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Prevalence and severity of periodontal disease in a historical Austrian population

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Abstract

Objective: To assess the prevalence and severity of periodontitis based on different diagnostic methods in a historical Austrian population from the early middle ages.

Background: The description of the oral health status of archaeological material can provide interesting insights into prevalence, severity, and extent of oral diseases. Herein, the periodontal health status of the skeletal remains of medieval Avars (700-800 AD), which were considered as one of the earliest Avarian settlements in Austria, was investigated.

Methods: The skeletal remains of 128 Avars were examined; age and gender were estimated by standard forensic methods and tooth loss and root caries were recorded. Periodontitis was assessed by (a) measurement of the alveolar bone levels (ABL) and (b) evaluation of the interdental septa.

Results: A mean ABL of 4.8 mm was determined, root caries tended to accumulate in teeth with a higher alveolar bone loss, and on average, 6.2 teeth were lost antemortem. Independent of the diagnostic method >90% of the subjects were judged as periodontally diseased, and age and tooth type were significant predictors. However, on the tooth level the presence of periodontitis varied considerably depending on the diagnostic method; that is, 7.6% versus 47.2% of the teeth were judged as healthy based on ABL or interdental septa, respectively.

Conclusion: The periodontal status of the skeletal remains of medieval Avars revealed a considerable high prevalence of periodontitis (ie, >90% of this population displayed periodontal tissue breakdown). However, the diagnostic method, disease definition, and data presentation should be considered when comparing results of archaeological material.

KEYWORDS

alveolar bone loss, archaeological population, Austria, Avars, periodontal disease, root caries

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1 | INTRODUCTION

Periodontal diseases (ie, gingivitis and periodontitis) are next to caries the main, microbial-associated oral diseases. While gingivitis is limited to an inflammation within the soft tissues, periodontitis affects the whole tooth-supporting apparatus. Periodontitis is considered as a multifactorial inflammatory chronic disease, which—if left untreated—is causing progressive destruction of the tooth-supporting structures and thereby finally leading to tooth loss. Clinical signs of periodontitis are gingival inflammation, increased probing pocket depths, and increased clinical attachment loss, and radiographically alveolar bone loss becomes evident. Nowadays, severe periodontitis is considered as the 6th most prevalent condition worldwide with an age-standardized prevalence of about 11%; this prevalence rate has been largely unchanged since 1990.[1] Periodontitis and associated tooth loss have not only a negative impact on oral health-related quality of life,[2,3] but also on general health (eg, diabetes, cardiovascular diseases, and adverse pregnancy outcomes).[4-7] In 2017, a World Workshop for a new classification of Periodontal and Peri-Implant Diseases and Conditions took place and defined that periodontitis should be classified according to a Staging and Grading system, which takes severity, complexity, extent, and finally progression rate into account.[8,9]

However, periodontal diseases are not the result of a developed civilization; in contrast, they are considered to be as old as humanity. Records on periodontitis as an inflammatory condition date back about 4000 years ago to Egyptians and Chinese populations.[10] Nevertheless, as only osseous structures (ie, the presence of alveolar bone loss and/or changes in the bone texture) can be examined, the assessment of periodontal diseases in archaeological material is naturally limited to the assessment of periodontitis. Investigations of archaeological jaws of diverse populations can reveal important knowledge about the natural course of and about the influence of varying living conditions during human history on periodontitis development and progression; as such, nutritional habits, changes of food and diet, the presence of physical stress, or other environmental parameters might be recognized as important factors. For example, a previous study[11] compared the extent of calculus and alveolar bone loss between 4th century Romano-British specimens and 18th century Londoners. Indeed, although a significantly higher prevalence of supragingival calculus—and partly also subgingival calculus—was present in the Romano-British specimens, the amount of alveolar bone loss did not vary significantly. In this context, the description of the oral health status of archaeological material can provide interesting insights into disease development and progression.

In 1971 during municipal construction works in the 11th district of Vienna (Austria), historical graves were discovered and the excavation of the cemetery revealed 705 graves. The graves were dated back to the 7th and 8th century and were judged to belong to one of the earliest Avarian settlements in Austria.[12] The Avars, a nomadic tribe of horseman, populated a large part of Eastern- and Middle-Europe in the years 567 to 796 AD and were considered as one of the most powerful European political and ethnical groups in the Early Middle Ages.[13] Initially a martial culture, they gradually settled in small villages centered on agriculture and animal husbandry,[14] which changed their diet from primarily meat and dairy products toward an increased intake of vegetables, fruits, nuts, and corn. In two previous publications, caries frequency and distribution[15] and alveolar ridge atrophy patterns after tooth loss[16] were described for this specific population, while the aim of the present study was to investigate the prevalence and severity of periodontitis; therefore, two different diagnostic methods were applied: (a) direct measurement of the alveolar bone level (ABL) and (b) evaluation of the bone quality and texture of the interdental septa. Secondary, any correlations between severity of periodontitis and (a) tooth loss rate and (b) root caries were assessed.

2 | MATERIAL AND METHODS

The skeletal remains were discovered 1971 in the 11th district of Vienna (Austria) and related archaeological findings indicated that they belonged to medieval Avars (700-800 AD). The excavation revealed 705 graves with 755 subjects; for 397, the jawbones were preserved of which 128 met the inclusion criteria of (a) identifiable gender, (b) age >20 years, and (c) a good preservation of the teeth and jawbone allowing assessment of the periodontal status.

2.1 | Estimation of age and identification of gender

As described in both previous publications,[15,16] well-established proven methods[17,18] were applied for the identification of gender and the estimation of age at death was based on several parameters (ie, degree of cranial suture synostosis, surface characteristics of the symphysis of the pubic bone and of the auricular surface of the ilium, and the degree of tooth abrasion).[19] The included subjects were allocated into one of three age cohorts[20,21]: (a) young adults (ie, 21 to 40 years of age), (b) middle-aged adults (ie, 41 to 60 years of age), and (c) old adults (ie, ≥61 years of age). Subjects with an estimated age ≤20 years were excluded, due to unreliable sex estimation and incomplete tooth development.

2.2 | Antemortem and postmortem tooth loss

Missing teeth were defined as either "postmortem tooth loss" (PMTL) or "antemortem tooth loss" (AMTL). Empty alveolar sockets, which showed no signs of bone remodeling and/or socket closure, were judged as PMTL, while partly or fully healed alveolar sockets were judged as AMTL (Figure 1).

2.3 | Assessment of periodontal disease

Periodontal disease prevalence and severity were assessed by two different methods: (a) direct measurement of the ABL and (b) evaluation of the bone quality and texture of the interdental septa. The assessment was performed on eight teeth, which were

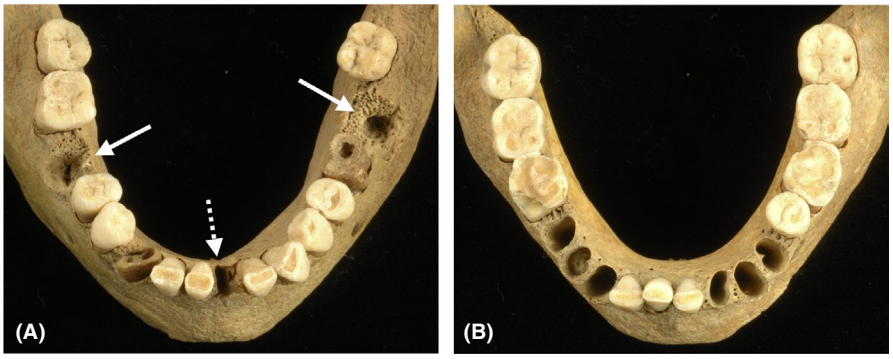


FIGURE 1 Two mandibles presenting with antemortem and postmortem tooth loss; A, #37 and #46 were judged as antemortem tooth loss due to signs of bone remodeling and partial socket healing (indicated by the full line arrows), while #31 was recorded as postmortem tooth loss (indicated by the dotted line arrow); B, mandible with several postmortem tooth losses in the premolar, canine, and incisor region

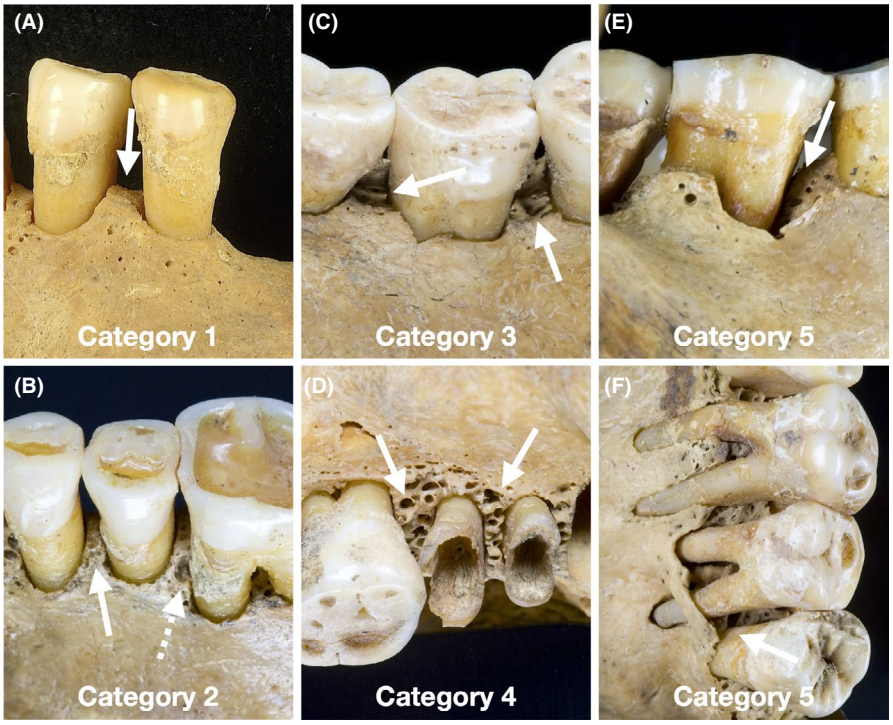


FIGURE 2 The bone quality and texture of the interdental septa was classified into the following categories; A, Category 1 with a characteristic shape of the septum and no foramina or grooves interrupting the cortical surface (indicated by the arrow); B, Category 2 with a characteristic shape of the septum, but the cortical surface shows small foramina (indicated by the full line arrow) and larger foramina (indicated by the dotted line arrow); C, Category 3 with the septum showing a breakdown of contour with bone loss with a sharp and ragged texture (indicated by the full line arrows); D, Category 4 with the septum showing a breakdown of contour with bone loss, but the surface shows a porous or smooth honeycomb effect with all defects rounded (indicated by the full line arrows); and E, F, Category 5 with the presence of a deep intra-bony defect (indicated by the full line arrows)

chosen as index teeth[22]: canine (#13) and second premolar (#15) of the right maxilla, central incisor (#21) and second molar (#27) of the left maxilla, canine (#33) and second premolar (#35) of the left mandible, central incisor (#41) and second molar (#47) of the right mandible.

The ABL as the distance between the cemento-enamel junction and the alveolar crest was measured at the buccal and oral midline of each index tooth. The measurements were performed by a single examiner under room light conditions with a digital calliper displaying the distance in mm including two digits after the decimal point. Teeth were excluded from the analysis when the alveolar bone appeared to be damaged postmortem and/or when the cemento-enamel junction was not visible due to caries or calculus. For the later classification, an ABL up to 2 mm was considered as healthy/no periodontitis (ie, 2 mm is frequently chosen as cutoff level, eg[11,23-25]), while an ABL of >2-4 mm (ie, corresponding to 1-2 mm alveolar bone loss) was judged as slight, an ABL of >4-6 mm (ie, corresponding to 3-4 mm alveolar bone loss) as moderate, and an ABL >6 mm (ie, corresponding

to ≥5 mm alveolar bone loss) as severe periodontitis; the diagnosis on the subject level was based on the worst tooth.

The evaluation of the bone quality and texture of the interdental septa was performed at the mesial and distal interdental space next to the above-mentioned index teeth according to the classification suggested by Kerr.[26,27] One examiner judged each interdental septum under a microscope (Olympus Zoom-Stereomikroskop SZH-ILLD) and classified it to one of the following 6 categories (Figure 2):

- Category 0: "Unrecordable"—tooth on either side of the septum was lost antemortem or the septum was damaged postmortem.
- Category 1: "Healthy"—Characteristic shape of the septum for its region and no foramina or grooves interrupted the cortical surface.
- Category 2: "Healthy/Gingivitis": Characteristic shape of the septum for its region, but the cortical surface shows a range from many small foramina and/or shallow grooves to larger foramina and/or prominent grooves.
- Category 3: "Acute periodontitis"—The septum shows a breakdown of contour with bone loss with a sharp and ragged texture.
- Category 4: "Quiescent periodontitis"—The septum shows a breakdown of contour with bone loss, but the surface shows a porous or smooth honeycomb effect with all defects rounded.
- Category 5: "Aggressive periodontitis"—Presence of a deep intra-bony defect with a depth of ≥3 mm either mesio-distally or bucco-lingually inclined.

For the later classification, category 1 and 2 were summarized as "healthy/no periodontitis", as both categories present neither a breakdown of the shape of the septum nor bone loss, and gingivitis as disease entity cannot be diagnosed in dry skulls. Similar to what was suggested previously[28] category 3 and 4 were pooled as "established periodontitis", and category 5 as "advanced periodontitis"; however, as this method does not quantify the amount of alveolar bone loss, the terms "established" and "advanced" were chosen instead of "moderate" and "severe", which indicate in most modern classifications/case definitions the amount of alveolar bone loss.[29,30] The diagnosis on the subject level was based on the worst afflicted septum.

The principal examiner (BB) was trained and calibrated on well-preserved archaeological skeletal material for both methods prior to the assessment of the ancient Avar material. The training results were discussed in the group of experienced investigators participating in this study. As long as inconsistencies emerged and disagreement occurred, the training evaluations were continued until a consensus how to perform the measurements and classifications in a reproducible and standardized manner was reached. However, due to the fragility and uniqueness of the material a re-assessment of about 25% of the material by the same and by a second examiner was not performed herein.

2.4 | Determination of root caries

The assessment of root caries was described previously.[15] Shortly, the presence of root caries was judged with the naked eye and by means of a dental probe and only lesions with a clear defect were recorded as caries lesions. The data on root caries, which were already published previously,[15] were re-used herein to assess any correlation between the severity of periodontitis and root caries.

2.5 | Statistical analysis

The data are summarized descriptively in tables and figures. For statistical inference, multiple imputations (50) were used to handle missing values (ie, missing ABL measurements), assuming missing at random[31]; missing at random was chosen to account for the postmortem damage of the material, which supposedly is not related to the severity of periodontitis. In order to account for the clustered structure of the data (multiple values per subject), the imputations were done in wide format.[32] Altogether, four primary outcome parameters were defined: (a) ABL (continuous), (b) periodontal diagnosis based on the evaluation of the bone quality and texture of the interdental septa (categorical), (c) occurrence of root caries (dichotomous), and (d) AMTL rate per subject (count). Further, the following predictors were considered: (a) gender, (b) age categories (ie, young/middle-aged/old adults), (c) tooth type (ie, the eight index teeth), (d) tooth aspect (ie, buccal/oral), (e) ABL (mm), (f) periodontal diagnosis based on ABL (ie, no/slight/moderate/severe periodontitis), and (g) periodontal diagnosis based on the evaluation of the bone quality and texture of the interdental septa (ie, no/established/advanced periodontitis). The following five regression analyses were performed to assess any relation between the above-mentioned primary outcome parameters and the predictors: (a) a mixed-effects multi-level regression analysis for the effect of gender, age, tooth type, and tooth aspect on ABL (mm); (b) a mixed-effects ordinal logistic regression analysis for the effect of gender, age, tooth type, and ABL (maximum value per tooth) on the periodontal diagnosis based on the evaluation of the bone quality and texture of the interdental septa; (c) a random-effects logistic regression analysis for the effect of gender, age, tooth type, and periodontal diagnosis based on ABL (per tooth) on the occurrence of root caries; and two negative binomial regression analyses for the effect of gender, age, and periodontal diagnosis on the subject level based on (d) the ABL or on (e) the evaluation of the bone quality and texture of the interdental septa on AMTL rate per subject. Statistical analysis was performed with STATA/IC 16.0 for Mac, and a *P*-value of ≤.05 was considered as statistically significant.

3 | RESULTS

The study sample consisted of 128 remains (61 female, 67 male) with 45, 49, and 34 subjects in the three age cohorts (ie, young, middle-aged, and old adults, respectively). On average, 25.1 tooth sites (including AMTL and PMTL sites) were considered as judgeable (ie, 27.4, 26.2, and 20.6 tooth sites per age cohort). Further, on average 4.9 index teeth were available per subject for ABL measurements and almost 11 interdental septa per subject for the assessment of the bone

quality and texture. However, the number of available index teeth and interdental septa decreased with increasing age (Table 1). In terms of periodontal diagnosis, four subjects each did not contribute either with ABL measurements or with data of the periodontal diagnosis based on the evaluation of the bone quality and texture of the interdental septa; that is, both diagnostic methods are based on 124 subjects.

3.1 | Antemortem and postmortem tooth loss

On average, 4.3 teeth per subject were lost postmortem with only a slight increase in the higher age cohorts; that is, on average 3.8 teeth among the young adults compared to 5.0 teeth among the old adults. The AMTL rate was on average 6.2 teeth per subject increasing with age; specifically, the AMTL rate almost doubled from 4.8 among the young adults to 8.0 among the old adults (Table 1).

3.2 | Periodontal diagnosis based on the ABL

The overall mean ABL was 4.8 mm with slightly higher values buccally compared to orally (ie, 4.9 mm compared to 4.6 mm). The mean ABL values increased with a higher age at death from 3.5 mm for the young adults to 6.3 mm for the old adults; a similar pattern was observed for buccal and oral aspects (Table 2; Figure 3). Only very few subjects of the youngest age cohort and a single subject of the middle-aged adults displayed a mean ABL ≤2 mm, which was considered as the cutoff value for a healthy periodontium (Figure 3). Evaluating each index tooth separately confirmed on the tooth level the low rate (ie, 7.6%) of periodontally healthy teeth (ie, mean ABL ≤2 mm), while 38.5%, 37.5%, and 16.4% of the teeth were categorized as having slight, moderate, and severe alveolar bone loss, respectively. Further, a slightly higher alveolar bone loss was observed for the lower anterior (ie, tooth #33 and #41; Figure 4A).

The periodontal diagnosis on the subject level was based on the ABL of the worst index tooth. Only a single subject was classified as periodontally healthy; that is, displaying no index tooth with an ABL >2 mm. Further, only five subjects presented maximum a slight alveolar bone loss of 1-2 mm (ie, an ABL of >2-4 mm), while 33 and 85 subjects presented at least one tooth with an ABL >4-6 and >6 mm, respectively. This resulted in about 80% of the middle-aged and about 90% of the old subjects being diagnosed with severe periodontitis (ie, at least one index tooth with an ABL >6 mm; Table 2).

The ABL was significantly affected by age and tooth type, while gender and tooth aspect (ie, buccal/oral) did not have a significant effect. Specifically, higher age at death and lower anterior teeth increased the risk for a higher alveolar bone loss (Appendix 1a; Figures 3 and 4A).

3.3 | Periodontal diagnosis based on the bone quality and texture of the interdental septa

Based on the assessment of the bone quality and texture of the interdental septa, 11 subjects were judged as periodontally healthy (ie, maximum category 2), while 92 and 21 subjects were classified as having established and advanced periodontitis, respectively. Most of the periodontally healthy subjects belonged to the youngest age cohort (ie, eight out of 11 subjects), while the two other age cohorts displayed a comparable distribution; that is, about 80 and 15% were classified as established and advanced periodontitis, respectively (Table 2; Figure 5).

On the tooth level, 47.2% of the teeth were classified as healthy, while 49.0 and 3.8% of the teeth were categorized as having established and advanced disease, respectively. The upper and lower incisors (ie, #21 and #41) presented the highest percentage of a healthy periodontium, while the molars (ie, #27 and #47) presented the highest percentage of advanced disease (Figure 4B).

Gender, age, tooth type, and ABL altered significantly the diagnosis based on the evaluation of the bone quality and texture of the interdental septa. Specifically, males presented a lower risk for a higher degree of periodontal disease, while higher age, upper molars, and higher ABL values increased the risk for a higher degree of periodontal disease (Appendix 1b; Figures 4B and 5).

3.4 | Root caries and AMTL in relation to periodontal disease

Only a single tooth (ie, 2.9%) of the periodontally healthy teeth had root caries, while the prevalence of root caries increased among the

TABLE 1 Subject characteristics and antemortem and postmortem tooth loss rate

	Subjects		Gender (female)		Judgeable tooth sites[a]	AMTL	PMTL	No. of teeth examined for ABL	No. of IDS examined
Age cohorts	n	%	n	%	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Young	45	35.2	20	44.4	27.4 ± 2.3	4.8 ± 3.1	3.8 ± 3.1	6.6 ± 1.1	13.8 ± 2.6
Middle-aged	49	38.3	20	40.8	26.2 ± 4.4	6.4 ± 2.8	4.4 ± 2.7	5.1 ± 1.7	11.4 ± 3.8
Old	34	26.5	21	61.8	20.6 ± 8.7	8.0 ± 3.9	5.0 ± 3.9	2.3 ± 1.6	5.1 ± 2.9
Total	128	100	61	47.7	25.1 ± 6.1	6.2 ± 3.4	4.3 ± 3.2	4.9 ± 2.2	10.6 ± 4.7

Abbreviations: ABL, alveolar bone level; AMTL, antemortem tooth loss; IDS, interdental septa; n, number; PMTL, postmortem tooth loss; SD, standard deviation.

[a]Including PMTL and AMTL sites.

TABLE 2 Periodontal diagnosis on the subject level based on the alveolar bone levels and on evaluation of the bone quality and texture of the interdental septa

	Periodontal diagnosis based on the alveolar bone level n (%)[a,b]				Alveolar bone level mm (mean ± SD)			Periodontal diagnosis based on the interdental septa n (%)[a,b]		
		Periodontitis							Periodontitis	
Age cohorts	Healthy	Slight	Moderate	Severe	Oral	Buccal	Overall	Healthy	Established	Advanced
Young	1 (2.2)	4 (8.9)	21 (46.7)	19 (42.2)	3.4 ± 0.9	3.5 ± 1.1	3.5 ± 1.0	8 (17.8)	29 (64.4)	8 (17.8)
Middle-aged	0 (0)	1 (2.0)	9 (18.4)	39 (79.6)	4.8 ± 1.2	5.3 ± 1.4	5.0 ± 1.1	3 (6.3)	37 (77.1)	8 (16.6)
Old	0 (0)	0 (0)	3 (10.0)	27 (90.0)	6.0 ± 1.7	6.9 ± 1.3	6.3 ± 1.5	0 (0)	26 (83.9)	5 (16.1)
Total	1 (0.8)	5 (4.0)	33 (26.6)	85 (68.6)	4.6 ± 1.6	4.9 ± 1.8	4.8 ± 1.6	11 (8.9)	92 (74.2)	21 (16.9)

Abbreviations: n, number; SD, standard deviation.

[a]Percentages represent the percentages per age cohort.

[b]Four patients each did not contribute either with measurements of the alveolar bone levels or with data of the periodontal diagnosis based on the evaluation of the bone quality and texture of the interdental septa; that is, both diagnostic methods are based on 124 patients.

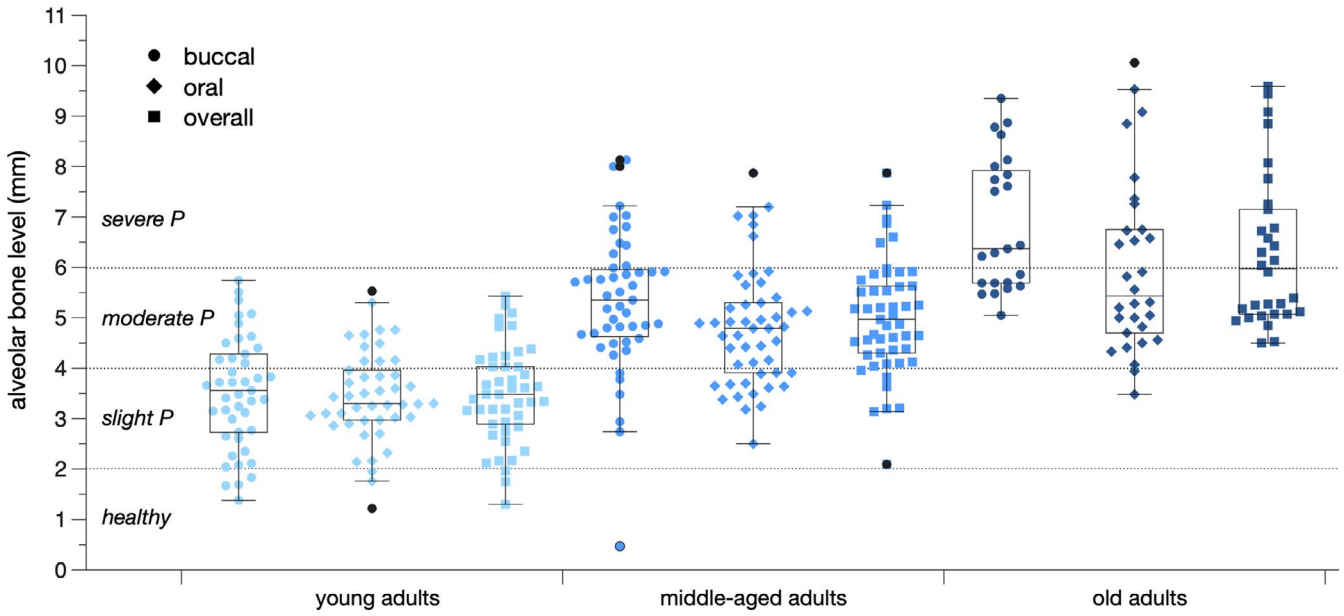


FIGURE 3 Buccal, oral, and overall alveolar bone levels per subject in relation to the age cohorts. P, periodontitis

periodontally diseased teeth. Specifically, 8 (ie, 4.9%), 14 (ie, 7.6%), and 13 (ie, 9.4%) teeth with an ABL >2-4, >4-6, and >6 mm, respectively, were diagnosed with root caries; that is, the prevalence of root caries tripled from periodontally healthy to severe periodontitis (Table 3; Figure 6). However, only age and tooth type depicted a statistically significant effect on the prevalence of root caries, while gender and periodontal diagnosis remained insignificant; specifically, the old adults and upper molars presented the highest risk for root caries (Appendix 1c).

AMTL rate per subject increased in the presence of periodontal disease. While the only periodontally healthy subject (based on ABL) lost two teeth antemortem, increased the number of AMTL from 4.6 to 5.6 and finally to 6.6 for subjects being judged as having slight, moderate, and severe periodontitis, respectively. This increase in AMTL rate from periodontally healthy to periodontally diseased subjects was also evident, if the periodontal diagnosis was based on the evaluation of the interdental septa. Specifically, the number of AMTL increased from 3.5 to about 6-7 teeth for the healthy and diseased subjects, respectively (Table 4). However, statistically only the diagnosis based on the evaluation of the interdental septa reached significance to cause an increased AMTL rate; additionally, higher age at death presented a significant effect (Appendix 1d and Appendix 1e).

4 | DISCUSSION

The description of the oral health status of archaeological material can provide interesting insights into prevalence, severity, and extent of oral diseases. Herein, the periodontal status of the skeletal remains of medieval Avars (700-800 AD) was examined and revealed a considerable high percentage of subjects (ie, >90%) presenting to some extent periodontal tissue breakdown. However, the diagnostic method, disease definition, and data presentation appear to have

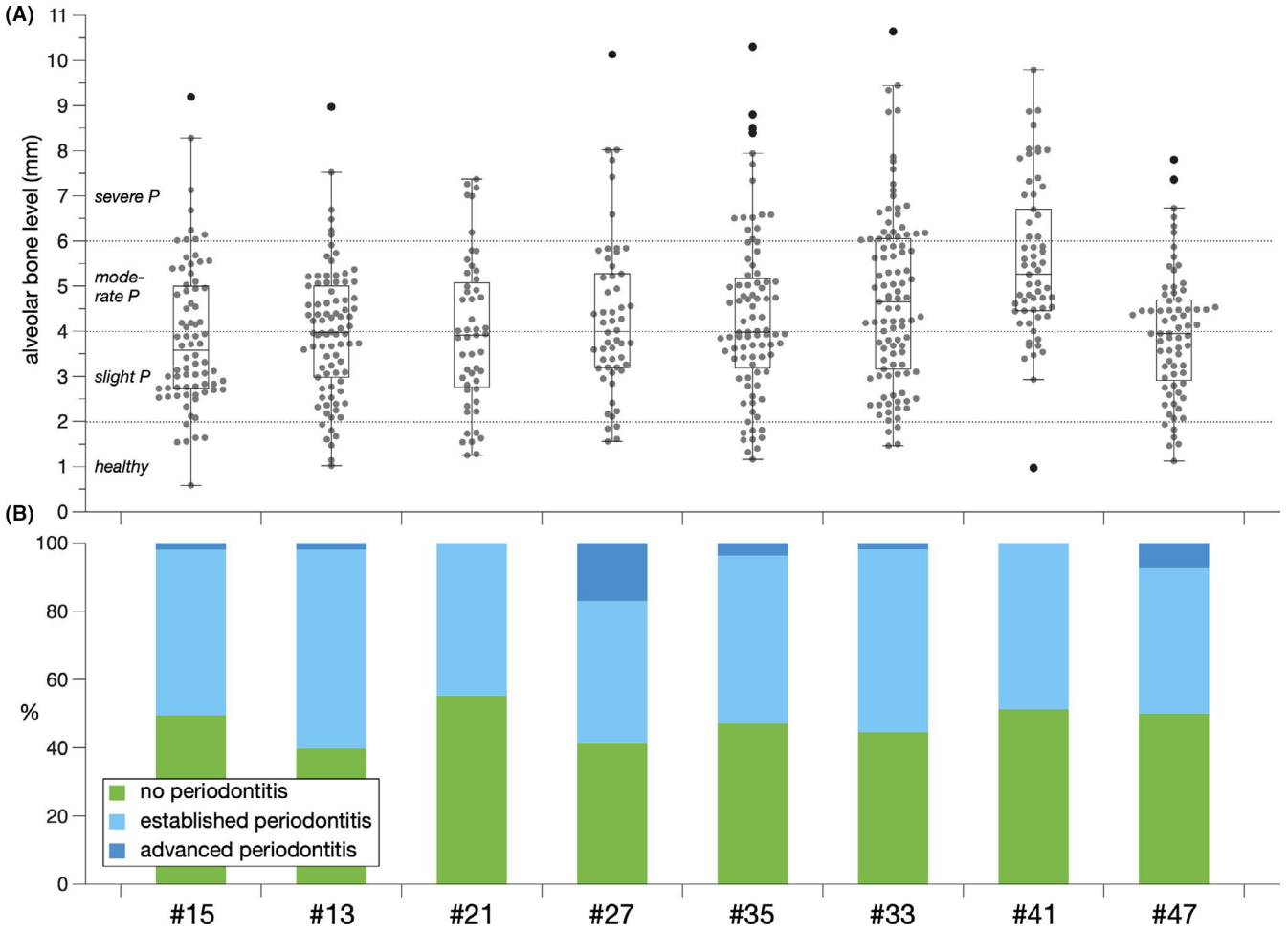
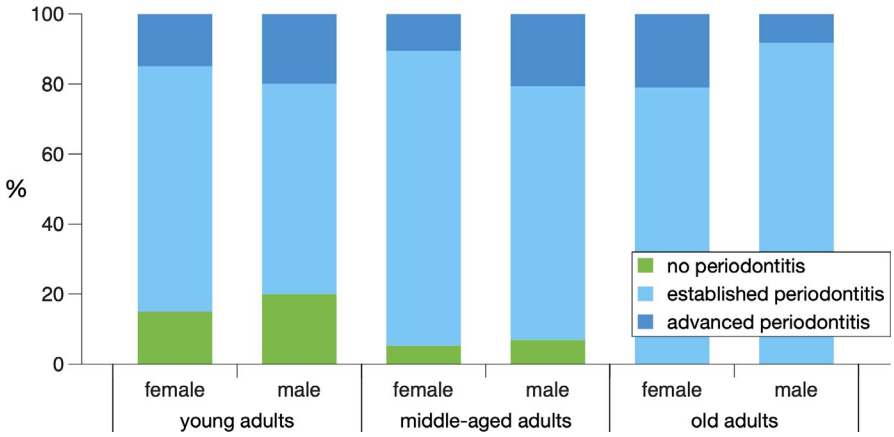


FIGURE 4 A, Alveolar bone levels in relation to the tooth types; B, periodontal diagnosis based on the evaluation of the bone quality and texture of the interdental septa in relation to the tooth types. P, periodontitis

FIGURE 5 Periodontal diagnosis based on the evaluation of the bone quality and texture of the interdental septa in relation to gender and age cohorts



a significant impact on the prevalence and extent of periodontitis in historical populations. In this context, periodontitis is classified nowadays by a newly introduced Staging and Grading system, which considers anamnestic, clinical, and radiographical parameters, and tooth loss rate due to periodontitis to judge severity, complexity, extent, and progression rate.[8,9] Archaeological material allows to judge alveolar bone quality, and to measure the amount of alveolar bone loss, and AMTL rate, although latter is naturally not specifically due to periodontitis only, but supposedly also caused by other reasons such as caries, odontogenic abscesses, fracture, and attrition. Further, also the validity of ABL to describe the presence and severity of periodontitis has been discussed controversial, as there are also other reasons beside inflammatory processes causing an increased distance between the cemento-enamel junction and the alveolar crest. Specifically, a missing opposing tooth and/or extensive occlusal tooth wear due to a diet containing high amounts of abrasive

TABLE 3 Prevalence of root caries per tooth type in relation to the periodontal diagnosis based on alveolar bone level

Periodontal diagnosis based on alveolar bone level	Tooth type								
	No. of teeth with root caries/No. of evaluated teeth								
	15	13	21	27	35	33	41	47	Overall[a]
Healthy	0/4	0/6	0/6	1/4	0/6	0/4	0/1	0/4	1/35 (2.9%)
Periodontitis									
Slight	0/33	1/27	0/16	1/17	2/22	1/25	0/4	3/18	8/162 (4.9%)
Moderate	4/25	1/33	0/20	3/17	3/24	0/27	0/17	3/22	14/185 (7.6%)
Severe	1/12	1/19	0/8	5/14	3/21	0/33	0/21	3/10	13/138 (9.4%)
Overall[b]	5/74 (6.8%)	3/85 (3.5%)	0/50 (0%)	10/52 (19.2%)	8/73 (11.0%)	1/89 (1.1%)	0/43 (0%)	9/54 (16.7%)	

[a]Percentages represent the percentages per periodontal diagnosis.

[b]Percentages represent the percentages per tooth type.

particles cause on the long-term over-eruption of the affected teeth and thereby lead to higher ABL values without periodontal inflammation[33]; additionally, older individuals might suffer from "normal" atrophic changes resulting in an exposed root surface especially at the buccal apsects.[34] In this context, it has been shown previously that the patterns of ABL and tooth wear/attrition correlate with each other, which implies that a solely assessment of ABL can be misleading for the assessment of periodontitis.[33] However, this depends on the dietary habits of the population and is more relevant in older age cohorts. In a late medieval United Kingdom population, subjects up to 45 years at death lacked a difference in the ABL in relation to tooth wear, while in the age cohort above 45 years the alveolar bone loss was 1.1 mm higher for teeth with high compared to teeth with low tooth wear.[24] Nevertheless, in the majority of the available studies (eg,[11,23-25,35-37]) ABL values were used to conclude on the presence and severity of periodontitis, which allows a certain comparability between the studies. A distance between the cemento-enamel junction and the alveolar crest up to 2 mm is regularly considered as "physiologic",[11,23-25] while any additional bone loss is supposed to be due to periodontal tissue breakdown. However, as described above, ABL values probably tend to overestimate the presence of periodontitis, especially in older subjects. To overcome this drawback, the constitution of the cortical plate at the crestal alveolar bone (ie, whether it shows signs of an inflammatory degenerative process)[38] and/or of the interdental septa can be taken into account. The latter was suggested by Kerr[26] and considers the shape of the interdental septum, the cortical structure, and the presence of intrabony defects (Figure 2). The advantage of this classification is that a breakdown of the interdental septum occurs supposedly only due to periodontal inflammation, but it does not display the total amount of alveolar bone loss; that is, whether a slight form of periodontitis with 1-2 mm of alveolar bone loss or a severe form with ≥5 mm of alveolar bone loss is present. Therefore, it was decided herein to apply both methods; that is, assessment of ABL and evaluation of the bone quality and texture of the interdental septa. By these means, this specific population presented on the subject level and independent of the diagnostic method a considerably high prevalence of periodontitis; that is, >90% were diagnosed as having suffered from periodontitis. However, the diagnosis on the subject level for both methods was based on the worst tooth/septum, which might imply that the prevalence has been overestimated, if already one "bad" tooth is sufficient for the diagnosis. Indeed, nowadays classifications/case definitions mostly require two periodontally affected teeth for diagnosis of periodontitis.[9,29,30] In this context, it was interesting to see, that redefining the case definition and requiring at least two periodontally affected teeth did not change the overall prevalence of periodontitis based on ABL measurements; however, if the diagnosis was based on the interdental septa, the percentage of periodontally healthy subjects almost tripled from 9% to 24% (Table 1, Appendix 2).

Further differences in dependence of the diagnostic method were depicted by the tooth level analysis. While the prevalence of periodontitis remained >90% based on the ABL measurements (ie, only 7.6% of the teeth had a mean ABL ≤2 mm; Figure 4A), the tooth level analyses based on the interdental septa revealed a clearly lower prevalence of periodontitis; specifically, 47.2% of the teeth were classified as healthy. Hence, although in general higher ABL values correlated significantly with a (more severe) periodontal diagnosis based on the interdental septa, these two diagnostic methods displayed distinct differences at the tooth level. For clarification, Figure 7 shows, that several teeth, which had been judged as periodontally healthy based on the interdental septum, were actually recorded as having slight or moderate alveolar bone loss. While comparing the two diagnostic methods on the subject level reveals that only a few individuals, which were judged as periodontally healthy based on the interdental septa, had an ABL higher than 4 mm. This underlines that the diagnostic method, disease definition, and data presentation (ie, subject or tooth/site level) can have a significant effect on the prevalence and severity of periodontitis in archaeological material.

One might additionally argue that the high periodontitis prevalence herein is due to a too low cutoff value (ie, ABL >2 mm) especially when looking at the middle-aged and old adults. For example, a previous study on a Romano-British population (200-400 AD)[38] applied stricter criteria resulting in a significantly lower prevalence; that is, a

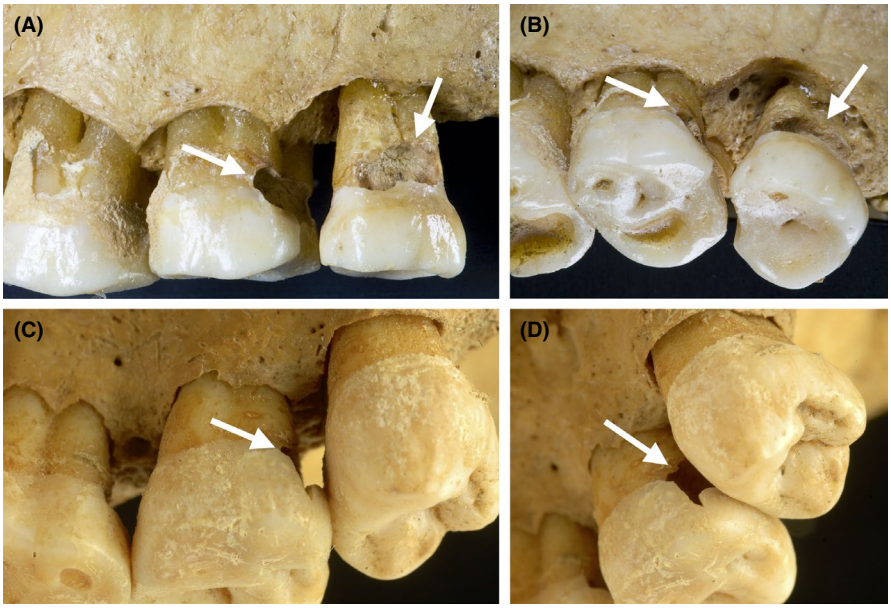


FIGURE 6 Two examples A, B, and C, D, with upper molars presenting with periodontal tissue breakdown and root caries (indicated by the arrows)

TABLE 4 Antemortem tooth loss rate per subject in relation to the periodontal diagnosis

Periodontal diagnosis based on alveolar bone level	AMTL n (mean ± SD)	Periodontal diagnosis based on IDS	AMTL n (mean ± SD)
Healthy	2.0 ± 0	Healthy	3.5 ± 2.0
Periodontitis		Periodontitis	
Slight	4.6 ± 3.3	Established	6.7 ± 3.5
Moderate	5.6 ± 3.7	Advanced	6.1 ± 3.3
Severe	6.6 ± 3.2		

Abbreviations: AMTL, antemortem tooth loss; IDS, interdental septa; SD, standard deviation.

case was judged as having periodontitis either in the presence of an ABL 2 mm above the mean of the corresponding age group or in the presence of an ABL ≥5 mm on at least three teeth resulting in a periodontitis prevalence of 5% to 10%. However, raising the cutoff level herein even to 6 mm hardly changed the prevalence of periodontitis for the middle-aged and old subjects (ie, 80% and 90% were classified as severely diseased, respectively). The severity on the subject/patient level is also nowadays predominantly based on the worst tooth; that is, a single tooth is sufficient for the staging of a periodontitis patient.[9] Yet, the diagnosis of severe periodontitis is herein to big parts not only due to one single bad tooth; that is, 54% and 62% of the middle-aged and old subjects, respectively, presented ≥2 teeth with ABL >6 mm (Appendix 2). Another aspect, which supports the high prevalence of periodontitis in this specific population, is a high AMTL rate. A meta-analysis of European populations[39] including the previous publication reporting on caries and tooth loss[15] revealed that the present population had a distinctly higher AMTL rate compared to other populations of the same time period (ie, 0-9th century), but also compared to earlier and later time periods (ie, BC and 10th-17th century). As tooth loss is the true endpoint of periodontal disease, one can argue that this high AMTL rate is related to the high rate of periodontitis observed herein. Indeed, AMTL rate was herein significantly increased in the presence of periodontitis and with higher age at death.

Various potential subject- and tooth/site-related predictors (ie, age, gender, tooth type, tooth aspect) for the presence/severity of periodontitis were investigated herein. A higher age at death was significantly increasing the prevalence and severity of periodontitis independent of the diagnostic method. The overall mean ABL almost doubled from the young adults to the old adults, none of the old adults was judged as periodontally healthy, and the overall mean ABL was for all subjects >4 mm (Figure 3); such an effect of age is well in agreement with previous studies.[11,24,37,38,40,41] Gender as another subject-related parameter showed controversial results. Specifically, gender was an insignificant predictor for the ABL, but male subjects presented a reduced risk for periodontitis if the diagnosis was based on the interdental septa; though, there have been some inconsistencies in the different age cohorts. While male subjects presented a slightly higher percentage of advanced periodontitis cases among the young and middle-aged adults, the rate of female subjects with advanced periodontitis was higher among the old adults (Figure 5). Considering additionally the controversial results on gender reported in previous publications,[11,23,25,37,42] this gender aspect in dependence of the diagnostic method is difficult to explain and might be considered arbitrary. Among the tooth/site-related predictors, the tooth aspect (ie, buccal or oral measurement of the ABL) had no significant effect, while tooth type had. However, depending on the diagnostic

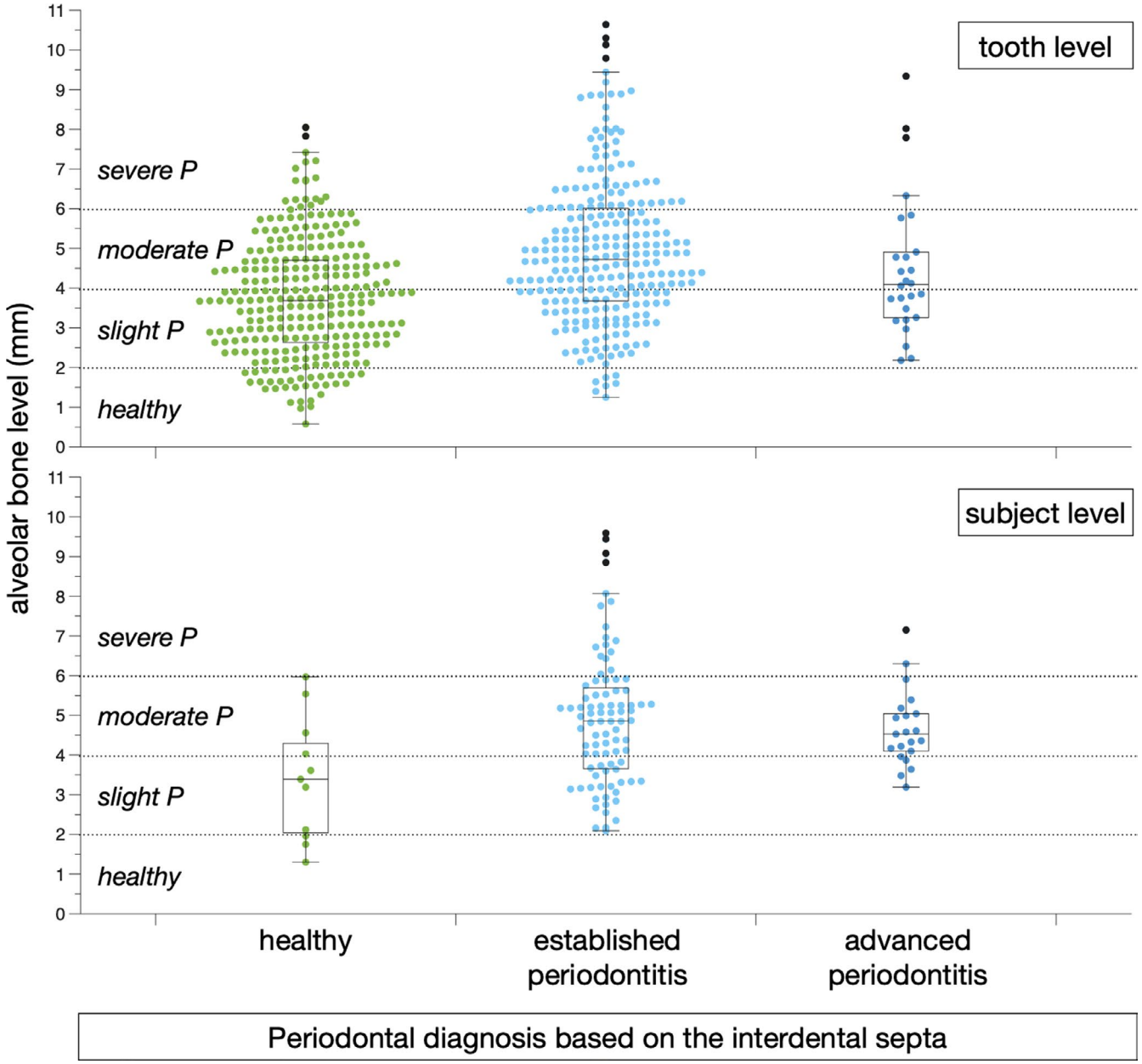


FIGURE 7 Periodontal diagnosis based on the alveolar bone level in relation to the periodontal diagnosis based on the evaluation of the bone quality and texture of the interdental septa on the tooth and subject level

method applied different tooth types displayed a higher risk for periodontitis. Specifically, while the lower anterior teeth presented higher ABL values, had the upper molars more often interdental tissue breakdown. Both tendencies correspond to what was reported previously[11,27,40,41]; especially data based on the judgment of the interdental septa confirmed the pattern of a higher disease prevalence among the molars and the incisors being least susceptible.[27,40,41]

In the previous publication,[15] root caries was the most frequent site for caries, whose frequency increased with higher age at death. Considering the high prevalence of periodontal tissue breakdown herein, it was obvious to examine alveolar bone loss as risk factor for developing root caries. Indeed, the prevalence of root caries tripled from the periodontally healthy teeth (ie, 2.9%) to the severely diseased teeth (ie, 9.4%); that is, only a single periodontally healthy tooth versus 35 periodontally diseased teeth presented with root caries (Figure 6). However, the statistical analysis depicted only higher age at death and the upper molars as risk factors for a higher root caries prevalence, while the periodontal diagnosis remained insignificant. Nevertheless, even nowadays, despite all available oral hygiene and treatment measures, the periodontal health status, respectively, periodontal attachment loss and thereby root exposure, is considered as risk factors for developing root caries; other age-related risk factors are xerostomia and/or functional disability.[43]

In this context, the change in nutrition habits and thereby potential malnutrition of this population should be additionally considered as a factor contributing to the high prevalence of both oral diseases—caries and periodontitis. With a lifestyle change from a nomad to a settled life, the food pattern of Avars switched from primarily meat

and dairy products toward a carbohydrate-rich nutrition, which was probably lacking proteins, minerals, and vitamins.[44,45] Nowadays, an optimized, anti-inflammatory diet (eg, low intake of carbohydrates and animal proteins, but high intake of omega-3 fatty acids, vitamin C and D, antioxidants, plant nitrates, and fibers) is described as having positive effects on gingivitis and partly also on periodontitis.[46,47] Hence, a diet rich in carbohydrates and low in vitamins supposedly had the opposite effect and therefore might have contributed to the inferior oral health status of this historical population.

During the planning of the present study, it was attempted to keep a balance between collecting the "best" data and preserving the valuable historical material. Thereby, a couple of limitations have been accepted; that is, partial-mouth assessment based on index teeth (instead of full-mouth assessment) and assessment of ABL at buccal and oral aspects only (instead of including interproximal sites). This lead among others to a considerably lower number of teeth and interdental septa being examined among the old adults compared to the young- and middle-aged adults. However, studies comparing full-mouth with partial-mouth periodontal examination protocols show—if at all—an underestimation of the "real" prevalence when using a partial-mouth protocol based on index teeth.[48] Nevertheless, these limitations in combination with the further above discussed differences in dependence of the diagnostic method, disease definition, and data presentation have to be taken into account when comparing the present prevalence rate with previous ones, which vary from very low (ie, 5% to 10%)[38] to average (ie, about 20% to 40%)[49] and finally to similar high rates as observed herein.[41] However, this huge range among studies assessing material from a similar time period also emphasizes the relevance of other factors, such as nutrition, genetic susceptibility, and habits.

In conclusion, the historical Austrian population assessed herein displayed on the subject level a considerably high prevalence of periodontitis (ie, >90%) independent of the diagnostic method applied. However, the diagnostic method, disease definition, and data presentation have a significant impact on the results in archaeological material. Hence, in the lack of an internationally accepted consensus on the recommended diagnostic method for assessing periodontitis in historical populations,[49] measurement of the ABL should be combined with an evaluation of the cortical bone quality and texture of the alveolar crest and/or interdental septa and the data should be reported on the subject and tooth/site level.

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CONFLICT OF INTEREST

All authors declare no conflict of interest.

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APPENDIX 1A

Multivariate analysis (mixed-effects multi-level regression analysis) for the effect of gender, age, tooth type, and tooth aspect on alveolar bone level (mm).

Predictor	Coef.	95% CI		*P*-value
		Lower	Upper	
Gender				
Female				
Male	−0.045	−0.322	0.231	.749
Age cohorts				
Young				
Middle-aged	0.987	0.693	1.280	**<.001**
Old	1.091	0.732	1.450	**<.001**
Tooth type				
#15				
#13	0.111	−0.261	0.483	.559
#21	0.132	−0.288	0.551	.538
#27	0.289	−0.120	0.697	.165
#35	0.215	−0.157	0.587	.257
#33	0.606	0.233	0.979	**.001**
#41	0.812	0.406	1.219	**<.001**
#47	0.091	−0.290	0.472	.640
Tooth aspect				
Buccal				
Oral	−0.135	−0.317	0.047	.145

Note: Statistically significant *P*-values are indicated in bold.
Abbreviation: CI, confidence interval.

APPENDIX 1B

Multivariate analysis (mixed-effects ordinal logistic regression analysis) for the effect of gender, age, tooth type, and alveolar bone level (maximum value per tooth) on the periodontal diagnosis based on the evaluation of the bone quality and texture of the interdental septa.

Predictor	Coef.	95% CI		*P*-value
		Lower	Upper	
Gender				
Female				
Male	−0.881	−1.466	−0.296	**.003**
Age cohorts				
Young				
Middle-aged	1.244	0.575	1.912	**<.001**
Old	2.182	1.319	3.046	**<.001**
Tooth type				
#15				
#13	0.434	−0.225	1.094	.197
#21	−0.221	−0.945	0.502	.549
#27	1.438	0.662	2.215	**<.001**
#35	0.085	−0.573	0.743	.801
#33	0.005	−0.647	0.657	.989
#41	−0.262	−0.966	0.443	.467
#47	0.410	−0.300	1.120	.258
Alveolar bone level				
mm	0.144	0.021	0.267	**.022**

Note: Statistically significant *P*-values are indicated in bold.
Abbreviation: CI, confidence interval.

APPENDIX 1C

Multivariate analysis (random-effects logistic regression analysis) for the effect of gender, age, tooth type, and periodontal diagnosis based on alveolar bone level (per tooth) on the occurrence of root caries.

Predictor	Coef.	95% CI Lower	95% CI Upper	*P*-value
Gender				
Female				
Male	0.503	−0.504	1.510	.327
Age cohorts				
Young				
Middle-aged	1.190	−0.024	2.405	.055
Old	1.721	0.126	3.315	**.034**
Tooth type				
#15				
#13	−0.794	−2.398	0.809	.332
#21[a]				
#27	1.710	0.240	3.180	**.023**
#35	0.682	−0.698	2.061	.333
#33	−2.280	−4.592	0.032	.053
#41[a]				
#47	1.391	−0.031	2.813	.055
Periodontal diagnosis based on alveolar bone level (per tooth)				
Healthy/No periodontitis				
Slight periodontitis	0.978	−2.425	2.620	.939
Moderate periodontitis	0.487	−2.031	3.004	.705
Severe periodontitis	0.594	−2.015	3.203	.656

Note: Statistically significant *P*-values are indicated in bold.
Abbreviation: CI, confidence interval.
[a]#21 and #41 presented no root caries.

APPENDIX 1D

Multivariate analysis (negative binomial regression analysis) for the effect of gender, age, and periodontal diagnosis based on alveolar bone loss (per subject) on ante-mortem tooth loss rate per subject.

Predictor	Coef.	95% CI Lower	95% CI Upper	*P*-value
Gender				
Female				
Male	−0.041	−0.224	0.143	.665
Age cohorts				
Young				
Middle-aged	0.285	0.060	0.510	**.013**
Old	0.502	0.249	0.756	**<.001**
Periodontal diagnosis based on alveolar bone level (per subject)				
Healthy/No periodontitis				
Slight periodontitis	0.727	−0.856	2.310	.368
Moderate periodontitis	0.881	−0.632	2.394	.253
Severe periodontitis	0.863	−0.652	2.377	.264

Note: Statistically significant *P*-values are indicated in bold.
Abbreviation: CI, confidence interval.

APPENDIX 1E

Multivariate analysis (negative binomial regression analysis) for the effect of gender, age, and periodontal diagnosis based the evaluation of the bone quality and texture of the interdental septa (per subject) on ante-mortem tooth loss rate per subject.

Predictor	Coef.	95% CI Lower	95% CI Upper	*P*-value
Gender				
Female				
Male	−0.083	−0.260	0.093	.354
Age cohorts				
Young				
Middle-aged	0.270	0.058	0.481	**.012**
Old	0.478	0.249	0.708	**<.001**
Periodontal diagnosis based on the interdental septa (per subject)				
Healthy/No periodontitis				
Established periodontitis	0.473	0.091	0.855	**.015**
Advanced periodontitis	0.424	0.002	0.846	**.049**

Note: Statistically significant *P*-values are indicated in bold.
Abbreviation: CI, confidence interval.

APPENDIX 2

Periodontal diagnosis on the subject level based on the alveolar bone levels and on evaluation of the bone quality and texture of the interdental septa with a case definition requiring at least 2 teeth fulfilling the same criteria.

	Periodontal diagnosis based on the alveolar bone level n (%)[a,b]				Periodontal diagnosis based on the interdental septa n (%)[a,b]		
		Periodontitis				Periodontitis	
Age cohorts	Healthy	Slight	Moderate	Severe	Healthy	Established	Advanced
Young	1 (2.2)	11 (24.5)	23 (51.1)	10 (22.2)	19 (42.2)	25 (55.6)	1 (2.2)
Middle-aged	0 (0)	3 (6.2)	19 (39.6)	26 (54.2)	9 (19.2)	34 (72.3)	4 (8.5)
Old	0 (0)	1 (4.8)	7 (33.3)	13 (61.9)	0 (0)	27 (100)	0 (0)
Total	1 (0.9)	15 (13.1)	49 (43.0)	49 (43.0)	28 (23.5)	92 (72.3)	5 (4.2)

Abbreviations: n, number; SD, standard deviation.

[a]Percentages represent the percentages per age cohort.

[b]Patients contributing with data of <2 teeth were excluded from this analysis; ie, diagnosis based on the alveolar bone levels and on evaluation of the bone quality and texture of the interdental septa was based on 114 and 119 subjects, respectively.