ARCHIVES OF ORAL BIOLOGY 57 (2012) 401–412

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: http://www.elsevier.com/locate/aob

Orthodontic anomalies and malocclusions in Late Antique and Early Mediaeval period in Croatia

Marin Vodanović [a,*], Ivan Galić [b], Mihovil Strujić [c], Kristina Peroš [d], Mario Šlaus [e], Hrvoje Brkić [a]

[a] Department of Dental Anthropology, School of Dental Medicine, University of Zagreb, Gundulićeva 5, HR-10000 Zagreb, Croatia
[b] Splitsko-Dalmatinska County – Public Health Center, HR-21000 Split, Croatia
[c] Department of Orthodontics, School of Dental Medicine, University of Zagreb, Gundulićeva 5, HR-10000 Zagreb, Croatia
[d] Department of Pharmacology, School of Dental Medicine, University of Zagreb, Šalata 11, HR-10000 Zagreb, Croatia
[e] Department of Archaeology, Croatian Academy of Sciences and Arts, Ante Kovačića 5, HR-10000 Zagreb, Croatia

ARTICLE INFO

Article history:
Accepted 15 September 2011

Keywords:
Orthodontic anomalies
Malocclusions
Paleodontology
Late Antique
Early Mediaeval
Croatia

ABSTRACT

Objective: Malocclusions are relative infrequently analysed in bioarchaeological investigations and if investigated the samples are very small. This research provides analysis of orthodontic anomalies of even 1118 individuals from the Late Antique (LA) and Early Mediaeval (EM) period. Aims were to describe the prevalence of orthodontic anomalies in this historical period and to analyse which orthodontic anomalies are best suitable for bioarchaeological investigations.

Methods: 1118 skulls were examined for anomalies of tooth number, tooth displacement (rotation, malposition, diastema and crowding) as well as for malocclusions.

Results: The prevalence of hypodontia in the LA was 41.02% and 30.61% in the EM sample. Tooth displacement was noticed in 15.63% individuals from the LA and in 12.42% individuals from EM. About 26% of the LA sample and 7.19% of the EM sample were affected with tooth crowding and the difference was statistically significant.

Conclusion: Orthodontic anomalies affecting only one tooth or group of teeth are more suitable for examination in bioarchaeological investigations than orthodontic features requiring presence of both jaws and all or almost all teeth. Clinical investigation protocols and methodology should be adopted for bioarchaeological researches and international standards and recommendations should be established for this kind of investigation on skeletal remains.

1. Introduction

Diagnosis and interpretation of dental diseases and their analysis in paleodemographic framework are an indispensable part of any attempt to reconstruct past life ways from human skeletal remains. The prevalence and distribution of dental diseases in skeletal series may yield valuable clues regarding diet, nutrition and methods of procuring the diet.[1–4] Considering this, dental caries, antemortem tooth loss, periapical pathology and tooth wear are probably the most examined dental and oral features on skeletal remains of archaeological origin.[5–13] Thanks to numerous studies, published papers and books, today, teeth and dental diseases,

* *Corresponding author*. Tel.: +385 1 4899 214; fax: +385 1 4802 159.
E-mail address: vodanovic@sfzg.hr (M. Vodanović).
URL: http://www.marinvodanovic.com
0003–9969/$ – see front matter
doi:10.1016/j.archoralbio.2011.09.006

especially dental caries provide us with an inappreciable insight in the everyday life of ancient populations from different historical periods as well as from different parts of the world.[14–18]

Compared with dental markers of health (dental caries, antemortem tooth loss, periapical pathology and tooth wear) orthodontic anomalies of any kind and malocclusions are relative infrequently analysed in bioarchaeological investigations. There are at least three reasons for this. First: orthodontic anomalies and malocclusions are not recognised by bioarchaeologists, anthropologists, and related scientists as an important and useful source of data about the oral and general health of ancient populations, as well as an important source of data about other aspects of their everyday life. Second: scientists involved in the examination of skeletal remains derived from archaeological contexts usually do not have enough knowledge for the identification (diagnosis) of orthodontic anomalies, or for the interpretation of malocclusions. Dentists, as experts educated in the diagnosis and interpretations of orthodontic status are rarely involved in bioarchaeological investigations. Third: even when the importance of orthodontic anomalies is recognised, and they are a focus of the investigation, and even if one of the researchers is a dentist, there is the final and possibly most important problem: the lack of usable samples.[4]

Modern indices of malocclusion consider few features that differentiate individuals with normal occlusion, from those with varying degrees of malocclusion: first molar relationship, overjet (horizontal incisor relation), overbite and open bite (vertical incisor relation), tooth displacement (crowding, rotations, etc.), congenitally missing teeth, and posterior crossbite.[19,20] These features can be analysed relatively simply in living patients, but in skeletal remains where soft tissues are missing and there is no connection between the upper and lower jaws the examination of these features is complicated as the jaws cannot be placed in their correct anatomical position as when the individual was alive.

Papers and reports about malocclusions and orthodontic anomalies in skeletal populations from archaeological contexts are relatively rare and often based on small samples. Lukacs described two prehistoric cases of maxillary canine-first premolar transposition from the Bronze and Iron ages of South Asia.[21] Mockers et al. investigated dental crowding in 43 adult mandibles from the Copper Age.[22] Corruccini and Pacciani examined a sample of 50 Etruscan skulls for tooth rotation, tooth displacement, first molar transverse crossbite and horizontal buccal segment relation.[23] Evensen and Ogaard examined 85 male and 61 female skulls to describe the prevalence and severity of malocclusions in a sample of mediaeval Norwegians.[24] Lindsten et al. measured dental arch space and permanent tooth size in the mixed dentition of a skeletal sample (48 skulls of Norwegian descent) from the 14th to the 19th centuries.[25,26] Rose and Roblee studied ancient Egyptian skeletons from Amarna, Egypt and wrote about the origins of dental crowding and malocclusions from an anthropological perspective.[27] Studies about malocclusions in Croatian skeletal populations are extremely rare and so far only a couple of reports have been published. Cabov et al. described a case of canine hypodontia in the early Croatian cemetery Strance-Gorica.[28] Rajic et al. reported an impacted canine in a prehistoric skull from the eneolithic site of Vucedol in Croatia.[29]

Traditional history describes the transition from the Late Antique (3rd–5th centuries AD) to the Early Mediaeval period (6th–10th centuries AD) in Croatia as uniformly catastrophic with destruction of major urban centres, depopulation, famine, and the spread of epidemic diseases. Except historical and archaeological evidence, this has been confirmed by bioarchaeological investigations. Šlaus et al. examined four markers of health: cribra orbitalia, linear enamel hypoplasia, nonspecific periostitis, and trauma in 981 skeletons from the Late Antique and Early Mediaeval period. They found that the transition from the Late Antique to the Early Mediaeval period was not a uniform process, but differentially affected the past inhabitants of Croatia because of local cultural, socio-economical, or political factors.[30] Dento-alveolar pathologies: caries, antemortem tooth loss, abscesses, calculus, alveolar resorption and tooth wear analysed in two composite skeletal series from Croatia's eastern Adriatic coast from the same historical periods confirmed the deterioration of dental health during the Early Mediaeval period.[31]

Our aims in this study are to describe the prevalence and severity of malocclusions and orthodontic anomalies in a large sample of individuals that inhabited Croatia during the Late Antique and Early Mediaeval period; to investigate whether dental health was equally adversely affected by malocclusions and orthodontic anomalies during the Late Antique/Early Mediaeval transition; and to analyse and determine which orthodontic anomalies are best suited for bioarchaeological investigations.

2. Materials and methods

This investigation was carried out on skeletal series that are currated in the Osteological collection of the Department of Archaeology, of the Croatian Academy of Sciences and Arts in Zagreb. The examined sample consists of 1118 skulls. The osteological material analysed in this study was divided into two composite series – a Late Antique and an Early Mediaeval skeletal series. The Late Antique series consists of a grand total of 457 skeletons from 5 urban sites (Zmajevac, Štrbinci, Osijek, Vinkovci, and Zadar) located in the eastern part of continental Croatia and along the eastern Adriatic coast. The sites were inhabited from the 1st to 5th centuries AD. The Early Mediaeval series consists of a grand total of 661 skeletons from 6 rural sites (Privlaka, Stari Jankovci, Velim Velištak, Glavice, Radašinovci, and Šibenik) also located in the eastern part of continental Croatia, and along the eastern Adriatic coast. These sites were inhabited from the 7th to 10th centuries AD. Because of differential preservation, the final number of skulls included in the investigation is significantly smaller and varies from 36 to 362 depending on the examined feature. The state of preservation varied from completely preserved skulls with complete mandibles, to cases where only small fragments of the maxilla or mandible with only few teeth were preserved (Tables 1 and 2). Adult age at death was estimated using as many methods as possible, including pubic symphysis morphology, auricular surface morphology, sternal rib end changes, and ectocranial suture fusion. Individuals

Table 1 – Preservation of the jaws.

	Level of preservation	Males		Females		Total	
		N	%	N	%	N	%
LA	1	78	81.25	74	84.09	152	82.61
	2	0	0.00	0	0.00	0	0.00
	3	17	17.71	14	15.91	31	16.85
	4	1	1.04	0	0.00	1	0.54
	Total	96	100.00	88	100.00	184	100.00
EM	1	187	83.11	125	85.03	312	83.87
	2	8	3.56	4	2.72	12	3.23
	3	30	13.33	18	12.24	48	12.90
	4	0	0.00	0	0.00	0	0.00
	Total	225	100.00	147	100.00	372	100.00
	Total LA + EM	321		235		556	

LA, Late Antique; EM, Early Mediaeval; N, number of individuals.
Level 1, indicating preservation of both maxilla and mandible and preservation of more than 50% of alveolar bone.
Level 2, indicating preservation of both maxilla and mandible but with preservation of less than 50% of alveolar bone.
Level 3, indicating preservation of only the maxilla or the mandible and preservation of more than 50% of alveolar bone.
Level 4, indicating preservation of only the maxilla or the mandible and preservation of less than 50% of alveolar bone.

Table 2 – Preservation of teeth.

	Tooth status	Males		Females		Total	
		N	%	N	%	N	%
LA	TP	2347	85.94	2127	85.46	4474	85.71
	AM	80	2.93	71	2.85	151	2.89
	PM	304	11.13	291	11.69	595	11.40
	Total	2731	100.00	2489	100.00	5220	100.00
EM	TP	4642	73.68	2894	72.12	7536	73.07
	AM	330	5.24	320	7.97	650	6.30
	PM	1328	21.08	799	19.91	2127	20.62
	Total	6300	100.00	4013	100.00	10313	100.00
	Total LA + EM	9031		6502		15533	

LA, Late Antique; EM, Early Mediaeval; N, number of teeth; TP, tooth present; AM, tooth lost antemortem; PM, tooth lost postmortem.

younger than 20 years were excluded from the study in order to avoid possible mistakes in diagnosis of orthodontic anomalies influenced by growth and development. Data were collected by sex for the presence and distribution of individual orthodontic anomalies. Sex determination was based on pelvic and cranial morphology. When these elements were missing or poorly preserved discriminant functions for the femur and tibia developed for antique and mediaeval Croatian populations were employed.[32]

All individuals were examined for anomalies of tooth number: tooth agenesis and hyperdontia. Tooth agenesis was evaluated for hypodontia (one to five congenitally absent permanent teeth) and oligodontia (six or more congenitally absent permanent teeth), including the third molars.[20] A tooth was recorded as congenitally missing when no trace of its presence could be found in the skeletal material. If there was doubt about the previous presence of a tooth in other words of possible antemortem loss, the tooth was excluded from further investigation. Hyperdontia was evaluated for supplemental teeth (additional teeth which resemble normal dentition) and supernumerary teeth (teeth with conical or tubercular shape).[20] Anomalies of tooth number were confirmed by radiographs except in cases of third molars. Diagnosis of third molar agenesis was established according to the positioning of the other teeth and the condition of the alveolar ridge.

Tooth displacement was evaluated for tooth rotation, tooth malposition, tooth diastema, and crowding.[20]

Tooth rotation was defined as the turning of a tooth around its longitudinal axis in the mesial or distal direction.[20]

Any improper position or irregularly placement of a tooth (excluding tooth rotation) in relationship to adjacent teeth in the same dental arch was considered as tooth malposition. Tooth positioned outside the dental arch were classified as either vestibular malposition (towards the lips or cheek), or oral malposition (towards the palate).[20]

Tooth diastema was defined as any space between two adjacent teeth of the same dental arch which would in an ideal, anatomically intact dental arch, be in contact. In order to exclude diastemata caused by antemortal tooth extraction or hypodontia, skulls with incomplete dentition were excluded. The distance between the most prominent points of interproximal walls of teeth was measured for each tooth diastema.[20]

Crowding was defined as the bunching together of teeth outside their normal alignment in an arch, or segment of an arch, causing them to be irregular or crooked. Crowding was qualitatively assessed by the number of individuals with malpositioned teeth and the severity of their displacement. According to Iscan three grades of crowding were recognised: slight, moderate and severe.[1]

Qualitative evaluation of malocclusion was performed by Angle's classification – one of the most widely used malocclusion classification system. Considering the limitations of working on skeletal remains all available samples were classified in one of four groups: Class I, Class II division 1, Class II division 2, and Class III according to Angle's classification.[4,20]

Malocclusions in the anterior region of the dental arches in the occlusal plane were recorded as: regular sagittal relationship, anterior crossbite and strong horizontal overlap (overjet).[4,20] Overjet was evaluated to the nearest 0.5 mm and normal range was determined at 0.5–4.0 mm. Anterior crossbite included mandibular overbite, and edge-to-edge position.

Malocclusions in the anterior region of the dental arches in the vertical plane were recorded as: deep bite (overbite), regular vertical relationship and anterior openbite.[4,20]

Transverse occlusal deviations of the posterior teeth were classified as: regular transverse occlusion, edge-to-edge bite (posterior crossbite tendency), posterior crossbite, buccal non-occlusion and lingual non-occlusion.[4,20]

Chi-square test was used to test differences in the frequencies of malocclusions and orthodontic anomalies between Late Antique and Early Mediaeval samples and to test the sex differences for those anomalies.

Because of the evident impact of tooth wear on teeth position and possible influence on the correctness of results obtained in this study for each examined individual average tooth wear score was calculated using the Smith and Knight tooth wear index.[33,34]

3. Results

A total of 362 individuals were examined for anomalies of teeth number. In the group of individuals with anomalies of teeth number, only individuals with hypodontia were found. No cases of hyperdontia or oligodontia were recorded. Although both jaws, and all teeth/tooth sockets were examined congenitally missing teeth were noted only in the upper second incisors, upper third molars, lower second premolars, and lower third molars. Of the 117 individuals examined from the Late Antique sample, 48 individuals (41.02%) were found to have at least one absent permanent tooth. As shown in Table 3 the most often missing teeth were the lower third molars, followed by the upper third molars. There were 4 cases of missing upper second incisor, and only one case of missing lower second premolar. In two cases the absence of the second incisor was unilateral, in one case it was bilateral. Of the 245 individuals examined from the Early Mediaeval sample, 75 individuals (30.61%) were found to have at least one absent permanent tooth. As shown in Table 3 the only missing teeth were the third molars and the lower second premolar. Although there was no statistically significant difference between the Late Antique and Early Mediaeval sample when calculated by the number of individuals with anomalies of teeth number, statistically significant differences were found between the frequencies of hypodontia for some tooth types (Table 3). Hypodontia of the upper second incisor is significantly higher in the Late Antique sample than in the Early Mediaeval sample ($p = 0.01$, $\chi^2 = 6.69$) and the same is true for hypodontia of the lower third molars ($p = 0.01$, $\chi^2 = 8.49$). In addition, Late Antique males have significantly more cases of hypodontia of upper third molars than Early Mediaeval males ($p = 0.01$, $\chi^2 = 12.51$).

A total of 225 individuals were examined for tooth displacement. The results according to tooth rotation (in either mesial or distal direction), tooth malposition (vestibular or oral position) are presented in Tables 4 and 5. There are no significant differences between the Late Antique (15.63%) and Early Mediaeval sample (12.42%) according to the number of individuals with these types of tooth displacement. The most common type of tooth displacement was tooth rotation. In both samples rotation of teeth in the distal direction was more common than in the mesial direction. In both samples, premolars were most often affected by tooth rotation,

Table 3 – Frequency of hypodontia.

		N	UI2			UM3			LP2			LM3		
			NS	NH	%	NS	NH	%	NS	NH	%	NS	NH	%
LA	Females	59	35	4	11.43[a]	53	6	11.32	46	0	0.00	49	24	48.98
	Males	58	25	0	0.00	34	21	61.76[c]	28	1	3.57	49	33	67.35[d]
	Total	117	60	4	6.67[b]	87	27	31.03	74	1	1.35	98	57	58.16[e]
EM	Females	101	71	0	0.00[a]	114	23	20.18	96	2	2.08	119	40	33.61
	Males	144	84	0	0.00	166	30	18.07[c]	114	0	0.00	182	55	30.22[d]
	Total	245	155	0	0.00[b]	280	53	18.92	210	2	0.95	301	95	31.56[e]
	Total LA + EM	362	215	4	1.86	367	80	21.80	284	3	1.06	399	152	38.10

LA, Late Antique; EM, Early Mediaeval; UI2, upper second incisor; UM3, upper third molar; LP2, lower second premolar; LM3, lower third molar; N, number of individuals; NS, number of tooth sockets examined; NH, number of teeth missing.

[a] $p = 0.05$, $\chi2 = 4.91$.

[b] $p = 0.01$, $\chi2 = 6.69$.

[c] $p = 0.01$, $\chi2 = 12.51$.

[d] $p = 0.01$, $\chi2 = 8.02$.

[e] $p = 0.01$, $\chi2 = 8.49$.

Table 4 – Frequency of tooth displacements.

		NTP		PM		VP		TR		PM + VM + -TR		Total
		N	%	N	%	N	%	N	%	N	%	N
LA	Females	27	79.41	1	2.94	2	5.88	4	11.76	7	20.59	34
	Males	27	90.00	0	0.00	0	0.00	3	10.00	3	10.00	30
	Total	54	84.38	1	1.56	2	3.13	7	10.94	10	15.63	64
EM	Females	52	91.23	0	0.00	2	3.51	3	5.26	5	8.77	57
	Males	89	85.58	0	0.00	3	2.88	12	11.54	15	14.42	104
	Total	141	87.58	0	0.00	5	3.11	15	9.32	20	12.42	161
	Total LA + EM	195	86.67	1	0.44	7	3.11	22	9.78	30	13.33	225

LA, Late Antique; EM, Early Mediaeval; N, number of individuals; NTP, normal tooth position; PM, palatinal malposition; VM, vestibular malposition; TR, tooth rotation.

Table 5 – Distribution of tooth displacements according to the tooth type.

		TRD	TRM	VM	PM	Total
LA						
Females	*N*	6	–	5	1	12
	Teeth	UI2 (2), UP1 (1), LC (1), LP1 (1), LP2(1)	–	UI2 (2), LC (3)	UC (1)	
Males	*N*	1	2	–	–	3
	Teeth	LP1 (1)	UP2 (1), LC (3)	–	–	
	Total	7	2	5	1	15
EM						
Females	*N*	2	1	1	–	4
	Teeth	LP2 (2)	UI2 (1)	LC (1)	–	
Males	*N*	12	3	3	1	19
	Teeth	UI2 (1), UP1 (3), UP2 (3), UM1 (1), LC (1), LP1 (1), LP2 (2)	UP1 (2), LC (1)	UC (1), UM3 (1), LM1 (1)	UC (1)	
	Total	14	4	4	1	23

LA, Late Antique; EM, Early Mediaeval; N, number of teeth; TRD, distal tooth rotation; TRM, mesial tooth rotation; PM, palatinal malposition; VM, vestibular malposition; U, upper jaw; L, lower jaw; I, incisor; C, canine; P, premolar; M, molar; number in parenthesis indicates the number of affected teeth.

followed by canines, and incisors. Vestibular malposition of teeth was more common than palatinal. According to tooth type, canines were most often in the vestibular malposition.

A total of 212 individuals were examined for tooth diastema. The frequency of individuals with tooth diastema was almost identical in both samples, slightly less than 5% (Table 6). Descriptive analysis of tooth diastema is shown in Table 7. Although only 10 individuals had diastemata (3 in the Late Antique sample and 7 in the Early Mediaeval sample), there were 19 cases of diastema. The most frequent were diastemata between the upper second incisors and the upper canines (31.6% of all diastemata), followed by upper medial diastema (26.3% of all diastemata). The average distance between upper central incisors was 3.4 mm for females, and 2.5 mm for males in the Early Mediaeval samples where all cases of medial diastema were found.

A total of 217 individuals were examined for tooth crowding. Tooth crowding appeared more often in the Late Antique sample than in the Early Mediaeval sample. About 26% individuals from the Late Antique sample, and only 7.19%

Table 6 – Frequency of tooth diastema.

		N	ND	%	WD	%
LA	Females	31	31	0.00	0	0.00
	Males	30	27	90.00	3	10.00
	Total	61	58	95.08	3	4.92
EM	Females	52	49	94.23	3	5.77
	Males	99	95	95.96	4	4.04
	Total	151	144	95.36	7	4.64
	Total LA + EM	212	202	95.28	10	4.72

LA, Late Antique; EM, Early Mediaeval; N, number of individuals examined; ND, number of individuals without tooth diastema; WD, number of individuals with tooth diastema.

Table 7 – Descriptive analysis of tooth diastema.

		Case number	Diastema Right jaw side			Medial diastema		Diastema Left jaw side	
			UI2–UC	LI2–LC	LC–LP1	U	L	UI2–UC	LC–LP1
LA	Females	–	–	–	–	–	–	–	–
	Males	1	2.8 mm	–	–	–	–	1.6 mm	–
		2	1.9 mm	1.2 mm	–	–	–	–	–
		3	–	–	1.8 mm	–	1.4 mm	–	1.1 mm
EM	Females	1	–	–	–	–	–	2.3 mm	–
		2	–	–	–	5.6 mm	–	–	–
		3	–	2.0 mm	–	1.2 mm	–	1.0 mm	–
	Males	1	–	–	–	3.7 mm	–	1.8 mm	–
		2	–	2.4 mm	–	1.2 mm	–	–	–
		3	–	–	–	2.6 mm	3.5 mm	–	–
		4	–	–	2.0 mm	–	–	–	–

LA, Late Antique; EM, Early Mediaeval; U, upper jaw; L, lower jaw; MD, medial diastema; I2, second incisor; C, canine; P1, first premolar.

individuals from the Early Mediaeval sample were affected with this kind of tooth displacement. The difference in the frequency of appearance was statistically significant (Table 8). In addition, the severity of tooth crowding was higher in the Late Antique sample (Table 9).

Because of poor preservation only 62 individuals were available for analysis of malocclusions by Angle's classification. All individuals from the Late Antique sample, and 96% of individuals from the Early Mediaeval sample had neutroocclusion (Class I). There was only one case with Class II division 1 malocclusion and one case of Class III malocclusion (Table 10).

Malocclusions in the anterior region of the dental arches in the occlusal plane could be determined in 37 individuals. Except for one case in the Early Mediaeval sample which was diagnosed as anterior crossbite, all other individuals had regular sagittal relationships (Table 11).

Malocclusions in the anterior region of the dental arches in the vertical plane were determined in 36 individuals. Three males (10.7%) from the Early Mediaeval sample had deep bite and all other individuals had regular vertical relationships (Table 12).

Transverse occlusal deviations of the posterior teeth were determined in 66 individuals. In the Late Antique sample all

Table 8 – Frequency of tooth crowding.

		N	NC	%	WC	%
LA	Females[a]	34	25	73.52	9	26.47
	Males[b]	30	22	73.3	8	26.67
	Total[c]	64	47	73.43	17	26.56
EM	Females[a]	53	51	96.22	2	3.77
	Males[b]	100	91	91.00	9	9.00
	Total[c]	153	142	92.81	11	7.19
	Total LA + EM	217	189	87.10	28	12.90

LA, Late Antique; EM, Early Mediaeval; NC, number of individuals without tooth crowding; WC, number of individuals with tooth crowding; N, number of individuals examined.

[a] $p = 0.05$, $\chi 2 = 7.72$.

[b] $p = 0.01$, $\chi 2 = 4.87$.

[c] $p = 0.01$ $\chi 2 = 11.86$

Table 9 – Severity of tooth crowding.

		Slight	%	Moderate	%	Severe	%	Total
LA	Females	4	44.44	4	44.44	1	11.11	9
	Males	3	37.50	4	50.00	1	12.50	8
	Total	7	41.18	8	47.06	2	11.76	17
EM	Females	2	100.00	0	0.00	0	0.00	2
	Males	7	77.78	2	22.22	0	0.00	9
	Total	9	83.33	2	16.67	0	0.00	11
	Total LA + EM	16	57.14	10	35.71	2	7.15	28

LA, Late Antique; EM, Early Mediaeval.

Table 10 – Malocclusions by Angle's classification.

		N – Class I	N – Class II division 1	N – Class II division 2	N – Class III	N – Total
LA	Females	7	0	0	0	7
	Males	2	0	0	0	2
	Total	9	0	0	0	9
EM	Females	26	0	0	0	26
	Males	25	1	0	1	27
	Total	51	1	0	1	53
	Total LA + EM	60	1	0	1	62

LA, Late Antique; EM, Early Mediaeval; N, number of individuals.

Table 11 – Malocclusions in the anterior region of the dental arches in the occlusal plane.

		N – Regular sagittal relationship	N – Anterior crossbite	N – Strong horizontal overlap	N – Total
LA	Females	6	0	0	6
	Males	2	0	0	2
	Total	8	0	0	8
EM	Females	13	0	0	13
	Males	15	1	0	16
	Total	28	1	0	29
	Total LA + EM	36	1	0	37

LA, Late Antique; EM, Early Mediaeval; N, number of individuals.

individuals had regular transverse occlusal relationships. In the Early Mediaeval sample one case with an edge-to-edge bite was found, whilst all other individuals had regular transverse occlusal relationships (Table 13).

Late Antique males have significantly more cases of hypodontia of upper third molars than Late Antique females ($p = 0.01$, $\chi^2 = 10.86$). Statistically significant differences in the frequencies of other malocclusions and orthodontic anomalies between males and females in the Late Antique and Early Mediaeval sample were not found.

Tooth wear score was calculated for 556 individuals (184 from the Late Antique sample and 372 from the Early Mediaeval sample) on 11,724 teeth (4424 from the Late Antique sample and 7300 from the Early Mediaeval sample). The average tooth wear score according to Smith and Knight was 2.15 for Late Antique males and 1.91 for females. The score was

Table 12 – Malocclusions in the anterior region of the dental arches in the vertical plane.

		N – Regular vertical relationship	N – Deep bite (overbite)	N – Anterior openbite	N – Total
LA	Females	6	0	0	6
	Males	2	0	0	2
	Total	8	0	0	8
EM	Females	13	0	0	13
	Males	12	3	0	15
	Total	25	3	0	28
	Total LA + EM	33	3	0	36

LA, Late Antique; EM, Early Mediaeval; N, number of individuals.

Table 13 – Transverse occlusal deviations of the posterior teeth.

		N – Regular transverse occlusion	N – Edge-to-edge bite	N – Posterior crossbite	N – Buccal non-occlusion	N – Lingual non-occlusion	N – Total
LA	Females	8	0	0	0	0	8
	Males	2	0	0	0	0	2
	Total	10	0	0	0	0	10
EM	Females	26	0	0	0	0	26
	Males	29	1	0	0	0	30
	Total	55	1	0	0	0	56
	Total LA + EM	65	1	0	0	0	66

LA, Late Antique; EM, Early Mediaeval; N, number of individuals.

Table 14 – Tooth wear score according to the Smith and Knight tooth wear index.

	Males			Females			Total		
	N	NT	AWTS	N	NT	AWTS	N	NT	AWTS
LA	96	2315	2.15	88	2109	1.91	184	4424	2.03
EM	225	4519	2.08	147	2781	1.98	372	7300	2.04
Total LA + EM	321	6834		235	4890		556	11724	

LA, Late Antique; EM, Early Mediaeval; N, number of individuals; NT, number of teeth; ATWS, average tooth wear score according to the Smith and Knight tooth wear index.

2.08 for Early Mediaeval males and 1.98 for females. There were no statistically significant differences between the samples (Table 14).

4. Discussion

In this research 1118 skulls from the Late Antique and Early Mediaeval period were examined for malocclusions and orthodontic anomalies. According to available literature, most anthropologic studies of malocclusion have been based on relatively small samples so this analysis probably presents one of the most comprehensive bioarchaeological investigations focusing on malocclusions and orthodontic anomalies. This sample size provided an opportunity to get reliable data about factors that limit research of malocclusions and orthodontic anomalies in skeletal remains derived from archaeological contexts. As, however, previously noted – whilst the total sample was sizable the number of individuals available for examination was significantly decreased for some features, resulting in a data base that contained from 36 to 362 individuals. Features requiring the presence of both jaws and all, or almost teeth were most difficult for examination. Heavy damage and fragmentation of the skulls and jaws, skulls without accompanying mandibles and a high prevalence of postmortem lost teeth (particularly one-rooted teeth in the frontal region) are the main reason why malocclusions in the anterior region of the dental arches in the vertical or occlusal plane were analysed only in 3.2% individuals of the total sample; why the analysis of malocclusions by Angle's classification was possible only on 5.5% individuals, and why the transverse occlusal deviations of the posterior teeth was performed only on 5.9% individuals. Orthodontic anomalies affecting single tooth like hypodontia, hyperdontia, tooth rotation or tooth malposition or group of teeth (frontal teeth) like diastema or tooth crowding were analysed in significantly more individuals than features requiring the presence of both jaws, and all or almost all teeth, varying from about 19% individuals (diastema and crowding) up to about 32% individuals (anomalies of teeth number). In archaeologically derived skeletal series it has generally been easier to describe the alignment of teeth than occlusal relationships because the mandible frequently becomes separated from the rest of the skull in archaeological skeletal remains.[24]

Malocclusion can occur as a result of: genetically determined factors, environmental factors, or more commonly a combination of both.[20] A number of primarily environmental causes are known including habits such as digit-sucking and nail biting, trauma, caries, periodontal disease, chronic nasal obstruction with mouth breathing, and reduced masticatory stress resulting from the soft consistency of foods in urbanised societies. Other known causes of malocclusion include clefts of the alveolus and palate that occur during foetal growth, genetic syndromes that affect the development of craniofacial structures, and supernumerary and congenitally absent teeth that predominantly result from heritable factors.[19] Analysis of malocclusion and orthodontic anomalies and their aetiology can provide a unique insight into the everyday life, diet, nutrition and methods of procuring the diet in archaeological populations.

Hypodontia is defined as a condition in which a person has missing teeth as a result of their failure to develop. Congenital hypodontia arises because of an abnormality in the induction of oral ectoderm by the ectomesenchyme. The congenital absence of some teeth is common with the most commonly absent teeth being the last teeth in each series (i.e. the lateral incisor, second premolar and third molar).[35] In this study, the frequency of individuals with at least one congenitally missing tooth varied from 30.61% in the Early Mediaeval sample to 41.02% in the Late Antique sample. Except for third molars (upper and lower) that were the most frequently missing teeth in both samples (15.64% of all examined tooth sockets in the Early Mediaeval sample, and 30.21% of all examined tooth sockets in the Late Antique sample), four cases of missing upper second incisors (1.43%) were recorded in females from the Late Antique sample, and three cases of missing lower second premolar (1 case or 0.36%. of all examined tooth sockets in the Late Antique sample and 2 cases or 0.21% of all examined tooth sockets in the Early Mediaeval sample).

The incidence of hypodontia in the permanent dentition in modern samples varies from 3.5 to 6.5% (excluding wisdom teeth, 9–37%), with a 1:1.4 male/female ratio.[35] There are only a few studies that published comparable data about hypodontia in archaeological populations. Nelsen et al. examined a skeletal sample from an Iron Age cemetery in Thailand and found a very high prevalence of 79% in adults (30/38) with at least one incisor missing in either maxilla or mandible.[36] Evensen and Ogaard examined the prevalence and severity of malocclusions in a sample of mediaeval Norwegians using the Norwegian need for orthodontic treatment index (NOTI).[24] Although this index includes the prevalence of hypodontia, separately presented data for the mediaeval population are not available. Cabov et al. examined 27 persons and a total number of 412 teeth and established a lower and an upper hypodontia incidence of 3.7% for the Croatian population in the Vinodol region in the period from the 9th to 11th century.[28] Their research included third molars. In an investigation of the prevalence of second incisor hypodontia in contemporary

Croatian inhabitants, Prskalo et al. found a prevalence of 2.46%.[37] In this study the prevalence of hypodontia expressed by teeth (all teeth including third molars) varied from 15.86% in the Early Mediaeval sample to 32.01% in the Late Antique sample.

Regarding malpositions of single teeth, in this study rotation, displacement, diastema and crowding were evaluated. Although it seems that dental malpositions are mostly caused by dysgnathia and exogenous factors, several observations give reasons to believe that, at least to some degree, hereditary factors also play a role.[4] Tooth rotation as the movement of a tooth around its long axis in the mesial or distal direction was found in 10.94% of individuals in the Late Antique sample and in 9.32% of individuals of the Early Mediaeval sample. Corruccini and Pacciani examined a sample of 50 Etruscan skulls for tooth rotation, and found 6.8% individuals with rotated teeth.[23] Vestibular and palatinal tooth malposition was registered in 5.26% of individuals in the Late Antique sample, and in 3.42% of individuals in the Early Mediaeval sample. Canine displacement is the most frequent case of tooth displacement and is generally classified into buccal or palatal displacement. More rarely, canines can be found lying horizontally above the apices of the teeth of the upper arch or displaced high adjacent to the nose.[20] In this research canines were the most affected teeth by tooth displacement: 63.64% of all displaced teeth were canines. The absence of radiological confirmation of some examined features, like third molar agenesis can be considered a limitation of the reliability of the data provided by this study. If non-invasive techniques are used in the examination of skeletal remains, like in this study, tooth agenesis and tooth displacement (including tooth impaction) can be only confirmed by radiographic analysis. Rajic et al. described a case of an impacted canine in a prehistoric female skull from Croatian enolithic site of Vucedol.[29] Their finding was confirmed by roentgencephalometric analysis. Although Lukacs recommended epidemiological analysis of large skeletal collections from different ecological and cultural contexts in order to yield important clues to the aetiology of dental transposition, expecting that a large sample size can provide more accurate data about dental transposition prevalence,[21] transposition of teeth as a change of position between two teeth in a dental arch was not registered in this study.

Criteria for diagnosis of tooth diastema were well defined (as described in Section 2) and strictly followed in this study. All cases where there was any doubt that the diastema was caused by an environmental factor (i.e. tooth extraction) were excluded from the study. In spite of this, 19 cases of diastema in 10/212 individuals available for examination were recorded. The most frequent were diastemata between upper second incisors and upper canines (the upper ''primate space''), 31.6% of all diastemata, followed by upper medial diastema (26.3% of all diastemata). The lower ''primate space'', the space that occurs between canine and first premolar in lower jaw was recorded three times in two individuals (15.8% of all diastemata) (Table 7). The prevalence of individuals with tooth diastema is approximately 5%. The prevalence of individuals with maxillary medial diastema is 2.4%. Lavelle studied the prevalence of maxillary medial diastema in 18–25 year old UK residents belonging to different races. He found that 3.4% of Caucasians, 5.5% of Negroids and 1.7% of Mongoloids were affected by this condition.[38]

The crowding of permanent teeth is considered to be an indicator for disproportion between the sizes of the jaw and the teeth. The most common location of crowding is in the frontal region of the dental arch.[4] Crowding is extremely common in Caucasians, affecting approximately two-thirds of the modern population. Whilst the size of the jaws and teeth is mainly genetically determined, environmental factors, such as premature deciduous tooth loss, can precipitate or exacerbate crowding. In evolutionary terms both jaw size and tooth size appear to be reducing. However, crowding is much more prevalent in modern populations than in prehistoric skeletal series. It has been suggested that this is due to the introduction of a less abrasive diet, so that less interproximal tooth wear occurs during the lifetime of an individual.[20] In this study the frequency of tooth crowding was about 26% of all individuals in the Late Antique sample, and 7.19% of all individuals in the Early Mediaeval sample. Mockers et al. examined dental crowding in a prehistoric population from the Copper Age in France. The prevalence of crowding was 100% in this prehistoric population.[22] In an epidemiological study of malocclusions in the modern population from island of Hvar, Croatia, Lauc found that the frequency of crowding was 57.1%.[39] Compared with our results this presents a significant temporal increase in the frequency of dental crowding. The increased prevalence of dental crowding is generally believed to have been caused by changes in diet (introducing a less abrasive diet) and lifestyle, but Rose and Roblee go a step further to find the underlying problem. They consider the problem of adaptation of the alveolar bone to the changes in diet and alveolar bone discrepancies as a leading cause of dental crowding and malocclusion.[27]

The importance and comparability of the results of the analyses of: malocclusions by Angle's classification, malocclusions in the anterior region of the dental arches (in the occlusal and vertical plane), and of transverse occlusal deviations of the posterior teeth in this study is of limited value because of the small sample size available for investigation. Angle's classification is based upon the premise that the first permanent molars erupted into a constant position within the facial skeleton, and can be used to assess the anteroposterior relationship of the arches.[20] Unfortunately first permanent molars are amongst the teeth that are most frequently lost antemortem in archaeological skeletal series.[6,7,9,15,17] This, together with the preservation of the sample, explains why malocclusions by Angle's classification were analysed in only 62 individuals (5.54% of the whole sample) in this investigation. The most frequent Angle Class was Class I (100.0% in the Late Antique sample, and 96.2% in the Early Mediaeval sample), followed by Class II division 1 (1.9%) and Class III (1.9%) in the Early Mediaeval sample. In the epidemiological study of malocclusions in recent population on Hvar Island, Croatia, the frequency of Angle Class I was 43.8%, followed by Class II (22.8%) and Class III (0.9%).[39] Uslu examined the malocclusions on living white subjects in Turkey and prevalence of malocclusions by Angle's classification was: Class I 39.8%, Class II 36.1%, Class II division 25.7% and Class III 18.4%.[40]

The term crossbite is a collective term for malocclusions in the anterior or posterior region of the dental arches in which the normal labio-lingual or bucco-lingual relationship between the teeth of the upper and lower dental arch is reversed.[4] In this study malocclusions in the anterior region of the dental arches in the occlusal plane were recorded as: regular sagittal relationship, anterior crossbite and strong horizontal overlap (overjet) and transverse occlusal deviations of the posterior teeth were classified as: regular transverse occlusion, edge-to-edge bite (posterior crossbite tendency), posterior crossbite, buccal non-occlusion and lingual non-occlusion. Malocclusions in the anterior region of the dental arches in the occlusal plane were analysed on 37 individuals (3.3% of the whole sample) and only one case of anterior crossbite was found. All other cases were considered as regular sagittal relationships. Of the transverse occlusal deviations on the posterior teeth only one case of edge-to-edge bite in the Early Mediaeval sample was found. In the investigation performed by Lauc on Island Hvar, Croatia, a normal overjet predominated with a frequency of 69.6% whilst anterior crossbite was observed in 1.0% of the cases.[39] In a Turkish sample Celikoglu et al. found the increased overjet in 41.7% of all examined cases, and 12.1% of individuals with edge-to-edge bite.[41] The two most important form of malocclusion in the anterior region of the dental arches in the vertical plane are an open bite and a deep bite.[4] In our research 36 individuals (3.2% of the whole sample) were examined. This feature cannot be examined without incisors and canines. Although these teeth are infrequently lost during life, they are easily lost postmortem. Because they have only one root, and a relatively thin bony coverage, they are amongst the most frequently postmortem lost teeth. In the Late Antique sample all of the examined individuals had regular vertical relationship in anterior regions (100.0%). In the Early Mediaeval sample three males (10.7%) with deep bite (overbite) were found, all other individuals had regular vertical relationship. In the modern population on Hvar, Lauc found deep bite in 49.1% of the cases.[39] Celikoglu et al. examined a sample of orthodontic patients from Turkey and found overbite in 36.6% of the cases.[41]

The composition and consistency of foods consumed determine the kinds of microorganisms that flourish in the oral cavity and the nature of biomechanical forces affecting the teeth and jaws.[1] Tooth wear is produced by tooth–tooth contact (attrition) and tooth–food interaction (abrasion) during mastication.[4] Wear of teeth increases proportionally to the abrasiveness of food and it is well known that diet of ancient populations was not so soft like today. This permits dental wear to be used for dietary reconstruction. All factors influencing the dimensions of teeth (tooth wear decreases the tooth height and tooth width in mesiodistal direction) could affect the normal intra- and inter-jaw relationships causing orthodontic anomalies and malocclusions.[19] Although there are different dietary patterns between Late Antique and Early Mediaeval samples analysed in this study which were confirmed by archaeological and bioarchaeological studies[30,31] our results of the tooth wear analysis showed that there was no statistically significant difference between this two samples which had almost the same average tooth wear score (2.03 in the Late Antique sample and 2.04 in the Early Mediaeval sample). Therefore, the influence of tooth wear on the differences in the frequencies of orthodontic anomalies and malocclusions analysed in this study was negligible.

Previously published studies which analysed markers of health in skeletal remains, demonstrated that the transition from the Late Antique to the Early Mediaeval period was not a uniform process, but differentially affected the past inhabitants of Croatia with, however, a clear trend of worsening living conditions during the Early Mediaeval period.[30,31] Although this study analysed a large skeletal sample dating to these periods it could not confirm that the clear worsening of living conditions in the Early Mediaeval period had a significant influence on the prevalence of malocclusions and orthodontic anomalies. Probably there are numerous explanations for this, but if it is considered in the light of the influence of genotype and phenotype it seems that genotype is more important for the development of malocclusions and orthodontic anomalies examined in this study. Namely, changes in diet, way of preparation of food, different diseases affecting growth and development, dental caries and other oral diseases which are usually considered as etiological contributors for development of malocclusions and orthodontic anomalies and which are confirmed in the Early Mediaeval period did not have influence on the examined features as shown in previous studies. Maybe the time span covered by this study was too short for the expression of the phenotypic (environmental) influence on the development of malocclusions and orthodontic anomalies.

Statistically significant differences between the Late Antique and the Early Mediaeval samples were recorded only in the frequencies of hypodontia and tooth crowding. In both cases individuals from the Late Antique period had higher frequencies of these features. According to criteria used in this study for recording hypodontia, this result suggests that the peoples that inhabited the territory of modern Croatia during the Late Antique and Early Mediaeval periods belonged to different populations. This assumption is supported by historical sources which indicate that during the Late Antique period modern Croatia was inhabited by a fairly heterogeneous mixture of various Romanised populations that were dislodged by Slavs, Avars, and finally Croats arriving from the east during the Early Mediaeval period.[30] Differences in the prevalence of tooth crowding can be explained by environmental factors like diet, and methods of procuring the diet.[42] Slavs, Avars, and Croats had simpler methods of procuring the diet and consumed more abrasive foods rich in grains and cereals. This caused more extensive wear of occlusal and interproximal tooth surfaces resulting in lower frequencies of tooth crowding.

5. Conclusion

Anthropological investigations of skeletal remains should be limited to abnormalities of the relationship between the upper and lower jaws, and to the identification of localised eugnathic anomalies.[4] Orthodontic anomalies affecting only one tooth or group of teeth are more suitable for examination in bioarchaeological investigations than orthodontic features that require the presence of both jaws and all, or almost all teeth. Malocclusions can be examined only on excellent preserved skulls that have almost all teeth preserved. Comparisons between the frequencies of orthodontic anomalies and malocclusion in archaeological remains are somewhat difficult because of different methodologies. Clinical investigation protocols and methodologies should be adopted for bioarchaeological analyses, and international standards and recommendations should be established for this type of investigation on skeletal remains.

6. Contributors

Marin Vodanović is the main researcher and contributed to the design of the study, measurements and work on the sample, manuscript preparation and interpretation of the results, literature search. Ivan Galić helped in measurements and work on the sample, manuscript preparation. Mihovil Strujić helped in the interpretation of the results, literature search and manuscript preparation. Mario Šlaus contributed in sample setup, demographic analyses of the sample, sex and age estimation. Kristina Peroš helped in measurements and work on the sample and interpretation of the results. Hrvoje Brkić is the principal investigator and grant holder.

Funding

This research was supported by theMinistry of Science, Education and Sports of the Republic of Croatia, Grant No. 065-0650445-0423 (Human dentition in forensic and archeological researches); principal investigator: Hrvoje Brkić.

Competing interest

None declared.

Ethical approval

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

REFERENCES

1. Iscan MY, Kennedy KAR. *Reconstruction of life from the skeleton*. New York: Alan R. Liss, Inc.; 1989.
2. Šlaus M. *Bioarheologija*. Zagreb: Školska knjiga; 2006.
3. Bowen WH. Food components and caries. *Adv Dent Res* 1994;**8**(2):215–20.
4. Alt KW, Rosing FW, Teschler-Nicola M. *Dental anthropology: fundamentals, limits, and prospects*. Wien, New York: Springer; 1998.
5. Wesolowski V. Caries prevalence in skeletal series – is it possible to compare? *Mem Inst Oswaldo Cruz* 2006;**101**(Suppl. 2):9–145.
6. Manzi G, Salvadei L, Vienna A, Pssarello P. 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. *Am J Hum Biol* 1999;**11**(3):327–41.
7. Slaus M, Pecina-Hrncevic A, Jakovljevic G. Dental disease in the late Medieval population from Nova Raca, Croatia. *Coll Antropol* 1997;**21**(2):561–72.
8. Belcastro MG, Mariotti V, Facchini F, Bonfiglioli B. Proposal of a data collection form to record dento-alveolar features – application to two Roman skeletal samples from Italy. *Coll Antropol* 2004;**28**(1):161–77.
9. Nelson GC, Lukacs JR, Yule P. Dates, caries, and early tooth loss during the Iron Age of Oman. *Am J Phys Anthropol* 1999;**108**(3):333–43.
10. Chazel JC, Tramini P, Valcarcel J, Pelissier B. A comparative analysis of periapical health based on historic and current data. *Int Endod J* 2005;**38**(5):277–84.
11. Kaidonis JA. Tooth wear: the view of the anthropologist. *Clin Oral Investig* 2008;**12**(Suppl. 1):S21–6.
12. Eshed V, Gopher A, Hershkovitz I. Tooth wear and dental pathology at the advent of agriculture: new evidence from the Levant. *Am J Phys Anthropol* 2006;**130**(2):145–59.
13. Vodanović M, Šlaus M, Galić I, Marotti MHB. Stafne's defects in two mandibles from archaeological sites in Croatia. *Int J Osteoarchaeol* 2011;**21**(1):119–26.
14. Keene HJ. Dental caries prevalence in early Polynesians from the Hawaiian Islands. *J Dent Res* 1986;**65**(6):935–8.
15. Kerr NW, Bruce MF, Cross JF. Caries experience in the permanent dentition of late mediaeval Scots (1300–1600 A.D.). *Arch Oral Biol* 1988;**33**(3):143–8.
16. Whittaker DK, Molleson T. Caries prevalence in the dentition of a late eighteenth century population. *Arch Oral Biol* 1996;**41**(1):55–61.
17. Vodanovic M, Brkic H, Slaus M, Demo Z. The frequency and distribution of caries in the mediaeval population of Bijelo Brdo in Croatia (10th–11th century). *Arch Oral Biol* 2005;**50**(7):669–80.
18. Gauta I, Vazdar MA, Vodanović M. Human molar crown traits in Croatian medieval and contemporary populations. *Acta Stomatol Croat* 2010;**44**(1):3–16.
19. Bishara SE. *Textbook of orthodontics*. Philadelphia: Saunders; 2001.
20. Mitchell L, Carter NE, Doubleday B. *An introduction to orthodontics*. 2nd ed. Oxford: Oxford University Press; 2001.
21. Lukacs JR. Canine transposition in prehistoric Pakistan: Bronze Age and Iron Age case reports. *Angle Orthod* 1998;**68**(5):475–80.
22. Mockers O, Aubry M, Mafart B. Dental crowding in a prehistoric population. *Eur J Orthod* 2004;**26**(2):151–6.
23. Corruccini RS, Pacciani E. Orthodontistry and dental occlusion in Etruscans. *Angle Orthod* 1989;**59**(1):61–4.
24. Evensen JP, Ogaard B. Are malocclusions more prevalent and severe now? A comparative study of medieval skulls from Norway. *Am J Orthod Dentofacial Orthop* 2007;**131**(6):710–6.
25. Lindsten R, Ogaard B, Larsson E. Dental arch space and permanent tooth size in the mixed dentition of a skeletal sample from the 14th to the 19th centuries and 3 contemporary samples. *Am J Orthod Dentofacial Orthop* 2002;**122**(1):48–58.

26. Lindsten R, Ogaard B, Larsson E, Bjerklin K. Transverse dental and dental arch depth dimensions in the mixed dentition in a skeletal sample from the 14th to the 19th century and Norwegian children and Norwegian Sami children of today. *Angle Orthod* 2002;**72**(5):439–48.
27. Rose JC, Roblee RD. Origins of dental crowding and malocclusions: an anthropological perspective. *Compend Contin Educ Dent* 2009;**30**(5):292–300.
28. Cabov T, Tomljenovic K, Legovic A, Kovac Z, Peric B, Jokic D. A case of canine hypodontia in an early Croatian cemetery Strance-Gorica. *Coll Antropol* 2006;**30**(2):443–6.
29. Rajic S, Muretic Z, Percac S. Impacted canine in a prehistoric skull. *Angle Orthod* 1996;**66**(6):477–80.
30. Slaus M. Osteological and dental markers of health in the transition from the Late Antique to the Early Medieval period in Croatia. *Am J Phys Anthropol* 2008;**136**(4):455–69.
31. Šlaus M, Bedić Ž., Rajić Šikanjić P, Vodanović M, Domić Kunić A. Dental health at the transition from the Late Antique to the early Medieval period on Croatia's eastern Adriatic coast. *Int J Osteoarchaeol* 2011;**2**:1. 10.1002/oa.1163.
32. Slaus M, Tomicic Z. Discriminant function sexing of fragmentary and complete tibiae from medieval Croatian sites. *Forensic Sci Int* 2005;**147**(2–3):147–52.
33. Smith BG, Knight JK. An index for measuring the wear of teeth. *Br Dent J* 1984;**156**(12):435–8.
34. Bardsley PF. The evolution of tooth wear indices. *Clin Oral Investig* 2008;**12**(Suppl. 1):S15–9.
35. Heasman PA. *Restorative dentistry, paediatric dentistry and orthodontics*. Edinburgh: Churchill Livingstone; 2003.
36. Nelsen K, Tayles N, Domett K. Missing lateral incisors in Iron Age South-East Asians as possible indicators of dental agenesis. *Arch Oral Biol* 2001;**46**(10):963–71.
37. Prskalo K, Zjaca K, Skaric-Juric T, Nikolic I, Anic-Milosevic S, Lauc T. The prevalence of lateral incisor hypodontia and canine impaction in Croatian population. *Coll Antropol* 2008;**32**(4):1105–9.
38. Lavelle CL. The distribution of diastemas in different human population samples. *Scandinavian J Dental Res* 1970;**78**(6):530–4.
39. Lauc T. Orofacial analysis on the Adriatic islands: an epidemiological study of malocclusions on Hvar Island. *Eur J Orthod* 2003;**25**(3):273–8.
40. Uslu O, Akcam MO, Evirgen S, Cebeci I. Prevalence of dental anomalies in various malocclusions. *Am J Orthod Dentofacial Orthop* 2009;**135**(3):328–35.
41. Celikoglu M, Akpinar S, Yavuz I. The pattern of malocclusion in a sample of orthodontic patients from Turkey. *Med Oral Patol Oral Cir Bucal* 2010;**15**(5):e791–6.
42. Corruccini RS. Australian aboriginal tooth succession, interproximal attrition, and Begg's theory. *Am J Orthod Dentofacial Orthop* 1990;**97**(4):349–57.