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Article

Assessing childhood stress in early mediaeval Croatia by using multiple lines of inquiry

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With 3 figures and 5 tables

Abstract: Childhood stress, using both subadult and adult remains from early mediaeval (8th–11th c. CE) sites on the eastern Adriatic coast is analysed in this report. A total of 242 individuals (83 subadults, 69 adult females, and 90 adult males) were assessed for the presence of linear enamel hypoplasia, cribra orbitalia, sub-periosteal new bone formation, and scurvy. In addition, the dietary profile of nine subadults was assessed by the analysis of carbon and nitrogen stable isotopes from bulk collagen. Over three quarters of individuals with preserved permanent dentition (44/56 or 78.6%) exhibited evidence of linear enamel hypoplasia, while analysis of the onset of this condition shows that all defects formed between 1.2 and 5.6 years of age. Cribra orbitalia was identified in 60 out of 190 individuals with preserved frontal bones (31.6%). Sub-periosteal new bone formation was recorded in 42.6% of analysed subadults (29/68) with fourteen cases still active at the time of death. Additionally, scurvy was identified in three subadults. The isotopic study of carbon and nitrogen suggests that diet of the analysed subadults was based on terrestrial C3 resources, with a varying input from C4 and a low intake of marine resources. The presented study strongly indicates that a large majority of the analysed individuals suffered from poor health during their childhood as indicated by the high frequencies of linear enamel hypoplasia, cribra orbitalia and sub-periosteal new bone formation.

Keywords: childhood stress; bioarchaeological analysis; diet reconstruction; Eastern Adriatic

Introduction

The early mediaeval period (5th–11th century CE) on the eastern Adriatic coast and its hinterland were times characterised by profound political, social and economic change (cf. Klaić 1971; Klaić 1972; Gunjača 1973; Budak 1994; Goldstein 1995; Raukar 1997; Džino 2010). This period was primarily characterised by the arrival of new cultural groups such as the Ostrogoths and Slavs (Croats) in the territory formerly occupied by the Roman Empire and the subsequent establishment of the Croatian kingdom. Consequently to the establishing of a Croatian state during the 9th and the 10th centuries CE (at first as a dukedom, and later a kingdom) there followed a long period of bitter armed conflict between Croatian rulers and Venice and the Byzantine Empire over control of the eastern Adriatic coast, particularly the wealthy Dalmatian towns. These political upheavals were accompanied by significant changes in the lifestyles of the populations inhabiting this area, but also by the degradation of the quality of life (Slaus 2008). The former Roman colonies characterised by their urban lifestyle and a high standard of living (Suić 2003) were replaced by small rural communities predominantly engaged in transhumant pastoralism and various forms of agriculture (Goldstein 1995). Unfortunately, only a few written historic sources provide information about these processes such as *De Administrando Imperio* (Moravcsik & Jenkins 1993) and *Historia Salonitanorum* (Perić et al. 2003). Hence, a primary and central source of knowledge about the lifestyle and general health of the early mediaeval inhabitants of this region is provided by recent bioarchaeological research on skeletal cemetery populations (e.g. Slaus 2006; Slaus et al. 2010; Sutlović et al. 2010; Bečić et al. 2014; Stipišić et al. 2014).

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Some of these studies (e.g. Slaus 2008; Slaus et al. 2011; Lightfoot et al. 2012; Vodanović et al. 2012) strongly suggest significant changes in living conditions, especially in terms of diet and general health, during the early mediaeval period in comparison to the previous Roman period, and this shift is usually associated with the arrival of the new populations and their significantly different lifestyles. For example, Slaus (2008) reported a remarkable deterioration of health in several sites from this region between the late Roman and the early mediaeval period expressed as a significant increase in prevalence of cribra orbitalia and sub-periosteal new bone formation in subadults.

Additionally, isotopic studies of carbon and nitrogen conducted by Lightfoot et al. (2012) recorded a shift from a diet largely based on C3 plants (wheat, barley, etc.) with a significant marine (fish and seafood) input during the Roman period toward terrestrial diet based on C3 products with a large C4 (millet) input during the early mediaeval period. Nevertheless, many aspects of the everyday life of the early mediaeval inhabitants of the eastern Adriatic coast and its hinterland, especially those belonging to marginalised social categories such as the poor, the sick and/or children are not well understood or completely unknown. Considering that children under ten years of age comprise a large part of the early mediaeval populations from the eastern Adriatic coast, it is necessary to conduct a comprehensive population-based study of childhood stress which will include multiple sites from a wider region.

When childhood stress in archaeological populations is discussed, three osteological/dental indicators are most often considered (individually or together): linear enamel hypoplasia, cribra orbitalia, and sub-periosteal new bone formation (e.g. Saunders & Keenleyside 1999; Slaus 2008; Walker et al. 2009; Geber 2014). Linear enamel hypoplasia and cribra orbitalia represent indicators of physiological childhood stress occurring due to various factors such as inadequate nutrition, metabolic or blood disorders, infectious diseases, parasitism and/or weanling diarrhoea, just to name a few (Pindborg 1982; Stuart-Macadam 1989; Goodman & Rose 1990; Guatelli-Steinberg & Lukacs 1999; Ortner 2003; Brickley & Ives 2008; Walker et al. 2009). Until recently, the occurrence of sub-periosteal new bone formation was considered a good indicator for the presence of 'non-specific' infectious diseases in an archaeological population (e.g. Larsen 1997; Ortner 2003). Nevertheless, recent studies (e.g. Weston 2012; Wheeler 2012) showed that this was an over-simplification as periosteal reactions in the youngest children could have had multiple aetiologies (Weston 2012), and cannot be associated solely with infectious diseases. Scurvy is a nutritional disease caused by prolonged vitamin C (ascorbic acid) deficiency usually resulting in the weakened walls of blood vessels, bleeding and reduced osteoblastic activity, and skeletal growth retardation (Aufderheide & Rodríguez-Martín 1998; Ortner 2003; Brickley & Ives 2006; Brickley & Ives 2008). It has been thoroughly investigated in bioarchaeological studies of childhood health in the past (e.g. Brown & Ortner 2011; Geber & Murphy 2012; Halcrow et al. 2014). Beside these skeletal/dental indicators, the present study also included stable isotopes analysis (nitrogen and carbon) as the results obtained by these studies proved to be a very good source of information when reconstructing subadult diet and health in past societies (e.g. Beaumont et al. 2015; Burt 2015; Tsutaya & Yoneda 2015; Beaumont & Montgomery 2016).

The primary aim of this study is to obtain information on childhood stress using both child and adult remains in early mediaeval Croatia through a comprehensive study of linear enamel hypoplasia, cribra orbitalia, sub-periosteal new bone formation and scurvy by using a population-based approach comprising six sites from the eastern Adriatic region. The data obtained by conventional bioarchaeological analysis will be combined with the results of stable isotopes analysis (carbon and nitrogen) conducted on the selected subadult skeletons. Additionally, the information thus obtained will be compared with some other series from the region from different time periods where similar studies have already been conducted. The use of multiple lines of inquiry as well as a population-based approach will provide new insight into subadult stress and diet on the eastern Adriatic during the early mediaeval period, but should also help in an attempt to reconstruct the lifestyle and health patterns of these social groups in mediaeval Europe.

Material and methods

In this study we examined 267 skeletons obtained from six Croatian early mediaeval sites, but due to partial preservation and intense post-mortem fragmentation only 242 are presented here. All sites (Dubravice, Glavice, Konjsko polje, Strančе, Šibenik, and Vaćani) represent small rural communities located on the eastern Adriatic coast and its immediate hinterland (Fig. 1), although Strančе is in a different geographical position to the rest as it is located more to the north. The studied sites were in use between the 8th and 11th centuries CE based on recovered artefacts, radiocarbon dates and stratigraphy (Gunjača 1987; Krnčević 2000 personal communication; Petrinec 2002; Petrinec 2005; Cetinić 2011; for more details see Table 1). All sites included in the study belong to the so-called '*starohrvatski*' (early Croatian) cultural circle. This is a cultural phenomenon that occurred on the eastern Adriatic coast and its hinterland between the 8th and 12th century CEand is best recognised by the presence of certain types of jewellery, weapons and everyday objects in graves, but also by certain types of architectural decorative elements (e.g. Croatian interlace) that are usually found in the pre-Romanesque churches. Again, all of the sites in question are located on the territory of an early mediaeval Croatian dukedom, and later kingdom. Therefore, all the sites were pooled together

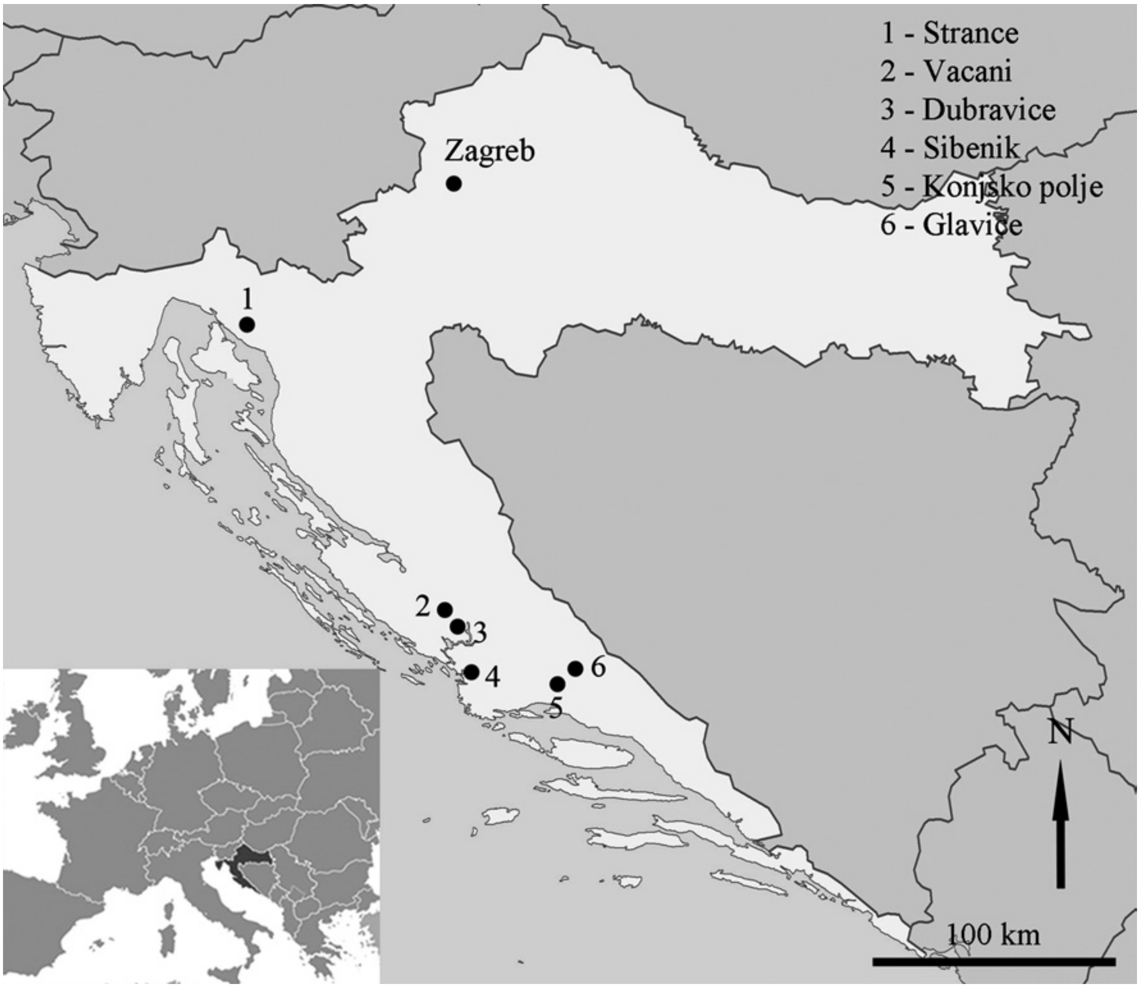

Fig. 1. Map of Croatia showing the geographical locations of the analysed sites.

Table 1. Location, chronology and sex distribution by site.

Site	Chronology	N
Dubravice[1]	8th–9th c. CE	31
Glavice[2]	8th–9th c. CE	54
Konjsko polje[3]	9th c. CE	30
Vaćani[4]	8th–10th c. CE	14
Stranče[5]	8th–11th c. CE	31
Šibenik[5]	9th–11th c. CE	82

[1]Gunjača 1987, [2]Petrinec 2002, [3]Petrinec 2005, [4]Krnčević personal communication, [5]Cetinić 2011, [6]Krnčević 2000

and treated as a single entity. All of the analysed inhumation burials were oriented west-east with the deceased's faces orientated towards the east. The individuals were lying supine with legs and arms extended by their sides. The graves were mostly constructed of stone linings and covered with irregular stone slabs usually containing one individual and in some cases two.

The bioarchaeological analysis was carried out at the Anthropological Centre of the Croatian Academy of Sciences and Arts in Zagreb. The biological sex of the studied individuals was established based on the macroscopic examination focusing on the differences in pelvic and cranial morphology between adult males and females (Krogman & Işcan 1986; Buikstra & Ubelaker 1994; Bass 1995). The age-at-death of adults was estimated by using the pubic symphysis (Brooks & Suchey 1990) and auricular surface morphology (Lovejoy et al. 1985), sternal rib end changes (Işcan et al. 1984; 1985), ectocranial suture fusion (Meindl & Lovejoy 1985), and the degree of occlusal surface wear on the dentition (Brothwell 1981). The age of subadults was assessed based on the changes occurring during the development and formation of deciduous and permanent teeth (Moorees et al. 1963a; Moorees et al. 1963b; Gustafson & Koch 1974), the degree of bone ossification (Scheuer & Black 2000), and the length of the diaphysis of long bones (Maresh 1970; Scheuer et al. 1980). All subadults were divided into four age groups according to the recommendations proposed by Powers (2008), with some modifications in the youngest age category due to a very small number of children from this group. These categories are: 'inter-uterine/neonates/infants' (< 4 weeks to 11 months), 'younger children' (1 to 5 years), 'older children' (6 to 11 years) and 'adolescents' (12 to 17 years). Adults were assigned to one of the three age categories: 'young adults' (18 to 35 years), 'middle adults' (36 to 50 years) and 'old adults' (over 50 years).

Both subadult and adult skeletons were examined macroscopically for the presence of cribra orbitalia and linear enamel hypoplasia, while only subadults were examined for the possible presence of sub-periosteal new bone formation and scurvy. All prevalence rates in this study were calculated by individual (crude prevalence rates). No significant differences between the sites in any of the pathologies presented in this paper (but also in other pathologies such as skeletal trauma, dento-alveolar lesions, etc.) were observed so all results are reported in a form of a composite early mediaeval sample and not by individual sites.

In order to get a better insight into the childhood stress in this region the data concerning cribra orbitalia, linear enamel hypoplasia and sub-periosteal new bone formation gathered by this study were compared with the results from several studies from the territory of the eastern Adriatic coast from different time periods. These include: Zadar (Novak & Slaus 2010), Nin (Novak et al. 2012), Dugopolje (Novak & Slaus 2007), Koprivno (Novak et al. 2007) and an early mediaeval Croatian composite sample consisting of three sites – Radašinovci, Šibenik and Velim (Slaus 2008). Unfortunately, the data regarding linear enamel hypoplasia for all mentioned sites except Dugopolje were recorded by using a different methodology (by tooth and not by individual) and as such are not directly comparable.

Linear enamel hypoplasia is usually recognised as one or more horizontal lines on the labial tooth surface. It was recorded only in permanent incisors and canines, and an individual was included into the study only if at least half of these teeth were present. The presence of linear enamel hypoplasia was recorded in both subadults and adults due to the fact that these defects cannot be remodelled after the formation of enamel and as such are excellent indicators of subadult stress in the first seven years of life (Goodman et al. 1980; Hillson 2014). According to Goodman & Rose (1990) canines are particularly susceptible to stressors causing developmental enamel defects. Additionally, Goodman & Armelagos (1985) suggested that the 'polar' teeth (upper first incisors, lower lateral incisors, canines, first premolars, and first molars) are more likely to form hypoplastic defects in response to physiological stress because genetics strongly control the size and shape of these teeth – this strong genetic control causes the teeth to respond in a form of poorer enamel quality. The anterior tooth surfaces were observed under strong illumination, and only macroscopically visible hypoplastic defects on both sides of the mandible and maxilla were taken into account. The timing of hypoplastic defects was assessed using the methods proposed by Reid & Dean (2000) based on the mineralization standard.

Cribra orbitalia is usually recognised by the occurrence of porosity/destructive lesions on the orbital vaults. All crania with at least one eye socket preserved were macroscopically examined under powerful illumination. Due to a partial preservation of some crania (frontal bones) no attempt was made to distinguish possible differences in expression of cribra orbitalia between the left and the right orbits. The recorded lesions were classified based on intensity (mild, moderate or severe) and condition (active or healed) at the time of death, according to the criteria proposed by Hengen (1971), and modified by Hauser et al. (1983). Cribra orbitalia was recorded in subadults and adults due to two main reasons: a) it is more frequently seen in subadults under five years of age which makes it an additional indicator of childhood stress (Stuart-Macadam 1985), and b) in adults the continued presence of this pathology suggests that healing and recovery were slowed and/or hindered and as such provides a window to childhood frailty (Stuart-Macadam 1985; Facchini et al. 2004).

Sub-periosteal new bone formation is a woven bone formation that is macroscopically recognised as osseous plaques with demarcated margins or irregular elevations of bone surfaces (Larsen 1997). The presence of sub-periosteal new bone formation was diagnosed when two or more skeletal elements exhibited periosteal inflammation – the criteria for the inclusion in the sample were the presence of at least 50% of all long bones (the humerii, radii, ulnae, femora, tibiae and fibulae). It was registered only in subadults in order to make certain that only the cases of sub-periosteal new bone formation occurring during childhood are taken into consideration. This pathological change was used to indicate non-specific infections, metabolic disorders and/or trauma rather than physiological stress.

Since subadult scurvy can be macroscopically diagnosed on both cranial and postcranial bones, all subadult skeletons were taken into consideration regardless of the state of their preservation. The main criterion was the presence of an increased vascular response comprising abnormal porosity penetrating the cortex following the criteria proposed by Brickley & Ives (2006; 2008), and Ortner & Ericksen (1997). For this purpose porosity was defined as "a localised, abnormal condition in which fine holes, visible without magnification but typically less than 1 mm in diameter, penetrate a lamellar surface" (Ortner & Ericksen 1997: 212). Based on the observations made by Ortner & Ericksen (1997), special consideration was given to the analysis of cranial bones such as the greater wings of the sphenoid, posterior maxilla, palatine bones, infraorbital foramen, the posterior zygomatic bone, medial coronoid process and temporal bones. In postcranial bones, scurvy was diagnosed based on the presence of periosteal lesions on the supraspinous area of the scapulae, and sub-periosteal new bone formation on the femora and tibiae as suggested by Brown & Ortner (2011), Ortner & Ericksen (1997), and Ortner et al. (1999; 2001). However, only those lesions on postcranial bones accompanied by similar changes on the cranium of the same skeleton were diagnosed as scurvy.

The analysis of stable isotopes (nitrogen and carbon) was conducted at the School of Archaeological Sciences, University of Bradford, UK. This investigation was conducted as a part of a larger study preliminary published by Novak et al. (2016). Initially, over twenty subadult samples from three sites (Dubravice, Strančе, and Vaćani) were selected, focusing on the ribs and clavicles as the most appropriate osteological elements for this type of analysis. The sampling strategy consisted of three main aspects: (i) osteological preservation (only skeletons with at least good preservation were included), (ii) archaeological context (presence/absence of grave-goods, burial type, etc.), (iii) health profile of an individual (individuals with and without evidence of skeletal/dental indicators of subadult stress were included). However, only nine subadult bone samples (three samples from each of the selected sites) provided enough collagen to be analysed.

The presented data were statistically analysed using the software package SPSS17.0 for Windows by IBM. The observed differences in the frequencies of analysed pathologies between the sexes and age groups were evaluated with the chi-square, and statistical significance was defined by the probability levels of $p \leq 0.05$.

Results

The skeletal and dental remains of 242 individuals were examined as a part of this study. The sample consists of 90 males (37.2%), 69 females (28.5%) and 83 subadults (34.3%) (Table 2). Adult males were more numerous in comparison to females with the male/female ratio at 1:0.77. The age distributions between the adult men and women do not show any statistical differences ($\chi 2 = 0.058$, df = 2, $p = 0.971$). The highest subadult mortality was recorded in ‘younger children’ (38/83 or 45.8%), while in adults (both males and females) the highest mortality is present in the ‘middle-age’ category (males 46/90 or 51.1%, females 34/69 or 49.3%).

Table 2. Demographic profile of the Croatian early mediaeval series.

Age group (years)	Subadults	Males	Females	Total
	n	n	n	N
0–11 months	8			8
1–5	38			38
6–11	19			19
12–17	18			18
18–35		21	17	38
36–50		46	34	80
50+		23	18	41
Total	83	90	69	242

The permanent dentitions of 56 individuals including 22 males, 19 females and 15 subadults were studied for the possible presence of linear enamel hypoplasia (Table 3). Hypoplastic defects were observed in over three quarters of all analysed individuals (44/56 or 78.6%): 93.3% (14/15) of subadults and 73.2% (30/41) of adults exhibited these changes. The prevalence of linear enamel hypoplasia was slightly higher in females in comparison to males (73.7% or 14/19 vs. 72.7% or 16/22), but the difference is not statistically significant ($\chi^2 = 0.005$, df = 1, $p = 0.943$). The age ranges of linear enamel hypoplasia formation vary between 1.7 and 5.0 years for the maxillary teeth, and between 1.2 and 5.6 years for the mandibular teeth. All studied teeth exhibit only one peak of linear enamel hypoplasia with the earliest peak present in mandibular first incisors (2.4 to 2.6 years) and the latest in mandibular canines (4.3 to 4.9 years).

Cribra orbitalia was registered in 31.6% (60/190) of the studied individuals. It was present in 48.6% (18/37) of subadults and in 27.4% (42/153) of adults. A slightly higher prevalence of this pathology was recorded in males (29.5 vs. 24.6%), but was statistically non-significant ($\chi^2 = 0.456$, df = 1, $p = 0.499$). In most cases cribra orbitalia appeared in the mild form (49/60 or 81.7%; Fig. 2), followed by moderate (8/60 or 13.3%), and severe form (3/60 or 5.0%). Seven cases of cribra orbitalia were still active at the time of death (7/60 or 11.7%) and all were present in subadults – five were recorded among ‘younger children’, one among ‘older children’, and one in the ‘adolescents’ group.

The skeletons of 68 subadult individuals were preserved well enough to be analysed for the possible presence of sub-periosteal new bone formation. Sub-periosteal new bone formation was recorded in 29 subadults (42.6%) with the highest prevalence in the youngest age group (75.0% or 3/4), followed by the ‘older children’ category (53.9% or 9/17), then the ‘younger children’ age group (43.3% or 13/30) while the lowest prevalence was registered in ‘adolescents’ (23.5% or 4/17). Almost half of the recorded sub-periosteal new bone formation cases (14/29 or 48.3%) were still active at the time of death: three of these were present among ‘neonates/infants’, six in ‘younger children’, one in the ‘older children’ category’, and four among ‘adolescents’. Lesions were mostly localised on tibiae (24/29 or 82.6%) and femora (4/29 or 13.8%), although one case of generalised occurrence of sub-periosteal new bone formation was also observed including the involvement of the cranium and both upper and lower extremities.

Only four subadult skeletons exhibited the simultaneous presence of cribra orbitalia, linear enamel hypoplasia

Fig. 2. Mild healed cribra orbitalia in both orbits. Šibenik, burial 171, adolescent.

Table 3. Frequency and distribution of cribra orbitalia, linear enamel hypoplasia, sub-periosteal new bone formation and scurvy in the studied sample by sex and age.

Age (years) / Sex	Linear enamel hypoplasia		Cribra orbitalia		Sub-periosteal new bone formation		Scurvy	
	A/O	%	A/O	%	A/O	%	A/O	%
0–11 month	0/0	0.0	0/8	0.0	3/4	75.0	0/8	0.0
1–5	0/0	0.0	7/13	53.8	13/30	43.3	1/38	2.6
6–11	3/3	100.0	6/7	85.7	9/17	52.9	1/19	5.3
12–17	11/12	91.7	5/9	55.5	4/17	23.5	1/18	5.5
Subadults	14/15	93.3	18/37	48.6	29/68	42.6	3/83	3.6
M 18–35	8/10	80.0	9/20	45.0				
M 36–50	8/12	66.7	15/45	33.3				
M 50+	0/0	0.0	2/23	8.7				
Males	16/22	72.7	26/88	29.5				
F 18–35	8/12	66.7	6/15	40.0				
F 36–50	6/7	85.7	8/32	25.0				
F 50+	0/0	0.0	2/18	11.1				
Females	14/19	73.7	16/65	24.6				
Total	44/56	78.6	60/190	31.6				

A – affected / O – observed

and sub-periosteal new bone formation. One belongs to the 'older children' age group and three are classified as adolescents; one of these skeletons is from Strančе and the others are from Glavice. In all cases cribra orbitalia was healed at the time of death, while sub-periosteal new bone formation was active in two and healed in the remaining two cases.

Scurvy was registered in three out of 83 subadult skeletons (3.6%). All three cases were found in the Glavice assemblage – the first was recorded in a 3–4 year old subadult who exhibited severe active cribra orbitalia, pronounced porosity on both palatines, the sphenoid, and the right temporal bone, while the right parietal bone and the right side of the occipital

Fig. 3. Porosity as an indicator of scurvy on: **A)** the left greater wing of the sphenoid, **B)** the left mandibular ramus. Glavice, burial 13, 12–13 year old individual.

Table 4. Comparison of cribra orbitalia, linear enamel hypoplasia and sub-periosteal new bone formation prevalence rates in eastern Adriatic skeletal samples from different time periods.

Site	Chronology	Linear enamel hypoplasia	Cribra orbitalia	Sub-periost. new bone formation
Zadar[1]	3rd–5th c. CE	61.1%[a]	20.1%	66.7%
EMCroatia[2]	6th–9th c. CE	54.1%[a]	32.5%	37.5%
Nin[3]	12th–15th c. CE	44.2%[a]	25.5%	20.0%
Dugopolje[4]	14th–16th c. CE	49.7%	33.7%	58.5%
Koprivno[5]	15th–18th c. CE	55.8%[a]	32.8%	79.7%
This study	8th–11th c. CE	78.6%	31.6%	42.6%

[1]Novak & Slaus 2010, [2]Slaus 2008 [3]Novak et al. 2012, [4]Novak & Slaus 2007, [5]Novak et al. 2007; [a] a different methodology was used, not directly comparable with this study

bone exhibited areas of a very coarse hypervasculated bone; the second case was recorded in a 8–9 year old individual who exhibits moderate porosity on the sphenoid, both temporal bones, and both palatines; the third was registered in a 12–13 year old individual exhibiting moderate healed cribra orbitalia, linear enamel hypoplasia, pronounced porosity on both palatines, the sphenoid (Fig. 3A), both temporal bones, and the left mandibular ramus (Fig. 3B), while moderate active case of sub-periosteal new bone was present on the femora.

The comparison of the data obtained by this study with the results of similar investigations from the eastern Adriatic region (Table 4) shows that the frequencies of cribra orbitalia vary between 20.1% in late Roman Zadar (Novak & Slaus 2010) and 38.7% in late mediaeval Dugopolje (Novak & Slaus 2007); no statistical differences were observed between the sample presented here and other samples. The prevalence rates of sub-periosteal new bone formation in subadults range from 20% in Nin (Novak et al. 2012) to 79.7% in early modern period site of Koprivno (Novak et al. 2007). In this context, Zadar, Dugopolje and Koprivno exhibit significantly higher values when compared to the present sample (Zadar vs. present sample $\chi^2 = 5.434$, df = 1, $p = 0.019$; Dugopolje vs. present sample $\chi^2 = 4.281$, df = 1, $p = 0.038$; Koprivno vs. present sample $\chi^2 = 20.677$, df = 1, $p < 0.001$). As already mentioned, the data concerning linear enamel hypoplasia for all mentioned sites except Dugopolje were recorded by using a different methodology in comparison to the one used in a present study and as such are not directly comparable. The comparison of the prevalence of LEH in Dugopolje and the present study shows significantly higher values in the early mediaeval sample ($\chi^2 = 35.551$, df = 1, $p = 0.000$).

Stable isotope analysis (carbon and nitrogen) included nine subadult bone samples from Dubravice, Strančе and Vaćani: three individuals from the 'younger children' age group, four belonging to 'older children' and two to 'adolescents'. All individuals except one (the youngest child from Strančе) had δ13C values between −19.7‰ and −18.2‰ and

Table 5. Summary of human bone collagen isotope results.

Sample ID	Site	Age (years)	Bone	Nitrogen	Carbon	C:N ratio
MAR12	Strančе	16–17	clavicle	9.3	–18.6	3.2
MAR26a	Dubravice	16–17	rib	9.0	–18.2	3.2
MAR27	Dubravice	2–3	rib	10.4	–19.7	3.3
MAR30	Vaćani	7–8	clavicle	9.4	–18.8	3.3
MAR32	Vaćani	5–7	rib	9.0	–19.1	3.2
MAR33	Dubravice	6–8	rib	10.4	–19.4	3.3
MAR34	Strančе	1.5–2	rib	11.7	–15.9	3.2
MAR35	Vaćani	6–7	rib	9.4	–18.6	3.2
MAR36	Strančе	4–5	rib	10.1	–18.4	3.2

δ15N values between 9.0‰ and 10.4‰ (Table 5), which is consistent with a diet based primarily on terrestrial C3 resources with little or no marine or C4 input. The already mentioned 1.5–2.5 year old child had high δ13C values, indicating the consumption of either marine foods or a C4 resource such as millet, while an elevated δ15N value suggests that he/she was probably consuming C4 or marine based weaning food whilst still breastfeeding. No other major differences in diet were observed between subadults from the analysed sample.

Discussion and conclusion

The few remaining early mediaeval written sources as *De Administrando Imperio* and *Historia Salonitanorum* provide no information about the everyday life of the largest parts of the population. This is particularly true for children – we know almost nothing about their health, diet and lifestyle. Limited information on this topic can be gained from various late mediaeval sources. However, these may not always provide a good portrayal of the health and social history of the earlier mediaeval populations since they may not be directly relevant to the topics discussed, such as weaning. Yet, the use of these sources will definitely help to gain better insight into the mentioned issues. Material culture records are also limited in this regard as the artefacts found within child burials from the early mediaeval period are generally scarce. Therefore, the best source of information about these individuals comes from a comprehensive bioarchaeological investigation of their skeletal and dental remains and the comparison of these data with data recovered from other sites.

High subadult mortality in the ‘younger children’ age group, recorded in the Croatian series, has also been observed by Lewis (2007) in her global summary of child mortality patterns derived from various archaeological skeletal collections. She suggests that peak subadult mortality occurs during the weaning period and that it might be associated with the negative effects weaning has on child health and wellbeing (Lewis 2007). Weaning is considered an extremely sensitive period in a child’s life as the transition from mother’s breast milk to supplementary foods (mostly uncooked foods such as vegetables and fruits as well as untreated drinking water) may expose the child to various bacterial and parasitic infections, potentially causing fatal diarrheal disease and malnutrition (King & Ulijaszek 1999). In the case of the eastern Adriatic, there are few mediaeval written sources focusing on this subject. According to these sources, weaning age during the late mediaeval period was between the first and second year of life (Nikolić Jakus 2011; Kurtović 2015). However, in this particular case we cannot associate all subadult deaths in this age category with the effects of weaning, as other factors such as outbreaks of various diseases could have played an important role. Late mediaeval written historical sources also address the frequent outbreaks of cholera in the region that resulted in diarrhoea, vomiting and dehydration primarily affecting children (Mlinarić 2007). Famine could be another possible common cause of death since Dalmatia could not produce enough bread grains to feed the whole population, and during the late mediaeval period the episodes of hunger occurred every 6–7 years (Mlinarić 2007).

The discussed child mortality peak is also in accordance with the results of the analysis of the timing of linear enamel hypoplasia. This analysis shows that all hypoplastic defects in the studied individuals formed between 1.2 and 5.6 years strongly suggesting that the majority of physiological stress in these individuals occurred before the age of five years. Numerous authors have offered several explanations for the occurrence of linear enamel hypoplasia in the past, and the most common are childhood disease and malnutrition (Larsen 1997; Roberts & Manchester 2005), poor sanitary conditions, the increased mobility of the child and the exposure to environmental hazards (Łukasik & Krenz-Niedbala 2014) as well as the effects of weaning (Blakey et al. 1994; Łukasik & Krenz-Niedbala 2014). Again, we cannot say with certainty which of these factors contributed most to the occurrence of linear enamel hypoplasia in the Croatian sample, but in all likelihood it was a combination of several factors rather than one specific that were responsible for the observed condition. Furthermore, the fact that over three quarters of the studied individuals (and over 90% of subadults) with preserved permanent teeth exhibited linear enamel hypoplasia suggests that most individuals from this population experienced severe episodes of physiological stress during early childhood which once again suggests poor childhood health.

The second studied pathology – cribra orbitalia – also shows high prevalence rates as almost half of the studied subadults, and over one quarter of adults, were affected by this condition. Similar values were recorded at other sites from the region and they range from 20.1% in Zadar (Roman period colony on the coast, *Colonia Iulia Iader*; Novak & Slaus 2010) to 33.7% in Dugopolje (late mediaeval rural community in the Adriatic hinterland; Novak & Slaus 2007). The fact that seven subadult cases of cribra orbitalia were active at the time of death indicates the presence of poor childhood health. As already mentioned, numerous authors today associate the presence of cribra orbitalia with acquired or genetic anaemia caused by inadequate nutrition, metabolic or blood disorders, infectious disease, parasitism and weanling diarrhoea (Stuart-Macadam 1985; Ortner 2003; Walker et al. 2009), and the presented data might suggest a widespread occurrence of various types of childhood anaemia at the analysed sites. Gowland & Western (2012) recently proposed malaria as a probable cause of cribra orbitalia in Anglo-Saxon England and it is possible that this causative agent was present in the eastern Adriatic coast. As a Mediterranean region, this part of Croatia has traditionally been afflicted by malaria (Dugački 2005). Several historic sources document outbreaks of malaria during the mediaeval period (and later) in various locations in the region, especially along the Cetina and Krka rivers (Mlinarić 2007). It was even suggested that during the early 20th century some 180,000 people (about one third of the entire population of Dalmatia) suffered from the disease, with the death rate between 43–49% (Dugački 2005). Therefore, malaria, if it is indeed responsible for cribra orbitalia, might be considered as an important factor contributing to high cribra orbitalia frequencies in the studied series. Beside malaria, scurvy could also represent a cause of cribra orbitalia in early mediaeval Croatia as vitamin C deficiency inhibits iron absorption and may cause sub-periosteal bleeding resulting in orbital lesions (Walker et al. 2009). This hypothesis is supported by presence of three cases of subadult scurvy in Glavice (one even with active cribra orbitalia).

In the last two decades palaeopathological study of scurvy has made a significant progress by combining different diagnostic tools (e.g. Ortner & Ericksen 1997; Brickley & Ives 2006; Geber & Murphy 2012; Koon 2012; Stark 2014; Zuckerman et al. 2014), nevertheless standard macroscopic methods still provide the basis for a scurvy diagnosis in archaeological populations (Armelagos et al. 2014). In the context of the current study, three subadults exhibited skeletal signs that can be associated with scurvy. Apart from these, very few similar cases have so far been identified in the mediaeval skeletal collections from the region: Slaus (2006) recorded one case in an adolescent skeleton from Velim-Velištak, Trupković et al. (2012) diagnosed a co-occurrence of tuberculosis and scurvy in a skeleton of a 10–12 years old child from Umag, while Bečić et al. (2014) registered several possible cases of scurvy in the subadult skeletons from Ostrovica. Such a low number of possible subadult cases of this disorder in the region during the mediaeval period might be a result of: a) subadult diet relatively rich in vitamin C, and/or b) under-representation of the disease due to fragmentary subadult remains that can make diagnosis of scurvy difficult as proposed by Geber & Murphy (2012) for other regions. Of course, one should also take into account a possibility of using different methodologies for recording this condition by various authors that may have led to different results.

Since humans are unable to synthesise ascorbic acid they have to acquire vitamin C from their diet. The best known dietary sources of vitamin C are oranges and lemons (Carpenter 1986), while vegetables such as cabbage, tomatoes and green peppers are also very rich in vitamin C (García-Closas et al. 2004). In this context, it is essential to investigate the diet of the studied individuals. Stable isotopes analysis showed that the everyday diet of subadults from Dubravice, Stranče and Vaćani was predominantly based on terrestrial C3 resources, with a varying input from C4 (most probably millet) and a very low intake of marine resources. The subadult diet at these sites did not differ significantly from the adult diet (Novak et al. 2016). Considering that vegetables such as cabbage are C3 plants it is possible that at least a part of subadult diet at these sites was based on these products. This hypothesis is furthermore supported by an analysis of metal concentration levels (iron, lead, cadmium, magnum, zinc, copper, strontium, and calcium) in bones of the early mediaeval inhabitants of Naklice conducted by Sutlović et al. (2010) suggesting that the probable main dietary components were leafy vegetables, legumes and small amounts of cereals. According to the presented data one might hypothesise that the diet of the subadults from the early mediaeval eastern Adriatic sites was relatively rich in vitamin C thus preventing the widespread occurrence of scurvy. Clearly, these data have to be interpreted with caution due to the small analysed sample, at least until larger subadult series become available.

There are no significant differences in the studied indicators of childhood stress between the sexes as both linear enamel hypoplasia and cribra orbitalia show very similar values in males and females from the analysed sites. Similar results were also obtained by Slaus (2008) in his study of cribra orbitalia and linear enamel hypoplasia, as well as by Bečić et al. (2014) in their analysis of cribra orbitalia in several Croatian contemporary series. Additionally, the results of a stable isotopes study conducted by Novak et al. (2016)

suggested there is no difference in diet between the sexes in Dubravice, Strančе and Vaćani. A similar study conducted by Lightfoot et al. (2012) at some other contemporaneous sites from the region provided almost identical values. Based on these data, it appears that sex differences in early mediaeval Croatia, at least for the majority of the population, did not play a significant role in childhood health. Besides, it seems that both sexes had equal access to the same foods, at least according to the present isotopic data.

Almost half of the studied subadults from six Croatian early mediaeval sites were affected by sub-periosteal new bone formation. When these values are compared to the results recorded in other sites from the region – from 20% in the late mediaeval Nin (Novak et al. 2012) to 79.7% in the early modern period Koprivno (Novak et al. 2007) – it is clear that the early mediaeval sample stands somewhere in the middle. It is likely that these disorders affected a large part of the population and probably had a significant negative impact on the lifestyle of the studied individuals, but the question is whether we can identify with certainty the conditions that contributed to the occurrence of sub-periosteal new bone at these sites. Recent studies (e.g. Weston 2012) showed that numerous factors can influence the presence of sub-periosteal new bone formation in an archaeological population. According to Wheeler (2012), the occurrence of this pathological change, beside 'non-specific infections', can also be associated with the conditions like birth trauma, metabolic disorders, hypervitaminosis A, leukaemia, and infantile cortical hyperostosis. At the moment, we can identify only some of these conditions such as scurvy that was registered in three individuals from Glavice. Additionally, the late mediaeval sources testify to frequent outbreaks of infectious and non-infectious diseases in the region – most frequent were the epidemics of malaria, bubonic plague, tuberculosis, and smallpox (Mlinarić 2007). Based on the available information, we might hypothesise that a large part of the studied subadults suffered from a combination of conditions causing periosteal inflammation which may have included scurvy, possibly other infectious and non-infectious diseases and some other, yet unidentified disorders.

The fact that three out of four individuals exhibiting the co-occurrence of cribra orbitalia, linear enamel hypoplasia and sub-periosteal new bone formation come from Glavice might suggest that a population inhabiting this site was more susceptible to the factors influencing the occurrence of childhood stress markers than the rest of the analysed sites. This hypothesis might be also supported by the fact that the only three cases of scurvy were found in Glavice. However, more comprehensive studies are necessary to confirm this assumption.

Another issue raised by Wood et al. (1992) is the so called 'osteological paradox'. It suggests that a general absence of childhood stress indicators is a result of acute conditions that did not leave any traces on skeletal/dental remains while their presence means that the affected individuals experienced and survived a significant physiological stress and continued to live thereafter. In other words, those populations characterised by low prevalence rates of childhood stress indicators experienced poor health in general, while higher frequencies of these disorders may indicate a better overall health in a population (Wood et al. 1992). However, there is no general agreement on this hypothesis and there have been some critiques (e.g. Cohen 1997). Based on the presented data, it seems that 'the osteological paradox' hypothesis is not in accord with the results reported here as a major part of the analysed subadults exhibit signs of stress on their bones and teeth with numerous cases still in the active form. Similarly, Slaus (2008) also detected a significant deterioration of childhood health at several sites from the region during the early mediaeval period. This is reflected by an increased prevalence of cribra orbitalia and sub-periosteal new bone formation. Furthermore, written mediaeval sources from a slightly later period mention frequent outbreaks of infectious diseases and starvation in the region. This must have had a very negative impact on the general health of children living there. By all accounts, we cannot speak of good childhood health on the eastern Adriatic coast and its hinterland between the 8th and 11th centuries, but rather of poor health that was caused by a combination of various factors resulting in high child mortality, frequent episodes of stress and a weakened immune system in the affected individuals.

In order to obtain a better picture of childhood stress, but also general health and lifestyle of the individuals inhabiting the region of the eastern Adriatic coast and its hinterland between the 8th and 11th centuries we used multiple lines of inquiry consisting of a population-based bio-cultural approach including six sites and involving a conventional bioarchaeological analysis, stable isotopes analysis, and mediaeval written sources. Our study showed that during the early mediaeval period most of the studied individuals were suffering from poor childhood health that could have been caused by various factors ranging from infectious and non-infectious diseases, anaemia, malaria, vitamin C deficiency, possibly episodes of hunger, and other, still unidentified conditions.

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