

Comparative analysis of dental health in two archaeological populations from Croatia: the late medieval Dugopolje and early modern Vlach population from Koprivno

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Abstract

Two skeletal series from the Dalmatian hinterland were examined for six dento-alveolar pathologies: caries, ante mortem tooth loss, abscesses, calculus, alveolar resorption and tooth wear. The aim of the research was to establish to what degree differences in subsistence strategies (pastoralists vs. agriculturalists) affected dental health. The first series consists of 30 skeletons from the late medieval Dugopolje site (13th - 16th century AD), the second of 30 skeletons from the early modern Koprivno Vlach site (15th -18th century). Different subsistence strategies in these sites resulted from Ottoman military intrusions and their conquest of large parts of Croatia, the catastrophic depopulation that followed, and the subsequent settlement of a new group of peoples known as Vlachs who practiced transhumance pastoralism. The results of our analysis show higher frequencies of calculus, alveolar resorption and heavy dental wear in the Late Medieval period, while higher frequencies of antemortem tooth loss (AMTL) and abscesses were recorded in the Vlach population. Caries frequencies are almost identical in both periods. These results are consistent with the hypothesis of differing diets in the two analyzed series with more protein in the Vlach Koprivno population and more carbohydrates in the late medieval agrarian Dugopolje population. Our results also suggest significant sex differences in the diet of the Vlach population with older females perhaps having reduced access to proteins in comparison to males. Additional research on larger samples will clarify if the trends noted in this study are valid.

Keywords: dental health; bioarchaeology; endemic warfare; Croatia



Introduction

The late medieval period (1100-1400 AD) in Croatia can be described as relatively peaceful and prosperous. It was characterized by social development, the founding of new settlements, development of both local and international trade, and the arrival of new colonists from Western Europe (1). In Dalmatia, it was marked by significant changes in demography, economy and social structure but was accompanied by political instability resulting from the decline of the royal Arpad dynasty that ruled over Croatia. This state of affairs deteriorated significantly in the second half of the 14th century due to the westward expansion of the Ottoman Empire, and particularly so after 1463 when the Ottomans conquered the medieval Kingdom of Bosnia making Croatia their next target. From then on, up until 1699 when the Treaty in Karlowitz was signed, Croatia was involved in unremitting low-intensity endemic warfare against the Ottoman Empire. The main feature of this warfare were raids carried out by the *akinji* – irregular light cavalry which used hit and run guerrilla style tactics to plunder, capture prisoners that were sold into slavery, and attack trading centers and communications to prevent transportation and food supply (2). Consequently, trade, with the exception of slave trading (3) diminished and this, together with the depopulation caused by constant *akinji* raiding, significantly lowered production of all goods and services leading to the economic ruin of the land holding nobles. A total of 89 raids were recorded just from 1463-1513 (4) resulting in massive emigration to the Adriatic islands and the Apennine Peninsula. When an area was in this manner depopulated, regular elements of the Ottoman army would advance and conquer any remaining point of resistance such as fortified military outposts, and incorporate the area into the Ottoman Empire. These largely deserted areas were then settled by a new heterogeneous group of peoples known as "Vlachs" who were cattle-breeders and transhumance pastoralists from the Balkan region. These were mountain people outside of the scope of medieval feudalism, in constant conflict with the agriculturally based lowland inhabitants. For economic and strategic reasons the Ottomans entrusted them with the tasks of protecting borders and used them as auxiliary troops. The subsequent development of a centrally organized military frontier made most of their services superfluous resulting in a

marked decline of their social status. Encouraged by Habsburg authorities, and in return for military service on the other side of the border, some of these peoples defected and settled the frontier areas of Croatia that were abandoned because of incessant *akinji* raiding (5,6).

Warfare affects health not only through elevated trauma frequencies, infectious diseases, and metabolic disorders but also through dental and alveolar pathologies. Not many studies in the field of bioarchaeology focus specifically on the nutrition and dental health of archaeological populations involved in warfare, which is surprising given that human teeth, because of its mostly inorganic origin, are usually the best preserved material in the human skeleton. Through the analyses of pathologies such as caries, antemortem tooth loss (AMTL), calculus, alveolar bone resorption, periapical abscesses and tooth wear teeth provide valuable data on subsistence strategies, habitual and social behavior, dental care, diet and nutrition. Of importance is the fact that diagnosis and interpretation of dental disease in a holistic bioarchaeological context not only allows us to rebuild elements of past lives, but additionally gives us the opportunity to identify crucial changes in subsistence strategies and nutrition brought on by political, economic, social, or religious perturbations (7-11).

The aim of this study is to explore whether there are differences in the dental health and dietary habits of the inhabitants of two archaeological sites in the Dalmatian hinterland: the late medieval site Dugopolje that was inhabited from the 13th-16th century AD, and the early modern Vlach site Koprivno inhabited from the 16th-18th century AD. Although geographically near to each other and temporally continuous, these peoples lived in different political, economic, religious and social environments. The inhabitants of Dugopolje had a nutrition based primarily on different agricultural crops with some meat (12), while the Vlach inhabitants of Koprivno mostly relied on animal products for their nutrition (13, 14). Besides comparing the dental health of these two groups, this study will also try to explore possible differences between the sexes and age groups in terms of frequency of dento-alveolar pathologies. In order to accomplish this, we analyze as a pilot study, the dentitions of 30 randomly picked skeletons from each site.

Materials and methods

In this study, the dentitions of 60 adult individuals (individuals over 18 years of age) from the late medieval Dugopolje and early modern Koprivno site were examined. Both sites are located in the Dalmatian hinterland. The number of skeletons, sex distribution and sum of analyzed teeth in the series is presented in Table 1. The geographical locations of the analyzed sites are shown in Figure 1.

Dugopolje is located in the southern Croatia, 20 km north-east of Split. The late medieval cemetery located there was excavated in 2004/2005 by the Museum of Archaeological Monuments in Split under the leadership of archaeologist H. Gjurašin. A total of 362 skeletons were exhumed. The cemetery was in use from the end of the 13th to the 16th century (12). For the purpose of this study, we analyzed 30 skeletons that were randomly picked while preserving similar ratios of males vs. females and young vs. old individuals.

The village of Koprivno is located north-east of Split, and is approximately 5 km south-east of Dugopolje. The cemetery was excavated by H. Gjurašin (15) and revealed a total of 146 skeletons that were dated to the early modern period, i.e. from the 16th to 18th century. As with the previous site we analyzed 30 randomly chosen skeletons.

Sex was determined based on pelvic morphology (16). If the pelvis was poorly preserved or absent, determination of sex was based on cranial morphology (17). Adult age at death was estimated using as many methods as possible including ectocranial suture closure (18), sternal rib end changes (19, 20), pubic symphysis morphology (21), auricular surface morphology (22) and epiphyseal fusion when dealing with younger adults (23). Thickness of cortical bone, trabecular density and the presence of degenerative osteoarthritic changes on joint surfaces were also used to determine age at death. The age of adults was expressed in five-year intervals. All individuals were assigned to one of two composite age categories: younger adults aged between 18 and 35 years, and older adults comprising an open ended 36+ years age category.

In this analysis the following dento-alveolar pathologies were recorded: caries, ante-mortem tooth loss (AMTL), abscesses, calculus, alveolar bone resorption and tooth

wear. The pathologies were analyzed by teeth and/or tooth socket.

A lesion was considered to be carious only if the cavity penetrated the tooth tissue. All teeth were examined macroscopically under a bright light with the naked eye and occasional use of a magnifier. A dental probe was used to differentiate discolored enamel from carious lesions. The number of carious lesions, as well as their location (occlusal, buccal, lingual, interproximal and root) was recorded for each tooth.

Tooth loss can be classified as ante- or postmortem. A tooth was considered to be lost ante-mortem if there were evident signs of bone remodelling at the level of tooth socket (24). If there was an empty socket without evidence of healing, the tooth was considered to be lost post-mortem.

In this study, abscesses were diagnosed by the presence of a perforating fistula and a sinus in the bone at the apex of the tooth (25). Dental calculus was recorded and assigned to one of three levels (slight, moderate and severe) using criteria proposed by Brothwell (26).

A tooth was considered positive for alveolar resorption if at least a 3 mm distance was observed between the cement-enamel junction of the tooth and the alveolar bone crest. Teeth whose associated alveolar bone crests were not completely preserved, or had calculus covering the cement-enamel junction, were excluded from analysis of alveolar resorption.

Dental wear was recorded according to Smith's criteria (27) that uses an eight-stage system to describe degree of wear on teeth. In this analysis degrees of dental wear were grouped into three categories: mild (Smith degrees 1 and 2), intermediate (degrees 3 and 4) and heavy (degrees 5 to 8). Teeth were also grouped as anterior (canines and incisors) and posterior (molars and premolars). In this study, we present only the results for heavy wear (degrees 5 to 8). Teeth whose occlusal surface was destroyed by caries were excluded from this analysis.

Statistical comparisons by sex and age were conducted using the chi-square test with Yates continuity correction.

		Dugopolje			Koprivno		
		<u>Number of individuals</u>					
Age (years)	Males	Females	Total	Males	Females	Total	
18-35	6	7	13	5	9	14	
36+	8	9	17	8	8	16	
Total	14	16	30	13	17	30	
Grand total						60	
		<u>Number of teeth</u>					
Age (years)	Males	Females	Total	Males	Females	Total	
18-35	160	188	348	113	238	351	
36+	202	218	420	198	129	327	
Total	362	406	768	311	367	678	
Grand total						1446	

Table 1. The age and sex distribution in the analyzed samples



Figure 1. Map of Croatia with the geographical positions of the analyzed sites.

Results

The Dugopolje sample consists of 14 males and 16 females yielding a male/female ratio of 1:1.1 (Table 1). The young adult/old adult ratio is 1:1.3. The Koprivno sample consists of 13 males and 17 females giving a male/female ratio of 1:1.3 (Table 1).

There are no significant differences between the two composite series in terms of either the male/female or young adult/old adult ratios.

Of the 1446 permanent teeth examined in this study, 768 (53.1%) were from the Dugopolje and 678 (46.9%) from the Koprivno sample. The Dugopolje sample comprises 406 female and 362 male teeth, while the Koprivno sample is comprised of 311 male and 367 female teeth.

Dental caries

In the Dugopolje sample, caries frequencies (Table 2) are higher in males (28/362 or 7.7%) than in females (20/406 or 4.9%), but the difference is not statistically significant ($\chi^2 = 2.119$; $P = 0.145$). At the level of the total sample, the frequency of carious lesions is higher in older than in younger individuals, but this difference is also not significant ($\chi^2 = 2.472$; $P = 0.116$). In the male subsample younger males exhibit a higher frequency of carious lesions (13/160 or 8.1%) than older males (15/202 or 7.4%) without achieving statistical significance while the female subsample follows the general trend of significantly higher caries frequencies in older individuals (7.8% vs. 1.6%; $\chi^2 = 7.02$, $P = 0.008$). Younger males in the series exhibit significantly higher frequencies of caries than younger females ($\chi^2 = 6.978$; $P = 0.008$).

Caries frequencies in Koprivno are almost identical in males and females (6.4% compared to 6.3%). Both males and females in the sample exhibit higher caries frequencies in the older age group. Older females exhibit significantly higher frequency of caries than younger females (16.3% compared to 0.8%; $\chi^2 = 31.367$, $P < 0.0001$). Males also exhibit higher frequency of carious lesions in older age category but this is not statistically significant (8.1% vs. 3.5%; $\chi^2 = 1.768$, $P = 0.184$). Of interest is the fact that older females exhibit significantly higher frequencies of caries than older males ($\chi^2 = 4.447$; $P = 0.003$). At the level of the total sample, the frequency of carious lesions is higher in older individuals ($\chi^2 = 24.704$; $P < 0.001$).

Comparative analysis (Table 3) shows that, at the level of complete samples, there are no differences in caries frequencies between the two samples (48/768 or 6.2% in Dugopolje

sample compared to 43/678 or 6.3% in Koprivno sample). The analysis also shows that younger adults from Dugopolje exhibit significantly higher frequencies of caries than younger adults from Koprivno ($\chi^2 = 3.882$, $P = 0.049$). Older females from Koprivno exhibit significantly higher frequencies of caries than those from Dugopolje ($\chi^2 = 5.139$, $P = 0.023$). Comparative analyses by sex show that males from Dugopolje exhibit higher caries frequencies than males from Koprivno (7.7% vs. 6.4%), while in females the trend is reversed, 4.9% of females from Dugopolje exhibit carious lesions compared to 6.3% of females from Koprivno.

AMTL

AMTL frequencies (Table 2.) in the Dugopolje sample are higher in females (26/509 or 5.1%) than in males (15/440 or 3.4%) but the difference is not significant ($\chi^2 = 1.263$; $P = 0.261$). At the level of the total sample, the frequency of AMTL is significantly higher in older individuals (6.9% vs. 1.0%; $\chi^2 = 18.355$; $P = 0.00002$).

In Koprivno, females exhibit significantly higher AMTL frequency than males (55/526 or 10.4% vs. 20/398 or 5.0%; $\chi^2 = 8.248$; $P = 0.004$), mostly because of the high frequency of AMTL in older females. In both sexes, AMTL frequencies are significantly higher in older age categories ($\chi^2 = 7.394$, $P = 0.006$ for males, and $\chi^2 = 58.97$, $P = 0$ for females).

Comparisons between the series (Table 3) at the level of complete samples show significantly higher total frequencies of AMTL in Koprivno than in Dugopolje (8.1% vs. 4.3%; $\chi^2 = 10.971$, $P = 0.0009$). When controlling for sex, no differences are noted in the male subsample, while females from Koprivno exhibit higher frequencies than those from Dugopolje (10.4% vs. 5.1%; $\chi^2 = 9.529$, $P = 0.002$) which is primarily the result of the significantly higher AMTL frequencies in older females from Koprivno compared to older females from Dugopolje (21.6% vs. 8.7%; $\chi^2 = 16.486$, $P = 0.00005$). Possibly because of this reason, at the level of complete samples, older adults from Koprivno exhibit significantly higher frequencies of AMTL than older adults from Dugopolje (14.4% vs. 6.9%; $\chi^2 = 14.736$, $P = 0.0001$).

Abscesses

Abscesses frequencies in Dugopolje are higher in males than in females (2.0% vs. 1.4%) without achieving statistical significance. In

both sexes, frequencies are significantly higher in older age categories ($\chi^2 = 5.245$, $P = 0.022$ for males and $\chi^2 = 3.877$, $P = 0.05$ for females). In Koprivno females show higher abscesses frequencies than males (3.0% vs. 2.5%), again without achieving statistical significance. As in Dugopolje, both sexes exhibit significantly higher abscesses frequencies in the older age category (males: $\chi^2 = 4.263$, $P = 0.039$; females: $\chi^2 = 9.474$, $P = 0.002$).

At the level of total samples there are no significant differences in abscess frequencies between the series.

Calculus

In Dugopolje males and females exhibit similar calculus frequencies (95.5% vs. 96.5%). Calculus frequencies in males are higher in the younger age category without achieving significance, while in females calculus frequencies are significantly higher in the older age category (100% vs. 92.6%; $\chi^2 = 14.3$, $P = 0.0001$). Male/female differences are significant in the older adult subsample where females exhibit significantly higher frequencies than males (213/213 or 100% vs. 187/197 or 95%, $\chi^2 = 9.052$, $P = 0.003$). At the level of the complete sample, older adults exhibit significantly higher calculus frequencies than younger adults ($\chi^2 = 4.584$, $P = 0.032$).

Calculus frequencies in Koprivno are higher in males than females (95.4% vs. 93.8%) without achieving significance ($\chi^2 = 0.035$, $P = 0.851$). In both sexes, calculus frequencies are significantly higher in older adults (males: $\chi^2 = 0.028$, $P = 0.867$; females: $\chi^2 = 5.495$, $P = 0.019$) but, as in Dugopolje, only in females is the difference significant. At the level of the complete sample older individuals exhibit significantly higher calculus frequencies than younger ones ($\chi^2 = 5.094$, $P = 0.024$).

Comparisons between Dugopolje and Koprivno at the level of complete samples (Table 3) show higher calculus rates in Dugopolje without achieving statistical significance ($\chi^2 = 1.429$, $P = 0.232$). Analysis of calculus by severity (Table 4) shows that calculus level 1 has similar rates in both series (95.4% vs. 94.6%), while calculus level 2 is present only in the Dugopolje series (5/758 or 0.6%). Calculus level 3 was not recorded in either series.

Alveolar resorption

In the Dugopolje series, alveolar resorption rates are identical in males and females (83/243 or 34.2% in males and 91/266 or 34.2% in females). Older individuals in both

sexes exhibit significantly higher alveolar resorption frequencies than younger individuals (in males: $\chi^2 = 19.865$, $P < 0.0001$; in females: $\chi^2 = 48.997$, $P < 0.0001$) and this trend is also evident at the level of the total sample ($\chi^2 = 67.664$, $P < 0.0001$).

Alveolar resorption frequencies in Koprivno are higher in females (50/231 or 21.6%) than in males (33/169 or 19.5%) but the difference is not significant ($\chi^2 = 0.153$, $P = 0.696$). Once again, in both sexes, alveolar resorption rates are significantly higher in the older age category (in males: $\chi^2 = 11.477$, $P = 0.0007$, in females: $\chi^2 = 115.053$, $P < 0.0001$). The frequency is also significantly higher in the older age category at the level of the complete sample ($\chi^2 = 79.874$, $P < 0.0001$).

Comparisons between the series (Table 3) show significantly higher alveolar resorption rates in Dugopolje in all age and sex categories except for older females.

Wear

Heavy wear was analyzed in 755/768 permanent teeth from Dugopolje that have preserved occlusal surfaces (98.3% of the complete sample) and in 661/678 (or 97.5%) permanent teeth from Koprivno.

At the level of complete samples (Table 5), the frequency of heavy tooth wear (wear equivalent to or greater than Smith's stage 5) is significantly higher in Dugopolje (22.0% vs. 14.9%; $\chi^2 = 11.302$, $P = 0.0008$). In the Dugopolje sample, males and females exhibit similar heavy wear frequencies (22.4% vs. 21.6%; $\chi^2 = 0.024$, $P = 0.877$) while in Koprivno, males exhibit significantly higher heavy wear than females (21.0% vs. 10.6%; $\chi^2 = 12.844$, $P = 0.0003$). In both series heavy wear frequencies are significantly higher in the older age category (for males from Dugopolje $\chi^2 = 77.454$, $P < 0.0001$; for females from Dugopolje $\chi^2 = 61.042$, $P < 0.0001$; for males from Koprivno $\chi^2 = 19.811$, $P < 0.0001$; for females from Koprivno $\chi^2 = 78.674$, $P < 0.0001$). In Koprivno younger males exhibit higher heavy wear than younger females ($\chi^2 = 14.022$, $P = 0.0002$). There is a significant difference in wear frequencies when comparing younger males— heavy wear in Koprivno is significantly more prevalent than heavy wear in Dugopolje ($\chi^2 = 6.749$, $P = 0.009$). When comparing older males the trend is reversed, males from Dugopolje exhibit more heavy wear than those from Koprivno ($\chi^2 = 4.725$, $P = 0.029$). The same trend is noted in younger females – females from Dugopolje have more heavy

wear than those from Koprivno ($\chi^2 = 8.028$, $P = 0.005$).

When heavy wear is analyzed by upper and lower jaws, as well as by anterior and posterior teeth (Table 6), 13 significant differences between Dugopolje and Koprivno are noted with 10/13 differences resulting from significantly higher heavy wear in the Dugopolje series. This is particularly evident in the posterior dentition where individuals from Dugopolje exhibit significantly higher rates of heavy wear in younger, older and total adult frequencies than those from Koprivno. Also of interest is the fact that in Dugopolje anterior and posterior teeth exhibit almost identical rates of heavy wear (22.1% vs. 22.3%), while in Koprivno anterior teeth exhibit significantly higher heavy wear rates than posterior teeth (19.9% vs. 12.8%; $\chi^2 = 5.511$, $P = 0.019$).

Discussion

Analyses of dental pathology frequencies in two archaeological series, one dating to the late medieval, and the other to the early modern period in Croatia indicate higher frequencies of calculus, alveolar resorption, and heavy dental wear in the late medieval period, while higher frequencies of AMTL and abscesses were recorded in the early modern period.

Caries frequencies are virtually identical in both periods. While the direct association between diet and calculus is not yet clearly understood, calculus depositions on teeth are important for reconstructing the dietary habits and nutrition of archaeological populations. High calculus rates have been recorded in both high carbohydrate, and high protein diets (28–30). This results from the fact that calculus formation is influenced by both dietary and non-dietary factors (31). Non-dietary factors include the mineral content of drinking water, rate of salivary flow, poor oral hygiene, culturally derived patterns of behavior, and the utilization of teeth as tools (29). In both series, males and females exhibit similar calculus frequencies suggesting both sexes consumed the same types of food and were exposed to the same kinds of non-dietary factors influencing calculus formation. The Dugopolje sample does, however, exhibit higher calculus rates at the level of complete samples than Koprivno.

Age	Dugopolje						Koprivno					
	Males	%	Females	%	Total	%	Males	%	Females	%	Total	%
<u>Dental caries</u>												
≤35	13/160	8.1	3/188	1.6	16/348	4.6	4/113	3.5	2/238	0.8	6/351	1.7
36+	15/202	7.4	17/218	7.8	32/420	7.6	16/198	8.1	21/129	16.3	37/327	11.3
Total	28/362	7.7	20/406	4.9	48/768	6.2	20/311	6.4	23/367	6.3	43/678	6.3
<u>AMTL</u>												
≤35	3/189	1.6	1/223	0.4	4/412	1.0	1/143	0.7	2/281	0.7	3/424	0.7
36+	12/251	4.8	25/286	8.7	37/537	6.9	19/255	7.4	53/245	21.6	72/500	14.4
Total	15/440	3.4	26/509	5.1	41/949	4.3	20/398	5.0	55/526	10.4	75/924	8.1
<u>Abscesses</u>												
≤35	0/189	0.0	0/223	0.0	0/412	0.0	0/143	0.0	2/281	0.7	2/424	0.5
36+	9/251	3.6	7/286	2.4	16/537	3.0	10/255	3.9	14/245	5.7	24/500	4.8
Total	9/440	2.0	7/509	1.4	16/949	1.7	10/398	2.5	16/526	3.0	26/924	2.8
<u>Calculus</u>												
≤35	154/160	96.2	174/188	92.6	328/348	94.2	107/113	94.7	215/235	91.5	322/348	92.5
36+	187/197	95.0	213/213	100.0	400/410	97.6	183/191	95.8	121/123	98.4	304/314	96.8
Total	341/357	95.5	387/401	96.5	728/758	96.0	290/304	95.4	336/358	93.8	626/662	94.6
<u>Alveolar resorption</u>												
≤35	23/117	19.6	20/139	14.4	43/256	16.8	1/48	2.1	9/176	5.1	10/224	4.5
36+	60/126	47.6	71/127	55.9	131/253	51.8	32/121	26.4	41/55	74.5	73/176	41.5
Total	83/243	34.2	91/266	34.2	174/509	34.2	33/169	19.5	50/231	21.6	83/400	20.7

Table 2. Frequencies of dental and periodontal pathologies in Dugopolje and Koprivno samples by age and sex

Dental feature	Dugopolje vs. Koprivno males			Dugopolje vs. Koprivno females			Dugopolje vs. Koprivno total		
	N	χ^2	P	N	χ^2	P	N	χ^2	P
<u>Dental caries</u>									
≤35	273	1.664	0.197	426	0.071	0.790	699	3.882	0.049*
36+	400	0.003	0.956	347	5.139	0.023 ^Δ	747	2.571	0.109
Total	673	0.255	0.613	773	0.429	0.512	1446	0.001	0.975
<u>AMTL</u>									
≤35	332	0.051	0.821	504	0.041	0.839	836	0.001	0.975
36+	506	1.138	0.286	531	16.486	0.00005 ^Δ	1037	14.736	0.0001 ^Δ
Total	838	0.99	0.319	1035	9.529	0.002 ^Δ	1873	10.971	0.0009 ^Δ
<u>Abscesses</u>									
≤35	332	-	-	504	0.302	0.583	836	0.473	0.492
36+	506	0.001	0.975	531	2.897	0.089	1037	1.849	0.174
Total	838	0.049	0.825	1035	2.584	0.108	1873	2.227	0.136
<u>Calculus</u>									
≤35	273	0.102	0.749	423	0.048	0.826	696	0.582	0.445
36+	388	0.03	0.862	336	1.278	0.258	724	0.143	0.705
Total	661	0.012	0.913	759	2.39	0.122	1420	1.429	0.232
<u>Alveolar resorption</u>									
≤35	165	7.103	0.008*	315	6.922	0.008*	480	17.264	0.00003*
36+	247	10.95	0.001*	182	4.874	0.027 ^Δ	429	4.013	0.045*
Total	412	9.836	0.002*	497	8.998	0.003*	909	19.278	0.00001*

* Differences between Dugopolje and Koprivno samples are the result of significantly higher frequencies in Dugopolje

Δ Differences between Dugopolje and Koprivno samples are the result of significantly higher frequencies in Koprivno

Table 3. Comparisons of occurrence of dental features in the analyzed samples

Series	N of teeth affected				Calculus rates (%)				
	1 ^a	2	3	Sum	1	2	3	Total	Total ^b
Late Medi.	723	5	0	728	95.4	0.6	0.0	96.0	758
Early Mod.	626	0	0	626	94.6	0.0	0.0	94.6	662

^a Calculus levels 1-3 according to Brothwell (1981); 1 = slight; 2 = moderate; 3 = severe.

^b Total number of teeth examined

Table 4. Calculus by severity in the Dugopolje and Koprivno samples

Age	Dugopolje						Koprivno					
	Males	%	Females	%	Total	%	Males	%	Females	%	Total	%
Maxilla												
18-35	0/79	0.0	4/93	4.3	4/172	2.3	5/48	10.4	0/117	0.0	5/165	3.0
36+	41/98	41.8	33/107	30.8	74/205	36.1	18/85	21.2	9/39	23.1	27/124	21.8
Total	41/177	23.2	37/200	18.5	78/377	20.7	23/133	17.3	9/156	5.8	32/289	11.1
Mandible												
18-35	1/81	1.2	4/95	4.2	5/176	2.8	3/65	4.6	0/118	0.0	3/183	1.6
36+	37/95	38.9	46/107	43.0	83/202	41.1	38/106	35.8	29/83	34.9	67/189	35.4
Total	38/176	21.6	50/202	24.7	88/378	23.3	41/171	24.0	29/201	14.4	70/372	18.8
Anterior teeth												
18-35	0/51	0.0	0/67	0.0	0/118	0.0	6/37	16.2	0/78	0.0	6/115	5.2
36+	32/69	46.4	28/84	33.3	60/153	39.2	23/74	31.1	20/57	35.1	43/131	32.8
Total	32/120	16.7	28/151	18.5	60/271	22.1	29/111	26.1	20/135	14.8	49/246	19.9
Posterior teeth												
18-35	1/109	0.9	9/121	7.4	10/230	4.3	2/76	2.6	0/157	0.0	2/233	0.8
36+	47/124	37.9	51/130	39.2	98/254	38.6	33/117	28.2	18/65	27.7	51/182	28.0
Total	48/233	20.6	60/251	23.9	108/484	22.3	35/193	18.1	18/222	8.1	53/415	12.8

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

Tooth wear	Dugopolje vs. Koprivno males			Dugopolje vs. Koprivno females			Dugopolje vs. Koprivno total		
	N	χ^2	P	N	χ^2	P	N	χ^2	P
Maxilla									
18-35	127	6.034	0.014 ^Δ	210	3.086	0.079	337	0.004	0.949
36+	183	7.973	0.005*	146	0.505	0.477	329	6.793	0.009*
Total	310	1.259	0.262	356	11.518	0.0007*	666	10.287	0.001*
Mandible									
18-35	146	0.538	0.463	213	3.036	0.081	359	0.171	0.679
36+	201	0.094	0.759	190	0.953	0.329	391	1.086	0.297
Total	347	0.161	0.688	403	6.175	0.013*	750	1.986	0.159
Anterior teeth									
18-35	88	6.507	0.011 ^Δ	145	-	-	233	4.411	0.036 ^Δ
36+	143	2.913	0.088	141	0.001	0.975	284	0.986	0.321
Total	231	0.003	0.956	286	0.468	0.494	517	0.261	0.609
Posterior teeth									
18-35	185	0.1	0.752	278	9.811	0.002*	463	4.286	0.038*
36+	241	2.135	0.144	195	2.044	0.153	436	4.798	0.028*
Total	426	0.267	0.605	473	20.214	0.000007*	899	13.199	0.0003*

* Differences between the Dugopolje and Koprivno samples are the result of significantly higher frequencies in Dugopolje.

^Δ Differences between Dugopolje and Koprivno samples are the result of significantly higher frequencies in Koprivno sample

Table 6. Comparisons of occurrence of heavy tooth wear in the analyzed series

Dental wear rates are multifactorial and depend on numerous factors including consistency and texture of food, different food preparation techniques, as well as the sex and age of consumers (32, 33). Heavy wear is significantly more prevalent in Dugopolje suggesting that the past inhabitants of Dugopolje had a diet different to that of the inhabitants of Koprivno, more precisely, a diet that contained more abrasive, fibrous foods that required vigorous mastication. In Dugopolje heavy wear is similar in anterior and posterior dentition unlike in Koprivno where heavy wear is significantly higher in the anterior dentition. This is an uncommon finding as posterior teeth are used to grind food while anterior teeth are used to cut pieces small enough for mastication. This may suggest that non-dietary factors played an important role in the increased attrition noted in the anterior teeth. Potential activities responsible for this include preparation and treatment of animal hides and processing branches for weaving baskets or fences, all activities that have been recorded in Koprivno in various historical and ethno-historical sources (34-36). As young males in Koprivno exhibit significantly higher heavy wear frequencies than young females, both in anterior and posterior dentition, they may have been the ones primarily involved in these activities.

Alveolar resorption rates are also significantly higher in Dugopolje. Alveolar resorption can be caused by dietary, hygienic, environmental and genetic components. It can also result from other diseases such as scurvy, diabetes, immunodeficiency diseases, generalized malnutrition and chronic occlusal trauma (37-39). Clarke et al. (40) have noted that the most common causes of alveolar resorption in archaeological populations are factors such as heavy attrition (resulting from occlusal trauma), pulp damage, infection, mineral imbalance and to a lesser extent, bacterial plaque, whether in the form of dental calculus or not. Furthermore, one of the most important factors for alveolar resorption development is the age of the individual since the prevalence of this pathology increases with age. As our analyses have shown that rates of both heavy wear and calculus are higher in the Dugopolje sample, it would appear that those two pathologies were the main contributors to alveolar resorption during the late medieval period. This is

consistent with the other data suggesting a high carbohydrate/low protein diet which required vigorous mastication causing occlusal trauma during the late medieval period.

As previously mentioned, caries frequencies at the level of complete samples are almost identical in the series. Generally speaking high caries rates result from diets high in carbohydrates, while low caries rates point to low carbohydrate/high protein diets. The reason for this is that micro-organisms in the bacterial plaque metabolize carbohydrates, thus lowering the pH of the oral cavity, and favoring the destruction of the hard tissues of the tooth (41). Other factors affecting caries rates are mouth acidity (alkaline), and fluoride levels in the water (42). In both series, carious lesions are more common in the posterior dentition. This trend has previously been noted in numerous studies (10, 43-45, as well as numerous others) and 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 (41). Careful analyses by sex and age reveal that while there are no significant differences at the level of complete samples in caries frequencies, important sex differences are present in the Koprivno series. While male/females caries frequencies in all age categories are similar in Dugopolje, the Koprivno series exhibits a significant sex difference in caries frequencies in older individuals. Older females from Koprivno exhibit significantly higher caries frequencies than older males suggesting differing diets with males consuming more proteins and females more carbohydrates in this site.

Penetrating and destructive carious lesions with pulp cavity exposure, heavy wear, and trauma are the most common etiologic factors for abscess development in past populations (46,47). Abscess frequencies are slightly higher in the Koprivno sample and, once again, older females exhibit significantly higher rates than older males in this sample. This is consistent with the higher caries rates recorded in older females from this series. It is important to remember that only macroscopic analyses were conducted in this study so abscess frequencies are in both series most likely underestimated. In both series, abscess rates are significantly higher in the older age

category reflecting the progressive deterioration of the tooth. Caries may appear at a young age but it requires time to invade the pulp cavity and cause an abscess (48). Similarly, time plays an important role if heavy wear is to result in pulp exposure and the onset of abscesses (49).

Abscesses, caries and the other dento-alveolar pathologies analyzed in this study are potential causes of AMTL, as also are trauma and metabolic diseases such as scurvy (24,50). Our analyses show that AMTL frequencies are significantly higher in Koprivno which is consistent with the higher abscess rates recorded in this series. Also, as noted before, significantly higher caries rates in older females resulting from possible sex differences in the diet of the past inhabitants of Koprivno most likely played an important role in the considerably higher female AMTL frequency recorded in this series and this no doubt affected total AMTL rates in Koprivno. Another non-pathological cause for higher AMTL rates in the early modern Koprivno series may be the development of dentistry. From the middle of the 15th century individual doctors started practicing dentistry in Croatia (51) while from the middle of the 17th century some Adriatic towns (Dubrovnik and Zadar for certain) have permanently employed doctors and dentists (52,51). Some of them may have passed across the border and practiced in Koprivno. As they had no knowledge or means to treat severe carious lesions, it is possible that they simply extracted them (51) thus elevating AMTL rates in Koprivno.

Conclusion

In conclusion, the results of this analysis, performed on a limited sample, suggest differing diets in the two analyzed

archaeological series with more protein in the Vlach Koprivno population and more carbohydrates in the late medieval agrarian Dugopolje population. Our results also suggest significant sex differences in the diet of the Vlach population with older females perhaps having reduced access to proteins in comparison to males. Additional research on larger samples will clarify if the trends noted in this study are valid.

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