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Analysis and comparison of tooth wear in late antiquity and early middle age in populations that lived in continental and coastal Croatia using digitized VistaMetrix method

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KEYWORDS

Tooth wear;
Dental age;
Tooth attrition;
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ABSTRACT

Background: Tooth wear is a non-pathological loss of hard tissues on the incisal and occlusal tooth surface. In archaeology, the loss of dental tissue through attrition is associated with living opportunities and habits, availability, characteristics and methods of food preparation. In forensics, tooth wear is used to estimate the dental age on cadavers. Material and methods: For this study, we used an archaeological sample from two sample collections. In this study, tooth wear was compared in archaeological samples of well-preserved maxilla and mandible specimens (n=392) from Croatian coastal and continental populations from Late Antiquity (LA) and the Early Middle Ages (EMA). The computer system VistaMetrix 1.38 was used to analyse the abrasion and attrition of hard dental tissues. The Shapiro-Wilk and chi-square tests were performed for categorical data to test the difference between two historical periods and two geographical locations, while the Kruskal-Wallis test was performed for continuous data. Results: There was a statistically significant difference in the proportion of tooth wear in total teeth area ($P < 0.001$) when comparing continental and coastal Croatia in LA and coastal Croatia between LA and EMA ($P = 0.006$ and $P < 0.001$, respectively). Samples from coastal Croatia from the LA period had the lowest percentage of tooth wear with a median of 8.35%, while samples from coastal Croatia from the EMA had the highest percentage of tooth wear with a median of 18.26%. Our results generally show greater tooth wear in the EMA period in male subjects.Conclusion: The results of the tooth wear research obtained with the Vista Metrix software can contribute to the study of life circumstances and changes that the analysed population has experienced in its historical development.

INTRODUCTION

One of the methods used to assess dental age is to analyse tooth wear. It can be used after the age of 20, when the teeth begin to wear on the occlusal surfaces and incisal edges due to their function. Tooth wear analysis is regularly used in forensic and archaeological analyses. [1,2] During lifetime, tooth enamel is subject to wear due to physical and mechanical influences, which is known as tooth abrasion. This phenomenon is known as tooth wear. It occurs during the chewing of food and can occur in varying degrees and patterns. The horizontal form of enamel abrasion is more common and affects the incisal edges and occlusal surfaces of premolars and molars, while vertical enamel abrasion occurs on the vertical surface of the teeth, particularly the incisors. [3-6] In contrast to abrasion of the enamel, attrition means the gradual and regular loss or physiological deterioration of tooth structures without the action of abrasive agents. These changes can be a reliable indicator of the lifestyle and dietary habits of a certain population. Frequent consumption of solid foods increases abrasion and tooth wear is more pronounced. The abrasion angle can also provide important information about the lifestyle of a particular population. For example, straight abrasion is characteristic of hunting and harvesting populations, while the dentition of those engaged in agriculture is characterised by oblique abrasion. [7] In previous studies, tooth wear has been used as one of the parameters for age estimation or to distinguish samples from different historical periods. [8,9] However, it is mainly assessed using visual scales that determine tooth wear according to the complex stages of tooth tissue involvement.

Insights into historical periods, lifestyles, political and religious aspects, art, philosophy, economics and other aspects of society can be obtained by applying modern multidisciplinary techniques. [10] The material heritage provides a rich source of information. In addition to buildings, weapons, tools, jewellery and art, skeletal remains such as teeth are also a source of information as they record the life experience of an individual. [11] They can provide information about living conditions, eating habits, work activities, dental and general health. Changes in the orofacial system, such as dental caries, loss of hard dental tissues due to abrasion and wear, as well as changes in the alveolar bone and orthodontic anomalies, are very useful for analysing and reconstructing the lives of people from different historical periods. [12, 13] Human teeth from individuals of different ages at the time of death can be preserved for thousands of years. Therefore, the dentition and teeth are often the subject of research in bioarchaeology and palaeostomatology and are used in forensic sciences. [14, 15] Analysing bone remains of the jaw and preserved teeth, including a detailed diagnosis and interpretation of diseases of the dentition itself and the dental system, can help in reconstructing the way of life of ancient people. They can also provide information about the type and origin of the food that ancient people consumed. [16] In addition, a careful and detailed examination of the oral cavity and teeth can reveal many details about a person's health status, work activities and lifestyle, which is extremely important for forensic odontology. [17]

The difference in diet between the two historical periods, Late Antiquity (LA) and the Early Middle Ages (EMA), is probably reflected in the loss of hard tissue. The consumption of various vegetables and fruits characterises the LA period. The diet included many raw fruits and nuts, which have an abrasive potential. People in LA also consumed different types of meat, which required vigorous chewing. In contrast, the diet in EMA was generally much milder and consisted of grains and other carbohydrate-rich foods, while meat and protein-rich foods were rare. Consumption of such food did not require vigorous chewing, which is reflected in the lower amount of tooth wear in samples from EMA compared to those from LA. [18, 19]

Some professional activities also leave traces in the oral cavity and on the teeth. Mechanical, chemical and thermal injuries to the mucosa and hard dental tissues are often the result of performing certain activities. [10] For example, professional brass players and craftsmen such as glass blowers, fish net makers, carpenters and tailors may have characteristic mechanical damage on their teeth due to gripping objects between their teeth during their daily work. [19]

This research is based on well-preserved osteological collections of known sex and skeletal age owned by the Croatian Academy of Sciences and Arts.

The aim of this study was to analyse and compare tooth wear in two different historical periods, LA and EMA, in populations living in two different geographical locations, the continental and the Croatian coastal area, using the new digitised VistaMetrix method.

Based on the obtained results, the possibility of their use for dental age estimation in forensic and archaeological research will be determined.

MATERIALS AND METHODS

Samples

Skeletal remains curated in the Osteological Collection of the Croatian Academy of Sciences and Arts (HAZU) were used in this study. This research was approved by the Ethics Committee of the School of Dental Medicine, the University of Zagreb, at the 18th regular session held on June 4th 2020, decision number 05-PA-30-XVIII-6/2020. The samples originate from seven archaeological sites in Croatia, four from inland (continental) and three from coastal regions of Croatia and belong to two historical periods: Late Antiquity (LA) and Early Middle ages (EMA).

The remains from the LA period originate from four inland (Zmajevac, Štrbinci, Osijek, and Vinkovci) and one coastal site (Zadar). The EMA samples were from one coastal site – (Velim Velištak) and one continental site (Radašinovci). From each of the sites, a number of skeletons were picked as a random sample to represent all of the sites equally.

The sex and osseal age were determined for each skeleton on the basis of the skeletal bones. This data comes from the archives of the Croatian Academy of Sciences and Arts. On the basis of this data, the examined sample according was staratified to sex (male and female) and three age groups: young age (18-30 years), middle age (30-50 years) and old age (50 and older).

The sample consisted of 130 remains of male and 75 remains of female skeletons from all the sites and both historical periods. Regarding the exact anatomical structure, 182 maxillary remains and 210 mandibular remains were included in the sample.

Unfortunately, due to the relatively poor preservation skulls of the individuals under 15 years old, and the impossibility of performing measurements, only teeth and skulls from adults were used in this analysis.

Digital photographs of the maxillary and mandibular remains were made with a LUMIX DMC-TZ50 photo camera (Panasonic, Osaka, Japan) at a 90-degree angle. A 1cm calibrated scale was included in each photography. All jaw samples were occlusally photographed with the help of a fixed camera holder at the same distance. With the help of a lens (85 mm : 3,5 G ED), and a circular flash (Sigma EM-140 DG), the recording was performed by one researcher (M.V.). Resolution and file format of the images acquired was 300dpi, 24 million pixels, Figure 1.

The measurements were taken from 392 photographs of teeth and jaw specimens using the VistaMetrix 1.38 computer system (SkillCrest LLC, Tucson AZ, USA).

Regarding the teeth, only the teeth present in the maxillary and mandibular remains were included in the study. Excluding factors were the teeth lost ante and post-mortem and teeth lost

Figure 1. Schematic representation of the recording of occlusal surfaces of skeletal remains in this research

during the archaeological excavation process. Since this study aimed to analyze tooth wear, teeth affected with severe carious lesions were also excluded, which brings the total number of excluded teeth to 1563 of all teeth from all maxillar and mandibular remains. Regarding the historical periods, the LA period had 739 lost and 26 caries-affected teeth, while the EMA period had 748 lost and 40 caries-affected teeth.

The study included 4408 teeth, of which 1545 molars, 1224 premolars, 647 canines, and 992 incisors.

The computer system VistaMetrix 1.38 consists of a transparent pattern overlaid with a photography or material to be edited and contains a measurement toolbar (Figure 2). VistaMetrix 1.38 allows quantitative measuring on digital images to obtain metric data and differs from the standard methods of qualitative evaluation of tooth wear.

In our study, tooth wear was analysed as the main parameter, and the involvement of hard dental tissues was measured objectively and precisely using computer software. One examiner (A. D.) analyzed all photographs using the VistaMetrix 1.38 software for one month.

Analysis of digital photographs included measurements of areas on each tooth of each sample of maxillary and mandibular remains.

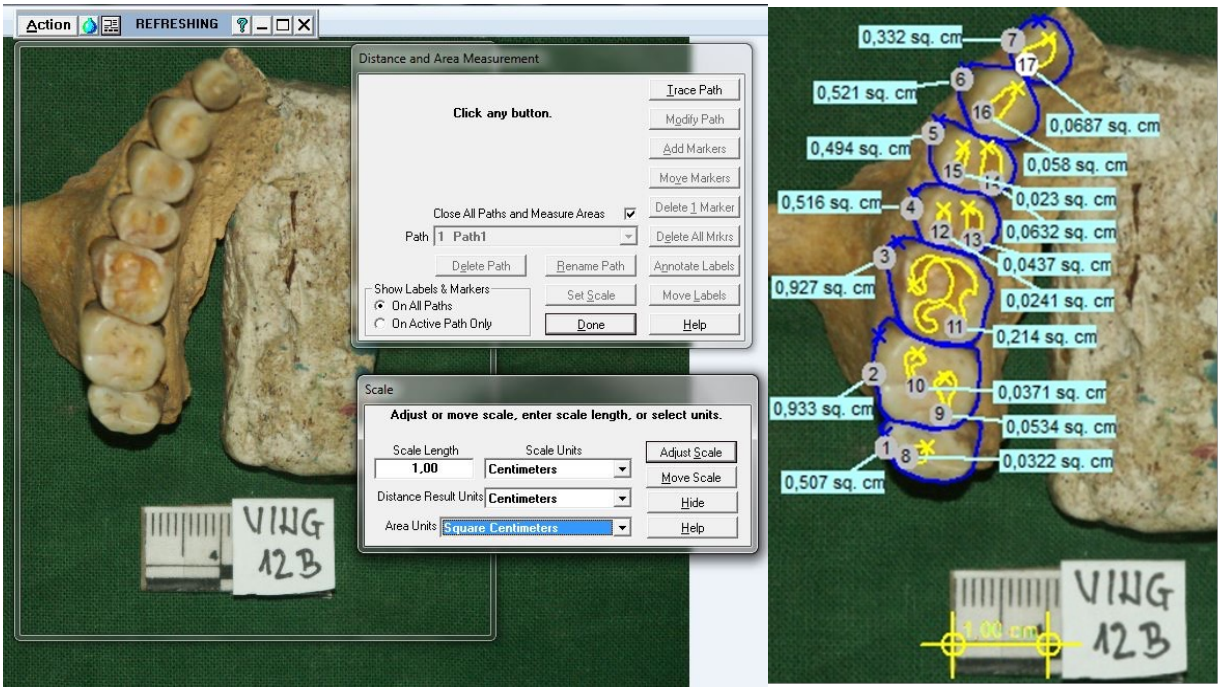
First, using VistaMetrix 1.38 software, the visible biting surfaces of the posterior teeth and the incisal edges of the anterior teeth were marked; they included all visible surfaces of the teeth above the alveolar bone. A blue line bounds each surface. The computer program records the bounded area in cm^2.

Then, on the same teeth, measurements are performed on surfaces that show signs of tooth wear by abrasion or attrition. A yellow line bounds such places, and their surface was also expressed in cm^2. If there is no visible loss of hard dental tissues on the tooth, it was recorded in the photograph with a dot, and in the data analysis, it was expressed as 0 cm^2. Finally, if there are two different tooth wear surfaces on one tooth, they are recorded separately in the photograph, and in the data analysis, such surfaces were added up for individual teeth (Figure 2).

To determine the inter- and intra-examiner agreements, two experienced and well-trained dentists (A. D., H. B.) evaluated the photographs. Before beginning the study, each examiner evaluated 40 randomly selected photography twice at different times to calibrate the methods and examiners.

In addition, 10% randomly selected one month after the initial evaluation were assessed by both examiners twice, one week apart.

Figure 2. Analyzed photography using VistaMetrix 1.38 computer software (SkillCrest LLC, Tucson AZ, USA)



All the obtained data is summarised in an Excel spreadsheet.

For the statistical analysis, we subdivided the sample according to gender, historical period and geographical location. With regard to the known skeletal age, we divided the sample into younger, middle and older ages.

The total tooth surfaces and the surfaces of tooth wear determined in this way are compared with each other in order to determine the differences in tooth wear between the sexes, historical periods, geographical locations and age groups.

Statistical analysis

All statistics were performed with R v3.2.2. (Team RC. R: A language and environment for statistical computing. Vienna, Austria 2013). The normal distribution of the continuous variables was first tested using the Shapiro-Wilk test. As not all variables followed a normal distribution, the results were presented as medians with the interquartile range (IQR). Subsequently, the $\chi 2$ test was performed for categorical data to test the difference between two historical periods and two geographical locations, while the Kruskal-Wallis test was performed for continuous data.

For significant associations, Dunn's post hoc tests were performed for multiple pairwise comparisons. The level of statistical significance was defined as $P < 0.05$. The interclass correlation coefficient (ICC) was used to determine agreement between and within investigators

RESULTS

Our results showed that there were no statistically significant differences between the two historical periods and geographical locations in terms of sex and estimated skeletal age (P = 0.115 and P = 0.174, respectively). However, when the sample was divided into three age groups: young age, middle age and old age, there was a statistically significant difference in EMA between continental and coastal samples, with the majority of samples in coastal Croatia estimated to be middle-aged, while in continental Croatia the majority of samples belonged to a younger group (post hoc = 0.005) (Table 1).

Table 1. Distribution of jaw remains by sex and estimated skeletal age depending on historical period and geographical location

	Total	Late Antiquity (LA)		Early Middle Ages (EMA)		P*
		Continental (N = 94)	Coastal (N = 35)	Continental (N =32)	Coastal (N = 44)	
Sex, N (%)						
Male	130 (63.41)	57 (60.64)	28 (80)	17 (53.12)	28 (63.64)	115
Female	75 (36.59)	37 (39.36)	7 (20)	15 (46.88)	16 (36.36)	
Estimated skeletal age, N (%)						
Young age (15-30)	50 (24.39)	23 (24.47)	9 (25.71)	15 (46.88)	3 (6.82)	0.005^{B}
Middle age (31-45)	120 (58.54)	54 (57.45)	22 (62.86)	11 (34.38)	33 (75.00)	
Old age (46+)	35 (17.07)	17 (18.09)	4 (11.43)	6 (18.75)	8 (18.18)	

* $\chi 2$ test with post hoc test (only significant results after pairwise comparisons labelled). Abbreviations for significant post hoc tests: A – LA Continental & LA Coastal; B – EMA Continental & EMA Coastal; C – LA Continental & EMA Continental; D – LA Coastal & EMA Coastal

Comparing coastal and continental Croatia in two historical periods, there was no statistically significant difference in the total number of teeth (P = 0.123) or the total area of all teeth (P = 0.150). However, there was a statistically significant difference in the proportion of tooth wear in the total teeth area ($P < 0.001$, Table 2).

Furthermore, the post hoc test revealed a significant difference when comparing continental and coastal Croatia in LA and coastal Croatia between LA and EMA (P = 0.006 and $P < 0.001$, respectively). Overall, samples from coastal Croatia from the LA period showed a minor proportion of tooth wear with a median of 8.35%, whereas samples from coastal Croatia from the EMA had the most significant proportion of tooth wear with a median of 18.26%.

When the samples were stratified by sex, a statistically significant difference was found only in the male population for the proportion of tooth wear to total teeth area, again between continental and coastal Croatia in LA and coastal Croatia between LA and EMA (P = 0.031 and P = 0.001, respectively).

Regarding estimated skeletal age, the proportion of tooth wear to total teeth area was not significant for the young and old age groups, but differed significantly in the middle-aged population group, where it was higher in coastal Croatia from EMA than in coastal Croatia from LA ($P<0.001$).

The proportion of tooth wear in total tooth area was also compared between these two historical periods and geographical locations, separately for each tooth group for the entire sample and stratified based on sex and age group. Overall, we found a statistically significant difference in all teeth groups except the right canines when we looked at the proportion of tooth wear to total tooth area by historical period and geographic location (Table 3). When the sample was stratified based on sex and age group, a statistically significant difference in tooth wear was found in all tooth groups in the male population and in incisors, right and left premolars, and left molars in the middle-aged population. The same trend was observed in all teeth groups, with a significant increase in tooth wear observed in continental samples compared to Croatian LA coastal samples and in EMA samples compared to LA coastal samples. No statistically significant difference was observed between LA and EMA samples from continental Croatia or between continental and coastal EMA samples.

Table 2. Distribution of the total number of teeth, total area, and tooth wear of all teeth depending on the historical period and geographical location and grouped by sex and estimated skeletal age

	Late Antiquity (LA)		Early Middle Ages (EMA)		P*
	Continental	Coastal	Continental	Coastal	
TOTAL					
Samples (N)	95	37	32	44	
Total number of all teeth, median (IQR)	23 (12)	23 (10)	20.5 (8.25)	22 (10.5)	123
Total area of all teeth (cm^2), median (IQR)	14.04 (6.18)	13.62 (6.69)	12.03 (6.39)	11.73 (6.39)	150
Tooth wear/total area of all teeth (%), median (IQR)	13.98(12.15)	8.35 (7.41)	13.6 (13.94)	18.26(13.03)	$<0.001^{A,D}$
MALE					
Samples (N)	57	28	17	28	
Total number of all teeth, median (IQR)	23 (11)	22.5 (8.5)	21 (8)	21.5 (10.5)	401
Total area of all teeth (cm^2), median (IQR)	14.87 (5.71)	13.56 (6.78)	12.57 (6.53)	12.06 (7.65)	351
Tooth wear/total area of all teeth (%), median (IQR)	14.26 (13.32)	8.3 (5.98)	15.36 (18.6)	20.64 (15.14)	$0.001^{A,D}$
FEMALE					
Samples (N)	37	7	15	16	
Total number of all teeth, median (IQR)	24 (15)	22 (8)	18 (9)	22 (8.75)	368
Total area of all teeth (cm^2), median (IQR)	13.48 (7.51)	13.96 (5.75)	11.97 (3.94)	11.14 (5.19)	443
Tooth wear/total area of all teeth (%), median (IQR)	13.75(11.34)	8.35 (7.28)	9.47 (10.95)	15.97 (9.93)	237
YOUNG AGE					
Samples (N)	23	9	15	3	
Total number of all teeth, median (IQR)	26 (6)	22 (5)	23 (8)	27 (7.5)	243
Total area of all teeth (cm^2), median (IQR)	15.16 (4.33)	14.93 (3.97)	13.67 (5.08)	14.04 (3.97)	529
Tooth wear/total area of all teeth (%), median (IQR)	8.44 (7.43)	5.7 (2.31)	8.78 (6.32)	5.33 (0.69)	48
MIDDLE AGE					
Samples (N)	54	22	11	33	
Total number of all teeth, median (IQR)	25 (12.25)	23 (9.5)	17 (9)	22 (10)	100
Total area of all teeth (cm^2), median (IQR)	14.92 (6.55)	13.56 (7.07)	12.06 (5.14)	11.91 (6.25)	319
Tooth wear/total area of all teeth (%), median (IQR)	13.95 (7.4)	9.29 (5.96)	15.76(14.25)	17.83(13.74)	0.001^{D}
OLD AGE					
Samples (N)	17	4	6	8	
Total number of all teeth, median (IQR)	15 (7)	15.5 (11.5)	14.5 (7.75)	15 (7)	861
Total area of all teeth (cm^2), median (IQR)	10 (5.35)	9.94 (5.6)	8.6 (2.79)	7.56 (3.82)	611
Tooth wear/total area of all teeth (%), median (IQR)	30.66 (15.05)	27.39 (16.96)	28.92 (11.65)	22.37 (5.62)	342

* Kruskal-Wallis test with Dunn's post hoc test for significant associations. Abbreviations for significant post hoc tests: A – LA Continental & LA Coastal; B – EMA Continental & EMA Coastal; C – LA Continental & EMA Continental; D – LA Coastal & EMA Coastal

Table 3. The ratio variables of canine teeth with significant differentiating function based on discriminant analysis

	Samples (N)	Late Antiquity (LA)		Early Middle Ages (EMA)		P*
		Continental	Coastal	Continental	Coastal	
INCISORS						
Tooth wear/total area (%), median (IQR)						
Total	1011	15.85 (15.68)	11.74 (9.64)	15 (16.72)	18.84 (12.24)	0.002^{A,D}
Male	620	15.94 (12.95)	11.11 (8.19)	19.89 (19.4)	18.42 (17.39)	0.008^{A,D}
Female	378	14.16 (16.38)	13.95 (10.53)	12.8 (15.69)	18.92 (7.72)	273
Young age	270	9.85 (7.75)	7.87 (9.45)	9.11 (16.48)	7.1 (0.95)	563
Middle age	603	15.91 (15.46)	13.75 (9.06)	16.02 (12.35)	19.01 (12.2)	0.031^{D}
Old age	125	25.97 (13.65)	19.68 (1.39)	28.5 (7.66)	19.66 (7.89)	274
Tooth wear/total area (%), median (IQR) – Right incisors						
Total	513	14.72 (14.22)	10.8 (12.97)	12.86 (15.22)	18.16 (13.68)	0.014^{A,D}
Male	317	16.09 (13.93)	10.71 (14.29)	21 (11.64)	17.31 (18.11)	46
Female	188	13.45 (14.36)	13.26 (10.3)	10.38 (8.46)	19.49 (8.69)	133
Young age	139	10.32 (8.61)	7.89 (9.05)	8.9 (9.38)	7.83 (1.05)	494
Middle age	306	14.97 (12.19)	11.18 (16.97)	18 (9.51)	18.64 (14.2)	144
Old age	60	24.89 (17.07)	17.32 (4.06)	24.64 (20.58)	19.25 (8.17)	363
Tooth wear/total area (%), median (IQR) – Left incisors						
Total	498	16.47 (14.13)	10.08 (9.72)	10.51 (18.82)	18.48 (12.39)	0.002^{A,D}
Male	303	16.12 (13.22)	8.69 (8.81)	13.03 (18.66)	18.65 (13.62)	0.020^{A,D}
Female	190	16.96 (16.49)	11.72 (10.21)	6.5 (9.88)	16.73 (8.91)	143
Young age	131	7.7 (9)	6.32 (11.11)	8.83 (5.36)	5.79 (0.68)	703
Middle age	297	16.52 (13.55)	10.08 (7.97)	9.75 (17.86)	18.65 (11.37)	0.009^{A,D}
Old age	65	26.58 (13.4)	21.02 (0.21)	20.69 (10.71)	19.78 (6.7)	230
CANINES						
Tooth wear/total area (%), median (IQR)						
Total	655	10.83 (11.41)	7.47 (7.37)	9.13 (13.77)	12.91 (9.81)	0.022^{D}
Male	412	11.21 (10)	7.59 (6.66)	9.81 (11.53)	14.9 (11.61)	0.003^{D}
Female	235	8.84 (12.72)	7.93 (8.23)	5.79 (9.97)	8.15 (5.26)	759
Young age	164	8.84 (9.72)	4.21 (4.49)	4.41 (5.12)	4.12 (2.34)	491
Middle age	392	9.45 (7.72)	7.59 (6.91)	10.47 (13.64)	12.81 (10.64)	56
Old age	91	22.27 (16.24)	15.15 (11.8)	15.78 (6.94)	14.92 (4.63)	196
Tooth wear/total area (%), median (IQR) – Right canines						
Total	336	10.69 (11.44)	7.9 (7.9)	9.48 (13.78)	11.55 (12.64)	65
Male	211	11.35 (9.44)	7.2 (7.43)	10.21 (19.3)	14.61 (13.98)	0.004^{D}
Female	121	7.76 (15.18)	12.29 (8.15)	8.73 (12.75)	8.04 (4.12)	916
Young age	83	7.22 (7.49)	5.55 (2.56)	6.67 (9.51)	7.13 (2.59)	907
Middle age	202	9.7 (7.88)	8.22 (7.27)	11.2 (18.88)	10.94 (13.88)	50
Old age	47	23.41 (21.36)	14.31 (14.68)	16.94 (7.56)	15.8 (8.79)	403
Tooth wear/total area (%), median (IQR) – Left canines						
Total	319	10 (12)	6.28 (8.21)	8 (9.94)	10.93 (13.18)	0.013^{D}
Male	201	11.84 (12.11)	6.53 (8.16)	11.13 (7.7)	16.2 (12.25)	0.008^{D}
Female	114	8.68 (13.25)	3.91 (7.55)	2.34 (6.96)	6.69 (3.1)	258
Young age	81	6.78 (10.3)	2.74 (3.3)	2.34 (4.71)	3.65 (4.42)	315
Middle age	190	8.68 (8.6)	6.53 (7.51)	10.22 (8.41)	11.44 (14.12)	143
Old age	44	24.01 (10.23)	14.59 (12.2)	14.02 (7.95)	16.95 (8.57)	210
PREMOLARS						
Tooth wear/total area (%), median (IQR)						
Total	1242	8.3 (10.36)	4.58 (4.75)	7.06 (7.35)	11.12 (12.9)	0.001^{A,D}

Male	785	8.3 (12.67)	4.4 (4.95)	12 (9.88)	11.63 (11.34)	0.004^{D}
Female	439	8.49 (9.76)	5.46 (3.31)	6.53 (2.19)	6.69 (10.47)	344
Young age	323	5.82 (5.42)	4.26 (3.64)	6.35 (3.4)	5.42 (2.97)	596
Middle age	749	7.95 (9.08)	4.15 (4.02)	7.54 (10.46)	11.16 (12.43)	$0.001^{A,D}$
Old age	152	24.62 (22.16)	36.85 (29.42)	15.88 (4.85)	13.84 (10.88)	293
Tooth wear/total area (%), median (IQR) – Right premolars						
Total	613	7.71 (11.12)	4.07 (5.49)	7.48 (10.67)	10.14 (8.91)	$<0.001^{A,D}$
Male	388	7.44 (10.99)	4.39 (3.84)	8.18 (12.45)	11.31 (10.03)	0.002^{D}
Female	217	8.35 (12.06)	3.9 (4.13)	7.06 (3.15)	6.3 (10.59)	258
Young age	161	5.59 (6.21)	4.72 (2.69)	6.9 (2.96)	3.39 (3.04)	240
Middle age	374	7.38 (11.16)	3.88 (3.54)	5.9 (15.52)	9.54 (8.07)	$<0.001^{A,D}$
Old age	70	24.69 (24.66)	20.81 (11.96)	16.71 (5.37)	14.46 (7.78)	382
Tooth wear/total area (%), median (IQR) – Left premolars						
Total	629	6.88 (10.91)	4.75 (5.31)	6.25 (5.37)	10.67 (11.6)	0.003^{D}
Male	397	6.88 (11.41)	4.73 (6.51)	7.8 (11.24)	11.02 (10.74)	0.021^{D}
Female	222	6.42 (8.6)	4.75 (2.9)	6.07 (4.85)	8.46 (11.21)	327
Young age	162	4.83 (3.77)	2.86 (2.09)	5.72 (3.74)	4.38 (2.73)	564
Middle age	375	6.71 (7.14)	4.73 (4.19)	9.47 (2.96)	10.62 (12.09)	0.008^{D}
Old age	82	25.11 (22.93)	41.17 (34.25)	11.24 (15.83)	12.87 (9.07)	277
MOLARS						
Tooth wear/total area (%), median (IQR)						
Total	1570	15.5 (15.56)	9.22 (10.51)	15.28 (21.8)	20.75 (23.05)	$<0.001^{A,D}$
Male	998	15.36 (15.16)	9.59 (8.79)	17.79 (22.18)	24.66 (24.39)	0.003^{D}
Female	547	16.19 (16.76)	8.58 (7.98)	8.41 (17.01)	19.71 (13.84)	395
Young age	445	8.7 (8.22)	5.61 (1.78)	8.21 (5.73)	6.08 (0.41)	81
Middle age	914	15.58 (10.33)	11.91 (7.5)	23.35 (17.53)	19.14 (20.75)	0.011^{D}
Old age	186	34.15 (19.64)	23.1 (13.49)	36.45 (9.29)	32.37 (12.71)	639
Tooth wear/total area (%), median (IQR) – Right molars						
Total	789	14.56 (16.22)	9.8 (9.86)	15.24 (25.07)	18.16 (24.91)	0.018^{D}
Male	494	13.14 (15.54)	9.88 (9.93)	15.59 (26.59)	19.51 (26.35)	0.022^{D}
Female	284	16.24 (16.09)	9.8 (3.21)	12.17 (15.11)	15.69 (17.99)	323
Young age	218	9.95 (9.12)	5.45 (1.79)	11.59 (7.5)	6.3 (0.38)	121
Middle age	466	14.66 (15.37)	10.76 (6.84)	22.15 (20.21)	18.1 (23.08)	91
Old age	94	36.54 (25.57)	17.77 (14.61)	37.63 (9.45)	36.24 (17.85)	732
Tooth wear/total area (%), median (IQR) – Left molars						
Total	781	15.12 (16.36)	8.74 (7.44)	13.28 (20.93)	21.44 (22.2)	$<0.001^{A,D}$
Male	504	16.55 (15.42)	9.6 (7.34)	19.28 (21.57)	24.07 (24.05)	$0.002^{A,D}$
Female	263	14.09 (18.29)	7.75 (7.06)	7.68 (18.96)	18.3 (17.06)	120
Young age	227	9.71 (7.92)	6.01 (2.79)	6.98 (6.73)	5.76 (1.12)	168
Middle age	448	14.87 (13.32)	9.95 (7.17)	23.14 (17.66)	21.44 (24.67)	$<0.001^{D}$
Old age	92	37.25 (21.98)	29.81 (15.23)	34.99 (9.78)	27.76 (8.83)	359

* Kruskal-Wallis test with Dunn's post hoc test for significant associations. Abbreviations for significant post hoc tests: A – LA Continental & LA Coastal; B – EMA Continental & EMA Coastal; C – LA Continental & EMA Continental; D – LA Coastal & EMA Coastal

DISCUSSION

To assess dental age in adults, we use invasive and non-invasive methods that have been scientifically tested. For the rapid assessment of dental age in adults, tooth wear analysis is most commonly used as a non-rapid method. The second method according to Bang and Ramm is the age estimation method, which is based on the translucency of the root dentin. However, this is an invasive method as it requires extraction of the tooth from the alveolus. [19]

Tooth wear is particularly important for studying the relationship between people from different historical periods, their environment and their lifestyles. [20] Ancient people consumed more natural and raw, unprocessed food, which led to a high degree of tooth wear. It has been shown that tooth wear gradually increases with age. Normally, tooth wear dominates in the molars. It

starts in the occlusal enamel and gradually extends to the dentin. Examination of teeth from different historical periods, from late antiquity to the Middle Ages, shows that tooth wear is a universal phenomenon. [20,21]
In our study, computer software was used to analyse tooth wear as the most important parameter for the loss of dental structure in continental and coastal geographical areas of Late Antiquity and the Middle Ages. Our results showed a significant difference in tooth wear between the two historical periods and between the two geographical areas. The results showed that the highest tooth wear was recorded in the middle-aged male population on the Croatian coast in the EMA. In terms of tooth groups, the highest tooth wear was found in the incisors, premolars and left molars.
Furthermore, tooth wear increases much more in the coastal later period for the middle adults and remains high in the older age group though it is only the molars that show a marked increase in old age.
The results showed that hard dental tissue loss differed between the two historical periods and between geographical locations, not so much in terms of the number of teeth and total tooth area as much as in tooth wear. We also found the difference between continental and coastal Croatia in LA and coastal Croatia between LA and EMA ($P = 0.006$ and $P < 0.001$, respectively).
Overall, samples from coastal Croatia from the LA period showed a minor proportion of tooth wear with a median of 8.35%, whereas samples from coastal Croatia from the EMA had the most significant proportion of tooth wear with a median of 18.26%. Furthermore, the middle-aged male population had more advanced tooth wear in coastal Croatia in EMA, and the most affected teeth were incisors, premolars, and left molars.
This study used the VistaMetrix 1.38 computer software to estimate tooth wear. This program allows quantitative editing of digital images and provides objective measurements. Unlike other standard methods, like the Scotts method [23], which is visual or qualitative, this computer software provides a more reliable measure of tooth wear expressed in cm^2 on each tooth.
The low price and user-friendliness of this software make it particularly suitable for this type of research. Several studies that have analysed tooth wear on archaeological samples have used less objective and sensitive methods, such as various visual scales. [24, 25] To the best of our knowledge, this is the first study that has analysed tooth wear on human archaeological samples using this software.
Excellent results for intra-rater and interrater repeatability show the applicability and objectivity of this approach to tooth wear analysis. Clements et al. [26], used digital photographs to measure tooth wear and found less than a 2% difference between repeated tests.
Tooth wear and carious lesions are the main potential causes of hard dental tissue loss. From the LA period to the present day, people's dietary and lifestyle habits have changed. It has been shown that tooth wear and loss of dental tissue have decreased with the change in dietary habits.
Our study showed that tooth wear as a proportion of total tooth area was significantly higher in the EMA than in LA, especially in the coastal region. Chazel et al [27] compared the prevalence of apical and dental lesions in an archaeological and modern population (4th to 20th century) and evaluated the influence of environmental factors. They showed that dietary and lifestyle factors in the EMA appeared to be the main risk factors for hard dental tissue loss due to dental care and subsequent caries lesions, which strongly influenced the modern population. [28]
It is well known that ancient populations based their dietary habits on rough, raw and potentially abrasive food. The higher rate of tooth wear in the EMA population may explain why these dietary habits required more vigorous mastication. Moreover, they were familiar with glass and leather manufacturing, the manufacture of fishing gear (e.g. fishing nets) and similar professions that required the use of teeth as tools. [29]
Estimating dental age in adults has proven to be very difficult because it requires knowledge and extensive experience. Compared to qualitative methods of assessment, quantitative methods are much more accurate and show less variation, which is why digital methods are favoured. A study conducted by Gkantidis et al [29] using 3D imaging for tooth wear status showed that the new, powerful 3D imaging methods facilitate the measurement of tooth wear and provide a better understanding of the problem and can be a good tool for assessing dental age.
Today, dental erosion, that impairs tooth wear, is one of the most common oral diseases of the

modern man. [30] This makes it difficult to take tooth wear into account when assessing the dental age. Therefore, it should be very careful when diagnosing tooth wear and dental erosion.

Our study had several limitations. Although our sample was representative, this study analyzed archaeological sites only in Croatia. We did not analyze tooth erosion and carious lesions in terms of loss of hard dental tissues, which can also be scope for further research. Although we did not notice the distortion of some images, there is a possibility of it occurring due to the equipment used.The measurer acquired good skills by measuring tooth wear, but it is possible that a minimal error crept in at the blurred boundaries of enamel and dentin.

We predicted a difference in tooth wear between the two observed periods according to the sex and estimated skeletal age and a group of teeth in coastal and continental Croatia populations. Gustafson included Dental wear in his research as one of the parameters in the assessment of dental age in adults. This method is regularly used even today in forensic analyses. Therefore, this research is recommended for further measurements in a recent human for possible forensic analyses. [31]

CONCLUSION

By analysing and measuring the tooth wear with the VistaMetrix computer software, we have obtained results that show the difference between the two historical periods, LA and EMA, in the population of two different geographical locations, continental and coastal Croatia. This finding that could explain changes in dietary and lifestyle habits over two time periods. The obtained results helped to estimate the tooth age of the observed archaeological samples.This software was used for the first time to analyse tooth wear and proved to be a fast, simple and reliable tool for analysing tooth wear. The possibility of using this method is suggested in archaeological and forensic analyzes due to its simplicity

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