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Dental Health at the Transition from the Late Antique to the Early Medieval Period on Croatia's Eastern Adriatic Coast

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ABSTRACT Dento-alveolar pathologies: caries, ante mortem tooth loss, abscesses, calculus, alveolar resorption and tooth wear were analysed in two composite skeletal series from Croatia's eastern Adriatic coast (Dalmatia). The first consists of 103 skeletons from seven Late Antique (3rd–6th century AD) sites, the second of 151 skeletons from three Early Medieval (7th–11th centuries AD) sites. As recent bioarhaeological studies (Šlaus, 2008) showed a significant increase of disease loads and trauma frequencies in Dalmatia during the Early Medieval period, the aim of this study was to investigate whether dental health was equally adversely affected by the Late Antique/Early Medieval transition. The results of our analyses show that the frequencies of carious lesions, ante mortem tooth loss, abscesses and alveolar resorption increased significantly during the Early Medieval period, as did the degree of heavy occlusal wear on posterior teeth. These data suggest a change in alimentary habits, with a significantly higher dependence on carbohydrates and a greater reliance on hard, fibrous foods requiring vigorous mastication in the Early Medieval diet. The combination of higher calculus and lower caries rates in the Late Antique series similarly suggests more protein in the Late Antique diet and is, therefore, also consistent with the hypothesised change in alimentary habits. In general (the two exceptions are male caries and female alveolar resorption frequencies) lesion frequencies increased uniformly in both sexes suggesting that the deterioration of dental health during the Early Medieval period equally affected males and females. Cumulatively, the collected data suggest that the political, social, economic and religious changes that characterised the Late Antique/Early Medieval transition in Dalmatia resulted in a clear discontinuity, not only from the cultural, but also from the biological point of view with an evident deterioration of oral health during the Early Medieval period. Copyright © 2010 John Wiley & Sons, Ltd.

Key words: bioarchaeology; dental caries; ante mortem tooth loss; dental abscess; dental wear; calculus; late antique; early medieval

Introduction

The transition from Late Antiquity (3rd–5th centuries AD) to the Early Middle Ages (6th–10th centuries AD) in Croatia has traditionally been described as catastrophic with profound political, cultural and social changes that resulted in the destruction of almost all major Late Antique urban centres, depopulation, famine and the spread of infectious diseases (Rački, 1881; Šišić, 1925). Different types of archaeological and historical data were used to support this assumption.

Archaeological data includes clear evidence for the destruction or abandonment of large urban centres such as *Mursa* (modern Osijek), *Cibalae* (Vinkovci), *Salona* (Solin), *Narona* (Vid) and numerous others. At the same time most Roman town names were replaced by Slavic names. Historical sources document numerous, generally short-termed, barbarian invasions (perpetuated in chronological order by the Goths, Huns, Lombards and Gepides), as well as the efforts of the Church to ransom captive Christians, and more importantly, stolen relics from the invading barbarians. After the 6th century Croatia was settled by various Slavic populations, including the Croats who migrated to this area probably in the beginning of the 7th century (Budak, 1994).

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The dramatic nature of this transition was by no means exclusive to Croatia. Archaeological, historical and demographic data suggest that similar changes affected all parts of the Western Roman Empire. There is, for instance, evidence that epidemics, famines, invasions and wars decreased the Italian population from about eight million in the 3rd century, to just over four million in the period from 6th to 9th centuries (Del Panta *et al.*, 1996).

In the last couple of decades Croatian historians have, however, begun pointing out important weaknesses and inconsistencies in the available data that allowed them to gain an appreciation of the complex nature of the Late Antique/Early Medieval transition (Gunjača, 1973; Budak, 1994; Goldstein, 1995). Among them are: (a) a lack of reliable historical sources caused by the fact that Early Croats left no written records meaning that the available sources for the transition are reports made by Frankish, Byzantine or Church historians that are either biased because of various local considerations (for instance Church historians found it impossible to be objective as the arrival of the pagan Croats interrupted and reversed two and a half centuries of Church development), or simply uninterested; (b) the retention of some Roman town names and (c) and the absence of the development of new urban centres in the Adriatic islands populated by Roman refugees fleeing from their destroyed cities. Therefore, while supporting in general the assumption that the transition from the Late Antique to the Early Medieval period in Croatia was characterised by profound political, social and cultural change, some historians suggest a more complex transition.

So far, few bioarhaeological studies have addressed this transition and the potential effects it had on population biology. Analyses of dento-alveolar lesions in the Tyrrhenian region of central Italy between two Roman Imperial age (1st–3rd centuries AD) samples and a Medieval sample from the Lombard era (7th century AD) showed a significant increase of caries, alveolar abscesses and ante mortem tooth loss in the Lombard sample suggesting a deterioration of living conditions with the transition to the Medieval period (Manzi *et al.*, 1999). In contrast to this, analyses of dento-alveolar pathologies, cribra orbitalia and periostitis frequencies between a Late Antique (1st–4th centuries AD) and an Early Medieval (7th century AD) sample from the Molise region in central Italy showed substantial continuity of dietary habits and ways of exploiting the meagre territorial resources (Belcastro *et al.*, 2007). In these samples ecological factors seemed to have affected living conditions considerably more than the cultural, social and economic changes that followed the fall of the Western Roman Empire (Belcastro *et al.*, 2007).

The situation in Croatia is additionally complicated by the fact that within the administrative framework of the Roman Empire the territory of modern Croatia was divided into two provinces: Pannonia in the continental part of Croatia, and Dalmatia along the eastern Adriatic coast. These two provinces are separated by the massive Dinarid mountain range that forms most of modern Bosnia and Herzegovina, and have significantly different ecological features. Continental Croatia is predominantly flat with numerous rivers and has a continental climate while Dalmatia is characterised by karst formations, few rivers and a Mediterranean climate. Analysis of four markers of health: cribra orbitalia, linear enamel hypoplasia, periostitis and trauma between a large ($n = 477$ skeletons) composite Late Antique series, and a similarly sized composite Early Medieval series ($n = 504$ skeletons) from Croatia highlights the complex nature of this transition. In this dataset the frequencies of the analysed markers of health were similar in continental Croatia, while a significant increase of cribra orbitalia, periostitis and trauma frequencies in the Dalmatian subsample suggests a significant deterioration of living conditions during the Early Medieval period in this part of Croatia (Šlaus, 2008).

Oral pathologies are strongly correlated to subsistence patterns, and as such have been used by numerous researchers to assess diet, food-preparation techniques and through these the quality of life of past populations (Lukacs, 1989; Larsen *et al.*, 1991; Hillson, 1996; Larsen, 1997; Eshed *et al.*, 2006).

Because the analysis carried out by Šlaus (2008) showed a marked deterioration of living conditions during the Early Medieval period in Dalmatia, the aim of this study is to investigate the impact that the Late Antique/Early Medieval transition had on the dental health of the past inhabitants of Dalmatia. To this end the frequencies and distributions of carious lesions, ante mortem tooth loss (AMTL), abscesses, calculus, alveolar resorption and tooth wear are compared in two composite skeletal series from Adriatic Croatia. The first consists of 103 skeletons from seven Late Antique sites, the second consists of 151 skeletons from three Early Medieval sites.

Materials and methods

In this study the dentitions of 254 adult individuals from seven Late Antique and three Early Medieval

Table 1. The age and sex distribution in the analysed sample

Age (years)	Late Antique			Early Medieval		
	Number of individuals					
	Males	Females	Total	Males	Females	Total
18–35	16	27	43	28	26	54
36+	33	27	60	59	38	97
Total	49	54	103	87	64	151
Grand total						254
	Number of teeth					
18–35	377	553	930	665	584	1249
36+	569	493	1062	925	533	1458
Total	946	1046	1992	1590	1117	2707
Grand total						4699

sites were examined. The number of skeletons, sex distribution and number of analysed teeth in the composite series is presented in Table 1. The geographical locations of the analysed sites are shown in Figure 1.

The Late Antique skeletal sample consists of 103 skeletons from seven archaeological sites. All of the sites were urban centres. The analysed material was recovered from: Zadar-Relja, Split-Ad basilicas pictas, Vid (Narona), Podvršje, Krk-Omišalj, Hvar-Dolac and Novigrad. All sites are located along the Eastern Adriatic coast. Their use is dated from 3rd to 6th century AD (Durman, 2006).

The Early Medieval sample consisted of 151 skeletons from three small rural communities located in the hinterland of the Eastern Adriatic coast: Tribalj,

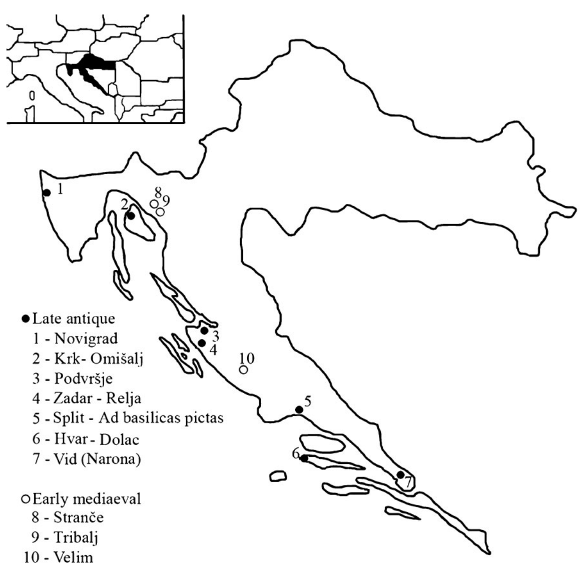

Figure 1. Map of Croatia with the geographical positions of the analysed sites. Full circles indicate Late antique, empty circles Early mediaeval sites.

Strančе and Velim. Archaeological material recovered from these sites dates their use to the period between 7th and 11th centuries AD (Cetinić, 1998; Jurić, 2004).

The sex and age of each individual was determined using standard anthropological criteria. Sex determination was based on cranial and pelvic morphology (Phenice, 1969; Bass, 1987; Buikstra & Ubelaker, 1994.). If these elements were missing or poorly preserved discriminant functions for the femur (Šlaus, 1997), and tibia (Šlaus & Tomičić, 2005) developed for antique and medieval Croatian populations were used. Age was estimated using pubic symphysis morphology (Brooks & Suchey, 1990), auricular surface morphology (Lovejoy *et al.*, 1985), ectocranial suture closure (Meindl & Lovejoy, 1985) and sternal rib end changes (Işcan *et al.*, 1984, 1985). All individuals were assigned to one of two composite age categories: younger adults falling between 18 and 35 years, and older adults comprising an open ended 36+ years age category.

There are no significant differences between the two composite series in terms of either the male/female ($\chi^2 = 2.09$, $p = 0.147$), or young adult/old adult ($\chi^2 = 0.69$, $p = 0.405$) ratios.

Six dento-alveolar parameters were recorded: caries, AMTL, abscesses, calculus, alveolar bone resorption and tooth wear. Pathologies in the series are analysed by teeth and teeth sockets (alveoli). The denominator will vary depending not only on their presence/absence, but also in the case of calculus and alveolar bone resorption, on the degree of their preservation.

Carious lesions were considered present only if the cavity penetrated the tooth enamel. All teeth were examined macroscopically under a bright light using magnification of up to 10X, and a dental probe was used to eliminate scoring of discoloured intact enamel as carious lesions. The number of lesions, as well as their location was recorded for each tooth.

A tooth was scored as lost ante mortem if the tooth socket showed any sign of alveolar bone resorption (Ortner & Putschar, 1981). If there was no evidence of remodelling, the tooth was considered to be lost post mortem. At this point it must be noted that unlike the other pathologies analysed in this study—where frequencies are based on the number of teeth or alveoli present, frequencies for ante mortem tooth loss are calculated based on the number of ante mortem absent teeth (per tooth socket available for examination).

Abscesses were diagnosed by the presence of a perforating fistula in which the internal zone of the bone (the site of the inflammation), and the buccal surface communicate by a canaliform connection (Brothwell, 1981). As this is a macroscopic analysis that does not evaluate the potential presence of small cavities in the periapical region, this study shows only cases resulting from acute or chronic abscesses (Alt *et al.*, 1998).

Calculus was broken down into three levels (slight, moderate and severe) according to the criteria of Brothwell (1981).

A tooth was considered positive for alveolar resorption if at least a 2 mm distance was observed between the cement enamel junction of the tooth and the alveolar bone crest (Clarke *et al.*, 1986).

Degree of dental wear was recorded according to Smith (Smith, 1984). Smith's method uses an eight-stage system to describe degree of wear on all teeth. For the purpose of this analysis teeth were additionally grouped as posterior (molars and premolars) and anterior teeth (canines and incisors). The degrees of dental wear were grouped as mild (Smith degrees 1 and 2), intermediate (degrees 3 and 4) and heavy (degrees 5–8). In this study we present only the results for heavy wear. Teeth in which the occlusal surface was destroyed by large carious lesions were excluded from the analysis.

Frequencies were calculated for each type of lesion recorded, and statistical comparisons by age and sex were performed using the χ^2 test employing Yates correction when appropriate. All statistical analyses were performed using the SPSS statistical package; version 14.0.

Results

The Late Antique series consist of 49 males and 54 females yielding a male/female ratio of 1:1.1 (Table 1). The Early Medieval series consist of 87 males and 64 females giving a male/female ratio of 1: 0.74. Both samples are biased towards older age categories. The percentage of individuals older than 36 years in the Late Antique series is 58.2%, in the Early Medieval series 64.2%.

Of the 4699 permanent teeth examined in this study, 1992 (42.4%) were from the Late Antique sample and 2707 (57.6%) were from the Early Medieval sample. The Late Antique sample comprised of 1046 female teeth and 946 male teeth. In the Early Medieval sample 1590 teeth are from males and 1117 from females.

Dental caries

Caries frequencies (Table 2) in the Late Antique series are higher in males (104/946 or 10.9%) than in females (89/1046 or 8.5%) but the difference is not significant ($\chi^2 = 3.227$, $p = 0.072$). Both males and females in the Late Antique sample exhibit higher caries frequencies in the older age category. This general trend, however, obscures important sex differences. Older males in the Late Antique series exhibit a significantly higher frequency of caries than younger males (14.9% compared to 5.0%; $\chi^2 = 21.706$, $p < 0.0001$), while in females the frequency of carious lesions in younger (7.6%) and older (9.5%) individuals is not significantly different ($\chi^2 = 1.021$, $p = 0.312$). At the level of the total Late Antique sample, however, the frequency of carious lesions is significantly higher in older individuals ($\chi^2 = 18.861$, $p < 0.0001$).

In the Early Medieval series caries frequencies are higher in females (12.6%) than males (11.1%) but the difference is not significant ($\chi^2 = 1.266$, $p = 0.260$). In the male subsample caries frequencies are significantly higher in the older age category (13.3% compared to 8.1%; $\chi^2 = 9.964$, $p = 0.001$), while in females these frequencies are almost identical (12.8% compared to 12.5%). Once again, however, at the level of the total Early Medieval sample the frequency of carious lesions is significantly higher in older individuals ($\chi^2 = 5.299$, $p = 0.021$).

Comparisons between the series (Table 3) indicate significantly higher caries frequencies in the Early Medieval series at the level of complete samples (193/1992 or 9.7% in the Late Antique series compared to 318/2707 or 11.1% in the Early Medieval series; $\chi^2 = 4.807$, $p = 0.002$), as well as in the younger age category (61/930 or 6.6% compared to 127/1249 or 10.2%; $\chi^2 = 8.356$, $p = 0.003$).

Analyses that control for sex show that these differences are primarily the result of significantly higher females caries frequencies in the Early Medieval period—both at the level of the complete female subsample (89/1046 or 8.5% in the Late Antique series

Table 2. Frequencies of dental and periodontal pathologies in the Late Antique and Early Medieval series by age and sex

Age	Late Antique						Early Medieval					
	Males	%	Females	%	Total	%	Males	%	Females	%	Total	%
Dental caries												
≤35	19/377	5.0	42/553	7.6	61/930	6.6	54/665	8.1	73/584	12.5	127/1249	10.2
36+	85/569	14.9	47/493	9.5	132/1062	12.4	123/925	13.3	68/533	12.8	191/1458	13.1
Total	104/946	10.9	89/1046	8.5	193/1992	9.7	177/1590	11.1	141/1117	12.6	318/2707	11.7
AMTL												
≤35	21/398	5.3	27/590	4.6	48/988	4.9	43/778	5.5	80/693	11.5	123/1471	8.4
36+	122/752	16.2	118/642	18.4	240/1394	17.2	387/1464	26.4	317/879	36.1	704/2343	30.0
Total	143/1150	12.4	145/1232	11.8	288/2382	12.1	430/2242	19.2	397/1572	25.3	827/3814	21.7
Abscesses												
≤35	4/398	1.0	7/590	1.2	11/988	1.1	22/778	2.8	22/693	3.2	44/1471	2.9
36+	24/752	3.2	20/642	3.1	44/1394	3.2	97/1464	6.6	55/879	6.3	152/2343	6.5
Total	28/1150	2.4	27/1232	2.2	55/2382	2.3	119/2242	5.3	77/1572	4.9	196/3814	5.1
Calculus												
≤35	289/377	76.7	332/508	65.3	621/885	70.2	327/566	57.8	324/525	61.7	651/1091	59.7
36+	294/361	81.4	388/453	85.6	682/814	83.8	616/845	72.9	351/512	68.5	967/1357	71.3
Total	583/738	79.0	720/961	74.9	1303/1699	76.7	943/1411	66.8	675/1037	65.1	1618/2448	66.1
Alveolar resorption												
≤35	115/234	49.1	110/247	44.5	225/481	46.8	177/277	63.9	142/272	52.2	319/549	58.1
36+	132/159	83.0	167/219	76.2	299/378	79.1	255/308	82.8	140/166	84.3	395/474	83.3
Total	247/393	62.8	277/466	59.4	524/859	61.0	432/585	73.8	282/438	64.4	714/1023	69.8

compared to 141/1117 or 12.6% in the Early Medieval series; $\chi^2 = 9.195$, $p = 0.001$), and for young females (42/553 or 7.6% compared to 73/584 or 12.5%; $\chi^2 = 6.987$, $p = 0.006$). No differences were noted in the male sub samples.

AMTL

AMTL frequencies (Table 2) in the Late Antique series are higher in males (143/1150 or 12.4%) than in females (145/1232 or 11.8%) but, similarly to the trend noted in

Table 3. Comparisons of occurrence of dental features in the analysed series

Dental feature	LA vs. EM males			LA vs. EM females			LA vs. EM total		
	N	χ^2	p	N	χ^2	p	N	χ^2	p
Dental caries									
≤35	1042	3.048	0.061	1137	6.987	0.006[a]	2179	8.356	0.003[a]
36+	1494	0.661	0.373	1026	2.361	0.102	3582	0.191	0.619
Total	2537	0.002	0.913	2163	9.195	0.001[a]	4699	4.807	0.002[a]
AMTL									
≤35	1176	0.002	0.858	1283	19.338	0.000[a]	2459	10.676	0.0008[a]
36+	2216	28.702	<0.001[a]	1521	55.954	<0.001[a]	3737	75.528	<0.001[a]
Total	3392	24.151	<0.001[a]	2804	79.685	<0.001[a]	6196	90.78	<0.001[a]
Abscesses									
≤35	1176	3.247	0.044[a]	1283	4.873	0.016[a]	2459	8.691	0.002[a]
36+	2216	10.695	0.001[a]	1521	7.157	0.005[a]	3737	18.849	0.0000[a]
Total	3392	14.448	<0.001[a]	2804	13.42	0.001[a]	6196	29.488	<0.001[a]
Calculus									
≤35	943	34.794	<0.001[b]	1033	1.323	0.250	1976	23.031	<0.001[b]
36+	1206	9.507	0.002[b]	965	38.223	<0.001[b]	2171	43.012	<0.001[b]
Total	2149	34.246	<0.001[b]	1998	22.409	<0.001[b]	4147	53.582	<0.001[b]
Alveolar resorption									
≤35	511	10.679	0.001[a]	519	2.750	0.097	1030	12.751	<0.001[a]
36+	467	0.000	1.000	385	3.333	0.067	852	2.221	0.136
Total	978	12.878	<0.001[a]	904	2.131	0.144	1882	15.652	<0.001[a]

[a] Differences between the LA and EM series are the result of significantly higher frequencies in the EM period.
[b] Differences between the LA and EM series are the result of significantly higher frequencies in the LA period.

caries frequencies, the difference is not significant ($\chi^2 = 0.189$, $p = 0.663$). Both males and females in the Late Antique sample exhibit significantly higher AMTL frequencies in the older age category ($\chi^2 = 27.647$, $p < 0.0001$ for males, and $\chi^2 = 55.094$, $p < 0.0001$ for females).

In the Early Medieval series AMTL frequencies are, at the level of the complete sample, significantly higher in females (397/1572 or 25.3%) than in males (430/2242 or 19.2%; $\chi^2 = 19.727$, $p < 0.0001$). The same trend is present in the young adult ($\chi^2 = 16.541$, $p < 0.0001$), and old adult ($\chi^2 = 23.773$, $p < 0.0001$) age categories. In both sexes AMTL frequencies are significantly higher in older age categories: 26.4% compared to 5.5%; $\chi^2 = 141.916$, $p < 0.0001$ in males, and 36.1% compared to 11.5%; $\chi^2 = 122.122$, $p < 0.0001$ in females.

Comparisons between the Late Antique and Early Medieval series (Table 3) show significantly higher frequencies of AMTL in the Early Medieval series in all age and sex categories except for young males.

Abscesses

Abscesses frequencies (Table 2) in the Late Antique series are similar in both sexes (28/1150 or 2.4% for males compared to 27/1232 or 2.2% for females). In both sexes frequencies are also significantly higher in the older age categories (for males: $\chi^2 = 4.357$, $p = 0.037$; for females $\chi^2 = 4.474$, $p = 0.034$).

Male (119/2242 or 5.3%) and female (77/1572 or 4.9%) abscess frequencies are also similar in the Early Medieval series. In both sexes, differences between abscess frequencies are, once again, significantly higher in the older age category (for males $\chi^2 = 13.834$, $p = 0.0001$; for females $\chi^2 = 7.256$, $p = 0.007$).

Comparisons between the series (Table 3) show significantly higher frequencies of abscesses in all age and sex categories in the Early Medieval series.

Calculus

In the Late Antique series males exhibit (Table 2) a marginally not significantly higher rate of calculus than females (583/738 or 79.0% compared to 720/961 or 74.9%; $\chi^2 = 3.657$, $p = 0.055$). This difference is primarily caused by the significantly higher calculus rates that young males have in comparison to young females (76.7% compared to 65.3%; $\chi^2 = 12.677$, $p = 0.0004$). Male/female differences are not significant in the older adult subsample (81.4% compared to 85.6%; $\chi^2 = 2.321$, $p = 0.128$). Both sexes exhibit higher calculus rates in the older age category but the difference is significant only in females (65.3% compared to 85.6%; $\chi^2 = 51.431$, $p < 0.0001$). At the level of the complete Late Antique sample the difference is, however, significant (83.8% compared to 70.2%; $\chi^2 = 43.207$, $p < 0.001$).

In the Early Medieval series the rates of calculus are similar in males and females (943/1411 or 66.8% compared to 675/10371 or 65.1%; $\chi^2 = 0.735$, $p = 0.392$). Both sexes exhibit significantly higher calculus rates in the older age category—in males 72.9% compared to 57.8% ($\chi^2 = 34.305$, $p < 0.0001$), in females 68.5% compared to 61.7% ($\chi^2 = 5.043$, $p = 0.025$).

Comparisons between the Late Antique and Early Medieval series (Table 3) show significantly higher calculus rates in the Late Antique series in all age and sex categories except for young females.

Similarly, when calculus is analysed by severity (Table 4) calculus levels 1 and 2 are significantly higher in the Late Antique series (for calculus level 1 $\chi^2 = 20.853$, $p < 0.0001$; for calculus level 2 $\chi^2 = 18.4770$, $p < 0.0001$). Calculus level 3 is, however, significantly higher in the Early Medieval series ($\chi^2 = 5.069$, $p = 0.024$).

Alveolar resorption

Alveolar resorption frequencies (Table 2) in the Late Antique series are similar in both sexes (247/393 or 62.8% for males compared to 277/466 or 59.4% for females; $\chi^2 = 0.902$, $p = 0.342$). In both sexes frequencies are also significantly higher in the older age categories (for males: $\chi^2 = 45.084$, $p < 0.0001$; for females $\chi^2 = 47.142$, $p < 0.0001$).

Table 4. Calculus by severity in the Late Antique and Early Medieval series

Series	*N* of teeth affected				Calculus rates (%)				
	1[a]	2	3	Sum	1	2	3	Total	Total[b]
Late Antique	1081	215	7	1303	63.6	12.6	0.4	76.7	1699
Early Med.	1383	208	27	1618	56.5	8.5	1.1	66.1	2448

[a] Calculus levels 1–3 according to Brothwell (1981); 1 = slight; 2 = moderate; 3 = severe.
[b] Total number of teeth examined.

In the Early Medieval series males exhibit significantly higher rates of alveolar resorption than females (432/585 or 73.8% compared to 282/438 or 64.4%; $\chi^2 = 10.194$, $p = 0.001$). This difference is primarily caused by the significantly higher rates of alveolar resorption that young males have in comparison to young females (63.9% compared to 52.2%; $\chi^2 = 7.235$, $p = 0.007$). Male/female differences are not significant in the older adult subsample ($\chi^2 = 0.090$, $p = 0.763$). In both sexes frequencies are also significantly higher in the older age categories (for males: $\chi^2 = 25.984$, $p < 0.0001$; for females $\chi^2 = 45.022$, $p < 0.0001$).

Comparisons between the series (Table 3) indicate significantly higher alveolar resorption rates in the Early Medieval series at the level of complete samples (524/859 or 61.0% in the Late Antique series compared to 714/1023 or 69.81% in the Early Medieval series; $\chi^2 = 15.652$, $p < 0.0001$), as well as in the younger age category (225/481 or 46.8% compared to 319/549 or 58.1%; $\chi^2 = 12.751$, $p < 0.001$).

Analyses that control for sex suggest that this is primarily caused by the significantly higher frequencies of alveolar resorption that young males in the Early Medieval period have in comparison to young males from the Late Antique series (63.9% compared to 49.1%; $\chi^2 = 10.679$, $p = 0.001$). No differences were noted in the female subsample.

Wear

Of the 1992 permanent teeth from the Late Antique sample, 1951 teeth with preserved occlusal surfaces (97.9% of the total sample) were examined for the presence of heavy wear. In the Early Medieval sample 2658/2707 (98.2% of the total sample) had sufficiently preserved occlusal surfaces.

At the level of complete samples (Table 5), the frequencies of heavy wear in the Late Antique and Early Medieval series are very similar: 739/1951 or 37.9% of teeth in the Late Antique series exhibit wear equivalent to, or greater than Smith stage 5, compared to 1006/2628 or 38.3% of teeth in the Early Medieval series ($\chi^2 = 0.061$, $p = 0.805$). In both samples males exhibit significantly higher wear than females. In the Late Antique series males have a 42.0% (387/922) frequency of heavy wear compared to 34.2% (352/1029) in females ($\chi^2 = 12.136$, $p = 0.005$), in the Early Medieval series males have a 42.7% (671/1571) frequency of heavy wear compared to 31.7% (335/10579) in females ($\chi^2 = 32.003$, $p < 0.001$). Differences between the series at the level of male ($\chi^2 = 0.101$, $p = 0.750$) and female ($\chi^2 = 1.381$, $p = 0.240$) subsamples are not significant. In both series heavy wear frequencies are significantly higher in the older age categories (for Late Antique males: $\chi^2 = 99.999$, $p < 0.0001$; for Late Antique females $\chi^2 = 229.235$, $p < 0.0001$; for Early Medieval males: $\chi^2 = 163.419$, $p < 0.0001$; for Early Medieval females $\chi^2 = 34.542$, $p < 0.0001$).

When, however, heavy wear is analysed by mandible and maxilla, as well as by posterior and anterior teeth (Table 6) significant differences between the series are revealed. A total of 15 significant differences are noted—three when heavy wear is analysed based on the location of the tooth in the upper or lower jaw, and 12 when the teeth were divided into anterior and posterior groups.

Table 5. Frequency of heavy tooth wear (Smith's stages 5–8) by age and sex

Age	Late Antique						Early Medieval					
	Males	%	Females	%	Total	%	Males	%	Females	%	Total	%
Maxilla												
18–35	33/181	18.2	35/229	15.3	68/410	16.6	59/310	19.0	46/283	16.2	105/593	17.7
36+	136/240	56.7	136/211	64.4	272/451	60.3	258/404	63.9	98/216	45.4	356/620	57.4
Total	169/421	40.1	171/440	38.9	340/861	39.5	317/714	44.4	144/499	28.8	461/1213	38.0
Mandible												
18–35	39/192	20.3	37/319	11.6	76/511	14.9	54/350	15.4	59/270	21.8	113/620	18.2
36+	179/309	57.9	144/270	53.3	323/579	55.8	300/507	59.2	132/288	45.8	432/795	54.3
Total	218/501	43.5	181/589	30.7	399/1090	36.6	354/857	41.3	191/558	34.2	545/1415	38.5
Anterior teeth												
18–35	55/142	38.7	48/197	24.4	103/339	30.4	55/227	24.2	65/226	28.8	120/453	26.5
36+	180/224	80.4	133/194	68.6	313/418	74.9	277/375	73.9	124/218	56.9	401/593	67.6
Total	235/366	64.2	181/391	46.3	416/757	55.0	332/602	55.1	189/444	42.6	521/1046	49.8
Posterior teeth												
18–35	17/231	7.4	24/351	6.8	41/582	7.0	58/433	13.4	40/327	12.2	98/760	12.9
36+	135/325	41.5	147/287	51.2	282/612	46.1	281/536	52.4	106/286	37.1	387/822	47.1
Total	152/556	27.3	171/638	26.8	323/1194	27.1	339/969	35.0	146/613	23.8	485/1582	30.7

Table 6. Comparisons of occurrence of tooth wear in the analysed series

Tooth wear	Late Antique vs. Early Medieval males			Late Antique vs. Early Medieval females			Late Antique vs. Early Medieval total		
	N	χ^2	*p*	*N*	χ^2	*p*	*N*	χ^2	*p*
Maxilla									
18–35	491	0.01	0.920	512	0.03	0.860	1003	0.14	0.706
36+	644	2.98	0.083	427	14.93	0.0001[a]	1071	0.78	0.375
Total	1135	1.78	0.181	939	10.05	0.001[a]	2074	0.40	0.523
Mandible									
18–35	542	1.75	0.185	589	10.52	0.001[b]	1131	2.02	0.154
36+	816	0.07	0.782	558	2.84	0.091	1374	0.22	0.633
Total	1358	0.54	0.460	1147	1.44	0.229	2505	0.87	0.349
Anterior teeth									
18–35	369	8.10	0.004[a]	427	0.82	0.363	792	1.26	0.260
36+	599	2.91	0.087	412	5.47	0.01[a]	1011	5.88	0.015[a]
Total	968	7.32	0.006[a]	839	1.02	0.312	1803	4.45	0.034[a]
Posterior teeth									
18–35	664	4.89	0.026[b]	678	5.15	0.023[b]	1342	11.52	0.0006[b]
36+	861	9.17	0.002[b]	573	11.07	0.0008[a]	1434	0.10	0.747
Total	1525	9.11	0.002[b]	1251	1.39	0.237	2776	4.11	0.042[b]

[a] Differences between the LA and EM series are the result of significantly higher frequencies in the LA period.
[b] Differences between the LA and EM series are the result of significantly higher frequencies in the EM period.

Higher frequencies of heavy wear were recorded in the Early Medieval series in seven cases, while in eight cases higher frequencies were recorded in the Late Antique series.

Analyses that divide the teeth by upper and lower jaw show no clear pattern. All differences were noted in females with older and total female heavy wear in the maxillary teeth being higher in the Late Antique series, and younger female heavy wear in the mandible higher in the Early Medieval series.

In contrast to this, analyses that control for the anterior or posterior position of the teeth in the dentition show a uniform pattern. Differences noted in the posterior teeth tend to be (in 6/7 cases) caused by significantly higher wear in the Early Medieval series. Three differences are noted in the male subsample, one in the female, and two are at the level of complete samples including among them, importantly, total heavy wear in all posterior teeth. Differences noted in the anterior teeth (in all five cases) were the result of higher wear in the Late Antique series. Two differences are noted in the male subsample, one in the female and two are at the level of complete samples including among them again, importantly, total heavy wear in all anterior teeth.

Discussion

As previously noted, historical sources for the Late Antique/Early Medieval transition in Croatia are remarkably rare. Early Croats did not leave written records, and the available scarce Byzantine and Frankish records that deal with the Croats focus primarily on their military and political characteristics. Early Croat culture, subsistence strategies, knowledge of medicine and everyday life were of little interest to these authors and thus remain unknown to us (Budak, 1994; Goldstein, 1995).

In contrast to this, data pertaining to the everyday life and thus the dietary habits and nutrition of Late Antique populations are available in the writings of numerous antique authors including *Cato* (234 BC–149 BC), *Silius Italicus* (25 AD–101 AD) and *Pliny* (61 AD–113 AD) (as reported in White, 1970; Dosi & Schnell, 1990). While these data primarily describe the dietary habits and nutrition of populations that inhabited central and southern Italy, two reasons suggest that they are applicable to the Late Antique populations that inhabited Croatia's eastern Adriatic coast. The first is that the ecological features of the eastern Adriatic cost are similar to those of central and southern Italy—both have a Mediterranean climate, and the populations inhabiting them based their subsistence strategies on the cultivation of olives, grapes, fishing and transhumance goat and sheep herding. The second is the marked cultural uniformity in dietary habits, nutrition and health practices that characterised the entire Roman Empire and expressed itself through such features as the enthusiastic spread of viticulture in all parts of the Roman Empire, the considerable effort that was put into the draining of marshes and swamps, and the emphasis that was placed on the availability of fresh drinking water and waste disposal in urban centres.

According to the available historical sources the typical meal of the lower and middle classes in Roman Italy consisted of bread (rich in bran and impurities), porridge of cereals (*puls*), wine, vegetables, some fruit and olives (Dosi & Schnell, 1990). The main staples of everyday diet included wheat, olives, wine and figs. Periodical fishing, as well as transhumance goat and sheep herding, also contributed to the dietary resource pool. With one provision there seems little doubt that the same foodstuffs dominated the nutrition of the Late Antique populations that inhabited Dalmatia. The provision applicable to the Croatian sample concerns the fact that all of the Late Antique osteological material derives from maritime urban communities, some of which—particularly Zadar-Relja, Vid (Narona) and Split-Ad basilicas pictas, were large centres for commercial activities and fishing. The social composition of the osteological sample reflects this and the recovered archaeological artefacts and available epigraphic data suggest that most skeletons belonged to middle or upper class individuals engaged in various commercial activities (Oreb *et al.*, 1999; Mardešić, 2004).

Comparisons between the Late Antique and Early Medieval series in Croatia show a general trend of deteriorating dental health. Significant increases, at the level of complete samples, are recorded for the frequencies of caries, abscesses, AMTL and alveolar resorption in the Early Medieval series. In addition, heavy wear on the posterior teeth is significantly higher in the Early Medieval series.

The higher frequency of heavy wear on the posterior teeth of the Early Medieval sample suggests a diet with more abrasive, hard, fibrous foods requiring vigorous mastication. It is also, however, possible that differential food preparing techniques—particularly those related to the preparation of vegetables (Bonfiglioli *et al.*, 2003) were responsible for this difference. Dental wear rates are multifactorial and depend on numerous factors including the consistency and texture of food, but also food preparation techniques, age and sex (Hillson, 1979; Walker *et al.*, 1991).

The Late Antique series exhibits significantly higher rates of heavy wear on the anterior dentition which raises the possibility that non-dietary factors, possibly activities related to fishing (making fishing nets) may have contributed to the wearing down of their front teeth. Of potential interest in this context is the fact that males in the Late Antique series consistently—in both age categories, and at the level of complete samples, exhibit significantly higher rates of anterior wear than females ($\chi^2 = 23.794$, $p < 0.001$, for the complete sample), and that significant differences in wear rates between the Late Antique and Early Medieval series are present only in the male subsamples.

An alternative explanation is that because of severe AMTL in the posterior dentition—in the Late Antique series AMTL is considerably more prevalent in the posterior (246/288 or 85.4%) than the anterior (42/288 or 14.6%) dentition, the canines and incisors took on the function of the molars (Højgaard, 1981). Given that the composite Early Medieval Croatian sample also exhibits consistently higher rates of heavy wear in the anterior dentition—and similarly has considerably more AMTL in the posterior dentition (658/827 or 79.6% compared to 169/827 or 20.4%), this interpretation seems more likely.

At the level of complete samples caries frequencies are significantly higher in the Early Medieval series. This general trend, however, obscures an important sex difference. While female caries rates are significantly higher in the early Medieval series (both at the level of complete samples, and in the younger age category), male frequencies are very similar (10.9% in the Late Antique compare to 11.1% in the Early Medieval series at the level of complete samples).

Most analyses of dental pathologies report a correlation between caries rates and diet. High caries rates are correlated with a greater consumption of carbohydrates, while low rates of caries are correlated with low carbohydrate diets. The reason for this is that micro-organisms in the bacterial plaque metabolise carbohydrates, thus lowering the pH of the oral cavity, and favouring the destruction of the hard tissues of the tooth (Powel, 1985). High levels of proteins and fat in the diet are, on the other hand, thought to inhibit caries. Other factors that affect the rates of caries are mouth acidity (alkaline), and fluoride levels in the water (Molnar & Molnar, 1985). At a global level, it is commonly accepted that with the onset of agriculture, a diet rich in carbohydrates was introduced resulting in a dramatic increase in caries rates (Hillson, 1979; Turner, 1979; Larsen, 1981; Larsen *et al.*, 1991).

The significantly different caries rates between the Late Antique and Early Medieval series suggest markedly different alimentary habits, and a significant increase in carbohydrates in the Early Medieval diet. This is consistent with the meagre historical sources that report on the alimentary habits of Early Medieval populations in Europe. According to these sources individuals belonging to lower socio-economic classes had a diet essentially based on cereals (bread represented 70% of the food intake), while the intake of proteins (in the form of fresh meat and fish) was low and infrequent (Cortonesi, 1981; Mazzi, 1981).

The significant increase in total and female caries rates in the Early Medieval period, combined with the absence of this trend in males is intriguing. As there are no significant sex differences in caries frequencies in either series, it seems reasonable to assume that males and females were consuming foods with similar cariogenic properties during both the Late Antique and Early Medieval period. A possible explanation why the hypothesised increase of carbohydrates in the Early Medieval diet did not adversely affect male dentitions lies in the following.

In both series carious lesions are more frequent in the posterior dentition (168/193 or 87.0% compared to 25/193 or 13.0% for the anterior teeth in the Late Antique series, and 277/318 or 87.9% compared to 41/318 or 13.0% in the Early Medieval series). This can be explained by the fact that bacterial plaque accumulates more easily on surfaces with pits and cracks, and is also less easily removed from these surfaces by saliva flow and the actions of the tongue and cheeks (Powel, 1985). In the last couple of decades some authors have reported a negative correlation between heavy wear and caries frequencies caused by the cancellation of the sulci and fossae that are the natural morphology of the tooth, and by the removal of carious tissue (Maat & Van der Velde, 1987; Kerr *et al.*, 1990; Hillson, 2001). Applying this information to the Croatian samples it becomes apparent that unlike the situation in females—where total rates of posterior wear are similar in the Late Antique and Early Medieval series, the posterior teeth of Early Medieval males exhibit significantly more heavy wear (in both age categories, and at the level of complete samples) than those of Late Antique males. It is, therefore, possible that some caries were removed by heavy wear resulting in similar caries rates between males despite an increase of carbohydrates in the Early Medieval diet.

Significantly higher abscess frequencies are recorded in all age and sex categories in the Early Medieval series. This is consistent with the total higher caries rates, and the higher male heavy wear rates in posterior teeth recorded in this series. The most common aetiologic factors of abscesses in archaeological populations are penetrating and destructive caries with pulp cavity exposure, heavy wear and trauma (Littleton & Frohlich, 1993; Dias & Tayles, 1997). It would appear that in this data set the higher caries rates in females and higher male heavy wear rates in posterior teeth were responsible for the significant increase in abscess frequencies during the Early Medieval period. In both series abscesses are significantly more frequent in the older age category reflecting the progressive deterioration of the tooth; caries may appear at a young age but need time to invade the pulp cavity and cause an abscess (Beckett & Lovell, 1994). Similarly, time is required if heavy wear is to result in pulp exposure and the onset of abscesses (Scott & Turner, 1988). At this point it is relevant to, once again, note that as only macroscopic diagnosis was employed in this study the figures reported for abscess frequencies in both series are underestimated.

Except for young males, AMTL frequencies are significantly higher in all age and sex categories in the Early Medieval series. Determining the causes of AMTL in archaeological populations is difficult. The causes include: caries, abscesses, heavy wear, calculus, alveolar resorption and trauma (Hillson, 2000). Metabolic diseases such as scurvy can also lead to AMTL (Ortner & Putschar, 1981). The fact that in both samples dental caries and AMTL most frequently affects the posterior dentition suggests that caries may have been a major cause of tooth loss in both series. Higher rates of AMTL in older males from the Early Medieval series may have also been caused by the considerable masticatory stress their posterior teeth were exposed to as revealed by the significantly higher rates of heavy wear that they exhibit on these teeth. This masticatory stress may have destabilised the tooth thus increasing its mobility and the likelihood of its loss (Belcastro *et al.*, 2007). Of interest is the fact that in this data set calculus did not contributed significantly to AMTL.

In contrast to the trend noted in caries, abscess and AMTL frequencies, calculus is significantly more prevalent in the Late Antique series. Calculus formation is related to both diet and non-dietary factors (Hillson, 2001). Among the non-dietary factors linked to its formation are: poor oral hygiene, the mineral content of drinking water, rate of salivary flow, culturally derived patterns of behaviour and teeth utilised as tools (Lieverse, 1999). The association between diet and calculus is not straightforward and high calculus rates have been recorded in both high carbohydrate, and high protein diets (Meiklejohn & Zvelebil, 1991; Lieverse, 1999; Lillie & Richards, 2000). In combination with caries rates, however, calculus has been used to assess the relative contribution of carbohydrates versus proteins to the diet. High calculus rates combined with low caries rates are characteristic of populations subsiding on high protein/low carbohydrate diets while high calculus rates combined with high caries rates are characteristic of populations subsiding on high carbohydrate/low protein diets (White, 1994; Lillie, 1996).

In this context, the characteristics of the Late Antique series—a combination of lower caries with higher calculus rates indicating a relatively high protein diet are consistent with the available archaeological and historical data that suggest most of the individuals from this series were from the middle or upper classes. Comparison between the series (lower caries and higher calculus rates in the Late Antique series compared to higher caries and lower calculus rates in the Early Medieval series) are also consistent with the hypothesised change from a diet with relatively more protein in the Late Antique period, to one with less protein in the Early Medieval period.

The same principle has been utilised to assess potential sex differences reflecting unequal access to dietary protein (Lillie & Richards, 2000). In this context, the absence of significant differences between males and females in both series suggests they consumed a similar diet.

At the level of total samples calculus is, like abscesses and AMTL, significantly more common in older individuals in both series. This trend has been observed in other populations and reflects the progressive build-up of calculus with age (Beiswanger *et al*., 1989).

At the level of both total samples, and younger adults, significantly higher frequencies of alveolar resorption are recorded in the Early Medieval series. These differences result primarily from significantly higher alveolar resorption frequencies recorded in the male subsample. The aetiology of alveolar resorption is multifactorial and includes dietary, hygienic, environmental and genetic components. In addition, Clarke *et al*. (1986) have noted differences between pre-modern and modern populations regarding the most common causes of alveolar resorption. According to their results, while the primary aetiologic factor of alveolar resorption in contemporary societies is bacterial plaque, whether mineralised (as dental calculus) or not, in archaeological populations factors such as heavy attrition (resulting from occlusal trauma), pulp damage, infection and mineral imbalance appear to be more important. As calculus rates are higher in the Late Antique than the Early Medieval series, it would appear that factors other than bacterial plaque contributed to the elevated rates of alveolar resorption during the Early Medieval period. Potential contributors include: systemic diseases such as scurvy, osteoporosis, diabetes and immunodeficiency diseases (Garcia *et al*., 2001), generalised malnutrition (Enwonwu, 1995) and chronic occlusal trauma (Carranza, 2002). The significantly higher rate of heavy wear noted in the posterior dentition of the Early Medieval series suggests that chronic occlusal trauma may have been a significant contributing factor. Trauma from occlusion can produce alveolar bone destruction in the absence or presence of inflammation. In the absence of inflammation changes caused by chronic occlusal trauma vary from increased compression of the periodontal ligament to necrosis of the periodontal ligament and bone with subsequent resorption of bone and tooth structure. When combined with inflammation, trauma from occlusion aggravates and increases bone destruction (Carranza, 2002). This is consistent with the hypothesised change to a diet with more abrasive, hard, fibrous foods requiring vigorous mastication—and hence greater occlusal trauma in the Early Medieval period. An additional factor that needs to be kept in mind is that extension of inflammation from the gingiva to the supporting periodontal tissues depends not only on the previously mentioned factors, but also on host resistance. Host resistance is determined by numerous factors including among them disease loads. In this context it is relevant to point out that, as previously noted, bioarhaeological analyses between a Late Antique and Early Medieval series from Croatia showed a significant increase in periostitis and cribra orbitalia frequencies suggesting an increase in parasite loads, and acute and chronic infectious diseases in males during the Early Medieval period in Dalmatia (Šlaus, 2008).

To put data on the dental health of the past inhabitants of Dalmatia during the Late Antique to Early Medieval transition into a broader geographical context, results from the Croatian series were compared to other Roman Imperial, and Middle Ages series from Italy (Manzi *et al*., 1999; Cucina *et al*., 2006; Belcastro *et al*., 2007), France (Esclassan *et al*., 2009), Austria (Meinl *et al*., 2009) and England (Wells, 1982). The results, presented in Table 7, show a generalised worsening of dental health in all parts of the Western Roman Empire, suggesting a deterioration of living conditions with the transition to the Medieval period. The frequencies of caries and AMTL in both Croatian series are intermediate, while abscess and calculus frequencies are slightly higher than in the other series.

In summary, the results of our analyses show that the frequencies of carious lesions, AMTL, abscesses and alveolar resorption significantly increased during the Early Medieval period, as did the degree of heavy occlusal wear on posterior teeth. These data suggest a change in alimentary habits, with a significantly higher dependence on carbohydrates in the Early Medieval diet. The combination of higher calculus and lower caries rates in the Late Antique series similarly suggests more protein in the Late Antique diet and is, therefore, also consistent with the hypothesised change in alimentary habits.

Table 7. Comparisons between Croatian and other Late Antique and Early Medieval samples from Europe[a]

	Caries (%)	AMTL (%)	Abscesses (%)	Calculus (%)
Late antique sites				
Isola Sacra, Italy 1–3 c. AD	4.0	6.8	0.2	33.9
Lucus Feroniae, Italy 2–4 c. AD	6.1	12.4	0.6	26.9
Quadrella, Italy 1–4 c. AD	15.0	12.5	1.3	50.8
Vallerano, Italy 2–3 c. AD	2.5	3.4	1.1	
Cirencester, England 3–5 c. AD	5.1	8.5	1.2	
Croatian sample, 3–6 c. AD (this study)	9.7	12.1	2.3	76.7
Early Medieval sites				
La Selvicciola, Italy 7 c. AD	12.6	18.2	0.8	27.1
Vicenne-Campochiaro, Italy 6–8 c. AD	15.1	13.5	4.5	60.6
Vilarnau d'Amont, France 12–14 c. AD	17.5	8.7		
Vienna, Austraia 6–8 c. AD	14.9	23.8		
Croatian sample, 7–11 c. AD (this study)	11.7	21.7	5.1	66.1

[a] All frequencies are per element (tooth/tooth socket).

In general (the two exceptions are male caries and female alveolar resorption frequencies) lesion frequencies increased uniformly in both sexes suggesting that the deterioration of dental health during the Early Medieval period equally affected males and females. The absence of a significant increase in male caries frequencies during the Early Medieval period may be a result of the significantly higher wear they exhibit on their posterior teeth and is therefore not inconsistent with an increase in carbohydrates in the Early Medieval diet. Similarly, female alveolar resorption frequencies increased during the Early Medieval period, almost achieving significance ($p = 0.097$ for younger, and $p = 0.067$ for older females) and are, therefore, also compatible with an increase in carbohydrates in the Early Medieval diet. As the same general trend of deteriorating health with the transition to the Early Medieval period in Dalmatia was observed when cribra orbitalia, linear enamel hypoplasia, non-specific periostitis and trauma frequencies were analysed (Šlaus, 2008) it would appear that the political, social, economic and religious changes that characterised the Late Antique/Early Medieval transition in Dalmatia resulted in a clear discontinuity, not only from the cultural, but also from the biological point of view with an evident deterioration of oral health during the Early Medieval period. Continued research of other Late Antique and Early Medieval skeletal series from Croatia are necessary to determine if data from these collections support the results of our analyses.

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References

Alt KW, Turp JC, Wachter R. 1998. Periapical Lesions—Clinical and Anthropological Aspects. In *Dental Anthropology. Fundamentals, Limits and Prospects*, Alt KW, Rosing FW, Teschler-Nicola M (eds). Springer-Verlag: Wien; 247–276.

Bass WM. 1987. *Human Osteology. A Laboratory and Field Manual of the Human Skeleton*. Missouri Archaeological Society: Columbia, MO.

Beckett S, Lovell NC. 1994. Dental disease evidence for agricultural intensification in the Nubian C-group. *International Journal of Osteoarchaeology* **4**: 223–240.

Beiswanger BB, Segreto VA, Mallatt ME, Pfeiffer HJ. 1989. The prevalence and incidence of dental calculus in adults. *Journal of Clinical Dentistry* **1**: 55–58.

Belcastro G, Rastelli E, Mariotti V, Consiglio C, Facchini F, Bonfiglioli B. 2007. Continuity or discontinuity of the lifestyle in Central Italy during the Roman Imperial Age – Early Middle ages transition: diet, health and behavior. *American Journal of Physical Anthropology* **132**: 381–394.

Bonfiglioli B, Brasili P, Belcastro MG. 2003. Dento–alveolar lesions and nutritional habits of a Roman Imperial age population (1st–4th c. AD): Quadrella (Molise, Italy). *Homo* **54**: 36–56.

Brooks S, Suchey JM. 1990. Skeletal age determination based on the os pubis: a comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods. *Human Evolution* **5**: 227–238.

Brothwell DR. 1981. *Digging Up Bones*. Oxford University Press: Oxford.

Budak N. 1994. *Prva stoljeća Hrvatske*. Hrvatska sveučilišna naklada: Zagreb.

Buikstra J, Ubelaker D. 1994. *Standards for Data Collection from Human Skeletal Remains*. Arkansas Archaeological Survey: Fayetteville.

Carranza FA. 2002. Bone Loss and Patterns of Bone Destruction. In *Carranza's Clinical Periodontology*, (9th edn), Newman MG, Takei HH, Carranza FA (eds). WB Saunders: Philadelphia; 354–370.

Cetinić Ž. 1998. *Stranče - Gorica starohrvatsko groblje*. Pomorski i povijesni muzej Hrvatskog primorja Rijeka: Rijeka.

Clarke NG, Carey SE, Sirkandi WS, Hirsch RS, Leppard PI. 1986. Periodontal disease in ancient populations. *American Journal of Physical Anthropology* **71**: 173–183.

Cortonesi A. 1981. Le spese in victualibus della Domus helemosine Sancti Petri di Roma. *Archeologia medievale* **8**: 193–225.

Cucina A, Vargiu R, Mancinelli D, Ricci R, Santandrea E, Catalano P, Coppa A. 2006. The necropolis of Vallerano (Rome, 2nd-3rd century AD): an anthropological perspective on the ancient Romans in the Suburbium. *International Journal of Osteoarchaeology* **16**: 104–117.

Del Panta L, Livi Bacci M, Pinti G, Sonnino E. 1996. *La popolazione italiana dal Medioevo ad oggi*. Editori Laterza: Bari.

Dias G, Tayles N. 1997. "Abscess cavity" – a misnomer. *International Journal of Osteoarchaeology* **7**: 545–554.

Dosi A, Schnell F. 1990. *A tavala con i Romani Antichi*. Nuova Editrice Romana: Roma.

Durman A. 2006. *Stotinu hrvatskih arheoloških nalazišta*. Leksikografski zavod Miroslav Krleža: Zagreb.

Enwonwu CO. 1995. Interface of malnutrition and periodontal diseases. *American Journal of Clinical Nutrition* **61**: 430–436.

Esclassan R, Grimoud AM, Ruas MP, Donat R, Sevin A, Astie F, Lucas S, Crubezy E. 2009. Dental caries, tooth wear and diet in an adult medieval (12th-14th century) population from mediterranean France. *Archives of Oral Biology* **54**: 287–297.

Eshed V, Gopher A, Hershkovitz I. 2006. Tooth wear and dental pathology at the advent of agriculture: new evidence from the Levant. *American Journal of Physical Anthropology* **130**: 145–159.

Garcia RI, Henshaw MM, Krall EA. 2001. Relationship between periodontal disease and systemic health. *Periodontology* **2000**(25): 21–36.

Goldstein I. 1995. *Hrvatski rani srednji vijek*. Novi Liber i Zavod za hrvatsku povijest Filozofskog fakulteta Sveučilišta u Zagrebu: Zagreb.

Gunjača S. 1973. *Ispravci i dopune starijoj Hrvatskoj historiji*. Školska knjiga: Zagreb.

Hillson S. 1979. Diet and dental disease. *World Archaeology* **11**: 147–162.

Hillson S. 1996. *Dental Anthropology*. Cambridge University Press: Cambridge.

Hillson S. 2000. Dental Pathology. In *Biological Anthropology of the Human Skeleton*, Katzenberg MA, Saunders SR (eds). Wiley-Liss: New York; 249–286.

Hillson S. 2001. Recording dental caries in archaeological human remains. *International Journal of Osteoarchaeology* **11**: 249–289.

Højgaard K. 1981. Dentition on Umm an-Nar c2500 BC. *Proceedings of the Seminar for Arabian Studies* **11**: 31–36.

Işcan MY, Loth SR, Wright RK. 1984. Age estimation from the rib by phase analysis: white males. *Journal of Forensic Sciences* **29**: 1094–1104.

Işcan MY, Loth SR, Wright RK. 1985. Age estimation from the rib by phase analysis: white females. *Journal of Forensic Sciences* **30**: 853–863.

Jurić R. 2004. Ranosrednjovjekovno groblje u Velimu kod Benkovca. *Obavijesti HAD–a* **36**: 20.

Kerr NW, Bruce MF, Cross JF. 1990. Caries in Mediaeval Scots. *American Journal of Physical Anthropology* **83**: 69–76.

Larsen CS. 1981. Skeletal and dental adaptations to the shift to agriculture on the Georgia Coast population. *Current Anthropology* **22**: 422–423.

Larsen CS. 1997. *Bioarchaeology. Interpreting behavior from the human skeleton*. Cambridge University Press: Cambridge, United Kingdom.

Larsen CS, Shavit R, Griffin MC. 1991. Dental Caries Evidence for Dietary Change: An Archaeological Context. In *Advances in Dental Anthropology*, Kelly MA, Larsen CS (eds). Wiley-Liss: New York; 179–202.

Lieverse AR. 1999. Diet and the aetiology of dental calculus. *International Journal of Osteoarchaeology* **9**: 219–232.

Lillie MC. 1996. Mesolithic and Neolithic populations of Ukraine: indications of diet from dental pathology. *Current Anthropology* **37**: 135–142.

Lillie MC, Richards M. 2000. Stable isotope analysis and dental evidence of diet at the Mesolithic-Neolithic transition in Ukraine. *Journal of Archaeological Science* **27**: 965–972.

Littleton J, Frohlich B. 1993. Fish-eaters and farmers: dental pathology in the Arabian Gulf. *American Journal of Physical Anthropology* **92**: 427–447.

Lovejoy CO, Meindl RS, Pryzbeck TR, Mensforth RP. 1985. Chronological metamorphosis of the auricular surface of the ilium: a new method for the determination of age at death. *American Journal of Physical Anthropology* **68**: 15–28.

Lukacs J. 1989. Dental Paleopathology: Methods of Reconstructing Dietary Patterns. In *Reconstruction of Life from the Skeleton*, Iscan M, Kennedy K (eds). A. R. Liss: New York; 261–286.

Maat GJR, Van der Velde EA. 1987. The caries-attrition competition. *International Journal of Anthropology* **2**: 281–292.

Manzi G, Salvadei L, Vienna A, Passarello P. 1999. Discontinuity of life conditions at the transition from the Roman Imperial age to the Early Middle Ages: example from central Italy evaluated by pathological dento–alveolar lesions. *American Journal of Human Biology* **11**: 327–341.

Mardešić J. 2004. The Burials: The Archaeological Context and the Pottery Finds. In *The Rise and Fall of an Imperial Shrine*, Marin E, Vickers M (eds). Arheološki muzej: Split; 255–264.

Mazzi MS. 1981. Consumi alimentari e malattie nel basso medioevo. *Archeologia medievale* **8**: 321–336.

Meiklejohn C, Zvelebil M. 1991. Health status of European Populations of the Agricultural Transition and the Implications for the Adoption of Farming. In *Health in Past Societies: Biocultural Interpretations of Human Remains in Archaeological Contexts*, Bush H, Zvelebil M (eds). British Archaeological Reports International Series 567: Oxford; 129–145.

Meindl RS, Lovejoy CO. 1985. Ectocranial suture closure: a revised method for the determination of skeletal age at death based on the lateral-anterior sutures. *American Journal of Physical Anthropology* **68**: 57–66.

Meinl A, Rottensteiner GM, Huber CD, Tangl S, Watzak G, Watzek G. 2009. Caries frequencies and distribution in an early medieval Avar population from Austria. *Oral Diseases Early View* published online 15 Sep 2009. DOI: 10.1111/j.1601-0825.2009.01624.x.

Molnar S, Molnar I. 1985. Observations of dental diseases among prehistoric populations in Hungary. *American Journal of Physical Anthropology* **67**: 51–63.

Oreb F, Rismondo T, Topić M. 1999. Groblje. In *Ad basilicas pictas*, Oreb F, Rismondo T, Topić M (eds). Ministarstvo kulture Uprava za zaštitu kulturne baštine: konzervatorski odjel u Splitu: Split; 51–59.

Ortner JD, Putschar WGJ. 1981. *Identification of Pathological Conditions in Human Skeletal Remains. Smithsonian Contributions to Anthropology*, 28 Smithsonian Institution Press: Washington DC.

Phenice TW. 1969. A newly developed visual method of sexing the os pubis. *American Journal of Physical Anthropology* **30**: 297–301.

Powel ML. 1985. The Analysis of Dental Wear and Caries for Dietary Reconstruction. In *The Analysis of Prehistoric Diets*, Gilbert RI, Mielke JH (eds). Academic Press: Orlando; 307–338.

Rački F. 1881. Hrvatska prije 12. vieka glede na zemljišni opseg i narod: 2. *Rad JAZU* **57**: 102–149.

Scott GR, Turner CG II. 1988. Dental anthropology. *Annual Review of Anthropology* **17**: 99–126.

Šišić F. 1925. Povijest Hrvata u vrijeme narodnih vladara. Nakladni Zavod Matice Hrvatske: Zagreb.

Šlaus M. 1997. Discriminant function sexing of fragmentary and complete femora from medieval sites in continental Croatia. *Opuscula Archaeologica* **21**: 167–175.

Šlaus M. 2008. Osteological and dental markers of health in the transition from the Late Antique to the Early Medieval period in Croatia. *American Journal of Physical Anthropology* **136**: 455–469.

Šlaus M, Tomičić Ž. 2005. Discriminant function sexing of fragmentary and complete tibiae from medieval Croatian sites. *Forensic Science International* **147**: 147–152.

Smith BH. 1984. Patterns of molar wear in hunter-gatherers and agriculturalists. *American Journal of Physical Anthropology* **63**: 39–56.

Turner CG II. 1979. Dental anthropological indications of agriculture among the Jomon people of central Japan. *American Journal of Physical Anthropology* **51**: 619–636.

Walker PL, Dean G, Shapiro P. 1991. Estimating Age from Tooth Wear in Archaeological Populations. In *Advances in Dental Anthropology*, Kelly MY, Larsen CS (eds). Wiley-Liss: New York; 169–178.

Wells C., 1982. The Human Burials. In *Romano-British cemeteries at Cirencester*, McWhirr A, Viner L Wells C, (eds). Cirencester Excavation Committee Corinium Museum: Cirencester; 135–202.

White CD 1994 Dietary Dental Pathology and Cultural Change in the Maya. In *Strength in Diversity*, Herring DA, Chan L (eds). Canadian Scholar's Press: Toronto; 279–302.

White KD. 1970. *Roman Farming*. Thames and Hudson: London.