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Health and disease in a Roman walled city: an example of *Colonia Iulia Iader*

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Summary – *The paper presents the results of the bioarchaeological study of a Roman period (3rd-5th century) skeletal sample from Zadar, Croatia with the focus on subadult stress indicators (cribra orbitalia and dental enamel hypoplasia) and indicators of non-specific infectious diseases (periostitis). The total frequency of cribra orbitalia, an indicator of iron deficiency anaemia, in Zadar is 20.1%. Half of the subadult skeletons from Zadar exhibit signs of cribra orbitalia, of which two are in active form. Adults not affected by cribra orbitalia lived on average 4.5 years longer than individuals affected by this pathological change. Total frequency of dental enamel hypoplasia in adults is 61.1% with somewhat higher frequency in females. The frequency of periostitis in subadults (66.7%) is significantly higher than in adults (30.4%). A positive correlation was established between cribra orbitalia and periostitis in males. The presented data suggest relatively low quality of life in Roman Zadar, most probably due to the overcrowding inside the walled city which led to deterioration of sanitary conditions and the occurrence of infectious diseases.*

Keywords – *Zadar, Roman period, cribra orbitalia, dental enamel hypoplasia, periostitis.*

Introduction

Study of various skeletal pathologies, including indicators of subadult stress such as *cribra orbitalia* and dental enamel hypoplasia, proved as a very successful method of determining of the living conditions of past populations (Cohen & Armelagos, 1984; Huss-Ashmore *et al.*, 1982; Larsen, 1987). The analysis of these pathological changes provides the data on possible stress pathogens during growth and development when the stress is most pronounced, and about the effects this kind of stress has on the children's health.

Since Welcker in 1888 introduced the term "*cribra orbitalia*", it was observed in numerous osteological samples around the world, and today is generally considered as an indicator of physiological stress (Huss-Ashmore *et al.*, 1982; Martin *et al.*, 1985; Mittler & Van Gerven, 1994).

The data collected throughout the various regions indicate that this pathology may develop in different ecological, social and cultural environments. Accordingly, the aetiology of *cribra orbitalia* can be understood only in close association with other biological indicators of stress (Fairgrieve & Molto, 2000; Larsen, 1997). Although, some factors such as parasitism, inadequate nutrition and infectious diseases occur in almost all environments, when interpreting *cribra orbitalia* in archaeological populations one has to take into account the circumstances that are specific to particular sites or geographical regions. Available data on living conditions and life quality of previous inhabitants of Zadar and the eastern Adriatic coast, such as population density, quality of nutrition, level of hygiene, housing conditions, and local ecosystems that surrounded these populations are often incomplete or ambiguous. Due to these limitations analysis and interpretation of the frequency of *cribra orbitalia* in this study was correlated with the frequency of another indicator of subadult stress – dental enamel hypoplasia.

Numerous factors can slow or stop the formation of dental enamel during childhood, but many studies have shown that dental enamel is particularly sensitive to metabolic disturbances that are the result of poor quality of diet and various diseases. Since dental enamel, unlike bone, does not have the ability of remodelling, developmental disorder, i.e. dental enamel hypoplasia will remain recorded until the affected part of the tooth crown is destroyed by abrasion (Šlaus, 2006).

Infectious diseases in archaeological populations have been the leading cause of death, especially during the earliest childhood (Ortner, 2003). Most infectious diseases that occur in the archaeological populations are of non-specific origin, which means that the pathological changes are caused by various microorganisms whose aetiology is not known, and these changes are usually manifested on bones as periostitis. This paper will try to determine the possible correlation of indicators of subadult stress with non-specific infectious diseases.

During the Roman period Zadar was one of the major cities on the eastern Adriatic coast, and as such was protected by powerful fortifications and city walls. Permanent natural population growth and immigration of new inhabitants likely lead to overcrowding at some point, which resulted in deterioration of sanitary standards in the city. It may be assumed that the overcrowding and poor sanitation in Zadar resulted in sporadic outbreaks of various infectious diseases such as measles and tuberculosis. So, the hypothesis is that such living conditions resulted in relatively poor health, especially in children, which should reflect in increased frequency of skeletal and dental indicators of subadult stress and indicators of non-specific infectious diseases. Comparison of the results obtained from this study with the data observed in other Roman period skeletal samples should indicate whether the health profile recorded in the Zadar sample is a characteristic only of the overcrowded urban communities living inside the city walls such as Zadar, or the high prevalence of subadult stress indicators is also a characteristic of other populations from the Roman Empire, regardless of their lifestyle.

Material and Methods

Skeletal material analysed in this paper originates from the Roman period necropolis of Zadar. Zadar is a city situated on the eastern Adriatic coast in contemporary Croatia (Fig. 1). The Caesar founded Zadar as a Roman colony in 48 BC (*Colonia Iulia Iader*). The city was organised on principals of Roman urbanism with major streets intersected at right angles surrounded by massive stone walls. Due to urban construction, rescue excavations of Roman necropolis were carried out in 1989/1990 and 2005/2006 in the city district Relja during which over 1000 graves (over 75% were inhumation burials) were excavated. Roman necropolis was located between 500 and 1 000 meters from the city walls along the road leading to the southeast. Inhumation burials, which are of the main interest in this analysis, are dated between 3rd and 5th century AD (Brusić & Gluščević, 1990). Graves from which osteological material was recovered were simple inhumations in plain ground or graves covered with tegulae (roof tiles) or fragments of amphorae. Differentiation between social categories based on grave goods and burial forms could not be performed, therefore, all individuals were treated as a single social category. The sample consists of 255 individuals (64 subadults, 80 females and 111 males) (Tab. 1). The average life span for males is 38.4 years, and for females 37.4 years.

During the analysis, carried out in the laboratory of the Department of Archaeology of the Croatian Academy of Sciences and Arts in Zagreb, the sex of the recovered skeletons was determined on the basis of pelvic and cranial morphology (Bass, 1995; Krogman & Iscan, 1986). No attempt was made to determine the sex of subadults.

Several factors were used to assess age at death: degree of obliteration of the cranial and maxillar sutures (Mann & Jantz, 1988; Meindl & Lovejoy, 1985), alterations in the pubic symphysis (Brooks & Suchey, 1990; Gilbert & McKern 1973), alterations in the auricular surface of the *ilium* (Lovejoy *et al.*, 1985), and changes on the sternal ends of the ribs (İşcan *et al.*, 1984, 1985).

The age of subadults was assessed on the basis of the changes that occur during the development and formation of deciduous and permanent teeth, the degree of bone ossification, and the length of the diaphysis of long bones (Bass, 1995; Fazekas & Kósa, 1978; Scheuer & Black, 2000). The age of the adults was given within a five-year range (e.g. 21-25), while the age of subadults was determined within a range of one year.

Cribra orbitalia occurs due to hypertrophy of the diploë, which leads to thinning and destruction of cortex and the formation of porous and spongy bone replacing cortex. Macroscopically it is manifested by the occurrence of perforating small lesions on the upper orbital vaults that are usually smaller than one millimetre in diameter. Changes can be observed in both adults and subadults, and may occur in an active or healed condition. Healed and active *cribra orbitalia* differ by size of the affected bone tissue, size of the perforating lesions and thickness of porous bone.

Some authors (e.g. Angel, 1966; Soren *et al.*, 1995) suggested that cranial pitting (porotic hyperostosis and *cribra orbitalia*) occur in correlation with hereditary haemolytic anaemia such as thalassemia and sickle cell anaemia, and these anaemias are usually prevalent in populations where malaria was endemic. On the other hand, Walker *et al.* (2009) hypothesize that porotic hyperostosis and many cases of *cribra orbitalia* are a result of the megaloblastic anaemia acquired by nursing infants through the synergistic effects of depleted maternal vitamin B12 reserves and unsanitary living conditions that are conducive to additional nutrient losses from gastrointestinal infections around the time of weaning, while *cribra orbitalia* can be attributed to a greater range of causes than porotic hyperostosis, such as subperiosteal bleeding associated with a codeficiency of vitamin C and B12. However, today most authors assume that *cribra orbitalia* is a result of iron deficiency anaemia (Carlson *et al.*, 1974; Cybulski, 1977; El-Najjar, 1976; Hengen, 1971; Huss-Ashmore *et al.*, 1982; Larsen, 1997; Mensforth *et al.*, 1978; Mittler & Van Gerven, 1994; Stuart-Macadam, 1985, 1991). This type of anaemia is defined as a reduction of haemoglobin and haematocrit in the blood below normal levels. Hengen (1971) concluded that the iron deficiency anaemia is primarily the result of parasitism, while Stuart-Macadam (1992) presumed, based on her research, that this type of anaemia is the adjustment of the organism to the disease, and its attempt to exhaust and starve pathogens such as bacteria and viruses who need the iron in order to be able to reproduce in the body of the host. Beside these, some other factors related to the occurrence of iron deficiency anaemia were noted in numerous archaeological populations: poor and inadequate diet, gastrointestinal and parasitic infections (Larsen & Sering, 2000; Mensforth, 1990; Reinhard, 1992; Walker, 1986), lead poisoning (Stuart-Macadam, 1991), thalassemia (Ascenzi *et al.*, 1991), changes in dietary habits (Roberts & Manchester, 1995), and diet rich in fitates (Carlson *et al.*, 1974) that prevent absorption of iron in the organism.

Fig. 1 - *Map showing geographical location of Zadar.*

Study of archaeological populations from different parts of the world has shown that active forms of this pathology are almost exclusive to subadults (Larsen *et al.*, 1992; Mensforth *et al.*, 1978; Mittler & Van Gerven, 1994; Šlaus, 2006; Walker, 1986; but see also Sullivan, 2005) suggesting that *cribra orbitalia*

Tab. 1 - Sex and age distribution in the Zadar sample.

AGE	SUBADULTS	FEMALES	MALES
0-4.9	26		
5-9.9	20		
10-14.9	18		
15-20		2	5
21-25		6	5
26-30		12	6
31-35		19	29
36-40		11	24
41-45		12	18
46-50		9	14
51-55		9	6
56-60		0	4
60+		0	0
Total	**64**	**80**	**111**
MEAN AGE AT DEATH		**X = 37.4 (SD = 9.43)**	**X = 38.4 (SD = 9.29)**

is an osteological response to childhood anaemia (Stuart-Macadam, 1985).

During analysis, all skulls with preserved orbital roofs were macroscopically examined under powerful illumination. All observed lesions were classified based on intensity (mild, moderate or severe) and condition (active or healed) at time of death according to criteria proposed by Mensforth *et al.* (1978) and Mittler & Van Gerven (1994). The adult subsample from Zadar was divided into two categories: "young" adults (individuals aged between 15 and 35 years) and "old" adults (individuals older than 35 years).

Dental enamel hypoplasia (DEH) is recognized as horizontal lines or deficiencies of the amount or thickness of enamel on the buccal surface of teeth (Goodman & Rose, 1990; Suckling, 1989). This is a subadult disorder that has for a long time been used as a non-specific indicator of systemic physiological stress (Goodman & Rose, 1990; Guatelli-Steinberg & Lukacs, 1999; Pindborg, 1982). Dental enamel hypoplasia may be caused by genetic factors, localized traumas and systemic physiological stress (Goodman & Rose, 1991), but many studies (e.g. Goodman *et al.*, 1991; Hillson, 1996; Pindborg, 1970) demonstrated that genetic factors and localized traumas are relatively rarely responsible for development of hypoplastic defects in archaeological populations. The vast majority of hypoplastic defects in archaeological and modern populations are associated with systemic physiological stress, which includes starvation, infectious diseases and metabolic disorders. The presence of DEH is therefore a reliable indicator of non-specific physiological stress and poor health in children.

The presence of DEH was analysed on the permanent maxillary central incisors and on the maxillary and mandibular canines. These teeth were chosen for the following reasons: 1) central incisors and canines are more susceptible to hypoplastic defects than other teeth (Goodman & Rose, 1990); 2) canines develop and grow for a relatively long time – from the fourth month to the sixth year of life (Lysell *et al.*, 1962); 3) incisors and canines have the lowest amount of mineralised dental deposits which sometimes may cover the crown of the teeth and prevent determination of the presence of hypoplasia. Only one tooth was analysed for each individual – in this case a tooth on the left side, and when it was not preserved, the tooth on the right side was analysed. Data were collected only for adults and only macroscopically visible hypoplastic defects were taken into account.

In order to get a better insight into the quality of life of the Roman period inhabitants of Zadar, the possible correlation between subadult stress indicators (*cribra orbitalia* and dental enamel hypoplasia) was analysed, as well as their possible correlation with the indicators of non-specific infectious diseases (periostitis).

Infectious diseases are the most common cause of non-specific periosteal reactions (Ortner, 2003). Periostitis is abnormal bone formation that affects the outer (periosteal) surface of bone, i.e. inflammation of the peripheral bone. Only cases of non-specific periostitis were included in this analysis. Non-specific periostitis was

Tab. 2 - The frequency of cribra orbitalia in the Zadar sample.

AGE/SEX		CRIBRA ORBITALIA			ACTIVE LESIONS	
		O[1]	A1[2]	%	A2[3]	% OF A1
0 – 4.9		12	8	66.7	2	25.0
5 – 9.9		8	2	25.0	0	0.0
10 – 14.9		12	6	50.0	0	0.0
SUBADULTS		**32**	**16**	**50.0**	**2**	**12.5**
Females	15 – 35	18	3	16.7	0	0.0
Females	35>	26	2	7.7	0	0,0
Females total		44	5	11.4	0	0.0
Males	15 – 35	21	4	19.0	0	0.0
Males	35>	32	1	3.1	0	0.0
Males total		53	5	9.4	0	0.0
ADULTS		**97**	**10**	**10.3**	**0**	**0.0**

[1]O = number of analysed frontal bones
[2]A1 = number of frontal bones showing signs of *cribra orbitalia*
[3]A2 = number of frontal bones with active forms of *cribra orbitalia*

diagnosed when two or more skeletal elements, excluding the endocranial surfaces of the skull, exhibited active or healed periostitis. Criteria for inclusion in the sample were the presence of at least 50% of all cranial bones and long bones. Trauma induced periostitis cases were not taken into consideration. In individuals with evidence of trauma, periostitis was not considered present if it was located on the same bone on which the fracture was located.

The differences in the average age-at-death for individuals with or without visible subadult stress indicators were evaluated using the non-parametric Kruskal-Wallis test. The differences in the frequencies of *cribra orbitalia*, dental enamel hypoplasia and periostitis between subadults and adults and between males and females were evaluated with the chi-square test using Yates correction when appropriate. Possible correlation between *cribra orbitalia*, dental enamel hypoplasia and periostitis was analysed using the Spearman test. A statistical computer program SPSS 14.0 for Windows was used for all statistical calculations and tests.

Results

In the Zadar sample *cribra orbitalia* was observed in 26 of 129 skulls (20.1%) with a minimum of one well-preserved orbit (Tab. 2). This pathology is present in healed and active condition, and by the intensity varies between mild and very severe.

The frequency of *cribra orbitalia* in adults from Zadar is 10.3% (10/97), without statistical significance between males (9.4%) and females (11.4%) (χ^2=0.001; P=0.97). The relationship between the frequency of *cribra orbitalia* with age-at-death was noted in both sexes, i.e. frequency of *cribra orbitalia* in males and females is reduced in older age groups (in younger females the frequency of *cribra orbitalia* is 16.7% and in older females it is 7.7%; in younger males this frequency is 19.0% and in older males it is reduced to 3.1%). Individuals not affected by *cribra orbitalia* lived on average 4.5 years longer than individuals affected by this pathological change (39.2 vs. 34.7 years), but the difference is not statistically significant (χ^2=2.092; P=0.148).

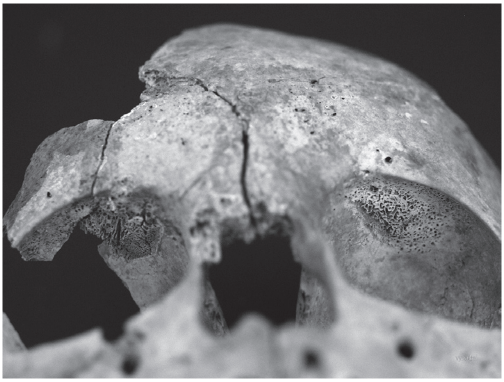

Fig. 2 - Active form of cribra orbitalia on the orbital roofs of a subadult (grave 334).

The frequency of *cribra orbitalia* among subadults is 50.0% (16/32) which is significantly higher than the frequency in adults (χ^2=20.153; P<0.01). The lowest frequency in subadults (25.0%) was recorded in the age group between 5 and 9.9 years, while the highest frequency (66.7%) was recorded in the age group between 0 and 4.9 years. In the same age group (0-4.9 years) *cribra orbitalia* in active condition was observed in two subadults (Fig. 2) representing 12.5% of all observed cases of this pathology among subadults in Zadar.

Analysis of intensity of *cribra orbitalia* shows that in subadults *cribra orbitalia* in a mild form occurs in 68.8% (11/16) of cases, moderate in 25.0% (4/16), and severe in 6.3% (1/16) of cases. In adults a mild form of *cribra orbitalia* was observed in 90.0% (9/10) of cases and moderate in 10.0% (1/10).

The frequency of dental enamel hypoplasia in Zadar is presented in Table 3. Total frequency of DEH (all analysed teeth combined) in adults is 61.1% with no statistically significant difference between the sexes (males 58.4% and females 64.3%) (χ^2=1.19; P=0.275). On all analysed teeth frequency of DEH is higher in females, but without any significant differences. In both sexes DEH is most frequent on the mandibular canines (in males 74.1%, and in females 79.7%). The DEH was especially pronounced on the teeth of a young male from grave 289 (Fig. 3).

In the Zadar sample stressors causing dental enamel hypoplasia did not have a significant effect on the average age-at-death: individuals not affected by DEH lived only 0.1 years longer than individuals affected by this pathology (38.3 vs. 38.2 years).

Of the 90 individuals with preserved frontal bones and all permanent teeth fit for the DEH analysis (central maxillary incisors, maxillary and mandibular canines) only six individuals (6.7%) were affected by both analysed subadult stress indicators. In adults the frequency of DEH is much higher than the frequency of *cribra orbitalia* (61.1% vs. 10.3%), and this pattern is also manifested in the following distribution: 66.7% of individuals affected by *cribra orbitalia* exhibit signs of dental enamel hypoplasia, while only in 7.8% of individuals affected by DEH the presence of *cribra orbitalia* was noted.

Table 4 presents the frequency of periostitis in the Zadar sample. The frequency of periostitis in subadults (66.7%) is significantly higher than in adults (30.4%) (χ^2=10.46; P<0.01). Most of the active periosteal lesions in subadults occur in the age group between 0 and 4.9 years from, and this is most often a severe, generalised active periostitis. Among subadults over the age of five, healed periostitis is most common, localised in the area of the lower extremities, primarily on the tibiae and fibulae. In adults, males exhibit significantly higher frequency of periostitis compared to females (50.0% vs. 27.3%; χ^2=4.472; P<0.05).

Analysis of possible correlation between the subadult stress indicators (*cribra orbitalia* and dental enamel hypoplasia) and indicators of non-specific diseases (periostitis) in the Zadar sample exhibits a significant positive correlation only between *cribra orbitalia* and periostitis in males (P=0.008).

Figures 4 and 5 present the frequencies of *cribra orbitalia* and dental enamel hypoplasia in several Roman period populations in comparison with the Zadar population. Data for the frequency of *cribra orbitalia* (subadults and adults combined) were taken from the following skeletal samples: Poundbury Camp, England (Stuart-Macadam, 1985), Cannington, England

Tab. 3 - The dental enamel hypoplasia frequency in the Zadar sample.

TEETH	ADULTS TOTAL		FEMALES		MALES	
	NWDEH/N[1]	%WDEH	NWDEH/N	%WDEH	NWDEH/N	%WDEH
Max I1[2]	54/119	45.4	27/55	49.1	27/64	42.2
Max C	73/128	57.0	35/58	60.3	38/70	54.3
Man C	118/154	76.6	55/69	79.7	63/85	74.1

[1]N = number of analysed teeth; NwDEH = number of teeth with DEH; % wDEH = % of N with DEH

[2] I = incisor; C = canine

(Robledo *et al.*, 1995), Kellis 2, Egypt (Fairgrive & Molto, 2000), Tarragona, Spain (Garcia *et al.*, 2002), Lucus Feroniae, Italy (Salvadei *et al.*, 2001), Ravenna and Rimini, Italy (Facchini *et al.*, 2004), Vallerano, Italy (Cucina *et al.*, 2006), Gloucester, England (Simmonds et al., 2008) and Štrbinci, Croatia (Novak *et al.*, 2009a). Data for the frequency of dental enamel hypoplasia (permanent dentition only) were taken from: Poundbury Camp, England (Stuart-Macadam, 1985), Lucus Feroniae and Isola Sacra, Italy (Manzi *et al.*, 1999), Quadrella, Italy (Bonfiglioli *et al.*, 2003), Ravenna and Rimini, Italy (Facchini *et al.*, 2004), Vallerano, Italy (Cucina *et al.*, 2006), and Štrbinci, Croatia (Novak *et al.*, 2009a).

Discussion

Until now, several papers dealing with the bioarchaeology of Roman period populations from Croatia were published (e.g. Bedić *et al.*, 2009; Novak *et al.*, 2009a; Rajić & Ujčić, 2003; Šlaus, 2002, 2004; Šlaus *et al.*, 2004a, 2004b), but these papers were primarily focused on the complete bioarchaeological analyses of skeletal samples. The frequency and distribution of subadult stress indicators has rarely been the primary object of research, and these data have been published combined with other bioarchaeological data within holistic studies of various skeletal samples from Croatia. Only two papers predominantly address the issue of *cribra orbitalia* and dental enamel hypoplasia in Croatian archaeological populations (Novak & Šlaus, 2007; Novak *et al.*, 2009b). The lack of such analyses in Croatian bioarchaeological science prompted us to write this paper, which presents an analysis of the frequency and distribution of subadult stress indicators in a Roman period population from Zadar (eastern Adriatic coast). As already emphasized in the introduction, the study of combinations of two or more indicators of stress proved to be a very successful method to determine the living conditions of archaeological populations, especially if written sources may not provide adequate information about the life quality of these people.

The average age-at-death of the adults from Zadar (males 38.4 and females 37.4 years) corresponds with values recorded in numerous Roman period populations (e.g. Brasili & Belcastro, 1998; Ery, 1981; Novak *et al.*, 2009a; Paine *et al.*, 2007, 2009; Rajić & Ujčić, 2003; Schweder & Winkler, 2004; Wiltschke-Schrotta & Teschler-Nicola, 1991).

Total frequency of cribra orbitalia in Zadar (20.1%) is somewhat lower than the frequencies recorded in most of the skeletal samples from the territory of the Roman Empire (Fig. 4). Low prevalence of orbital lesions in Zadar could suggest poor living conditions and the occurrence of frequent episodes of acute ailments that killed the affected individuals fairly quickly without leaving trace on their bones, unlike the chronic conditions (Paine *et al.*, 2009; Wood *et al.*, 1992).

Given the fact that the Roman period Zadar was a large urban conglomeration the entire city

Fig. 3 - Severe dental enamel hypoplasia on the teeth of a young male (grave 289).

Tab. 4 - The frequency of periostitis in the Zadar sample.

	PERIOSTITIS		
	A[1]	O[2]	%
Subadults	24	36	66.7
Males	29	58	50.0
Female	12	44	27.3
Adults total	41	102	40.2
Total	**65**	**138**	**47.1**

[1] A = number of well-preserved skeletons showing signs of periostitis;

[2] O = number of well-preserved skeletons

had to be organised by specific principles and had to satisfy certain architectonic and construction criteria. From archaeological studies and historical sources it is known that all streets in Zadar were paved by stone while the housing problem was solved by construction of family houses and *insulae* (multi-storey buildings in which the poorer people lived). Numerous public drinking fountains in the city were fed by water from the 40 km long aqueduct that was built by emperor Traianus (Suić, 1981). However, due to its limited usable construction area and location on the peninsula inside the city walls, the population density over time reached its maximum resulting in deterioration of sanitary conditions in the city.

Diet of the inhabitants of Roman period *Iader* was mostly based on cereals (wheat), and some authors believe that the region around Zadar was a granary of the entire province of Dalmatia (Pericic, 1999). Fishery was one of the main economic branches in Zadar, as witnessed by numerous ancient writers such as Pliny the Elder (Suić, 1981). The results of dental analysis also suggests relatively good quality of nutrition based on low frequency of caries and ante-mortem tooth loss, which is most likely the result of a large share of fish rich in fluoride (e.g. anchovies and sardines) in the everyday diet (Novak, 2008).

Cribra orbitalia was recorded on half of the analysed subadult skeletons from Zadar with significantly higher frequency of this pathological change in relation to adults. Main cause for this difference is probably a combination of various factors such as higher demand for iron in small children and low levels of iron in the mother's milk. Also, the diet of subadults after the weaning is usually rich in carbohydrates and phytates that decelerate the absorption of iron in the digestive system (Mensforth *et al.*, 1978; Morris, 1987). The weaning is an extremely sensitive period in a life of a child: during this period the child transits from the diet based on a sterile mother's milk to a diet and water filled with numerous microorganisms that can cause various infectious diseases that are accompanied by diarrhoea (Rowland *et al.*, 1988). Diarrhoea reduces appetite in children and increases metabolic loss of important nutritional substances such as iron, which may lead to the occurrence of anaemia despite diet containing sufficient amounts of iron and other necessary materials (Gordon *et al.*, 1963; Mittler & Van Gerven, 1994). In the youngest subadult age group *cribra orbitalia* was recorded in 66.7% of the frontal bones, while all subadults exhibiting this pathology are older than six months. In age under six months iron deficiency, which is the main cause of *cribra orbitalia*, is very rare, since the amount of iron accumulated during nine months *in utero* is sufficient for the first half year of child's life (Bernat, 1983), so the frequency of *cribra orbitalia* in subadults younger than six months is generally very low (Mensforth *et al.*, 1978; Mittler & Van Gerven, 1994). Increased prevalence of *cribra orbitalia* in the subadult age group between 10 and 14.9 years is probably a result of the fact that the children and adolescents between 9 and 16 years are particularly at risk of anaemia due to strong physiological needs of the organism for iron during growth and development. Soren *et al.* (1995) noted that 13% (6/47) of the analysed subadult skeletons from the Roman infant cemetery near Lugnano exhibited cranial and long bone pitting, and concluded that malaria was a common health issue in this community. Although anaemia associated with malaria cannot be ruled out as one of the possible causes of high prevalence of *cribra orbitalia* in subadults from Zadar, at present it is still unclear whether malaria had any influence on the quality of life in Roman *Iader*.

Only two cases of active form of *cribra orbitalia* might reflect a poor quality of life in Zadar. As already mentioned, Wood *et al.* (1992) suggested that general lack of skeletal lesions is a result of acute conditions that did not leave any trace on bone or teeth, and as such could indicate very poor living conditions; on the other hand, those skeletons that display skeletal lesions are the healthy individuals who have suffered from chronic stressors and lived long enough to display such lesions (for different views see Cohen, 1997; Cohen & Crane-Kramer, 2007). Additionally, Facchini *et al.* (1999) and Salvadei *et al.* (2001) associated the occurrence of active forms of *cribra orbitalia* among subadults in several Roman populations from Italy with unhealthy ecological systems that surrounded cities in the region, i.e. marshy and wooded environment that could be a host for various parasitic infections. Active bone pitting, according to Ortner & Putschar (1981), is one of the indicators of malaria infection, so the cases of active form of *cribra orbitalia* in Zadar might indicate the presence of malaria in this community. However, Soren *et al.* (1995) suggested that the combination of cranial and long bone pitting is an indicator of anaemia associated with malaria, but since postcranial pitting was not recorded in neither of the two subadult skeletons exhibiting active form of *cribra orbitalia*, it is more justifiably to conclude that active *cribra orbitalia* in Zadar was probably related to parasitism, unhygienic living conditions or/and

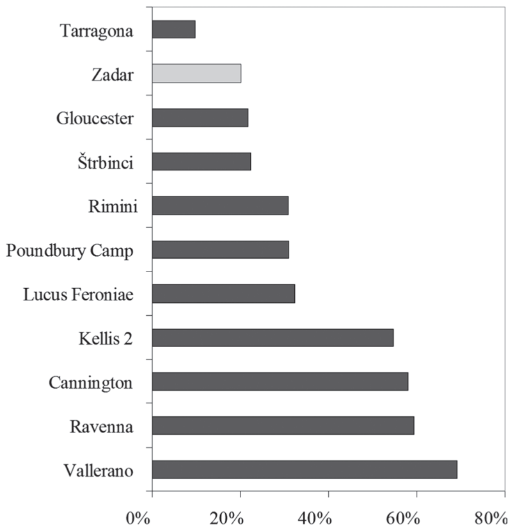

Fig. 4 - The frequency of cribra orbitalia in Zadar in comparison with other Roman period populations.

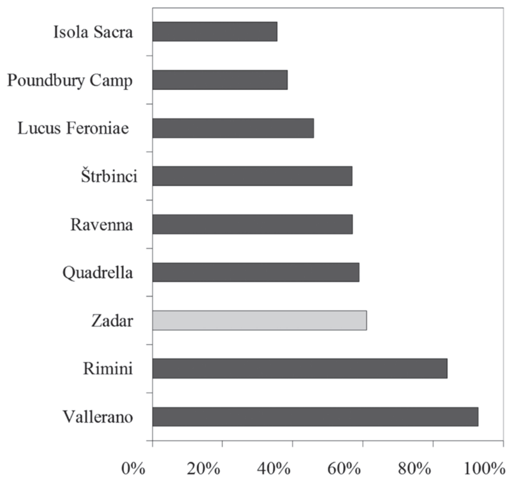

Fig. 5 - The frequency of dental enamel hypoplasia in Zadar in comparison with other Roman period populations.

some other environmental factor. Distinction between active and healed forms of *cribra orbitalia* is extremely important: healed form indicate that the individual survived anaemia that caused hypertrophy and porosity of superior orbital vaults, while active form show that the total physiological stress was to strong and severe for the individual to survive it (Šlaus, 2006). The absence of active *cribra orbitalia* in adults from Zadar, as in numerous Croatian skeletal samples (e.g. Novak & Šlaus, 2007; Novak *et al.*, 2009a; Šlaus 2000, 2002, 2006, 2008; Šlaus *et al.*, 2007) support the thesis of Stuart-Macadam (1985) that *cribra orbitalia* is a disorder that mainly occurs during the childhood.

Numerous authors recorded higher frequency of *cribra orbitalia* in females, especially during the reproductive age (e.g. Cybulski, 1977; Fairgrieve & Molto, 1999; Hengen, 1971; Novak & Šlaus, 2007; Stuart-Macadam 1985; Sullivan, 2005; Šlaus, 2002; Walker, 1986; Wapler *et al.*, 2004), which is probably the result of differences between males and females. Namely, it is known that females in the reproductive age often have a lower level of iron in the organism, which is directly associated with the physiology of the female organism. Menstruation, pregnancy, childbirth and lactation are the factors that most contribute to higher levels of iron reduction in the female organism. Therefore, it is very likely that the increased demand for iron and regular depleting of iron reserves in the female organism, incurred as a result of the reproductive functions, brought a large number of females into a state of anaemia caused by the iron deficiency (Sullivan, 2005). On the other hand, Mittler & Van Gerven (1994) suggested that a slightly higher frequency of *cribra orbitalia* in females (as is the case in the analysed sample) is a consequence of weaker ability of female organism to create new and healthy bone tissue. However, in the study of the Roman period skeletal sample from San Donato and Bivio CH, Paine *et al.* (2009) reported somewhat higher frequency of *cribra orbitalia* in males, but did not offer possible explanation for the observed difference.

Pathogens associated with *cribra orbitalia* (primarily iron deficiency anaemia) strongly influenced on the life quality of the Roman population from Zadar which can be gauged by the fact that adults with *cribra orbitalia* lived on average 4.5 years shorter than the adults without *cribra orbitalia*. Novak *et al.* (2009a) observed an almost identical situation in the Štrbinci sample (continental Croatia) where the difference was 5.9 years. Iron deficiency may have negative consequences on the health of individuals, which may lead to the aforementioned difference. Inadequate amounts of iron in the individual may have an effect on cognition and behaviour (Pollitt, 1987; Taras, 2005); reduced work load ability (Lozoff, 1989; Scrimshaw, 1991); and significantly less resistance to infectious disease (Bhaskaram, 1988; Dallman, 1987). Besides, Basta *et al.* (1979) recorded more frequent occurrence of infectious diseases in anaemic individuals comparing to healthy ones.

The frequency of dental enamel hypoplasia in Zadar is similar to the data observed in other Roman period populations (Fig. 5). Such frequencies are characteristic of sedentary populations with agriculture-based diets (Lanphear, 1990). Numerous studies (e.g. Goodman *et al.*, 1980; Lanphear, 1990; Larsen & Hutchinson, 1992; Malville, 1997; Ubelaker, 1992) imply that rapid increase of the frequency of this disorder occurred during the transition from hunting-gathering economy to economy based on agriculture. It is believed that the sedentary way of life, changes in diet and a sudden increase in population led to a significant increase in the quantity of stress that is manifested in an increase of the frequency of hypoplastic defects (Cohen & Armelagos, 1984). High frequency of DEH in Zadar suggests that almost two thirds of the analysed individuals survived strong metabolic stress during their childhood, possibly during the weaning period. Namely, some authors (Goodman, 1988; Goodman *et al.*, 1984; Lanphear, 1990) noted that most of the hypoplastic defects in sedentary populations are formed between the first and third year of life, i.e. during the transition from the diet based on the sterile breast milk to the diet rich with microorganisms. However, it is important to stress that serious doubts about this interpretation have been raised (Blakey *et al.*, 1994), and that serious methodological problems related to the age assessment of the defects have been identified (Hodges & Wilkinson, 1990). Additionally, Ritzman *et al.* (2008) reported that histological studies provide significantly higher age estimates than the commonly used macroscopic methods and this difference is particularly marked in early forming DEHs. They also suggest that re-evaluation of the methods used to estimate ages of DEH formation may be justified.

Frequency of dental enamel hypoplasia in Zadar is slightly higher in females compared to males. Authors who noticed higher frequencies of DEH in females (e.g. Goodman *et al.*, 1987; Guatelli-Steinberg & Lukacs, 1999; Gurri *et al.*, 1996; Lukacs, 1992; May *et al.*, 1993; Šlaus, 2000) suggested this may be a result of cultural differences – in most archaeological populations male children are likely to be better protected from stress than female children, i.e. girls were less favoured than boys, especially during the period of breastfeeding when boys had better parental care and nutrition (Guatelli-Steinberg & Lukacs, 1999; Lukacs, 1992). As a confirmation of this hypothesis the numerous written sources testify of frequent infanticide of newborn female children in the Antique period (e.g. Harris, 1982; Ingalls, 2002; Milner, 1998). In the Roman (pre-Christian) world, males were more valuable as labourers and warriors, while females required a costly marriage dowry. A common Roman expression states, '*Everyone raises a son, including a poor man, but even a rich man will abandon a daughter*' (Milner, 1998).

Factors responsible for the occurrence of DEH in Zadar did not have significant impact on the life quality because adults exhibiting hypoplastic defects lived only 0.1 years shorter than the adults without dental enamel hypoplasia. In the Roman period population from Štrbinci (continental Croatia) this difference is somewhat more pronounced and amounts to 2.0 years (Novak *et al.*, 2009a). Authors who noticed that frequent episodes of stress causing DEH have significant affect on average age-at-death (Duray, 1996; Goodman *et al.*, 1980; Keenleyside, 1998; Stodder, 1997) explain this process by the fact that individuals who were exposed to severe stress during early childhood are biologically damaged and have a reduced ability to resist to the stressful episodes later in life. At present it is still unclear why this difference in the Zadar skeletal sample is not more pronounced, but future studies concerning subadult stress indicators should resolve this issue.

A positive correlation between *cribra orbitalia* and dental enamel hypoplasia was not recorded in the Zadar sample. To date, only few authors tried to determine the possible correlation of these disorders, and the results of their studies are contradictory. A positive correlation between *cribra orbitalia* and DEH in adults was recorded by Facchini *et al.* (2004) and Obertová & Thurzo (2007), while Stuart-Macadam (1985) recorded increased frequency of hypoplastic defects in individuals who exhibited signs of *cribra orbitalia*. She also states that, although there is no direct interdependence between these pathological changes, subadults with inadequate nutrition and impaired immunity are much more vulnerable to pathogens of these disorders (Stuart-Macadam, 1985). Unlike these authors, Kozak & Krenz-Niedbala (2002), Marcsik & Baglyas (1989), Novak & Šlaus (2007), Novak *et al.* (2009b), and Turbón *et al.* (1991/1992) did not identify correlation of these subadult stress indicators in their studies. On the other hand, Mittler *et al.* (1992) concluded that individuals with *cribra orbitalia* have a significantly lower frequency of hypoplastic defects in comparison with individuals without *cribra orbitalia*, while Turbón *et al.* (1991/1992) suggested that there is no direct connection between these two pathologies, i.e. they reflect different nutritional aspects: *cribra orbitalia* is more associated with iron deficiency, while DEH is associated with the level of calcium in the organism.

The intensity and distribution of periostitis in the Zadar sample, especially pronounced in subadults, implies the emergence of systemic bacterial infections. As already mentioned, the occurrence of various infectious diseases is probably associated with the overcrowding of Zadar during the Roman period. *Colonia Iulia Iader* was located on the isolated peninsula and protected by the city walls, occupying the area of barely 50 hectares (1000 × 500 meters), while estimates of the size of the population of Zadar during the 4th century vary between 20 000 (Graovac, 2004) and 40 000 (Peričić, 1999). Very high population density in a small area between the sea and the city walls, without any room for further expansion, most probably resulted in overcrowding that led to rapid deterioration of sanitary conditions in the city favouring the occurrence and spread of infectious diseases.

The frequency of periostitis in *Iader* is almost two times higher in males comparing to females. Higher frequency of periostitis in males Brothwell (1986) and Paine *et al*. (2007) interpret by the fact that males were subjected to stronger stress due to the sex based division of labour, where males performed more difficult physical tasks. This scenario is probable in the Zadar sample because Novak (2008) reported significantly higher frequencies of indicators of hard physical labour (Schmorl's nodes and vertebral osteoarthritis, and benign cortical defects on the muscular attachments) in males in the Roman period Zadar.

A study of possible correlation between subadult stress indicators and indicators of non-specific diseases in the Zadar sample exhibit a significant positive correlation between the *cribra orbitalia* and periostitis in males, which corresponds with the view of Stuart-Macadam (1992) that the occurrence of non-specific infectious diseases is often associated with iron deficiency anaemia. A positive correlation between these biological stress indicators strongly suggests synergistic effect of several different factors (overcrowding, poor sanitation, infectious diseases) on the life quality of the Roman period inhabitants of Zadar.

Conclusion

Detailed bioarchaeological analysis of the Zadar skeletal sample provided very valuable data of the life quality of the residents of *Colonia Iulia Iader* between the 3rd and 5th century AD. A comprehensive study of subadult stress indicators (*cribra orbitalia* and dental enamel hypoplasia) and indicators of non-specific infectious diseases (periostitis) suggests relatively unfavourable living conditions most probably due to overcrowding, poor sanitation and occurrence of infectious diseases.

The prevalence of *cribra orbitalia* in Zadar might suggest the occurrence of acute ailments that killed the affected individuals fairly quickly without leaving any trace on their bones. The frequency of dental enamel hypoplasia in a present study is in accordance with the data observed in other sedentary populations with agriculture-based diets, while somewhat higher frequency of this disorder in females suggests that female children were less favoured than male children, especially during the period of breastfeeding, when the boys had better parental care and nutrition. The intensity and distribution of periostitis in the Zadar sample implies the occurrence of systemic bacterial infections probably as a result of overcrowding which led to the substantial worsening of the living conditions.

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