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Periodontal diseases at the transition from the late antique to the early mediaeval period in Croatia

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ABSTRACT

Objective: We tested the hypothesis that the transition from the late antique to the early mediaeval period in Croatia had a negative impact on the periodontal health.

Methods: 1118 skulls were examined for dental calculus, alveolar bone resorption, fenestrations, dehiscences and root furcation involvement.

Results: The prevalence of teeth with calculus varied from 40.7% in the LA sample of continental parts of Croatia to 50.3% in the LA sample of Adriatic Croatia. The prevalence of alveolar bone resorption ranged between 21.2% in the EM sample from continental Croatia and 32.3% in the LA sample from Adriatic Croatia. The prevalence of individuals with alveolar bone dehiscences varied from 8.6% in the LA sample from continental Croatia up to 15.0% in the EM sample from Adriatic Croatia. The prevalence of individuals with alveolar bone fenestrations varied from 21.5% in the LA sample from Adriatic Croatia up to 36.2% in the LA sample from continental Croatia. The prevalence of individuals with exposed root bifurcations or trifurcations varied from 9.0% in the EM sample from Adriatic Croatia up to 20.7% in the EM sample from continental Croatia. Statistically significant differences were found between samples.

Conclusion: The transition from the late antique to the early mediaeval period in Croatia did not have a negative impact on periodontal health. Studies of periodontal health of ancient populations should be performed to provide a better and more reliable reconstruction of living conditions in the past.

1. Introduction

Periodontal diseases are a group of acute or chronic inflammatory conditions that affect the tissues that support and anchor the teeth in the jaws. They are caused by specific microbial organisms, many of which derive their nutrient requirements from the host. They are characterised by infiltration of leukocytes, particularly the polymorphonuclear neutrophils, loss of connective tissue, alveolar bone resorption, and formation of periodontal pockets.[1] Periodontal diseases, in their various forms, have affected humans since the dawn of human existence. The results of some paleopathology studies have shown that destructive periodontal

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disease as evidenced by bone loss affected early humans.[2] Periodontal diseases are related to systemic health in many important ways in both directions: systemic diseases having periodontal manifestations and periodontal diseases contributing to the development or causing systemic diseases. It is widely known that certain systemic diseases and conditions, such as osteoporosis, diabetes, immune disorders, malnutrition, syndromes and pregnancy, can increase the risk for periodontal disease.[3] On the other hand, there is more and more evidence of the influence of chronic oral diseases, including periodontal diseases, on systemic health.[4]

Taking this into account, an examination of periodontal diseases could be an excellent indirect source of data on general and oral health, dietary habits and oral-hygiene of ancient populations. In order to highlight the importance of the periodontal research in archaeological samples and to emphasize the importance of standardised methodology for scoring periodontal disease, we provide a brief overview of few studies performed on skeletal material. Keenleyside analysed health and disease in arctic peoples prior to contact. For the purpose of the analysis, the prevalence of periodontal disease in five pre-contact skeletal samples ($N = 193$), representing four Eskimo populations from northern coastal Alaska and one Aleut population from the eastern Aleutian Islands was recorded.[5] Dento-alveolar pathologies including dental wear, caries, abscesses, ante mortem tooth loss, calculus, hypoplastic defects, chipping and skeletal markers of health (cribra orbitalia and periostitis) were analysed in two skeletal samples from the necropolises of Quadrella (I–IV c. AD) and Vicenne-Campochiaro (VII c. AD) in the Molise region of central Italy by Belcastro et al.[6] The purpose of this paper was to document and interpret dental and osseous markers of health in this two skeletal series. In order to determine the prevalence of oral pathologic findings in prehistoric skeletal remains of the Pica-Tarapaca cultural complex from the Atacama desert in northern Chile, Meller et al. examined ante- and postmortem tooth loss, prevalence and location of caries, apical periodontitis sequela, alveolar bone resorption and attrition on the remains of 57 individuals.[7] The investigation of Wasterlain et al. is one of the few bioarchaeological studies focused primary on periodontal health. They examined the periodontal status in 600 adult dentitions from Coimbra, Portugal from the late nineteenth and early twentieth century.[8] Greene et al. examined 145 Egyptian Predynastic individuals from the site of Hierakonpolis, 104 Predynastic individuals from Naqada, Egypt, and 101 Meroitic Nubians from Semna South, present-day Sudan and suggested a new quantitative approach to the assessment of dental calculus in human archaeological skeletal samples for the purpose of diet and dental health analysis.[9] In order to make a paleodietary reconstruction, Polo-Cerda et al. examined 6 adults and 3 children from the Bronze Age burials from Cova Dels Blaus in Spain. A thorough examination of dental pathology included dental calculus, caries, periodontal disease, enamel hypoplasia, ante-mortem tooth loss and abscesses.[10] For the purpose of diet analysis, Listi examined 288 adult dentitions from eight sites that range in date from 800 B.C. to A.D. 1200 from southern lower Mississippi valley in USA.[11] Whittaker et al. investigated calculus deposits and bone loss on the teeth of Romano-British and eighteenth-century Londoners. They studied calculus deposition in two skeletal populations with known differences in attrition rates and caries prevalence suggesting differences in dietary habits.[12] Sakashita et al. studied the dental diseases in the Chinese Yin-Shang Period with respect to relationships between citizens and slaves. They examined seventy-one skull from the Yin-Shang period tombs of Anyang, China, for the incidence of observable dental diseases, including dental caries, alveolar bone resorption, ante-mortem tooth loss and tooth attrition.[13] This study is an example of how investigation of periodontal diseases can be used for the purpose of reconstruction of social relationships in the past. Although there are numerous studies on the periodontal health of ancient populations, their methodologies are inconsistent.

There were only few studies published on the periodontal health of ancient populations living in the territory of present-day Croatia and the region of former Yugoslavia. Mucić performed an analysis of condition of the periodontium which concerned the skeletal material of Yugoslavia dated from the first century A.D. to the beginning of the 20th century. She examined 534 skulls for alveolar bone resorption, condition of the interdental septum, and existence of fenestrations and dehiscences on the alveolar bone.[14] Topić et al. examined the supraalveolar pockets on human skulls of the Roman and Middle Ages from former Yugoslavia.[15] Djurić Srejić examined the pattern of dental disease in two late mediaeval populations from cemeteries excavated at archaeological sites in western Serbia. Her research was based on the study of tooth wear, ante-mortem tooth loss, caries, dental enamel hypoplasia, alveolar resorption, abscesses and calculus.[16] Malčić et al. examined the caries prevalence and periodontal health in 18th century adult population of Požega in Croatia.[17]

The transition from the late antique (3rd–5th centuries) to the early middle ages (6th–10th centuries AD) represents an important period in Croatian history. This was the period of arrival of Slavs (including Croats) and Avars to the territory of present-day Croatia. In the late antique the territory of present-day Croatia was inhabited by the Roman population. The Romans built large urban centres in the Roman provinces of Pannonia (Sirmium – modern Srijemska Mitrovica; Mursa – modern Osijek; Cibalae – modern Vinkovci) and Dalmatia (Salona – modern Solin and Narona – modern Vid). They were a civilization with all of its achievements: its arts, technology, sciences, religions, and politics. Besides, they had a rich cultural heritage. By the arrival of Slavs and Avars during the second half of the 6th century and the beginning of the 7th century numerous urban centres were destroyed or abandoned and local residents were expelled.[18] Slavs and Avars brought with them their culture which was completely different, that is less developed, from the Roman one. For this reason, the period was characterised by profound cultural, social, economic, and political changes and was also considered to be catastrophic. Recent bioarchaeological studies also support the historical evidence of complex transition from antiquity to the middle ages. Two most important studies were performed by Šlaus et al. and the hypothesis that the transition from the late antique to the early mediaeval period was catastrophic with destruction of major urban centres, depopulation, famine, and the spread of epidemic diseases, was confirmed by osteological and dental markers of health analysed in 981 skeletons.[19,20]

Compared with some other oral features, such as dental caries, the studies of periodontal diseases for the purpose of reconstruction of life of ancient populations are sporadic, quite rare and methodologically limited. Lack of standardised and internationally accepted protocols in examination of periodontal diseases of ancient populations makes the results of many studies incomparable. Belcastro et al. suggested a data collection form to record dento-alveolar features including calculus and alveolar bone loss.[21] Although their attempt was praiseworthy, the analysis of calculus and alveolar bone loss cannot be considered sufficient. In order to obtain more valid results, a thorough analysis of other features that made up the periodontal health of ancient people should have also been included. For a comprehensive analysis, inclusion of more periodontal parameters is recommended.

The aim of this paper is to highlight some problems that can arise when analysing the periodontium of ancient people and also to give some practical recommendations for periodontal research of ancient skeletal remains. These recommendations could be a basis for internationally accepted protocols in examination of periodontal diseases of ancient populations, which can contribute to the comparability of different studies. In order to apply these protocols and recommendations in practise, we analysed the periodontal diseases at the transition from the late antique to the early mediaeval period in Croatia. Our aim was to detect the prevalence of dental calculus, alveolar bone resorption, alveolar bone fenestrations, alveolar bone dehiscences and root furcation involvement in the examined samples. The specific hypotheses we tested were that the transition from the late antique to the early mediaeval period in Croatia had a negative impact on the periodontal health.

2. Materials and methods

The sample evaluated for this analysis is a part of the osteological collection of the Croatian Academy of Sciences and Arts and it is curated in Zagreb at the Department of Archaeology of Croatian Academy of Sciences and Arts. The osteological material analysed in this study was divided into two composite series – a late antique (LA) and an early mediaeval (EM) skeletal series. The late antique series consists of 457 skeletons from 5 urban sites located in the eastern part of continental Croatia and at the eastern Adriatic coast. The early mediaeval series consists of 661 skeletons from 6 sites also located in the eastern part of continental Croatia and along the eastern Adriatic coast. The geographical locations of the analysed sites are shown in Fig. 1, the number of skeletons and sex distribution in each site in Table 1, the number of skeletons and age distribution in each site in Table 2. The sex and age of each individual was determined by using standard anthropological criteria. Sex determination was based on cranial and pelvic morphology.[18] If these elements were missing or poorly preserved, the discriminant functions for the femur and tibia developed for antique and mediaeval Croatian populations were used.[22] Age was estimated by using pubic symphysis morphology, auricular surface morphology, ectocranial suture closure and sternal rib end changes.[18] In order to avoid misinterpretation of the results caused by the preservation status of the remains, only individuals with at least 8 teeth and tooth sockets in each jaw were included in the analysis of periodontal diseases (for subadults the number of teeth was reduced to 5). For each individual, a periodontal status assessment was made using the following five parameters: calculus, alveolar bone resorption, alveolar bone fenestrations, alveolar bone dehiscences and root furcation involvement. Only fully erupted teeth without excessive tooth wear and excessive caries (caries on more than a half tooth crown) and without complex tooth crown fracture were scored for periodontal parameters.

All deposits at teeth were considered potential deposits of dental calculus. By a careful examination of the deposits, they were classified as true dental calculus deposits or postmortem

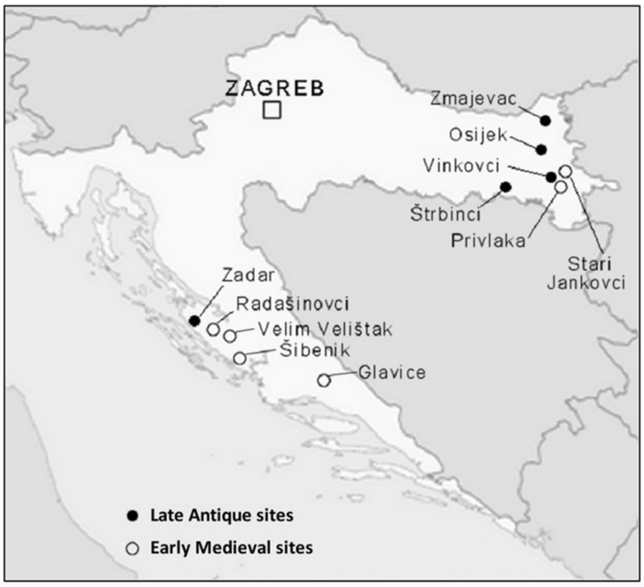

Fig. 1 – Geographical locations of the analysed sites.

Table 1 – Total number of skeletons analysed by site and sex.

Site	Century (period)	Male	Female	Subadult (<15 years)	Total
Continental Croatia					
Zmajevac	4 (LA)	58	61	44	163
Štrbinci	4 (LA)	43	38	24	105
Osijek	3–4 (LA)	34	28	10	72
Vinkovci	4 (LA)	8	9	8	25
Privlaka	8–9 (EM)	76	74	60	210
Stari Jankovci	7–8 (EM)	23	24	9	56
Adriatic Croatia					
Zadar	1–5 (LA)	39	30	23	92
Velim Velištak	7–9 (EM)	55	50	32	137
Glavice	8–11 (EM)	24	12	20	56
Radašinovci	9 (EM)	38	33	42	113
Šibenik	9 (EM)	23	33	33	89
	Total	421	392	305	1118

LA – late antique; EM – early mediaeval.

Table 2 – Total number of skeletons analysed by age.

Age (years)	Late antique – continental Croatia												Late antique – Adriatic Croatia			Total
	Zmajevac			Osijek			Štrbinci			Vinkovci			Zadar			
	M	F	S	M	F	S	M	F	S	M	F	S	M	F	S	
0.0–0.9			5			1			1			1			2	10
1.0–3.9			14			3			6			0			7	30
4.0–9.9			16			2			10			2			6	36
10.0–14.9			9			4			7			5			8	33
15–29	10	16		7	11		7	5		4	3		6	8		77
30–44	29	26		22	10		24	28		2	3		20	13		177
45+	19	19		5	7		12	5		2	3		13	9		94
Total	58	61	44	34	28	10	43	38	24	8	9	8	39	30	23	457

Age (years)	Early mediaeval – continental Croatia						Early mediaeval – Adriatic Croatia												
	Privlaka			Stari Jankovci			Radašinovci			Velim velištak			Šibenik			Glavice			Total
	M	F	S	M	F	S	M	F	S	M	F	S	M	F	S	M	F	S	
0.0–0.9			1			0			2			1			4			0	8
1.0–3.9			20			4			15			14			14			11	78
4.0–9.9			25			4			16			11			8			4	68
10.0–14.9			14			1			9			6			7			5	42
15–29	25	36		3	6		10	12		4	5		3	5		6	4		119
30–44	40	29		16	9		15	13		36	31		7	11		12	5		224
45+	11	9		4	9		13	8		15	14		13	17		6	3		122
Total	76	74	60	23	24	9	38	33	42	55	50	32	23	33	33	24	12	20	661

M – number of males; F – number of females; S – number of subadults.

deposits. The distinction between them was based on the usual position of dental calculus deposits, on the colour of the deposits and on the morphology of the surface of the deposits. The amount of calculus was scored on a widely used six-grade scale suggested by Knussmann[23] as follows:

1. Absent
2. Band of calculus (<2 mm) at the cervical portion of the tooth at the buccal or oral surface
3. Band of calculus (2–3 mm) at the cervical portion of the tooth at the buccal and oral surface
4. Calculus covers up to 2/3 of the tooth crown
5. Calculus covers more than 2/3 of the tooth crown
6. Calculus covers the whole tooth crown and the exposed cervical part of tooth root(s).

The prevalence of dental calculus was expressed by a tooth and calculated by using the following formula: total number of teeth with calculus deposits/total number of examined teeth.

By careful examination of the alveolar bone with magnifying glasses, the changes at the alveolar bone were classified as alveolar bone resorption or postmortem damages of alveolar bone which looked like resorption. Only finely pitted lesions on the bone surface were considered alveolar bone loss due to periodontal disease. To obtain reliable data on the condition and resorption of the alveolar bone, the alveolar bone was a subject of a non-metric and metric assessment. The resorption of alveolar bone was scored by using a five-grade scale[23] as follows:

1. Mild resorption (less than 1/3 of the tooth root is exposed)
2. Mean resorption (more than 1/3 of the tooth root is exposed)
3. Strong resorption (more than 1/2 of the tooth root is exposed)
4. Extreme resorption (more than 2/3 of the tooth root is exposed)
5. Total resorption (the whole root is exposed and tooth will soon fall out).

Metric assessment implied the measurement of the alveolar bone resorption at the buccal side of the tooth. By using the digital sliding calliper, the perpendicular distance between enamel–cementum junction and alveolar bone was measured on each tooth.[24] The prevalence of alveolar bone resorption was expressed by tooth and calculated by using the following formula: total number of teeth affected by alveolar bone resorption/total number of examined teeth.

The defects of the alveolar bone located at the cortical plate over the tooth root extending from the former gingival margin apically were considered potential alveolar bone dehiscences.[24] By careful examination with magnifying glasses, these defects were classified as true alveolar bone dehiscences or postmortem damages of the alveolar bone. The distinction was based on the morphology of the border of the defect and on the condition of the surrounding alveolar bone according to antemortem changes caused by inflammation of periodontal tissues. If it was confirmed that the defect was a dehiscence of the alveolar bone, the depth of the defect (distance between the cementoenamel junction and the bottom of the defect) was measured by a digital sliding calliper. The prevalence of alveolar bone dehiscences was expressed per individual and calculated by using the following formula: total number of individuals with dehiscences/total number of examined individuals.

Openings, located at the cortical plate over the tooth root, which do not communicate with the crestal margin of the alveolar bone were considered potential alveolar bone fenestrations. By careful examination with magnifying glasses, these openings were classified as true alveolar bone fenestrations or postmortem damages of the alveolar bone. The distinction was based on the position of the opening and on the morphology of the border of the opening. In case of appearance of an alveolar bone fenestration, shape (round, elliptical or square) and dimensions (height and width) were recorded. By using the height and width, the size of the affected area was calculated.[24] The prevalence of alveolar bone fenestrations was expressed per individual and calculated by using the following formula: total number of individuals with fenestrations/total number of examined individuals.

In cases of extreme alveolar bone resorption, where the root bi- or trifurcation was exposed, the distance between the roof of furcation and the alveolar bone was measured by a digital sliding calliper.[24] The prevalence of furcation involvement was expressed per individual and calculated using the following formula: total number of individuals with furcation involvement/total number of examined individuals.

Data for this study were collected by first two authors (Marin Vodanović and KP). In order to test the intra- and inter-examiner reliability, identical measurements were repeated on a random sample (10% of the total sample) after 3 weeks.

Differences in the frequencies of examined periodontal features between the samples were tested by Student's *t*-test and χ^2 test employing Yates correction when appropriate. *p*-Values <0.05 were considered statistically significant. All statistical analyses were performed using the SPSS statistical package version 10.0 (SPSS Inc.).

3. Results

Although the whole analysed sample consists of 1118 skeletons (457 from LA and 661 from EM period), respecting the condition that only individuals with at least 8 teeth and tooth sockets in each jaw can be included in the analysis of periodontal diseases, the final number of available skeletons was significantly reduced. Only 273 adult skeletons (151 from the LA sample and 122 from the EM sample) were suitable for periodontal analysis and this is only 24.4% of the whole sample. The majority of the subadult sample (subjects younger than 15 years) did not fit the condition of at least 5 teeth and tooth sockets in each jaw and were excluded from further investigation. Less than 5% of the subadult sample met the recommended conditions, but there were no traces of dental calculus, alveolar bone resorption, dehiscences, fenestrations or furcation exposure and they were excluded from further statistical analysis.

3.1. *Dental calculus*

Dental calculus was analysed on total of 273 individuals (151 from the LA sample and 122 from the EM sample) with 5542 teeth (3013 from the LA sample and 2529 from the EM sample). The prevalence of teeth with calculus varied from 40.7% in the LA sample of continental Croatia to 50.3% in the LA sample of Adriatic Croatia, Table 3. χ^2 test showed that in the LA males from the Adriatic Croatia (53.1%) had statistically significant more calculus than males from continental Croatia (46.7%), $\chi^2 = 6.44$, $p < 0.05$. The same results were obtained for females (Adriatic Croatia 46.6% and continental Croatia 33.0%), $\chi^2 = 24.25$, $p < 0.01$. The same trend exists in EM, but the difference is statistically significant only in the female sample, $\chi^2 = 10.95$, $p < 0.01$. The prevalence of dental calculus in the EM females from the Adriatic Croatia was 42.9% and 30.9% in the EM females from the continental Croatia. Furthermore, in continental Croatia, LA females had statistically significant more calculus (33.0%) than EM females (30.9%), $\chi^2 = 0.27$, $p < 0.01$. There were no age-related statistically significant differences between the samples. In all samples males had significantly higher prevalence of dental calculus than females (LA-C-M vs. LA-C-F, $\chi^2 = 24.73$, $p < 0.01$; LA-A-M vs. LA-A-F, $\chi^2 = 6.73$, $p < 0.01$; EM-C-M vs. EM-C-F, $\chi^2 = 21.54$, $p < 0.01$; EM-A-M vs. EM-A-F, $\chi^2 = 22.54$, $p < 0.01$).

Table 3 – Prevalence of dental calculus.

Sample	N individuals	N teeth	N teeth with calculus	Prevalence (%)
LA-C-M	32	736	344	46.7
LA-C-F	26	584	193	33.0
Total LA-C	58	1320	537	40.7
LA-A-M	53	957	508	53.1
LA-A-F	40	736	343	46.6
Total LA-A	93	1693	851	50.3
EM-C-M	12	234	122	52.1
EM-C-F	10	249	77	30.9
Total EM-C	22	483	199	41.2
EM-A-M	57	1185	635	53.6
EM-A-F	43	861	369	42.9
Total EM-A	100	2046	1004	49.1

LA – late antique; EM – early mediaeval; C – continental Croatia; A – Adriatic Croatia; M – males; F – females; N – number of.

The distribution of teeth according to the dental calculus score is presented in Table 4. In the group of teeth with calculus deposits, the majority of them had only a band of calculus (<2 mm) at the cervical portion of the tooth at the buccal or oral surface (score 1) and their frequency varied from 27.9% (LA sample Adriatic Croatia) to 32.5% (LA sample continental Croatia and EM sample Adriatic Croatia). Calculus deposits covering the entire tooth crown and the exposed cervical part of tooth root were found in only one case in the EM sample from Adriatic Croatia (0.1%).

As shown in Table 5, in the upper jaw, calculus deposits were most often located at the buccal side of the first molar, with frequency varying from 14.6% (EM sample of continental Croatia) to 21.1% (LA sample of Adriatic Croatia). In the lower jaw, calculus deposits were most often located at the lingual side of second incisor. Their frequency varied from 12.5% (LA

Table 4 – Distribution of teeth according to the dental calculus score.

Sample	Dental calculus score												
	0	%	1	%	2	%	3	%	4	%	5	%	Total
LA-C-M	392	53.3	262	35.6	51	6.9	27	3.7	4	0.5	0	0.0	736
LA-C-F	391	67.0	167	28.6	26	4.5	0	0.0	0	0.0	0	0.0	584
Total LA-C	783	59.3	429	32.5	77	5.8	27	2.0	4	0.3	0	0.0	1320
LA-A-M	449	46.9	270	28.2	219	22.9	15	1.6	4	0.4	0	0.0	957
LA-A-F	393	53.4	203	27.6	121	16.4	18	2.4	1	0.1	0	0.0	736
Total LA-A	842	49.7	473	27.9	340	20.1	33	1.9	5	0.3	0	0.0	1693
EM-C-M	112	47.9	99	42.3	20	8.5	3	1.3	0	0.0	0	0.0	234
EM-C-F	172	69.1	54	21.7	12	4.8	11	4.4	0	0.0	0	0.0	249
Total EM-C	284	58.8	153	31.7	32	6.6	14	2.9	0	0.0	0	0.0	483
EM-A-M	550	46.4	402	33.9	187	15.8	34	2.9	11	0.9	1	0.1	1185
EM-A-F	492	57.1	262	30.4	79	9.2	27	3.1	1	0.1	0	0.0	861
Total EM-A	1042	50.9	664	32.5	266	13.0	61	3.0	12	0.6	1	0.0	2046
Total LA-C + LA-A + EM-C + EM-A	2951	53.2	1719	31.0	715	12.9	135	2.4	21	0.4	1	0.0	5542

LA – late antique; EM – early mediaeval; C – continental Croatia; A – Adriatic Croatia; M – males; F – females.

sample of Adriatic Croatia) to 17.9% (EM sample of continental Croatia).

3.2. *Alveolar bone resorption*

Alveolar bone resorption was analysed on total of 273 individuals (151 from the LA sample and 122 from the EM sample) with 4424 teeth (2346 from the LA sample and 2078 from the EM sample). The alveolar bone of 1118 teeth was damaged postmortem and was excluded from the further analysis. This explains the difference in the number of teeth involved in analysis of dental calculus and alveolar bone resorption.

The prevalence of alveolar bone resorption ranged between 21.2% in the EM sample from continental Croatia and 32.3% in the LA sample from Adriatic Croatia, Table 6. χ^2 test showed that males in LA period in Adriatic Croatia (32.3%) had statistically significant higher prevalence of alveolar bone resorption than males from the same period in continental Croatia (31.5%), $\chi^2 = 8.63$, $p < 0.01$. In Adriatic Croatia, LA males (38.2%) had statistically significant higher prevalence of alveolar bone resorption than EM males (30.2%), $\chi^2 = 11.44$, $p < 0.01$. In LA females statistically significant difference in prevalence of alveolar bone resorption between continental (33.0%) and Adriatic Croatia (24.2%) was found, $\chi^2 = 9.07$, $p < 0.01$. In the EM sample, females from continental Croatia had statistically significant lower prevalence of alveolar bone resorption (16.3%), than females from Adriatic Croatia (28.8%), $\chi^2 = 10.90$, $p < 0.01$. Difference between LA and EM sample in the prevalence of alveolar bone resorption was statistically significant only in the continental Croatia female sample. LA females from continental Croatia had the prevalence of alveolar bone resorption of 33.0%, and the prevalence in the EM females was 16.3%, $\chi^2 = 16.92$, $p < 0.01$. There were no age-related statistically significant differences between the samples. In the late antique sample form Adriatic Croatia, males had significantly higher prevalence of the alveolar bone resorption than females (LA-A-M vs. LA-A-F, $\chi^2 = 26.57$, $p < 0.01$). In the early mediaeval period sample form continental Croatia, males had significantly higher prevalence of alveolar bone resorption than females (EM-C-M vs. EM-C-F, $\chi^2 = 4.38$, $p < 0.05$).

Distribution of teeth according to the alveolar bone resorption score is presented in Table 7. The majority of teeth with alveolar bone resorption had mild resorption with less than 1/3 of the tooth root exposed and their frequency varied from 45.2% in the LA sample from Adriatic Croatia to 72.7% in EM sample from continental Croatia. More than 1/3 and less than 1/2 of the tooth root exposed was found in 46.4% of teeth from LA Adriatic Croatia (maximum value). Teeth where the whole root was exposed (total resorption) were not found.

The results of the metric analysis of alveolar bone resorption are presented in Tables 8 and 9. The differences between all samples were statistically significant. In the upper jaw, maximum average values of the alveolar bone resorption were recorded at the first premolar (3.4 mm LA sample from Adriatic Croatia) and the minimum average values at the first molar (0.4 mm LA sample from Adriatic Croatia). In the lower jaw, maximum average values of the alveolar bone resorption were recorded at the first incisor (3.9 mm EM sample from Adriatic Croatia) and the minimum average values at the third molar (1.0 mm EM sample from continental Croatia).

3.3. *Alveolar bone dehiscences*

The dehiscences of the alveolar bone were analysed on total of 273 individuals (151 from the LA sample and 122 from the EM sample). The prevalence of individuals with alveolar bone dehiscences varied from 8.6% in the LA sample from continental Croatia up to 15.0% in the EM sample from Adriatic Croatia. The maximum measured depth of the dehiscence was 11.7 mm and it was found in the LA sample

Table 5 – Distribution of dental calculus according to the tooth type.

Sample	I1	%	I2	%	C	%	P1	%	P2	%	M1	%	M2	%	M3	%	Total
Upper jaw																	
LA-C-M	11	10.7	11	10.7	15	14.6	12	11.7	15	14.6	20	19.4	13	12.6	6	5.8	103
LA-C-F	1	2.4	1	2.4	4	9.8	6	14.6	8	19.5	9	22.0	7	17.1	5	12.2	41
Total LA-C	12	8.3	12	8.3	19	13.2	18	12.5	23	16.0	29	20.1	20	13.9	11	7.6	144
LA-A-M	5	3.8	5	3.8	14	10.8	19	14.6	28	21.5	30	23.1	18	13.8	11	8.5	130
LA-A-F	4	4.5	7	8.0	11	12.5	13	14.8	14	15.9	16	18.2	14	15.9	9	10.2	88
Total LA-A	9	4.1	12	5.5	25	11.5	32	14.7	42	19.3	46	21.1	32	14.7	20	9.2	218
EM-C-M	3	10.7	3	10.7	4	14.3	3	10.7	3	10.7	5	17.9	5	17.9	2	7.1	28
EM-C-F	3	15.0	2	10.0	4	20.0	2	10.0	3	15.0	2	10.0	2	10.0	2	10.0	20
Total EM-C	6	12.5	5	10.4	8	16.7	5	10.4	6	12.5	7	14.6	7	14.6	4	8.3	48
EM-A-M	12	4.2	23	8.1	36	12.7	46	16.3	49	17.3	54	19.1	46	16.3	17	6.0	283
EM-A-F	8	5.2	14	9.2	20	13.1	25	16.3	24	15.7	29	19.0	24	15.7	9	5.9	153
Total EM-A	20	4.6	37	8.5	56	12.8	71	16.3	73	16.7	83	19.0	70	16.1	26	6.0	436
Lower jaw																	
LA-C-M	34	14.1	36	14.9	35	14.5	35	14.5	29	12.0	33	13.7	26	10.8	13	5.4	241
LA-C-F	25	16.4	24	15.8	16	10.5	17	11.2	20	13.2	21	13.8	19	12.5	10	6.6	152
Total LA-C	59	15.0	60	15.3	51	13.0	52	13.2	49	12.5	54	13.7	45	11.5	23	5.9	393
LA-A-M	35	9.3	42	11.1	44	11.6	60	15.9	56	14.8	54	14.3	56	14.8	31	8.2	378
LA-A-F	35	13.7	37	14.5	37	14.5	39	15.3	37	14.5	29	11.4	26	10.2	15	5.9	255
Total LA-A	70	11.1	79	12.5	81	12.8	99	15.6	93	14.7	83	13.1	82	13.0	46	7.3	633
EM-C-M	16	17.0	15	16.0	16	17.0	9	9.6	10	10.6	13	13.8	12	12.8	3	3.2	94
EM-C-F	8	14.0	12	21.1	6	10.5	5	8.8	3	5.3	10	17.5	9	15.8	4	7.0	57
Total EM-C	24	15.9	27	17.9	22	14.6	14	9.3	13	8.6	23	15.2	21	13.9	7	4.6	151
EM-A-M	48	13.6	57	16.2	57	16.2	45	12.8	43	12.2	40	11.4	33	9.4	29	8.2	352
EM-A-F	31	14.4	38	17.6	44	20.4	29	13.4	25	11.6	20	9.3	20	9.3	9	4.2	216
Total EM-A	79	13.9	95	16.7	101	17.8	74	13.0	68	12.0	60	10.6	53	9.3	38	6.7	568

LA – late antique; EM – early mediaeval; C – continental Croatia; A – Adriatic Croatia; M – males; F – females; I1 – central incisor; I2 – lateral incisor; C – canine; P1 – first premolar; P2 – second premolar; M1 – first molar; M2 – second molar; M3 – third molar.

Table 6 – Prevalence of alveolar bone resorption.

Sample	N individuals	N teeth	N teeth with ABR	%
LA-C-M	32	622	189	30.4
LA-C-F	26	476	157	33.0
Total LA-C	58	1098	346	31.5
LA-A-M	53	723	276	38.2
LA-A-F	40	525	127	24.2
Total LA-A	93	1248	403	32.3
EM-C-M	12	186	48	25.8
EM-C-F	10	178	29	16.3
Total EM-C	22	364	77	21.2
EM-A-M	57	992	300	30.2
EM-A-F	43	722	208	28.8
Total EM-A	100	1714	508	29.6

LA – late antique; EM – early mediaeval; C – continental Croatia; A – Adriatic Croatia; M – males; F – females; N – number of; ABR – alveolar bone resorption.

from continental Croatia. The minimum value was 9.3 mm and it was measured in the EM sample from Adriatic Croatia. There were no statistically significant differences in the prevalence of the alveolar bone dehiscences between the samples, Table 10. In both jaws alveolar bone dehiscences were mostly recorded around the roots of the first molars. Dehiscences around the roots of incisors and third molars were the rarest. There was no statistically significant difference in prevalence of the alveolar bone dehiscences between males and females.

3.4. *Alveolar bone fenestrations*

Fenestrations of the alveolar bone were analysed on total of 273 individuals (151 from the LA sample and 122 from the EM sample). The prevalence of individuals with alveolar bone fenestrations varied from 21.5% in the LA sample from Adriatic Croatia up to 36.2% in the LA sample from continental Croatia, Table 11. Statistically significant difference in the prevalence of alveolar bone fenestrations was found only in the male sample from Adriatic Croatia, where EM males had

Table 7 – Distribution of teeth according to the alveolar bone resorption score.

Sample	Alveolar bone resorption score										Total
	1	%	2	%	3	%	4	%	5	%	
LA-C-M	114	60.3	68	36.0	7	3.7	0	0.0	0	0.0	189
LA-C-F	104	66.2	52	33.1	1	0.6	0	0.0	0	0.0	157
Total LA-C	218	63.0	120	34.7	8	2.3	0	0.0	0	0.0	346
LA-A-M	126	45.7	132	47.8	17	6.2	1	0.4	0	0.0	276
LA-A-F	56	44.1	55	43.3	14	11.0	2	1.6	0	0.0	127
Total LA-A	182	45.2	187	46.4	31	7.7	3	0.7	0	0.0	403
EM-C-M	32	66.7	16	33.3	0	0.0	0	0.0	0	0.0	48
EM-C-F	24	82.8	4	13.8	1	3.4	0	0.0	0	0.0	29
Total EM-C	56	72.7	20	26.0	1	1.3	0	0.0	0	0.0	77
EM-A-M	154	51.3	110	36.7	26	8.7	10	3.3	0	0.0	300
EM-A-F	94	45.2	74	35.6	29	13.9	11	5.3	0	0.0	208
Total EM-A	248	48.8	184	36.2	55	10.8	21	4.1	0	0.0	508

LA – late antique; EM – early mediaeval; C – continental Croatia; A – Adriatic Croatia; M – males; F – females.

higher prevalence (36.0%) of the alveolar bone fenestrations than LA males (20.8%), $\chi^2 = 4.81$, $p < 0.05$. The shape and dimensions of the fenestrations are shown in Table 12. In the upper jaw, the majority of fenestrations were found at the roots of first molar. The alveolar bone of the second premolars was the least affected with fenestrations. In the lower jaw, fenestrations were most frequently found at the roots of canines. In the lower jaw, the smallest number of fenestrations was found at first and second molar. There was no statistically significant difference in prevalence of the alveolar bone fenestrations between males and females.

3.5. *Exposure of root bi- and trifurcations*

The exposures of root bi- and trifurcations were analysed on total of 273 individuals (151 from the LA sample and 122 from the EM sample). The prevalence of individuals with exposed root bi- or trifurcations varied from 9.0% in the EM sample from Adriatic Croatia up to 20.7% in the EM sample from continental Croatia, Table 13. There were no statistically significant differences between the samples. The highest vertical dimension of the exposed furcation was 3.6 mm and it was recorded on an individual from the EM sample from continental Croatia. Furcation of roots of upper and lower first molars were most frequently exposed, Table 14. There was no statistically significant difference in prevalence of exposed root bi- or trifurcations between males and females.

On a repeated random sample, performed after 3 weeks, identical findings were observed, so kappa value was 1, confirming intra- and inter-examiner reliability.

4. Discussion

As previously mentioned, examination of periodontal diseases could be an excellent indirect source of data on general and oral health, dietary habits and oral-hygiene of ancient populations. Understanding periodontal diseases, their aetiology and pathophysiology is the basis for correct interpretation of the data obtained by examination of skeletal remains. Unfortunately, the level of knowledge on periodontal diseases between bioarchaeologists, anthropologists and other non-dental experts involved in examination of ancient periodontal tissues is often limited; it is focused on the objectives of the

Table 8 – Results of the metric analysis of alveolar bone resorption.

Group 1	Group 2	Group 1			Group 2			
		N	Mean (mm)	SD	N	Mean (mm)	SD	
LA-C-M	LA-A-M	624	2.4	1.3	493	3.2	1.4	$p < 0.01$
EM-C-M	EM-A-M	194	2.7	1.5	516	3.0	1.8	$p < 0.01$
LA-C-M	EM-C-M	624	2.4	1.3	194	2.7	1.5	$p < 0.01$
LA-A-M	EM-A-M	493	3.2	1.4	516	3.0	1.8	$p < 0.01$
LA-C-F	LA-A-F	503	2.4	1.2	222	3.3	1.7	$p < 0.01$
EM-C-F	EM-A-F	182	2.0	1.4	352	2.9	1.9	$p < 0.01$
LA-C-F	EM-C-F	503	2.4	1.2	182	2.0	1.4	$p < 0.01$
LA-A-F	EM-A-F	222	3.3	1.7	352	2.9	1.9	$p < 0.01$

LA – late antique; EM – early mediaeval; C – continental Croatia; A – Adriatic Croatia; M – males; F – females; N – number of teeth; SD – standard deviation.

Table 9 – Alveolar bone resorption according to the tooth type.

Sample	I1	I2	C	P1	P2	M1	M2	M3
Upper jaw – average alveolar bone resorption (mm)								
LA-C-M	2.4	2.1	2.4	2.7	2.2	1.2	2.7	2.2
LA-C-F	2.5	2.5	2.4	2.7	2.1	2.6	2.5	1.8
Total LA-C	2.5	2.3	2.4	2.7	2.2	1.9	2.6	2.0
LA-A-M	3.0	3.4	2.8	3.5	2.7	0.7	3.2	2.8
LA-A-F	3.5	3.9	3.8	3.3	2.6	0.0	2.6	2.9
Total LA-A	3.3	3.7	3.3	3.4	2.7	0.4	2.9	2.9
EM-C-M	1.4	2.5	2.3	2.5	2.3	1.1	2.7	2.4
EM-C-F	0.7	2.4	1.7	2.2	1.7	0.0	1.8	1.7
Total EM-C	1.1	2.5	2.0	2.4	2.0	0.6	2.3	2.1
EM-A-M	3.4	3.0	2.5	3.2	2.2	0.0	3.2	3.1
EM-A-F	3.0	2.7	2.8	2.9	2.0	2.1	2.4	2.2
Total EM-A	3.2	2.9	2.7	3.1	2.1	1.1	2.8	2.7
Lower jaw – average alveolar bone resorption (mm)								
LA-C-M	2.9	2.2	2.6	2.6	3.0	2.3	2.7	2.2
LA-C-F	3.0	2.7	2.6	2.6	3.0	2.1	2.5	1.9
Total LA-C	3.0	2.5	2.6	2.6	3.0	2.2	2.6	2.1
LA-A-M	3.1	2.7	3.0	3.0	3.6	3.1	3.8	3.3
LA-A-F	3.8	3.3	3.4	3.4	4.0	2.9	4.2	3.4
Total LA-A	3.5	3.0	3.2	3.2	3.8	3.0	4.0	3.4
EM-C-M	2.9	3.0	3.1	3.1	3.1	2.6	3.6	2.9
EM-C-F	2.6	2.5	2.4	2.4	2.4	2.8	2.3	1.7
Total EM-C	2.8	2.8	2.8	2.8	2.8	2.7	3.0	2.3
EM-A-M	3.7	2.6	2.7	2.7	3.6	3.0	3.3	3.2
EM-A-F	4.0	3.1	3.4	3.4	3.5	2.4	3.7	3.6
Total EM-A	3.9	2.9	3.1	3.1	3.6	2.7	3.5	3.4

LA – late antique; EM – early mediaeval; C – continental Croatia; A – Adriatic Croatia; M – males; F – females; I1 – central incisor; I2 – lateral incisor; C – canine; P1 – first premolar; P2 – second premolar; M1 – first molar; M2 – second molar; M3 – third molar.

Table 10 – Prevalence and dimensions of the alveolar bone dehiscences.

Sample	N total	N with dehiscences	%	Average depth (mm)
LA-C-M	32	2	6.3	14.6
LA-C-F	26	3	11.5	8.7
Total LA-C	58	5	8.6	11.7
LA-A-M	53	8	15.1	10.2
LA-A-F	40	3	7.5	12.5
Total LA-A	93	11	11.8	11.4
EM-C-M	12	1	8.3	7.6
EM-C-F	10	2	20	13.3
Total EM-C	22	3	13.6	10.5
EM-A-M	57	11	19.3	10.7
EM-A-F	43	4	9.3	7.8
Total EM-A	100	15	15.0	9.3

LA – late antique; EM – early mediaeval; C – continental Croatia; A – Adriatic Croatia; M – males; F – females; N – number of individuals.

research. Very often, only a good collaboration between doctors of dental medicine and experts in periodontology leads to the correct interpretation and understanding of the broader context in which periodontal diseases appear.

Periodontal disease is defined as a group of disorders that affect the tissues that surround and support the tooth and its alveolus. Periodontal disease occurs as a pathological response of periodontal tissues to the external – local irritation. Etiological factors of periodontal disease can be divided into local (exogenous), systemic (endogenous, general), and genetic. Local etiological factors or factors of the oral environment which lead to the development of periodontal disease are most commonly deposits on the teeth and the factors that favour their formation on teeth. Deposits on the teeth are: pellicle, plaque, materia alba, debris, and dental calculus. The group of factors that favour the formation of plaque on teeth are caries, food impaction, tooth loss, bad habits (pushing the tongue between teeth, bruxism, mouth breathing, etc.) and anatomical characteristics (malocclusions, anatomical and orthodontic anomalies).[2,25,26] The most important general factors affecting the development of periodontal disease are: hormonal disorders (diabetes, pregnancy), blood diseases (anaemia, thrombocytopenia, leukaemia, etc.), tuberculosis and malnutrition (deficiency of vitamins A, B and C, calcium,

Table 11 – Prevalence of the alveolar bone fenestrations.

Sample	N total	N with fenestrations	%
LA-C-M	32	10	31.3
LA-C-F	26	11	42.3
Total LA-C	58	21	36.2
LA-A-M	53	11	20.8
LA-A-F	40	9	22.5
Total LA-A	93	20	21.5
EM-C-M	12	2	16.7
EM-C-F	10	4	40.0
Total EM-C	22	6	27.3
EM-A-M	57	24	42.1
EM-A-F	43	12	27.9
Total EM-A	100	36	36.0

LA – late antique; EM – early mediaeval; C – continental Croatia; A – Adriatic Croatia; M – males; F – females; N – number of individuals.

carbohydrates, proteins).[1,3,4,27–31] Group of the genetic etiological factors for the development of periodontal disease includes: hypophosphatasia, cyclic neutropenia, Hurler syndrome etc.[2]

Dental calculus is mineralised bacterial plaque that accumulates on the teeth. It is well-known that the greatest amount of calculus is present on the lingual surfaces of mandibular anterior teeth and it decreases towards the third molars. In the maxilla, calculus frequently forms on the buccal surfaces of the first molars. In both the mandible and maxilla, these are the sites that are close to the orifices of salivary ducts.[32] Because of masticatory movements and frequent contacts between teeth of upper and lower jaws, dental calculus cannot be found on the occlusal or incisal surfaces, except in cases when some teeth are in cases of malocclusion. Dental calculus is divided into supragingival and subgingival. On skeletal remains where the soft periodontal tissues are absent, both types of dental calculus can be visible. During the lifetime, dental calculus irritates the gingiva and causes gingival inflammation (gingivitis) and later it can lead to development of periodontal disease. Mild gingivitis does not cause any changes on the alveolar bone. Severe and long lasting gingivitis is a beginning of a severe periodontal disease which can lead to resorption of the alveolar bone. In the initial stages of periodontal disease, microscopic porosities and mild periostis appear on the alveolar bone. They cannot be easily recognised on skeletal remains. Local or generalised alveolar bone loss occurs later in advanced stages of periodontal disease. It is difficult to make distinctions between pathological degenerative changes of the alveolar bone and normal atrophic changes resulting from ageing of the organism. Sarajlić et al. measured the alveolar bone loss and correlated it with age. Their study showed that the alveolar bone loss increased in older age groups, showing a regular time dependent pattern.[33]

Therefore, not only the alveolar bone resorption and dental calculus should be included in the assessment of periodontal health but also the registration of alveolar bone dehiscences, furcations and furcation involvement.[34] The comparison of the frequency and intensity of periodontal disease in different studies is difficult because they apply different diagnostic criteria and assessment methods. Therefore, in order to obtain a better comparison of results, some previously used and tested ways of assessments of periodontal tissues are needed. The determination of periodontal status and registration of pathological changes in periodontal tissues of skeletal remains is not as common procedure in bioarchaeological researches as the evidence of pathological changes in hard dental tissues, for example, dental caries. This happens because dental caries, as the most common pathological change, remains on hard dental tissues after death and permanent marks on bones caused by periodontal diseases are visible only in advanced stages of the disease. Initial stages

Table 12 – Shape and dimensions of the alveolar bone fenestrations.

Sample	N total	N elliptical	%	N square	%	Average height (mm)	Average width (mm)	Average area (mm^2)
LA-C-M	22	13	59.1	9	40.9	5.2	2.0	12.0
LA-C-F	26	11	42.3	15	57.7	3.8	1.9	7.8
Total LA-C	48	24	50.0	24	50.0	4.5	2.0	9.9
LA-A-M	22	10	45.5	12	54.5	4.9	2.0	9.8
LA-A-F	17	7	41.2	10	58.8	4.1	2.2	9.1
Total LA-A	39	17	43.6	22	56.4	4.5	2.1	9.5
EM-C-M	3	2	66.7	1	33.3	5.9	2.0	12.3
EM-C-F	6	4	66.7	2	33.3	4.4	2.0	10.0
Total EM-C	9	6	66.7	3	33.3	5.2	2.0	11.2
EM-A-M	63	30	47.6	33	52.4	4.9	2.2	10.9
EM-A-F	21	8	38.1	13	61.9	6.2	2.5	15.8
Total EM-A	84	38	45.2	46	54.8	5.6	2.4	13.4

LA – late antique; EM – early mediaeval; C – continental Croatia; A – Adriatic Croatia; M – males; F – females; N – number of fenestrations.

Table 13 – Prevalence of exposure of root bi- and trifurcations and their dimension.

Sample	N total	N with furcation exposure	%	Average vertical dimension (mm)
LA-C-M	32	7	21.9	2.8
LA-C-F	26	5	19.2	2.2
Total LA-C	58	12	20.7	2.5
LA-A-M	53	11	20.8	2.7
LA-A-F	40	6	15.0	2.9
Total LA-A	93	17	18.3	2.8
EM-C-M	12	2	16.7	4.3
EM-C-F	10	1	10.0	2.9
Total EM-C	22	3	13.6	3.6
EM-A-M	57	5	8.8	3.2
EM-A-F	43	4	9.3	3.2
Total EM-A	100	9	9.0	3.2

LA – late antique; EM – early mediaeval; C – continental Croatia; A – Adriatic Croatia; M – males; F – females; N – number of individuals.

Table 14 – Distribution of exposure of root bi- or trifurcations according to the tooth type.

Sample	M1	%	M2	%	M3	%	Ukupno
Upper jaw							
LA-C-M	0	0.0	0	0.0	0	0.0	0
LA-C-F	2	50.0	2	50.0	0	0.0	4
Total LA-C	2	50.0	2	50.0	0	0.0	4
LA-A-M	6	85.7	1	14.3	0	0.0	7
LA-A-F	1	25.0	1	25.0	2	50.0	4
Total LA-A	7	63.6	2	18.2	2	18.2	11
EM-C-M	0	0.0	0	0.0	0	0.0	0
EM-C-F	0	0.0	0	0.0	0	0.0	0
Total EM-C	0	0.0	0	0.0	0	0.0	0
EM-A-M	1	25.0	2	50.0	1	25.0	4
EM-A-F	2	40.0	2	40.0	1	20.0	5
Total EM-A	3	33.3	4	44.4	2	22.2	9
Lower jaw							
LA-C-M	7	87.5	1	12.5	0	0.0	8
LA-C-F	7	63.6	4	36.4	0	0.0	11
Total LA-C	14	73.7	5	26.3	0	0.0	19
LA-A-M	13	61.9	8	38.1	0	0.0	21
LA-A-F	5	55.6	3	33.3	1	11.1	9
Total LA-A	18	60.0	11	36.7	1	3.3	30
EM-C-M	4	50.0	4	50.0	0	0.0	8
EM-C-F	1	100.0	0	0.0	0	0.0	1
Total EM-C	5	55.6	4	44.4	0	0.0	9
EM-A-M	2	50.0	1	25.0	1	25.0	4
EM-A-F	7	63.6	4	36.4	0	0.0	11
Total EM-A	9	60.0	5	33.3	1	6.7	15

LA – late antique; EM – early mediaeval; C – continental Croatia; A – Adriatic Croatia; M – males; F – females; M1 – first molar; M2 – second molar; M3 – third molar.

of the periodontal diseases do not leave changes that are visible after death. Therefore, it is difficult to perform an epidemiological study on the prevalence of periodontal diseases on the skeletal remains of ancient populations. Only dental calculus, alveolar bone resorption, fenestrations, dehiscences and furcation involvement are relatively easy to examine. These periodontal parameters were examined in this research to test the hypothesis that the transition from the late antique to the early mediaeval period in Croatia had negative impact on the lives and health of the people living at that time.[19,20] The comparison of the continental and Adriatic Croatia showed that the prevalence of dental calculus and alveolar bone resorption in both historical periods and in both sexes was higher in Adriatic Croatia than in continental Croatia. The only exception was the LA females from continental Croatia who had a higher prevalence of alveolar bone resorption than females from Adriatic Croatia, Tables 3 and 6. This could indicate that the overall living conditions are more influenced by the geographic area and available traditional dietary patterns than by the turbulent historical processes. Continental and Adriatic Croatia have significantly different ecological features. Continental Croatia has a continental climate, with harsh winters that typically last 4 months during which time the average temperature falls just below 0 °C. The area is rich in rivers that combined with the predominantly flat terrain result in marshes. In the arable fields, wheat and barley were cultivated. Horse and cattle breeding was common, and there is some evidence that pigs were also raised.[35] Adriatic Croatia has a Mediterranean climate, with short, wet winters during which the temperature rarely falls below 5 °C. The area has a few rivers that frequently disappear into limestone subterranean passages. Adriatic Croatia has few arable fields that lie between the Adriatic Sea and the large Dinarid mountain range. Olives and grapes were cultivated in these fields since the Iron Age but the primary sources of nutrition, besides fishing, were transhumance goat and sheep herding.[35] Furthermore, Adriatic Croatia is part of a karst region with lack of surface water and complex underground water circulation. This is a typical phenomenon of Dinaric karst which is in accordance with hydrogeological properties of dominant rock formations. Waters in Adriatic Croatia are poorly mineralised, predominantly of the hydrocarbon type, with low sulphate and chloride concentrations.[36] This specific composition and water hardness could have had a significant influence on the dental calculus formation in the population of Adriatic Croatia. The analysis of distribution of teeth according to the dental calculus score (Table 4) showed that the prevalence of teeth with dental calculus score higher than 1 varied in the Adriatic sample between 16.6% in the early mediaeval up to 22.4% in the late antique. In the continental sample they were ranged between 8.2% in the late antique up to 9.5% in the early mediaeval period. It is well known that the amount of calculus is positively correlated with the prevalence of periodontal disease.[2]

Other examined parameters: fenestrations, dehiscences and furcation involvement showed some differences but they were not statistically significant, Tables 10, 11 and 13. Although expected, comparing the same geographic area in LA and EM period no statistically significant differences were noted between the periods. According to this, it could be concluded that the transition from the late antique to the early mediaeval period in Croatia did not have a negative impact on the periodontal health, but it must not be forgotten that the periodontal parameters examined in this research (except dental calculus) are indicators of an advanced periodontal disease. If gingivitis as an indicator of initial periodontal disease could have been examined, the prevalence of periodontal disease would have been much higher. However, gingivitis is limited only to soft periodontal tissues which disappear postmortem and therefore could not be examined on skeletal remains [2]. The same problem appears in all studies focused on periodontal diseases of skeletal remains. This fact is important to comparability of obtained data. Presence of dental calculus is not necessarily a sign of periodontal disease. It could be considered a predisposing factor the formation of which is influenced by various factors.[32] Similarly, dehiscences and fenestrations of the alveolar bone are primary non-pathological conditions that develop under the circumstances such as a closed teeth-supporting bone relationship and if undiagnosed or unexpected may compromise periodontal surgical procedures or require changes in implant placement protocols.[37] Although they are considered non-pathological conditions and although their use to diagnose periodontal disease may seem incorrect, they can be used as indirect indicator of periodontal disease. In many studies, including the recently published study by Yagci et al., fenestrations and dehiscences are considered an important etiological factor contributing to the development of periodontal disease, especially gingival recession.[38]

Unfortunately, data on the periodontal health of skeletal populations in the region of south-east Europe in general, and especially those relating to the period of late antique and early mediaeval are quite poor and there are only few studies focused on this segment of oral health. However, such data are usually incomparable due to different diagnostic criteria. Examining dental health at the transition from the late antique to the early mediaeval period on the eastern Adriatic coast of Croatia, Šlaus et al. found significantly higher frequencies of dental calculus in the LA period than in the EM period and significantly higher frequencies of alveolar bone resorption in the EM period than in the LA period.[20] These trends are confirmed by the results of this study. Malčić et al. examined the periodontal status in 18th century population of Požega, in Croatia, using periodontal parameters and methodology similar to those used in this study.[17] They recorded the alveolar bone loss, dehiscences and fenestrations. The prevalence of teeth with moderate bone loss (3–6 mm) was 29.83% and the prevalence of teeth with considerable bone loss (>6 mm) was 23.99%. In this study, the frequency of moderate bone loss (grade 2) varied between 26.0% (EM continental Croatia) and 46.4% (LA Adriatic Croatia); and considerable bone loss (grade 3 and higher) varied between 1.3% (EM continental Croatia) and 14.9% (EM Adriatic Croatia). The overall observed frequency of alveolar bone dehiscences was 3.11%. The frequency of alveolar bone dehiscences recorded in this study was higher and it varied between 8.6% (LA continental Croatia) and 15.0% (EM Adriatic Croatia). The total observed frequency of fenestrations for all teeth examined was 5.65%. The frequency of fenestrations was also higher in both samples examined in our study, showing a range between 21.5% (LA Adriatic Croatia) and 36.2% (LA continental Croatia).

The results of the investigation on the skeletal material of Yugoslavia dated from the 1st century A.D. to the beginning of the 20th century performed by Mucić showed the prevalence of alveolar bone dehiscences of 27.8%–33.9%. The recorded prevalence of alveolar bone fenestrations was 19.3%–25.95%. These results are similar to the results obtained in this study. Alveolar bone resorption ranged from 1.0 mm to 8.0 mm.[14] In the late mediaeval sample from western Serbia, Djurić Srejić found the prevalence of dental calculus of 14.1% expressed per tooth and the prevalence of alveolar bone resorption of 18.3% expressed also per tooth.[16] Examining the life style in central Italy during the Roman imperial age to early Middle Ages transition, Belcastro et al. found out that the prevalence of dental calculus expressed per tooth ranged from 50.8% in the Roman sample to 60.6% in the early mediaeval sample.[6] The prevalence of dental calculus recorded in this study (expressed per tooth) varied between 40.7% and 50.3% in the LA sample and was similar to the results obtained by Belcastro et al. On the other hand, the prevalence of calculus in the early mediaeval sample in our study varied between 41.2% and 49.1% and was lower than in central Italy around the same time period. DeWitte and Bekvalac examined the association between periodontal disease and periosteal lesions in the St. Mary Graces Cemetery, London, England A.D. 1350–1538.[39] The overall prevalence of periodontal disease in the examined sample was 30%. Periodontal disease was scored as present if the alveolar bone displayed porosity or if the distance between the cementoenamel junction and the alveolar crest was greater than 2 mm. They concluded that the association between periodontal disease and periosteal lesions might be explained by underlying reduced immune competence. In this way, susceptibility to pathogens that cause periodontal disease or periosteal lesions was increased. They also believed that exposure to environmental factors, or underlying heightened inflammatory responses also played a big role. Whittaker et al. used a four-grade scale to score the amount of supra- and subgingival calculus on the teeth of Romano-British and eighteenth-century Londoners and measured the length of exposed tooth root in order to analyse the alveolar bone loss.[12] The prevalence of teeth with supragingival calculus deposits ranged from 44% to 75% and the prevalence of subgingival deposits from 19% to 31%. In the upper arch, bone loss was at a similar level in the anterior and premolar sites (mean 2.8 mm) but increased markedly in the molar sites (mean 3.5 mm). In the lower arch, bone loss was considerable anteriorly (mean 3.3 mm), low in the premolar site (mean 2.3 mm) and rising to a mean of 2.9 mm in the molar sites. Keenleyside analysed health and disease in arctic peoples prior to contact, including periodontal diseases. Periodontal disease was assessed by the shape and appearance of the interdental septa. The prevalence of periodontal diseases was 8–10%.[5] Meller et al. investigated into the skeletal sample from Atacama Desert. The marginal bone level around the teeth was recorded by measuring the vertical distance between the cementoenamel junction and the highest level of the alveolar bone crest with a periodontal probe at six sites per tooth.[7] A mean value, expressed in millimetres, was then calculated for each tooth. A resultant value of 5 mm or more was interpreted as severe periodontitis. 44% of the examined sample were affected by alveolar bone loss >5 mm.

There are numerous methods for assessment of periodontal health of skeletal populations. Wasterlain et al. proposed the use of six category assessment of the interdental septal areas suggested by Kerr as a reliable way to record periodontal disease frequency more precisely in past populations and make direct comparisons with epidemiological studies on modern populations.[8] Listi proposed the use of methods developed by Brothwell or Buikstra and Ubelaker for recording dental calculus and the method developed by Lukacs for assessment of periodontal disease based on a scale that standardises the progressive deterioration of the alveolar region for each tooth.[11] All these suggested methods are good, reliable, easy to use and sufficiently precise for the purposes they were developed. However, their biggest disadvantage is lack of a sufficient number of users. We believe that only widely used methods should be used in order to obtain the comparable results. This is of utmost importance to bioarchaeological investigations where the problem of a small sample size often arises thus making the interpretation of results less reliable, as seen in this investigation where the sample size decreased by 75% due to postmortem damages.

Examination of periodontal health in skeletal populations is extremely difficult due to fragility of the investigation object. Calculus can easily be removed during the phases of excavation and restoration; the alveolar bone is so thin and fragile and postmortem damages are very common both in the alveolar crest region and on the cortical plate over tooth roots. Openings, located at the cortical plate over the tooth root and defects of the alveolar bone can easily been misdiagnosed as fenestrations and dehiscences rather than postmortem damages of the alveolar bone. Postmortem deposits on teeth can be misdiagnosed as dental calculus. Periodontal disease in archaeological specimens has to be identified with care since the increase in the distance between the cementoenamel junction and the alveolar crest, which has erroneously been used as an indicator of periodontal disease in the past, has been shown to be caused by continuing eruption as a result of tooth wear.[31] Examination of periodontal status on skeletal remains must be performed by an experienced examiner in order to avoid false diagnosis and misinterpretations. Continuous training and education is recommended. Proven and recommended methods should be used for examination of periodontal health of skeletal remains. Detailed examination of dental calculus and alveolar bone resorption are essentials of each periodontal examination in paleodontology and bioarchaeology. It is also recommended to extend the periodontal parameters and investigate the dehiscences, fenestrations and furcation involvement.

5. Conclusion

Given the limitations of this study it could be concluded that the transition from the late antique to the early mediaeval period in Croatia did not have a negative impact on periodontal health. Although examination of periodontal health in skeletal populations is extremely complex and difficult to perform due to fragility of the investigation object, studies of the periodontal health of ancient populations should be performed for a better and more reliable reconstruction of living conditions in the past. They should be performed in such a way to respect standardised diagnostic criteria, which will make the obtained data comparable.

Contribution

Marin Vodanović the main researcher has contributed himself in design of the study, measurements and work on the sample, manuscript preparation, interpretation of the results, literature search. Kristina Peroš, Marjana Knežević endeavoured manuscript preparation. Kristina Peroš has done measurements and worked on the sample, interpretation of the results.

Amila Zukanovć has done statistical analysis, interpretation of the results, manuscript preparation and interpretation of the results, manuscript preparation, literature search. Mario Novak has done demographic analyses of the sample, sex and age estimation. Mario Šlaus endeavoured sample setup, demographic analyses of the sample, sex and age estimation. Hrvoje Brkić was a principal investigator and grant holder.

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Conflict of interest

None of the authors has possible conflicts of interest.

Ethical approval

This investigation was carried out on skeletal series that are currated in the Osteological collection of the Department of Archaeology, of the Croatian Academy of Sciences and Arts in Zagreb. Ethical Committee of the School of Dental Medicine University of Zagreb, Croatia, approved usage of this collection for the purpose of the Grant No. 065-0650445-0423 Human dentition in forensic and archaeological researches supported by Ministry of Science, Education and Sports of the Republic of Croatia.

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