threat of Germanic and Persian tribes, and possible earthquakes of medium intensity (Berger, 2012). The two wells differ significantly in their location, with one located next to a bathing facility directly on the road leading to the Rhine bridge at the foot of the Kastelen hill (Specimens : 01, 08, 09, 10–3, 12, 17, and 20), and the other located in the town of Augusta Raurica (12 specimens labeled 02–1 through 07–3). The skulls from individuals no. 11 and 19 originate from dogs that were disposed of in pits. In both cases, the pits were located outside a residential area in an industrial zone. Skull no. 11 is chronologically the oldest dog from Augusta Raurica examined in this study. The remains of this animal were found in the uppermost part of a pit, with backfill containing pebbles, sand, and ceramics that were dated 70–100 CE (Breuer, 1992). Skeleton no. 19 dates to late Roman times (late 3rd to the first half of 5th century) and was recovered from a pit filled with bullion stones not far from a quarry (Müller et al., 2004).

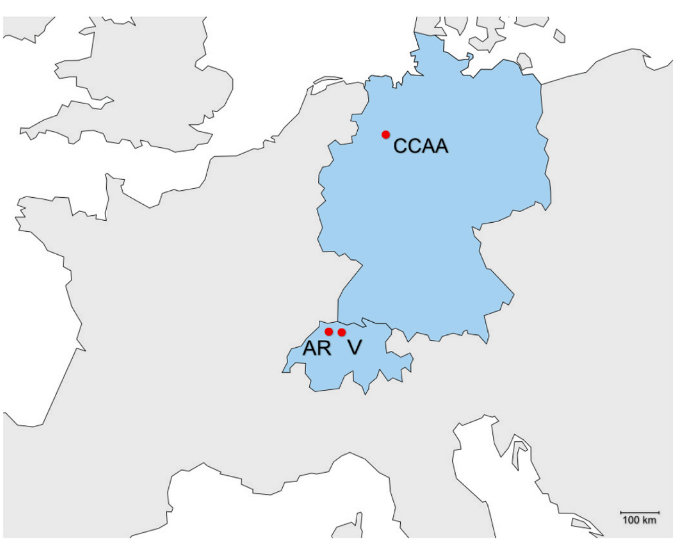

Fig. 1. Archaeological sites: Augusta Raurica (AR); Vindonissa (V), and Colonia Claudia Ara Agrippinensium (CCAA).

Table 1
Archaeological contexts of sample Roman Dogs (n = 28).

Specimen number	Arch. Site	Excavation no.	Date
01	Augusta Raurica	1999.60	2nd half of 3rd century CE or post-roman
02–1	Augusta Raurica	2012.001	2nd half of 3rd century CE
02–2	Augusta Raurica	2012.001	2nd half of 3rd century CE
02–3	Augusta Raurica	2012.001	2nd half of 3rd century CE
02–4	Augusta Raurica	2012.001	2nd half of 3rd century CE
03	Augusta Raurica	2012.001	2nd half of 3rd century CE
04	Augusta Raurica	2012.001	2nd half of 3rd century CE
05	Augusta Raurica	2012.001	2nd half of 3rd century CE
06–1	Augusta Raurica	2012.001	2nd half of 3rd century CE
06–2	Augusta Raurica	2012.001	2nd half of 3rd century CE
07–1	Augusta Raurica	2012.001	2nd half of 3rd century CE
07–2	Augusta Raurica	2012.001	2nd half of 3rd century CE
07–3	Augusta Raurica	2012.001	2nd half of 3rd century CE
08	Augusta Raurica	1999.60	2nd half of 3rd century CE
09	Augusta Raurica	2000.60	2nd half of 3rd century CE
10–1	Augusta Raurica	2000.60	2nd half of 3rd century CE
10–2	Augusta Raurica	2000.60	2nd half of 3rd century CE
10–3	Augusta Raurica	2000.60	2nd half of 3rd century CE
11	Augusta Raurica	1991.65	ca. 70–100 CE
12	Augusta Raurica	2000.60	2nd half of 3rd century CE
13	Cologne-Feldkassel	FSF 1980/6	1st century CE?
14	Cologne-Alteburg	FB 1998.001	1st century CE
15	Cologne-Alteburg	FB 1998.001	1st century CE
16	Vindonissa	Bru. 012.2	2nd third of 1st century CE
17	Augusta Raurica	1999.60	2nd half of 3rd century CE
18	Augusta Raurica	2004.54	ca. 200 CE
19	Augusta Raurica	2003.06	late 3rd-1st half of 5th century CE
20	Augusta Raurica	1999.60	2nd half of 3rd century CE

The remains of dogs no. 16 and 18 were recovered from unusual contexts. Dog no. 16 was found in Vindonissa, a 20-hectare legionary military camp, 40 km away from Augusta Raurica. It was discovered in the Brugg-Remigersteig cemetery immediately next to a human neonatal burial in a rectangular pit without grave goods and dates from the second third of the 1st century CE (Trumm and Huber, 2014; personal communication by A. Maspoli and J. Trumm). The skeleton of dog no. 18 was recovered from a hypocaust room within a peristyle house and deposited in a layer of soot and charcoal. It dates to the end of the 2nd to the beginning of 3rd century CE (personal communication, B. Pfäffli).

2.2. Brief archaeological context of the dog skulls from the surrounding area of Colonia Claudia Ara Agrippinensium (CCAA) (Germany)

Two skeletons (nos.14 and 15) derive from the Roman fleet camp Cologne-Alteburg. Both finds date to the 1st century CE and were discovered during an excavation in 1998 associated with the crew barracks in barrel pits whose primary use was probably related to tanning (Berke, 2003). Dog skeleton no. 13 was found close to brickyard kilns in

Cologne-Feldkassel. The brickyard was located north of CCAA and was operated by two different legions during the 1st century CE (Ljamić-Valović, 1986). Numerous paw prints on bricks also indicate the presence of dogs in this area (personal communication, M. Rossa).

3. Methods

3.1. Macroscopic examination

A standardized examination of oral lesions was carried out. The following parameters were assessed and recorded: ante- and post-mortem absent teeth, abrasion, attrition, caries, enamel hypoplasia, jaw fractures, malformations, occlusion, periodontal disease, persistent deciduous teeth, supernumerary teeth, tooth fractures, non-vital teeth and tooth resorption. The examination protocol is described in detail in Janssens et al. (2016). Nomenclature and assessment of pathological conditions followed the American Veterinary Dental College (AVDC, 2022; https://avdc.org/avdc-nomenclature/).

3.2. Radiographic examination

Full-mouth dental radiography was performed on all specimens. Radiographs were obtained with a parallel and/or bisecting angle technique (Bannon, 2013). Phosphor plates size 2 and 4 (Dürr Dental, Germany) and a dental x-ray generator RXDC (my-ray, Italy) were used for image acquisition. The exposed phosphor plates were scanned with a CR7 Vet (Dürr Dental, Germany) and processed with the software Vet-Exam plus (Dürr Dental, Germany).

3.3. Computed tomography (CT) examination

CT images were acquired with a CT unit Philips iCT 256 Multislice (Philips Healthcare, Cleveland, OH, USA). Exposure parameters for CT image were 120 KV, and 350mAs were used as an initial value and determined based on the scout. The FOV of the acquisition was 160 mm. The image data were reconstructed in 0.6 mm layer thickness, with 0.3 mm increments. All image data were processed and stored as DICOM datasets.

3.4. Age at death estimation

Zooarchaeological estimation of age at death of dogs use a variety of methods. Tooth eruption and tooth replacement, for instance, allow age estimation in dogs seven months of age or younger (Habermehl, 1975), while epiphyseal fusion (Habermehl, 1975) and tooth wear also contribute to age at death estimations (Gipson et al., 2000; Horard-Herbin, 2000). Tooth wear, however, can significantly vary based on type of nutrition, use of the dentition, and differences in occlusion that may result in variable patterns of attrition and abrasion (Janssens et al., 2016; Niemiec et al., 2020). More precise results can be achieved by counting incremental lines in tooth cementum, which, unfortunately, is an invasive procedure (Goodwin and Ballard, 1985; Landon et al., 1998; Mbizah et al., 2016).

Age estimation using the ratio of pulp cavity-root width is widely used in veterinary medicine. In dogs, the canine tooth develops from a thin-walled tooth with a large pulp cavity into a thick-walled tooth with an increasingly narrow pulp cavity. This development is used for age estimation. Several methods have been described, such as thin section preparation (Schmidt, 1984) (see Supplemental Information, Fig. 1), conventional radiography (Morgan and Miabayashi, 1991), and dental radiography (Pires et al., 2020). The measurements for this pilot study were made in accordance with Nomokonova et al. (2020) (see Supplemental Information, Fig. 2), except for those using pulp cavity and root width, for which the software Synedra View Personal (Switzerland) was used. The eruption of permanent teeth and the closure of their root tips were used as additional criteria (Schmidt, 1984; Supplemental Information, Fig. 1). For this study, six age groups were defined: 4–6 months, 7–11 months, 12–23 months, 24–35 months, 36–59 months, and older than 60 months.

3.5. Pathological conditions

Pathological conditions were examined macroscopically and radiographically. If teeth were absent, it was essential to distinguish whether they were congenitally absent, lost during the individual's lifetime, or post-mortem events. There is some confusion in the literature regarding terminology. Hence, the following clinical terms were used: 1) congenital — of or relating to a disease, condition, or characteristic that is present at birth and may be inherited or result from an insult during pregnancy; 2) anodontia — failure of all teeth to develop; 3) hypodontia — developmental absence of few teeth; 4) oligodontia — developmental absence of numerous teeth (AVDC, 2022). In zooarchaeology and clinical veterinary medicine, examination of the remodeled alveoli may be insufficient to determine if ante-mortem loss is congenital or acquired (Pires et al., 2020; personal communication, F. Wegehaupt, Center of Dental Medicine, University of Zurich). For this reason, the term 'ante-mortem absent tooth' was used since it is descriptive and does not presume etiology (see Supplemental Information, Fig. 3).

Although Holmes et al. (2021) conducted a study using archaeological criteria for periodontal disease in ruminants, in this study, veterinary dental criteria for carnivores following the American Veterinary Dental College Nomenclature Committee (AVDC, 2022) were used. For instance, in periodontal disease stage 1, only the soft tissue is affected, while in stage 2, bone loss is up to 25% of the root length, in stage 3 25–50% of the root length is exposed, and in stage 4 more than 50% is exposed (see Supplemental Information, Fig. 4).

3.6. Recording

Results were recorded using the electronic Veterinary Dental Scoring (e-VDS) system, a computer program developed for veterinary practitioners and dentists. The program is based on David Crossley's graphics and the modified Triadan system (Floyd, 1991) (see Supplemental Information, Fig. 5). The e-VDS has been adapted to archaeological needs (http://www.e-vds.vet, 2022).

3.7. Osteometry

Measurements of long bones and skulls were carried out to obtain information on wither height and skull proportions. Postcranial measurements were only used, when possible, to determine size ratios. Especially in the dogs from the wells, it was partly not possible to relate skull remains to postcranial remains. Wither height was calculated by the greatest length (GL) of long bones according to the methods of Clark (1995) and Koudelka (1885). Dog sizes were divided in three groups: small (<39 cm), medium (40–59 cm), or large (>60 cm). Detailed assessment of skull shape, the ratio of the cranium to the facial skull, the S-index (Koch et al., 2012), as well as the total skull length to total skull width, and the length-width index (Brehm et al., 1985), were used to detect mesocephalic (medium length, with skull lengths greater than width) and brachycephalic (short-length, with skulls equally long and wide) skull shapes (see Supplemental Information, Fig. 6).

4. Results

4.1. Age at death estimation

The estimated age at death for this sample ranged from 4 to 6 months old (n = 1) to over 60 months old (n = 7) (Table 2), with the greatest number of dogs estimated to be 36–59 months old (n = 8), and the average age of death occurring at 38 months.

Table 2
Estimated age at death and size of Roman dogs sample (N = 28).

Estimated Age at Death	Size of Dog			
	Small	Medium	Large	Undetermined
4–6mo		1		
7–11mo	3	2		
12–23mo	1	2		1
24–35mo	1		2	
36–59mo	2	3	1	2
> 60mo	1	3		3
Total	8	11	3	6

4.2. Size of specimens

In 22 dogs, the withers height (WH) could be determined and was divided into three categories: small (< 39 cm) n = 8, medium (40–59 cm) n = 11, and large (>60 cm) n = 3 (see Table 2). For six dogs, insufficient data was available for size determination.

4.3. Dental pathology

4.3.1. Absent teeth

Twelve specimens showed one or more ante-mortem absent teeth, while all specimens had one or more teeth lost post-mortem. Bilateral tooth absence with no evidence of bone remodeling and closed alveoli, indicative of congenital absence, was observed in specimens nos. 10–3 and 14.

4.3.2. Tooth fractures

Nineteen of the dogs showed tooth fractures analyzed by their location in the dentition and by the damage to the tooth. Large teeth were most frequently affected. Nine individuals had a fracture of a canine tooth, five had a fracture of a maxillary fourth premolar, and six of a mandibular first molar (Fig. 2). In four dogs, the incisors were fractured, in eight dogs, premolars other than the maxillary fourth were noted, and in two dogs, molars other than the mandibular first molar were fractured. Eight individuals showed multiple fractures (for details see Supplemental Information, Table 2).

Ten of the individuals had an uncomplicated crown fracture (pulp not exposed), seven displayed complicated crown fractures (pulp exposed), seven crown-root fractures (crown and root involved), one individual had a root fracture (only root involved). Overall, in this sample of Roman dogs, 19 out of 28 dogs (67%) displayed tooth fractures of some type.

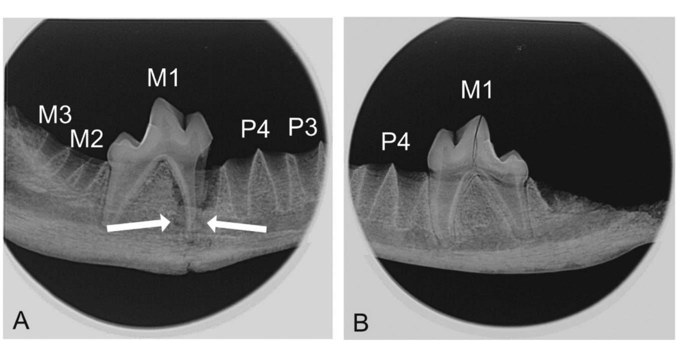

Fig. 2. Specimen no. 05. A) Crown-root-fracture of the right mandibular first molar (M1). The fracture line extends from the crown to the mesial root. The mandible fracture arises from an external force and must have occurred during the lifetime of the individual due to the callus formation (arrows). The third and fourth premolars (P3 + P4) and the second and third molars (M2 + M3) were lost post-mortem. B) Contralateral mandible.

4.3.3. Non-vital teeth

In this study, the terms vital and non-vital are used to describe whether the tooth was vital, that is, had a persistent blood supply, or was non-vital, indicating that the tooth was essentially dead at time of death of the individual. Six individuals showed signs of non-vital teeth (Table 5), an occurrence often caused by trauma leading to inflammation and eventual necrosis of the pulp and the inability to form dentine. Radiologically, non-vital teeth may appear with a relatively wider pulp cavity when compared to contralateral, adjacent, or opposing normal teeth (Fig. 3A). Bacteria colonize necrotic pulp tissue and may directly or indirectly access the surrounding bone tissue through the root's tip, eventually causing a radiographically evident periapical lesion (periapical lucency) surrounding the roots (see Supplemental Information, Fig. 7). In some cases, a draining tract (fistula) forms in the alveolar bone, which was observed in two individuals (Fig. 3C).

4.3.4. Periodontal disease

Periodontal disease is primarily caused by the deposition of bacterial biofilm (plaque) on teeth and along the gumline. Toxic products of these microorganisms' metabolism and the host's immune response against the infection trigger the inflammatory process. The inflammation spreads in the periodontium and leads to bone loss, which in the end, may lead to the loss of the tooth (Niemiec et al., 2020). While plaque may mineralize to calculus, the pathogenic connection with periodontal disease is relatively low (Wiggs and Lobprise, 1997; Niemiec, 2008b). Furthermore, it seems to be difficult to differentiate calculus from other deposits macroscopically (see Supplemental Information, Fig. 8). For these reasons, along with the variable preservation of calculus in archaeological remains, these deposits were not evaluated.

In this study, nine dogs displayed periodontal disease (32%), with eight displaying late stages (stages 3 and 4) (Table 3). However, when evaluating archeological material, stages 1 and 2 cannot be detected, so all recognizable instances of the condition in this population, by default, are more advanced stages. The disease was mainly found in cheek teeth

Table 3
Presence of periodontal disease in Roman dogs.

Specimen	Estimated Age at Death	Periodontal Disease
02–3	1	
02–4	2	
05	2	
06–2	2	
16	2	
19	2	
03	3	
07–1	3	
10–2	3	
18	3	
02–1	4	
09	4	1
10–3	4	
04	5	
06–1	5	
07–2	5	
11	5	
12	5	2
13	5	
14	5	2
15	5	
01	6	1 *
02–2	6	2
07–3	6	
08	6	2
10–1	6	2
17	6	2
20	6	
		*unilateral

Estimated age at death: 1 = 4–6 mo., 2 = 7–11 mo., 3 = 12–23 mo., 4 = 24–35 mo., 5 = 36–59 mo., 6 = >60 mo. Periodontal disease (highest score recorded): 1 = stage 3, 2 = stage 4.

Table 4
Attrition and abrasion in Roman dogs.

Specimen	Estimated Age at Death*	Attrition* *	Abrasion* **
02–3	1		
02–4	2		
05	2		
06–2	2		
16	2		
19	2	1	
03	3		
07–1	3		
10–2	3		
18	3		
02–1	4		1
09	4		1
10–3	4		
04	5		3
06–1	5		
07–2	5		1
11	5	1, 2	2
12	5		3
13	5	1,2	3
14	5		
15	5		
01	6		1
02–2	6	1	2
07–3	6		3
08	6	2	
10–1	6	1	2
17	6		3
20	6		3

*Age at death: 1 = 4–6 mo., 2 = 7–11 mo., 3 = 12–23 mo., 4 = 24–35 mo., 5 = 36–59 mo., 6 = >60 mo.
* *Attrition: 1 = canines, 2 = incisors.
* **Abrasion: 1 = moderate, 2 = medium, 3 = advanced.

and incisors. In most cases, dogs diagnosed with periodontal disease showed advanced age. Specimen no.10–1 showed a high degree of periodontal disease (Fig. 4).

4.3.5. *Caries*

Caries is the loss of dental hard tissue due to acid produced by bacteria. Hillson (2001) created a recording protocol for caries in human remains. However, protocol and classifications cannot be directly applied to carnivore canine teeth, as the enamel is only 0.1–1.0 mm thick (Crossley, 1995). Caries was only observed in the occlusal surface of the right first maxillary molar of dog no. 10–1 (4 ×5 mm and 1.5 mm deep) (see Fig. 5).

4.3.6. *Tooth wear*

Tooth wear occurs from friction, with attrition caused by tooth-to-tooth wear and abrasion occurring as the result of biting foreign objects such as food, bones, stones. As teeth wear, the thin enamel layer is removed, which causes the formation of reparative dentin. This reparative dentin may become discolored due to environmental influences. It may appear brownish to black in color, depending on the degree of tooth wear. Tooth wear, even if it appears black, displays a completely smooth surface (not to be confused with the presence of caries).

Abrasion occurs on the occlusal surface and can affect all teeth. The degree of tooth abrasion depends on external factors such as types of food consumed, biting and working habits, and age (Niemiec et al., 2020). In thirteen of the examined dogs, different stages of abrasion were observed.

Attrition is due to malocclusion and generally occurs in the front teeth (canines and incisors). It appears as brownish discoloration (Fig. 6A) and in the form of shortening or a groove in the crown (Niemiec et al., 2020). Six specimens showed signs of attrition.

4.3.7. *Persistent deciduous teeth*

In this study, two individuals showed persistent deciduous teeth (Table 5). In dog no. 16, the permanent dentition had fully erupted and was functional. Two deciduous canines persisted in the upper jaw (Fig. 7A and B). The upper permanent canine teeth were misaligned and incompletely erupted. In dog no. 02–3, two persistent mandibular deciduous premolars were visible; both had no tooth germs of permanent teeth, which indicates congenital absence of the permanent teeth (Fig. 7C and D).

Table 5
Roman dogs with non-vital teeth, persistent deciduous dentition, convergent roots, tooth resorption, and supernumerary teeth.

Specimen	Age at Death*	Non-Vital Tooth	Persistent Deciduous Tooth	Convergent Roots	Tooth Resorption	Supernumerary Teeth
02–3	1		X			
02–4	2	X				
05	2					
06–2	2					
16	2		X	X		
19	2					X
03	3					X
07–1	3					
10–2	3					
18	3					
02–1	4	X		X		
09	4					X
10–3	4			X		
04	5	X				
06–1	5	X				
07–2	5					
11	5	X				
12	5				X	
13	5			X		
14	5					
15	5					
01	6			X		
02–2	6	X		X		
07–3	6					
08	6					
10–1	6					
17	6					
20	6					

*Estimated age at death: 1 = 4–6 mo., 2 = 7–11 mo., 3 = 12–23 mo., 4 = 24–35 mo., 5 = 36–59 mo., 6 = >60 mo.

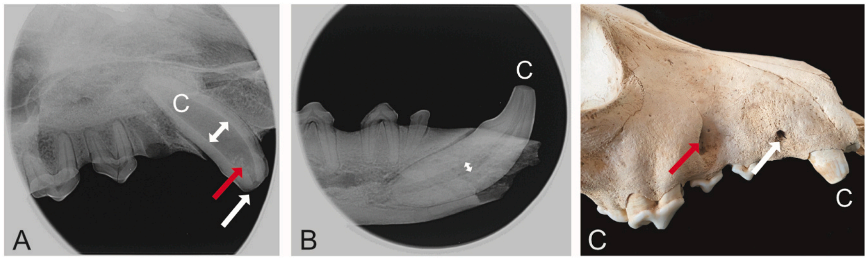

Fig. 3. Non-vital right maxillary canine of specimen no. 02–1. A) Dental radiograph demonstrating a fractured cusp (white arrow) and foreign material in the pulp cavity (red arrow) of the non-vital maxillary right canine (C). The pulp cavity of the maxillary canine (double-headed arrow) is relatively much wider compared to B) the vital right mandibular canine tooth which has a narrower pulp cavity (double-headed arrow). C) Photograph showing a draining tract (white arrow) derived from a periapical infection associated with the canine tooth (C), not to be confused with the foramen infraorbitale (red arrow).

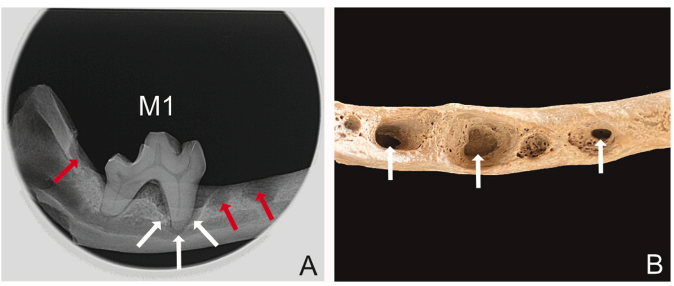

Fig. 4. Advanced periodontal disease in the right mandible of specimen no. 10–1. A) Dental radiograph showing advanced bone loss around the mesial root of the first molar (M1) (white arrows). The partly remodeled dental alveoli of the adjacent teeth lost during the dog's life are visible (red arrows). B) For some root tips, infection penetrate the mandibular canal (arrows) (M1 removed for photograph).

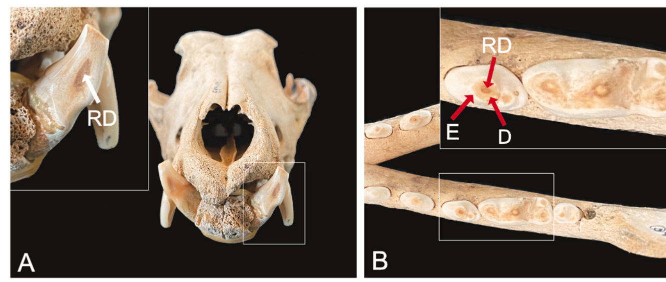

Fig. 6. A) Specimen no. 02–2. Attrition caused by the maxillary third incisors. Reparative dentine (RD) demonstrated on the mandibular canines (arrow). B) Specimen 07–3. Abrasion of the mandibular premolars and molars. Enamel appears white (E), dentine light brownish areas (D), and reparative dentine (RD) as darker brown spots.

4.3.8. *Loss of crown structure*

Specimen no. 01 showed abnormal loss of tooth structure in all four canines (Fig. 8). The top half of the crowns was missing, in contrast to mild wear on all other teeth. In a slow process of abrasion or attrition, the tooth itself would generally react to the loss of tooth mass by producing reparative dentine, which could not be seen in any of the canines. Microscopic observations indicate that the tooth surfaces were not smooth, as expected with normal abrasion or attrition. Initial traceological examinations (performed by D. Wojtczak) showed unusual patterns on the surface, which do not correspond to tooth fracture or abrasion.

4.3.9. *Tooth resorption*

One individual, dog no. 12, suffered from tooth resorption, a progressive destruction of the calcified structure of permanent teeth by clastic cells (Niemiec et al., 2020). In this study, tooth resorption was diagnosed with dental radiographs. Based on the analysis of CT scans of the mandibular premolars and molars, areas of resorption display replacement with bone and, using Peralta et al., (2010) classification, was determined to be external replacement resorption (Fig. 9A and B, Table 5). All four canines showed signs of tooth resorption but classifying the change in these teeth was difficult. They might possibly be classified as external surface resorption (Fig. 9C-E).

4.3.10. *Other findings*

Six specimens showed convergent roots of two-rooted teeth where the roots did not separate at the cementum level during germination. Supernumerary teeth were present in three skulls, and impacted teeth were present in three specimens. No cases of enamel hypoplasia were observed (see Table 5, and Supplemental Information, Table 1).

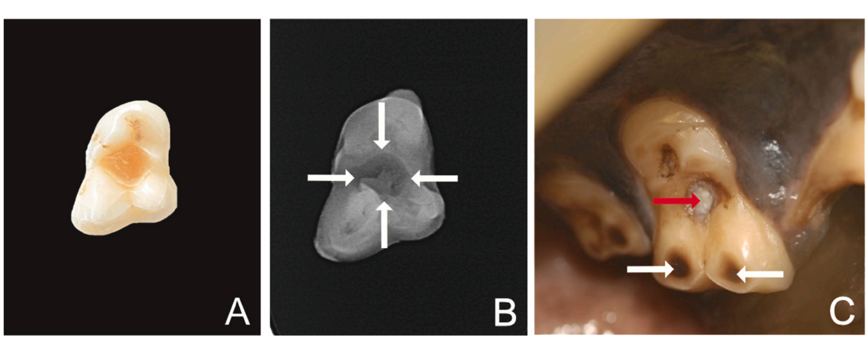

Fig. 5. Caries lesion on the first maxillary molar of specimen no. 10–1. A) photograph showing the cavity. B) Dental radiograph of the same tooth: the lesion is visible as grey shading (arrows). C) Left maxillary first molar of a modern dog with tertiary dentine on the cusps as a result of abrasion (white arrows) and dental decay in the groove (red arrow).

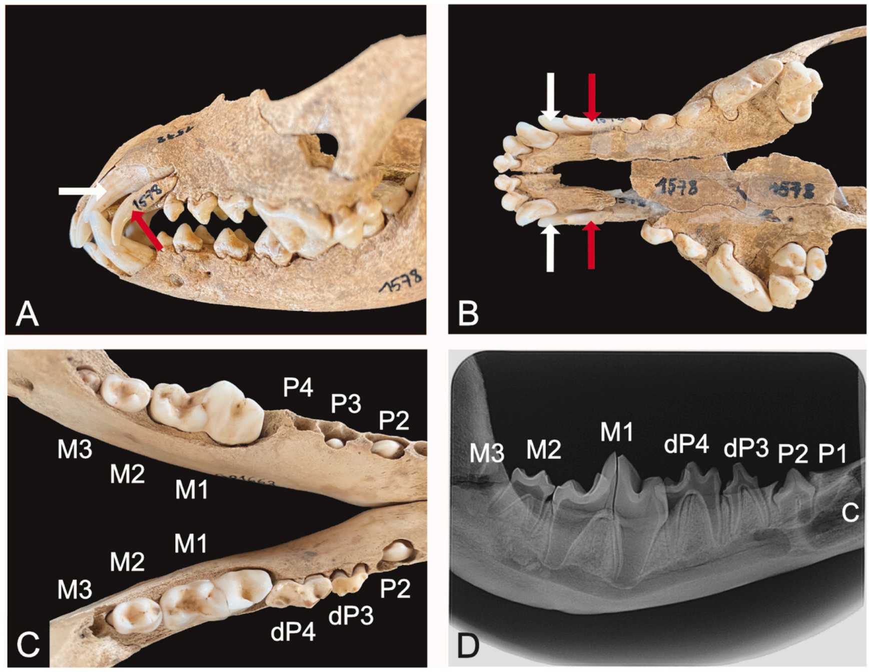

Fig. 7. Persistent deciduous teeth. A) lateral aspect and B) occlusal aspect of dog no. 16. The persistent deciduous upper canines (red arrows) influenced the growth direction of the permanent canines (white arrows). C) Dog no.02–3 with changing teeth displaying difference in the development of permanent teeth in the right and left mandible. The left side shows no persistent deciduous teeth but erupting second and third premolars (P2 and P3). The right mandible shows persistent deciduous third and fourth premolars (dP3 and dP4). D) Dental radiograph of dog no.02–3 demonstrating the status of the right mandible. Canine tooth (C), first premolar (P1), and third molar (M3) were lost postmortem, second premolar (P2) erupting, persistent deciduous third and fourth premolars (dP3 and dP4) with no tooth germs of permanent teeth, first and second molars (M1 and M2) fully erupted. Note: the permanent teeth display open root apices, while the apices of the persistent primary teeth are closed.

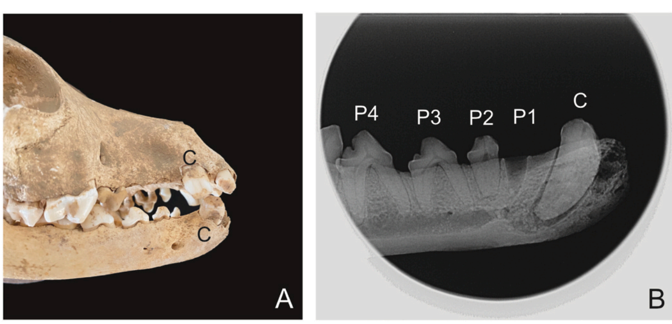

Fig. 8. Loss of crown structure of canine teeth of specimen no. 01. A) Photograph showing a significant reduction in crown height (C), which likely led to non-vitality of both canines. B) Dental radiograph of the right mandible. The relatively narrow pulp cavity of the canine tooth (C) indicates that the loss of tooth substance and loss of vitality of the canine tooth must have occurred late during the individual's life.

4.4. Skeletal findings

4.4.1. Occlusion

Occlusion refers to the alignment of teeth and jaws. When the jaw is aligned in normal occlusion, the teeth interlock like scissors and the maxillary incisors are situated anterior to mandibular incisors (scissor bite). Brothwell (1991) developed a method for recording malocclusion and malpositioned teeth in archaeological material. However, in this study, the criteria of veterinary dentistry followed the Committee of Nomenclature of the American Veterinary Dental College were used (AVDC, 2022).

Eight skulls showed a normal occlusion (Fig. 10A), while in eleven dogs, the occlusion could not be determined due to the incompleteness of the skulls (Table 6). One dog showed a mandibular distoclusion

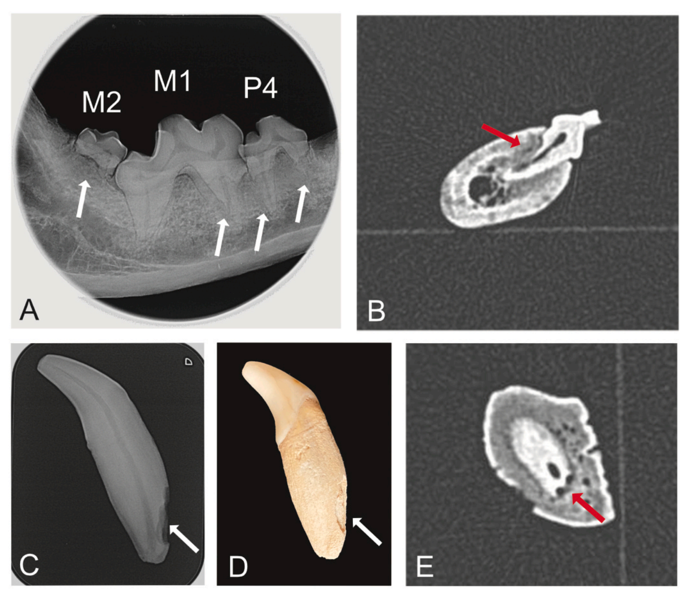

Fig. 9. Tooth resorption of specimen no. 12. A) Dental radiograph of the fourth premolar (P4) and first and second molars (M1 and M2) of the right mandible with external replacement resorption (white arrows). B) CT scan (cross-section) of the fourth premolar demonstrating bone replacement (red arrow). C and D) Dental radiograph and photograph of the right mandibular canine with external surface resorption (white arrows). E) CT scan (cross-section) of the right mandibular canine demonstrating resorption (red arrow).

(overbite, relatively short mandible) (Fig. 10C), and eight dogs showed a mandibular mesioclusion (underbite, relatively long mandible) (Fig. 11). Specimen no. 8 displayed a type of mesioclusion referred to as

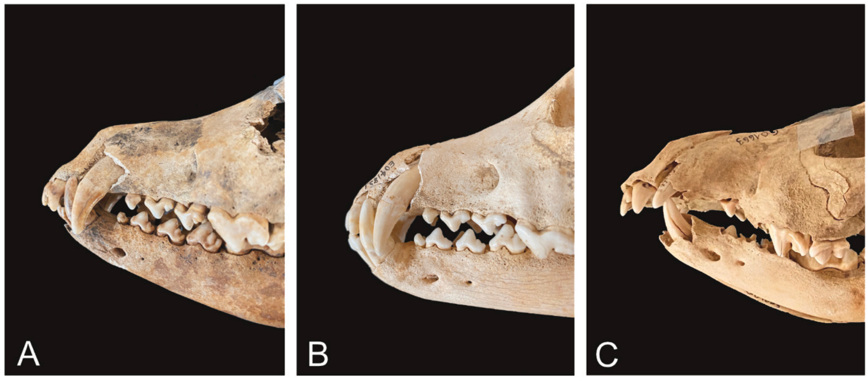

Fig. 10. Types of occlusion. A) Normal occlusion (specimen no. 18) – the maxillary incisors are located anterior to the mandibular incisors (scissor bite). B) Level bite (specimen no. 8) – the incisors occlude along the entire occlusal surface of the crown. C) Mandibular distoclusion (specimen no. 02–3) – the mandible is too short in relation to the maxilla. Please note: the left mandibular canine seems to force the left maxillary canine into a mesial position.

Table 6
Age at death, size of animal, dental occlusion, skull form, and presence of bone fractures in Roman dogs.

Specimen	Estimated age at Death*	Size* *	Occlusion* **	Skull Form[#]	Bone Fracture[##]
02–3	1	2	2	1	
02–4	2	2	4	3	
05	2	1	4	3	1
06–2	2	1	4	3	
16	2	1	1	3	
19	2	2	1	1	
03	3	2	1	1	
07–1	3	4	4	3	1
10–2	3	1	1	3	
18	3	2	1	1	
02–1	4	3	1	1	
09	4	3	3	3	
10–3	4	1	3	2	
04	5	3	1	3	
06–1	5	2	1	1	
07–2	5	4	4	3	
11	5	2	3	1	
12	5	4	4	3	
13	5	2	3	1	
14	5	1	4	2?	
15	5	1	3	2	
01	6	2	3	1	
02–2	6	2	3	1	
07–3	6	4	4	3	
08	6	2	3	1	
10–1	6	1	4	3	
17	6	4	4	1	2
20	6	4	4	3	

*Age at death: 1 = 4–6 mo., 2 = 7–11 mo., 3 = 12–23 mo., 4 = 24–35 mo., 5 = 36–59 mo., 6 = >60 mo.
* * Size: 1 = small, 2 = medium, 3 = large, 4 = not determined
* ** Occlusion: 1 = normal occlusion, 2 = mandibular distoclusion, 3 = mandibular mesioclusion, 4 = undetermined
[#] Skull Form:1 = mesocephalic, 2 = brachycephalic, 3 = not determined
[##]Bone Fractures: 1 = mandible, 2 = os nasale

level bite. In these instances, the mandible is slightly too long and causes the maxillary and mandibular incisors to occlude along the crown surfaces (Fig. 10B). Jaw-length malocclusions are considered heritable (Niemiec et al., 2020).

4.4.2. *Skull form*

Craniofacial diversity in modern domestic dog breeds results from tens of thousands of years of continued human intervention. The morphological variation among these breeds is notable: flat-faced dogs with particularly short and wide heads are called brachycephalic, 'short-headed' (e.g., pug, pekingese or bulldog), while mesocephalic dogs have a moderate skull shape, 'medium headed' (dalmatian, poodle or Siberian husky) and dolichocephalic breeds (borsoi, saluki and collie) have a narrow, elongated snout (Schoenebeck and Ostrander, 2013). The skull shape could be determined in 15 specimens, while 13 could not be classified due to incompleteness of the skull (Table 6). Twelve specimens had a mesocephalic skull shape, and two dogs, no. 10–3 (Fig. 11) and no. 15, showed features of brachycephaly with shortened nose, widely placed shallow orbits, loss of space for premolar teeth and mesioclusion, while specimen no. 14 could not be clearly classified (see Supplemental Information, Fig. 6).

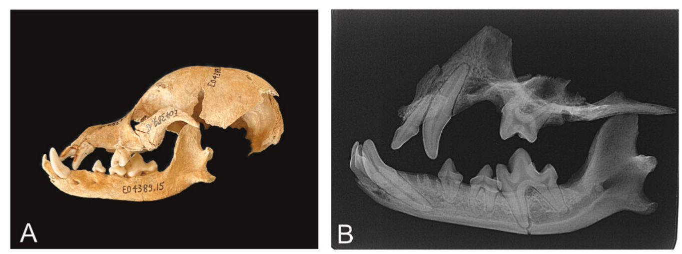

Fig. 11. Brachycephaly. A) Photograph of specimen no. 10–3 with features of a brachycephalic dog. B) Dental radiograph of the same individual. Note the absence of the maxillary first to third premolars and the pronounced mandibular mesioclusion.

4.4.3. *Bone fractures*

Two specimens displayed mandibular fractures (Table 6). In both individuals, the right mandible was affected. In dog no. 05, hard callus formation was noted and the fracture line appeared anterior to the first molar, which displayed a complicated crown-root-fracture (Fig. 2). Individual no. 07–1 showed a fracture at the location of the third premolar with a fully remodeled callus and root remnants still present (Fig. 12). A healed comminuted fracture of the os nasale was present in dog no. 17 (see Supplemental Information, Records). Phillips (1979) reports that 2.6% (n = 7) out of 256 dogs brought in for veterinary care for fractures displayed mandibular fracture.

All results are summarized in a single table (see Supplemental Information, Table 1). For detailed recordings, such as dental assessments, photographs and radiographs, see Supplemental Information, Records.

5. Discussion

The adoption of modern veterinary standards to assess archaeologically recovered dog remains provides insight into the lives of this Roman dog sample and provides means for cross-population comparisons. The

Fig. 12. Mandibular fracture in dog no. 07–1. A) Photograph of callus formation on the right mandible (white arrow). Overlapping of the third and fourth mandibular premolars due to healing without correct reposition of the bone fragments (red arrow), root remnants in dental alveoli (white arrow heads). B) Right and left sides of the mandible displaying incorrect and correct alignment of dentition.

majority of diseases found in recent dogs have been detected in the specimens in this study, which is remarkable considering the small size of this sample.

In order to place the results into context, comparisons between results of this study and those provided in the veterinary literature can be useful. However, comparing studies poses some problems. First, it is important to use standardized examination methods and to consider the composition of the subject groups: Roman dogs are assumed to be a cross-section of a population of domesticated dogs, whereas wolves are a cross-section of wild animals with no interaction with humans. Similarly, modern studies look at a selected group of dogs that are not only domesticated but also have access to veterinary care, sometimes very specialized care. Hence, comparisons between published clinical studies of canine pathological conditions should be made with caution. It must also be noted that the prevalence of various diseases in recent dogs is based on more extensive sampling, which this pilot study could not provide.

5.1. Age estimation

The estimated ages at death in the Roman era sample indicate that many died before or around the age of five years, with the greatest number of dogs estimated to be 36–59 months old (n = 8), and the average age of death occurring at 38 months. Comparison with other studies of Roman dogs is difficult since age was not consistently reported and/or different methods of assessment were used (Zedda et al., 2006; De Sandes-Moyer, 2013; Bennett and Timm, 2016; Martínez Sánchez et al., 2020). The average lifespan of the dogs examined in this study was approximately half the lifespan of modern dogs (Hoffman et al., 2013), but is comparable to modern wild-living dingo-populations and European wolves, which are strongly limited by environmental factors (Lovari et al., 2007; Smith and Watson, 2015). This might suggest that wild canidae, along with Roman dogs, were subjected to harsh living conditions (Berger (2012)). Alternatively, it is possible that Roman dogs suffered premature death at the hands of humans, which is plausible given the archaeological contexts of the dogs in this sample (20 out of 28 were recovered from wells). For Roman dogs in this sample that lived more than five years (see Supplemental Information, Table 1), no correlation between size and age was found, which may indicate an interest in a long-term life companion independent of body size.

The age groups in this study were defined following Nomokonova et al. (2020). The root-pulp ratio method is not well established in zooarchaeology. The evaluation depends heavily on the quality of the equipment and the experience of the investigator, which can be problematic for zooarchaeologists who do not use the method frequently. Further studies will show whether the age group classification can be drawn as narrowly as in this study or whether a simplified classification, as proposed by Pires et al. (2020) with only four age groups, is more appropriate for zooarchaeology.

Table 7
Comparison between clinical reports on modern dogs and Roman dog sample.

	Modern dogs	Roman dog sample
Mean estimated age at death	7.9 yrs*	3.2 yrs
Tooth fracture	20–27%* *	67%
Periodontal disease	a) 9.3–18.2%# b) 86.3%#	32%
Caries	5.2%##	3.50%
Persisting deciduous dentition	5.4%†	7.10%
Bone fractures	2.6%††	7.10%
Super numerary teeth	3.86%†	10.7%

* Hoffmann et al. (2013) based on intact (non-sterilized) dogs
* * Soltero-Rivera et al., (2019), Soukup et al. (2015)
a) Wallis and Holcombe (2020) based on un-anaesthetized dogs in clinical veterinary context; b) Stella et al. (2018) based on standardized examination including dental x-rays on anaesthetized dogs
Hale (1998) based on dogs in veterinary dental context
no data could be evaluated
† Butković et al. (2001) based on dogs in clinical veterinary context
†† Philipps (1979) based on 7 mandibular fractures out of 266 dogs under clinical care for bone fracture(s)

5.2. Tooth fracture

External forces often cause fractures of the canine teeth. Fractures of the cheek teeth, on the other hand, are usually caused by a biting force (cheek teeth are protected against external forces by the masseter muscle and the zygomatic arch). The most common cause of cheek teeth fracture in modern dogs is biting on hard objects with resistance greater than 1200 Newton (Soltero-Rivera et al., 2019).

Data from clinical literature suggests that 20–27% of dogs seen in veterinary contexts display tooth fractures (Soukup et al., 2015, Soltero-Rivera et al., 2019); while studies on Scandinavian wolves show a 51% prevalence (Van Valkenburgh et al., 2019). It is difficult to determine in archaeological dog remains whether tooth fractures occurred ante or post-mortem. This may explain the higher prevalence (67%) of dogs with tooth fractures in this study (Table 7).

Interestingly, Van Valkenburgh et al. (2019) established a correlation between food supply and fracture prevalence in gray wolves: the lower the food supply, the higher the fracture rate, related to complete carcass depredation and increased consumption of bones. In modern dogs, molar fractures are caused predominantly by play and excessive chewing on hard materials. Whether Roman dogs suffered from food shortage, chewed, or were trained to bite hard materials (fighting dogs), requires further investigation.

5.3. Non-vital teeth

Trauma is the main cause for tooth death. In dogs, it occurs most frequently after a complicated tooth fracture with exposed pulp. Unfortunately, there are no recent studies to compare the results of this study with the clinical occurrence of non-vital teeth because the focus in veterinary dentistry is on the fact that a tooth is fractured and its treatment. The vitality of the tooth plays a minor to non-existent role in the determination of veterinary treatment of dogs. There is research on non-vital teeth in recent dogs, but the focus is different, e.g., Proulx et al. (2022) investigated several non-invasive methods to determine vitality. In this study 18% of the dogs evaluated displayed non-vital teeth. Whether this is a high percentage is impossible to assess but may be important data as more studies on dental pathology in ancient dogs are undertaken using dental radiography as an assessment tool.

5.4. Periodontal disease

Studies of modern dogs show great variation in the prevalence of periodontal disease depending on the examination method. Wallis and Holcombe (2020) report that 9.2–18.3% of unanaesthetized dogs seen in

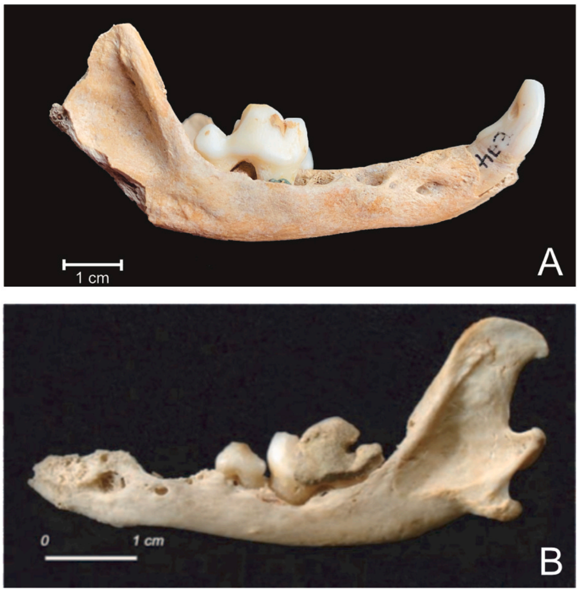

Fig. 13. Similar patterns of advanced periodontal disease, both dated 3rd century AD. A) Specimen no. 10–1 from Augusta Raurica, Switzerland. B) Specimen from Yasmina, Carthage, Tunisia (photograph MacKinnon, 2010).

clinical veterinary settings display periodontal disease, while Stella et al. (2018) report a high percentage (86.3%) in their clinical sample using a standardized examination protocol including dental X-ray on anaesthetized patients. The latter method corresponds more to the situation in archaeological studies (Table 7). The variation of recent results compared to this Roman dog sample (32%) could be due to differences in diet (soft diets do not contribute effectively to plaque and calculus removal) (Pinto et al., 2020), or because the earliest stages of periodontal disease cannot be effectively identified in ancient skulls.

In general, the disease occurs more often in small breeds of modern dogs, and the incidence increases with advancing age (Stella et al., 2018). Brachycephalic breeds and dogs with malocclusion are particularly vulnerable to developing advanced stages of the disease. Untreated periodontitis may lead to tooth loss (Niemiec et al., 2020). These factors were observed in this study (see Supplemental Information, Table 1). For example, specimen 10–1, a small and relatively old dog, showed very advanced periodontal disease (Fig. 4). A similar disease pattern was reported in a lapdog from the Roman cemetery of Yasmina, Carthage, Tunisia, dated to the 3rd century CE (MacKinnon, 2010) (Fig. 13). This, combined with caries diagnosed in no. 10–1 may indicate a widespread culture of keeping tiny 'best friends' and spoiling them. The presence of a large number of small dogs in this sample (8 out of 21 = 38% of the dogs whose morphology could be determined) supports Harcourt's postulation (1974, page 164): "… at this time a new phenomenon appeared, the lap or house dog; one that was too small to have served any useful purpose, even as a scavenger, or to have survived without human shelter and protection.".

Several investigations on dog skeletal remains from the Roman era report strong differentiation in body size and shape in many regions of the Roman Empire (Harcourt, 1974; Bökönyi, 1984; Kokabi, 1993; Peters, 1997; Cram, 2000; Grossi Mazzorin and Tagliacozzo, 2000; Berke, 2003; Baxter (2006); Zedda et al., 2006; Colominas, 2016; Pires et al., 2017; Bennett and Timm (2018); Mráz, 2018; Martínez Sánchez et al., 2020). In addition to hunting dogs, farm dogs, and shepherd dogs, small 'society dogs' were especially popular in ancient cities. According to Strabo (Strabo, 6277) and Aelianus (Ael. NA. 7,40), the Romans called these small lapdogs *catuli Melitaei.* Aristotle wrote about the small body size of ancient dogs, comparing them to the size of a marten (Arist. Hist. an. 9,6).

5.5. Abrasion/ attrition

In some instances, a dog's age and the position of abrasion and/or attrition can provide information about the animal's life circumstances. For example, Niemiec et al. (2020) report on cage-biter syndrome, which typically results in abrasions on the distal surfaces of canine teeth.

In dog no. 01, no abrasion was presented (except in the reduced canines) even though this animal reached an advanced age. This may suggest that there was little or no hard food in the dog's diet. Compared to dog no. 20, which belonged to the same age group, a significant difference in abrasion is noted (see Supplemental Information, Fig. 2).

Dog no. 11 showed advanced wear on the incisors, while the rest of the teeth showed only mild abrasion. This may indicate abnormal use of anterior teeth, which is recognized in modern dogs with irritating and itchy skin conditions or flea infestation, as hair is very abrasive and can cause severe wear of incisor and canine teeth (Niemiec, 2014; Janssens et al., 2016). It may also indicate that the dog repeatedly used anterior teeth to remove flesh from bones.

In wild wolves, dental abrasion is common on different teeth and in various degrees. These abnormalities were not associated with age, but instead with different feeding habits such as bone consumption, eating food contaminated with sand, or due to flea biting (Pavlovic et al., 2007; Janssens et al., 2016; Döring et al., 2018; Pires et al., 2020).

5.6. Caries

Most dog teeth do not provide a surface for food deposition due to their conical shape and therefore are rarely affected by caries. Exceptions to this are the molars, especially the distal part of the mandibular first molar and the maxillary and mandibular molars. Caries in modern dogs occurs very rarely (about 5%) and is connected to four factors: suitable position, bacteria, carbohydrate-rich nutrition, and time (Hale, 1998; Hale, 2009). Janssens et al. (2016) report on different wolf subspecies from varied geographical regions, and with one exception in Croatia, no occurrence of caries in wolves was observed. The study noted that caries observed in wolves from Croatia (Pavlovic et al., 2007) should be diagnosed as abrasion with reparative dentine.

The carious tooth in dog no. 10–1 may indicate that the animal had been fed a carbohydrate-rich diet. Foods containing carbohydrates appeared to have played a significant role in Roman dog nutrition. According to Columella (Columella, Rust. 7,12,10), guard and shepherd dogs should be fed barley flour with whey or emmer or wheat bread mixed with bean broth. Dog food made of bread, milk, bone broth, and chopped bones is also mentioned by Varro (Varro, Rust. 2,9,8).

5.7. Persistent deciduous teeth

Persistent deciduous teeth are relatively common in modern breeds, especially in pet dogs, and may cause orthodontic and periodontal problems if untreated (Niemiec, 2008b). In clinical practice, Butković et al. (2001) report that out of 259 dogs examined, 5.4% (n = 14) displayed persistent deciduous teeth. Occasionally, persistent deciduous teeth have been observed in the premolar region on mandibles in free-living grey wolves (Döring et al., 2018). In dog no. 16, the positioning of the permanent upper canine teeth was disturbed by persistent deciduous teeth.

5.8. Loss of crown structure

The unnatural shortening of the canines of dog no. 01 and the preliminary traceological examinations suggest that the crown reduction was caused by an external factor, possibly a coarse metal file (personal communication by D. Wojtczak). Flat files have been archaeologically recovered in Augusta Raurica (Mutz, 1976). Similar practices are known for other animals from the same Roman city. A shortening of canines with a metal saw in a young bear, causing severe dental pathology, has been documented from the 3rd century CE (Mráz, 2018).

This raises the question of why a dog's canine teeth should be shortened. In a bear living in captivity, this is done to reduce the risk of injury to humans. But why should such a procedure be performed on a medium-sized dog, even at an older age? Because the dog may have become aggressive? It could also be that the tips of the teeth were removed post-mortem, but then the question arises for what purpose. At this point, no answers to these questions can be offered.

5.9. Pathologic tooth resorption

Tooth resorption (TR) is, by definition, the loss of dental hard tissues due to the activity of the body's own cells (odontoclasts). Pathological resorption occurs when odontoclasts become active in adulthood, which has been reported in several animal species and in humans (Niemiec et al., 2020). The trigger is unknown for most forms of tooth resorption (Niemiec et al., 2020).

TR was traditionally considered a disease of modern civilization and is common in modern dog breeds (Niemiec et al., 2020). There is only one archeological report of tooth resorption: in a cat from the 13/14th century from Germany (Berger et al., 2004). However, evidence of TR in a Roman dog from Augusta Raurica (no. 12) suggests that this disease is not new, and that further investigation is needed in order to better understand the prevalence, etiology, and evolution of the disease.

5.10. Occlusion

Malocclusions in recent dogs are known to have severe impact on the quality of the animal's life, e.g., mandibular distoclusion may not only result in oral pain and head-shy behaviors, but can result in non-vital teeth, dental attrition, periodontal disease, and oronasal fistula formation (Niemiec et al., 2020). In dog 02–2, who suffered from dental misalignment (see Fig. 5A), it can be assumed that the mandibular mesioclusion is associated with advanced periodontal disease (see Supplemental Information, Records).

Research on Scandinavian wild wolves have reported the presence of malocclusion. These instances may be associated with inbreeding within the population resulting in reduced genetic variability (Räikkönen et al., 2013). It is assumed that skeletal malocclusion in dogs is highly heritable (Wegner, 1987). One in three of the examined dogs in this study suffered from malpositioned teeth. This may be due to inbreeding and genetic variability reduction in Roman cities or due to genetic mutation introduced through gene flow and manifesting quickly due to its high heritability. Within the relatively small number of dog skulls from Augusta Raurica from different time horizons, continuity in dogs with malocclusions was observed. Hence, dental anomalies were already evident in the 1st century CE and certainly continued into the late 3rd century CE.

5.11. Bone fractures

Traumatic injury to the snout is not rare in dogs. Studies on trauma etiology in modern dogs have shown that 62% of fractures of the mandible region and 50% in the craniomaxillofacial region are sustained during dog fights, with nearly 60% of the dogs with a broken lower jaw being younger than one year (Kitshoff et al., 2013; De Paolo et al., 2020). This trend is also seen at Augusta Raurica, where the two dogs with mandibular fractures are juvenile to subadult age. Hence, trauma to the snout of dogs in archaeological contexts does not necessarily indicate hunting or rough human handling but can occur within normal social interaction between dogs.

5.12. Other findings

Enamel hypoplasia in canids is rare. Losey et al. (2014) report that only 17 modern dogs and wolves, out of a sample of 544 displayed the condition. Enamel hypoplasia is closely associated with stress factors, such as trauma to the facial region (focal defects), malnutrition or severe diseases like canine distemper (creating generalized defects) during enamel formation. The absence of hypoplasia may indicate that the dogs in this study did not suffer from such conditions during amelogenesis (2–4 mo. of age) or did not survive the stress episode.

5.13. Brachycephaly

Brachycephaly is common in modern dogs and cats. Nearly all breeds in the brachycephalic group have shown a tendency for increased nasal shortening during the last century, driven to extremes by selective breeding (Koch and Sturzenegger, 2015). Characteristics of brachycephalic dogs include large and protruded eye bulbs, brawny head shape, strong lower jaws, shortened upper jaws, shortened facial length in relation to the overall skull dimensions, oversized cheek teeth, cheek teeth that rotate or overlap due to lack of space, often missing premolars, narrow nostrils, overlong and thickened palates and sometimes everted laryngeal pouches (Koch et al., 2003).

There are a number of examples of archaeologically recovered dogs with brachycephalic features from Roman Empire regions. For instance, an investigation of Roman dogs from Britain yielded two individuals with a domed head from Godmanchester (Harcourt, 1974). A dog from the cemetery of Yasmina, Roman province *Africa proconsularis,* dated to 3rd century CE, located in a grave at the foot region of a young adolescent, was described as highly brachycephalic (MacKinnon and Belanger, 2006). Three medium-sized dogs with a wide and short skull, as well as short and wide maxilla, were found in the western necropolis of the Roman city of *Barcino* (Spain), dated between the first half of the 2nd century CE and mid 3rd century CE (Colominas, 2016). A dog with a short skull and visible mesioclusion, dated to the first half of the 1st century CE, was discovered in the cemetery of *Colonia Patricia Corduba* (Spain), the capital of the *Baetica* province (Martínez Sánchez et al., 2020).

These widely scattered finds and modern clinical and radiographic data suggest that brachycephalic dogs were not isolated single mutations. The wide geographic distribution during the Roman era indicates a genetic pool existed at that time and that these dogs were intentionally bred. It is also possible that the dogs found in urban contexts were kept as lapdogs and in some contexts were used to hunt rodents, especially at economically important transshipment points in the Mediterranean (Engler, 2017). This might serve as a possible explanation of the location dogs no. 14 and 15 in this sample.

6. Conclusion

In this pilot study, modern veterinary dental examination methods for dogs were used to assess archaeological remains. In particular, dental radiology proved useful in diagnosing oral pathologies and for estimating age at death. These approaches are new but essential to the field of zooarchaeology, which seeks to understand the etiology, evolution, and circumstances surrounding the presence of disease in dogs in the past.

The evaluation of a sample of 28 dog skulls from Roman era sites in Germany and Switzerland indicated that the lifespan of Roman era dogs was substantially shorter than that of modern dogs. While this difference may be an archaeological bias created by the contexts within which the dog remains were recovered (the majority of dogs of this study were recovered within the fill of wells), it is interesting that many of the dental pathological conditions noted in the veterinary clinical literature appear in the Roman era sample. The presence of high rates of tooth fractures, periodontal disease, and non-vital teeth may suggest that the ways in which Roman dogs may have used their dentition differed somewhat from modern dogs. For instance, documentary evidence of high carbohydrate diets of Roman dogs, along with environmental conditions encouraging use of teeth for chewing hard substances, and dental conditions associated with brachycephaly, potentially contributed to the onset of dental pathological conditions. However, these assumptions need to be substantiated by further investigations. Despite the small number of specimens, pathological trends were discernible in this sample. Periodontal disease appears often in older dogs, unassociated with the size of the animal, while dental fractures occur in all sizes and ages. Brachycephaly is noted in the small dogs, perhaps indicating that these were purposefully bred as lapdogs and suffered from the effects of reduced genetic variation.

Along with providing insight into the past, this pilot study provides interesting perspectives from the point of view of modern veterinary medicine. For instance, tooth resorption, detected in one specimen, sheds new light on the antiquity of a condition often considered to be an artifact of “modern civilization.” In order to offer comprehensive and robust statements about the past, further studies using standardized veterinary methods (for instance, detailed dental examination and dental radiographs, and computed tomography, if indicated), allowing statistical analysis and cross-population comparisons, are required. Studies in many different regions of the Roman Empire should be initiated to provide a broader and more sophisticated view of the life of Roman dogs. Furthermore, research on dog remains from archaeological sites across the globe, from different time periods, and associated with different human cultures will provide unprecedented insight into the evolution of dental diseases. These studies will vastly improve our understanding of the life of dogs and their coexistence with humans.

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Conflicts of interest

Gottfried Morgenegg is the developer of the electronic Veterinary Dental Scoring. The authors confirm that there are no other conflicts of interest.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ijpp.2023.09.007.

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