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Osteological and Dental Markers of Health in the Transition From the Late Antique to the Early Medieval Period in Croatia

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ABSTRACT The purpose of this study is to analyze health at the transition from the Late Antique (LA) to the Early Medieval (EM) period in Croatia. Results of the analyses of skeletal remains are compared with historical and archaeological data to test the hypothesis that the transition was catastrophic. An additional objective is to determine whether the transition was a uniform process, or differentially affected the past inhabitants of Croatia because of various local considerations. To accomplish this, four markers of health: cribra orbitalia, linear enamel hypoplasia, nonspecific periostitis, and trauma were compared in 981 skeletons: 477 from nine urban LA sites, and 504 from six rural EM sites. Data were collected by sex and age for individual, and for co-occurrences of various features. Because continental and Adriatic Croatia has different ecological features, data were specifically tabulated for the two regions. Comparisons between the continental and Adriatic regions of the LA series showed no significant differences in the frequencies of the analyzed markers of stress. Comparisons between the LA and EM series showed similar frequencies in continental Croatia—suggesting no significant discontinuity of living conditions, and a significant increase of cribra orbitalia, periostitis, and trauma frequencies during the EM period in Adriatic Croatia. The deterioration of living conditions primarily affected subadults and males. These data suggest that the transition from the LA to the EM period in Croatia was not a uniform process, but differentially affected population biology most likely because of local cultural, socio-economical or political considerations. Am J Phys Anthropol 136:455–469, 2008.

Traditional history describes the transition from the Late Antique (3rd to 5th centuries. AD) to the Early Medieval period (6th to 10th centuries AD) in Croatia as uniformly catastrophic with destruction of major urban centers, depopulation, famine, and the spread of epidemic diseases (Rački, 1881; Strohal, 1913; Šišić, 1925). Three lines of evidence were used to support this argument. First, there is historical and archaeological evidence for the destruction of large urban centers in the Roman provinces of *Pannonia* (which included modern continental Croatia) and *Dalmatia* (which included Adriatic Croatia). *Sirmium* (modern Srijemska Mitrovica), *Mursa* (Osijek), *Cibalae* (Vinkovci), *Salona* (Solin), *Narona* (Vid), and numerous other urban centers were destroyed or abandoned during the second half of the 6th century and the beginning of the 7th century.

The second line of evidence concerns the disappearance of most Roman town names in both provinces—the only Roman town names that have survived to the present from *Pannonia* are Ptuj (Roman *Poetovia*), Sisak (*Siscia*), Raab (*Arrabona*), and possibly Vienna (*Vindobona*). The third line of evidence concerns reports related to the endeavors of the Church to ransom captive Christians and stolen relics from the invading Slavs and Avars. The general picture emerging from these data is that the Late Antique population of Croatia was annihilated, with the surviving refugees fleeing to small defendable centers in the Dinarid mountain range or, more likely, to the Adriatic islands where they could be protected by the Byzantine fleet.

During the last three decades, historians have begun challenging this interpretation and pointing out several important inconsistencies (Klaić, 1971; Gunjača, 1973; Goldstein, 1995). While supporting, in general, the assertion that the transition from the Late Antique (LA) to the Early Medieval (EM) period was characterized by profound cultural, social, economic, and political change, they note that historical sources for the period are remarkably rare. Unlike some newly arrived ethnic groups, most notably the Ostrogoths and Lombards, who recorded their achievements, Slavs—including Croats, and Avars left no written records. Sources dealing with them were written by Byzantine, Frankish, and Church historians. Because the Slavs and Avars were located on the peripheries of the large Byzantine and Frankish empires they were of limited interest to their historians and the available records are both sparse and inconsistent (Goldstein, 1995). Church historians, on the other hand, while located much closer, found it impossible to be objective as the arrival of the various Slavic tribes and Avars genuinely represented a catastrophe to them. All of these peoples were pagan, and remained so until 791 (Avars) and 830–890 (Croats). Their arrival thus in-

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terrupted and reversed two and half centuries of Church development. The result is that contemporary historical sources dealing with the political and military relationships between the newly arrived ethnic groups and their neighbors are scant, those dealing with their religious beliefs, diet, knowledge of medicine etc., are nonexistent.

Apart from the rare and unreliable historical sources additional problems were seen in the presence of some Roman town names in Dalmatia—for instance Karin, Nadin, Aserija, Klis etc. (Gunjača, 1973). Although considerably smaller towns than the large urban centers previously mentioned, the retention of these names argued for at least some type of continuity between the LA and EM period. Finally, the emigration of many Roman refugees to the Adriatic islands seems improbable in view of the fact that none of these islands developed large centers comparable to, for instance, Venice or Ravenna on the western Adriatic coast, whose location in easily defendable lagoons led to significant population increase and their subsequent rise to prominence.

Recent bioarchaeological studies also support a more complex transition from Antiquity to the Middle Ages. Analyses of dento-alveolar lesions in two Roman Imperial age (1st to 3rd centuries AD) necropolises, and a 7th century AD Lombard cemetery from the Tyrrhenian coast in central Italy showed a marked increase of caries, alveolar abscesses, and antemortem tooth loss in the EM sample suggesting a deterioration of living conditions in the transition to the Medieval period (Manzi et al., 1999). A similar, although less pronounced increase in cribra orbitalia and porotic hyperostosis frequencies in the EM series also argued for a significant discontinuity in the quality of life (Salvadei et al., 2001). In contrast to this, analyses of dento-alveolar pathologies, cribra orbitalia, and periostitis frequencies between a LA (1st to 4th centuries AD) and an EM (7th century AD) sample from the Molise region in central Italy showed substantial continuity of dietary habits and ways of exploiting the territorial resources (Belcastro et al., 2007). In these samples ecological factors seemed to have affected living conditions considerably more than the cultural, social, and economic changes that followed the fall of the Western Roman Empire.

The purpose of this study is to analyze health at the transition from the Late Antique to the Early Medieval period in Croatia by using a series of osteological and dental indicators of health. Results of the analyses of the skeletal remains will be compared with the available historical and archaeological data to test the hypothesis that the transition was catastrophic. An additional objective is to try to determine whether the transition was a uniform process, or differentially affected the past inhabitants of Croatia because of various local considerations. To accomplish this, osteological and dental markers of health are analyzed in two large composite skeletal series from Croatia. The first consists of 477 skeletons from nine urban LA sites in continental and Adriatic Croatia, the second of 504 skeletons from six rural EM sites in continental and Adriatic Croatia.

Continental and Adriatic Croatia have significantly different ecological features. Continental Croatia has a continental climate, with harsh winters that typically last 4 months during which time the average temperature falls just below 0°C. The area is rich in rivers that combined with the predominantly flat terrain result in marshes. In the arable fields wheat and barely were cultivated. Horse and cattle breeding was common, and there is some evidence that pigs were also raised (Goldstein, 1995).

Adriatic Croatia has a Mediterranean climate, with short, wet winters during which the temperature rarely falls bellow 5°C. The area has a few rivers that frequently disappear into limestone subterranean passages. Adriatic Croatia has few arable fields that lie between the Adriatic Sea and the large Dinarid mountain range. Olives and grapes were cultivated in these fields since the Iron Age but the primary sources of nutrition, besides fishing, were transhumance goat and sheep herding (Goldstein, 1995).

A further consideration that needs to kept in mind when analyzing the transition from the LA to the EM period in Croatia is the fact that all of the LA samples come from large urban centers, while all of the EM samples are from small rural communities. The first large urban centers in medieval Croatia appear around the 13th century (Goldstein, 1995). All of the sites included in this analysis pre-date them.

The health status of the analyzed groups depended on numerous factors. Among them are their cultural practices, subsistence strategies, military strengths, and the ecological features of the regions they inhabited. In theory, if the ecological features of continental and Adriatic Croatia were sufficiently different to significantly diminish the quality of life in one region, interpretation of the nature of the transition from the LA to the EM period in Croatia could be compromised. To control for this, the analyzed indicators of health were first compared between the continental and Adriatic regions of the LA series. Because cultural, socioeconomic, religious, and health practices were uniform in the Roman Empire, and all of the samples derive from urban sites—significant differences in the frequencies of the analyzed biological markers of health would indicate harsher living conditions in one region, a fact that would have to be taken into account when interpreting the nature of the transition from the LA to the EM period. If no significant differences are noted, differences between the LA and EM series can be attributed to differential subsistence strategies, cultural practices, military strengths, and the ability of the newly arrived ethnic groups to adapt to the ecological features of Croatia, which may have been different from those in their ancestral homelands.

MATERIALS AND METHODS

The osteological material analyzed in this study was divided into two composite series—a LA and an EM skeletal series. The geographical locations of the analyzed sites are shown in Figure 1, the number of skeletons and sex distribution in each site in Table 1.

The LA series consists of 477 skeletons from 9 urban sites located in the eastern part of continental Croatia and along the eastern Adriatic coast. The sites were inhabited from the 2nd to 5th centuries AD (Durman, 2006). The majority of sites (Osijek, Vinkovci, Split, Zadar, and Vid) were large urban centers that first achieved the status of *municipium* (self governing center of the Roman Empire), and later that of colony. The osteological material for this series was recovered from necropolises outside city walls. Two types of graves were noted. Elite graves are represented by stone sarcophagi, or were constructed with bricks and had flat or ridged roofs (Iskra-Janošić, 2001). Osteological material from

these graves was not, however, available as these graves had been looted and the skeletal remains destroyed. Graves from which osteological material was recovered were simple inhumations. The graves goods recovered in them (fibulae, coins, knives etc.) were too uniform to allow differentiation between social categories.

The EM series consists of 504 skeletons from 6 sites also located in the eastern part of continental Croatia, and along the eastern Adriatic coast. These sites were inhabited from the 6th to 9th centuries AD (Belošević, 2002; Durman, 2006). The skeletons were recovered from cemeteries related to small rural settlements. One of the most important features of the cemeteries is their multiethnic context. Two cemeteries belong to the Avar-slav cultural complex (Privlaka and Stari Jankovci), one is Gepid (Vinkovci), and three (Velim, Radašinovci and Šibenik) are Croat. Avar-slav populations were a composite of various Central Asian peoples (the Avars) and similarly heterogeneous Slavic tribes (Liptak, 1983). The Gepids were a Germanic tribe that migrated to the Pannonian basin during the 6th century, while Croats are a Slavic people that migrated to the eastern Adriatic coast during the 7th to 8th centuries taking advantage of a temporary Avar decline in power following their unsuccessful attempt in 626 AD to occupy Constantinople (Šišic, 1925). All of the cemeteries had graves arranged in parallel rows with the deceased oriented in an east (feet) to west (head) direction. Graves from continental Croatia were simple inhumations with uniform grave goods: pins and bone combs in the Gepid graves, and simple earrings, knives, belt buckles, and flint in the Avar-slav graves (Šmalcelj, 1976). Graves from Adriatic Croatia were made with large, unprocessed or partially worked stone slabs that lined the oval or trapezoid forms of the graves and in some cases covered the deceased (Belošević, 2002). The recovered grave goods: pottery, knives, jewelry etc. were too uniform to allow social differentiation. Therefore, for the purposes of this analysis all individuals, from both composite series, are treated as a single social category.

Fig. 1. Map of Croatia with the geographical positions of the analyzed sites. Full circles indicate urban, empty circles rural sites. Numbers correspond to the following sites: 1-Štrbinci, 2-Zmajevac, 3-Osijek necropolis, 4-Osijek barracks, 5-Vinkovci necropolis, 6- Stari Jankovci, 7-Privlaka, 8-Vinkovci Gepid, 9-Split, 10-Zadar, 11-Vid, 12-Kaštel Sučurac, 13-Velim, 14-Radašinovci, 15-Šibenik.

The studied samples are part of the osteological collection of the Croatian Academy of sciences and arts. They are curated in Zagreb where they were analyzed for the following osteological and dental markers of health: cribra orbitalia, linear enamel hypoplasia (LEH), nonspecific periostitis, and trauma. These features were chosen for two reasons. First, they are common and leave relatively unambiguous traces in the skeleton. Second, although all of these markers are nonspecific indicators of health, when analyzed together they create a composite profile of general health and quality of life. All samples were also analyzed for the potential presence of specific dietary problems such as rickets and scurvy.

TABLE 1. Total number of skeletons analyzed by site and sex

Site	Male	Female	Subadult	Total
Continental Croatia				
Late Antique sites				
1. Štrbinci (4 c. AD) urban site	28	19	8	55
2. Zmajevac (4 c. AD) urban site	43	41	18	102
3. Osijek necropolis (3–4 c. AD) urban site	13	20	5	38
4. Osijek barracks (3–4 c. AD) urban site	3	6	7	16
5. Vinkovci necropolis (4 c. AD) urban site	7	6	8	21
Early Medieval sites				
6. Stari Jankovci (7–8 c. AD) rural site	22	23	6	51
7. Privlaka (8–9 c AD) rural site	63	66	30	159
8. Vinkovci Gepid (6 c. AD) rural site	2	1	5	8
Adriatic Croatia				
Late Antique sites				
9. Split (5 c. AD) urban site	2	1	1	4
10. Zadar (3–4 c. AD) urban site	65	55	50	170
11. Vid (5 c. AD) urban site	11	13	12	36
12. Kaštel Sučurac (2–4 c. AD) urban site	10	16	9	35
Early Medieval sites				
13. Velim (7–9 c. AD) rural site	50	42	24	116
14. Radašinovci (9 c. AD) rural site	29	31	31	91
15. Šibenik (9 c. AD) rural site	23	28	28	79
Total	371	368	242	981

Cribra orbitalia is a sievelike expansion in the orbital plates of the frontal bone that is generally considered to be part of, or an initial stage of similar bone changes that affect the skull vault (porotic hyperostosis) (Carlson et al., 1974; Cybulski, 1977; Stuart-Macadam, 1985; Mittler and Van Gerven, 1994; Fairgrieve and Molto, 2000). Numerous causal factors have been suggested for porotic hyperostosis including anemia, metabolic diseases such as scurvy and rickets, syphilis, cancer, and pressure from binding and carrying (Williams, 1929; Angel, 1966; Moseley, 1966; Stuart-Macadam, 1985; Ortner, 2003). Regardless of the specific cause, most researchers currently agree that porotic hyperostosis is the osseus result of marrow hyperplasia (Trancho, 1987; Stuart-Macadam, 1991; Mittler and Van Gerven, 1994; Larsen, 1997; Fairgrieve and Molto, 2000; but see Ortner et al., 1999, 2001; Schultz, 2001).

Marrow hyperplasia and its potential skeletal manifestations porotic hyperostosis and cribra orbitalia result from various disease processes. Possible, although rare causes are renal osteodystrophy, hereditary spherocytosis, and cyanotic congenital heart disease (Angel, 1966; Moseley, 1966; Ortner, 2003; Blom et al., 2005). More common causes include genetically inherited forms of anemia such as thalassemia and sickle-cell anemia, and acquired iron-deficiency anemia (Tayles, 1996; Hershkovitz et al., 1997; Larsen, 1997; Ortner, 2003). Cumulative evidence from numerous bioarchaeological studies worldwide has resulted in a general consensus linking porotic hyperostosis in archaeological skeletal samples with acquired iron deficiency anemia (Larsen, 1997). The potential causes of acquired iron deficiency anemia are numerous and include among others: maternal anemia, increased iron needs during growth, iron deficient diets, inhibited iron absorption, infectious disease processes, and high parasite loads (Stuart-Macadam, 1992; Bloom et al., 2005).

In the analyzed data set the presence of cribra orbitalia was assessed in all individuals with at least one orbital roof preserved. No attempt was made to evaluate the severity of the lesion but a distinction was made between active and nonactive (healed) lesions according to criteria suggested by Mittler and Van Gerven, 1994), and Mensforth et al., 1978). Because other conditions including metabolic diseases, cancer, and infectious diseases can mimic the osseous changes that result from acquired iron-deficiency anemia, all effort was made to distinguish between conditions that resulted in marrow hyperplasia, from those that did not according to criteria described by Ortner, 2003).

Similarly, because genetic anemias can theoretically be present in Croatian skeletal series—particularly those from the Adriatic region where malaria was endemic, all skeletons were carefully screened for the presence of thalassemia and sickle-cell anemia, once again according to criteria suggested by Ortner, 2003). All cases potentially suspect for genetic anemias, cancer, metabolic and infectious diseases were eliminated from the sample.

LEH or chronological aplasia is generally defined as any macroscopic defect in the enamel surface (Pindborg, 1970). These defects appear as band like depressions (linear enamel hypoplasia), or as pits, and have long been used as a nonspecific indicator of systemic physiological stress (Goodman and Rose, 1990; Gautelli-Steinberg and Lukacs, 1999). Data on enamel hypoplasias were collected on the permanent maxillary central incisors and canines, and on the permanent mandibular canines. It is recognized that by not including the entire dentition in the analysis some data may be lost, but the inclusion of only these tooth categories was dictated by the large data set, and the variable preservation of the posterior teeth in the sample. Central incisors and canines were chosen because these teeth are considered to be more susceptible to stress than other teeth (Goodman and Armelagos, 1985; Goodman and Rose, 1990), and because canines have a long developmental period, from around 4 months to 6 years (Gustafson and Koch, 1974). Hypoplasia frequencies were tabulated by individual. Enamel defects were counted on teeth from the right side of the mouth, with teeth from the left side being substituted if the one on the right was missing. Criteria for inclusion in the sample were the presence of at least one tooth from each tooth category. Data were collected only for adults. It is recognized that not including subadult dentition in the analysis is a limitation of the study, but the following reasons prohibited it. Deciduous incisor and canine crowns develop *in utero* and therefore reflect pre-natal stress. The analysis of permanent incisors and canines in the subadult dentition is therefore the logical solution to this problem but leads to the following complications. Permanent maxillary central incisors erupt at about 6–6.5 years, maxillary canines at about 10.5–12.0 years and mandibular canines at about 9–10.5 years. This means that no LEH data would be available for the two youngest subadult age categories (0.0–0.9 and 1.0–3.9 years). An additional complication in the analyzed data set was the poor preservation (possibly related to the fact that these are single root teeth), of permanent incisors and canines in subadult remains. The result of this poor preservation is that the percentages of subadults with preserved permanent incisors and canines in the analyzed series range from 27% to 39%. To base any kind of conclusion about LEH in subadults on such a small proportion of the subadult sample does not seem reasonable.

Nonspecific periostitis is a basic inflammatory response that develops because of nonspecific bacterial infection (Ortner, 2003). It is macroscopically recognized as osseous plaques with demarcated margins or irregular elevations of bone surfaces (Larsen, 1997). Periostitis represents a basic inflammatory response that results not only from nonspecific bacterial infection, but also from trauma and from specific infectious diseases such as leprosy, tuberculosis, treponemal disease, and even by conditions such as fluorosis (Larsen, 1997; Ortner, 2003). Both leprosy and tuberculosis have been reported in EM series from Croatia (Šlaus, 2006), and trauma is a frequent finding in almost all archaeological series. To ensure that the presence of periostitis in these instances was not counted as nonspecific periostitis, all skeletons with osteological evidence of leprosy or tuberculosis (n = 7) were excluded from the periostitis sample. 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. Nonspecific periostitis was 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 long bones.

Traumatic injuries such as fractures, projectile injuries, and puncture wounds are an excellent skeletal marker for the study of conflict in archaeological populations (Judd and Roberts, 1999; Djurić et al., 2006; Roksandić et al., 2006; Tung, 2007). Unlike the previously

TABLE 2. The frequency and distribution of cribra orbitalia in the analyzed series

	Continental LA		Continental EM		Adriatic LA		Adriatic EM	
Age (years)/sex	O/A	%	O/A	%	O/A	%	O/A	%
0.0–0.9	2/0	0.0	3/0	0.0	6/0	0.0	6/0	0.0
1.0–3.9	8/3	37.5	7/3	42.9	11/5	45.5	22/15	68.2
4.0–9.9	20/11	55.0	18/10	55.6	38/16	42.1	41/26	63.4
10.0–14.9	16/11	68.8	13/9	69.2	17/7	41.2	14/10	71.4
All subadults	46/25	54.3	41/22	53.7	72/28	38.9	83/51	61.4
Females 15–29	25/5	20.0	39/8	20.5	22/5	22.7	18/7	38.9
Females 30–44	48/5	10.4	34/4	11.8	45/6	13.3	48/7	14.6
Females 45+	19/0	0.0	17/0	0.0	18/2	11.1	35/5	14.3
All females	92/10	10.9	90/12	13.3	85/13	15.3	101/19	18.8
Males 15–29	22/6	27.3	23/4	17.4	12/0	0.0	13/7	53.8
Males 30–44	46/8	17.4	48/4	8.3	47/6	12.8	53/11	20.8
Males 45+	26/1	3.8	16/1	6.3	29/2	6.9	36/5	13.9
All males	94/15	16.0	87/9	10.3	88/8	9.1	102/23	22.5
All adults	186/25	13.4	177/21	11.9	173/21	12.1	203/42	20.7

LA, Late Antique samples; EM, Early Medieval samples; O, number of individuals observed; A, number of individuals with cribra orbitalia.

TABLE 3. The frequency and distribution of active cribra orbitalia in the analyzed series

	Continental LA		Continental EM		Adriatic LA		Adriatic EM	
Age (years)/sex	C/Ac	%	C/Ac	%	C/Ac	%	C/Ac	%
0.0–0.9	0/0	0.0	0/0	0.0	0/0	0.0	0/0	0.0
1.0–3.9	3/3	100.0	3/2	66.7	5/2	40.0	15/3	20.0
4.0–9.9	11/5	45.5	10/8	80.8	16/3	18.8	26/3	11.5
10.0–14.9	11/0	0.0	9/3	33.3	7/0	0.0	10/0	0.0
All subadults	25/8	32.0	22/13	59.1	28/5	17.9	51/6	11.8

LA, Late Antique samples; EM, Early Medieval samples; C, number of individuals with cribra orbitalia; Ac, number of individuals in whom cribra orbitalia is active at time of death.

described skeletal or dental changes they are not caused by factors such as nutrition, hygiene, parasitic or bacterial infestation, although all of these factors may affect the healing of fractures. Trauma result from interpersonal violence such as warfare, or from accidents incurred during everyday activities. The sex distribution of trauma, as well as their location in the skeleton, can provide insight into their cause. Interpersonal violence is characterized by the presence of perimortem fractures and high frequencies of male trauma to the cranium and face. Traumas that result from accidents are more often nonlethal injuries to the appendicular skeleton.

Fractures were diagnosed macroscopically based on the presence of callus formation, angular deformity, diaphysis asymmetry, or depressions in the skull vault. All bones were also analyzed for the presence of trauma caused by sharp-edged instruments such as swords or axes, penetrating wounds caused by pointed weapons such as spears and daggers, and projectile injuries. Trauma was scored as antemortem or perimortem, and by anatomical segment: cranium, upper extremities, and lower extremities. Because of differential bone preservation of the vertebrae and ribs between the analyzed sub-series, trauma was not scored on the thorax. For the purposes of this analysis the clavicle was considered to be apart of the upper extremities. Criteria for inclusion in the sample were the presence of at least 50% of all long bones, the frontal bone, one parietal and the occipital bone.

Data were collected by sex and age for the presence and distribution of individual markers of health, as well as for the co-occurrences of various markers.

The analyzed remains were aged and sexed according to the following criteria. Sex was determined based on pelvic (Phenice, 1969; Bass, 1987) and cranial (Krogman and Işcan, 1986) morphology. When these elements were missing or poorly preserved discriminant functions for the femur (Šlaus, 1997) and tibia (Šlaus and Tomičić, 2005) developed for antique and medieval Croatian populations were employed. No attempt was made to estimate the sex of subadult individuals.

Adult age at death was estimated using as many methods as possible, including pubic symphysis morphology (Todd, 1920, 1921; Gilbert and McKern, 1973; McKern and Stewart, 1957; Brooks and Suchey, 1990), auricular surface morphology (Lovejoy et al., 1985), sternal rib end changes (Işcan et al., 1984, 1985), and ectocranial suture fusion (Meindl and Lovejoy, 1985). In subadult remains, age at death was estimated using epiphyseal fusion, diaphyseal lengths, and dental eruption criteria (McKern and Stewart, 1957; Moorrees et al., 1963; Bass, 1987; Scheuer and Black, 2000). Adults were aged into one of three composite adult age categories: young adults falling between ages 15 and 29, middle adults falling between ages 30 and 44, and older adults comprising an open ended 45+ category. Subadults were aged into one of four age categories: 0.0–0.9; 1.0–3.9; 4.0–9.9, and 10.0–14.9.

Differences in the frequencies of individual markers of health as well and the co-occurrences of different markers of health between the samples were tested with the χ^2 test employing Yates correction when appropriate.

RESULTS

Individual markers of health

Cribra orbitalia. Cribra orbitalia frequencies in the analyzed series are presented by sex and age in Table 2. The frequencies and distribution of active cases are shown in Table 3. In all series the expression of this con-

TABLE 4. The frequency and distribution of linear enamel hypoplasia in the analyzed series

	Continental LA		Continental EM		Adriatic LA		Adriatic EM	
Age (years)/sex	O/A	%	O/A	%	O/A	%	O/A	%
Females 15–29	24/18	75.0	31/26	83.9	20/15	75.0	16/9	56.3
Females 30–44	42/29	69.0	17/10	58.8	34/17	50.0	42/20	47.6
Females 45+	15/4	26.7	6/5	83.3	16/11	68.8	30/13	43.3
All females	81/51	63.0	54/41	75.9	70/43	61.4	88/42	47.7
Males 15–29	20/13	65.0	17/12	70.6	11/8	72.7	11/7	63.6
Males 30–44	40/30	75.0	27/20	74.1	41/26	63.4	44/28	63.6
Males 45+	20/12	60.0	5/4	80.0	25/16	64.0	29/16	55.2
All males	80/55	68.8	49/36	73.5	77/50	64.9	84/51	60.7
All adults	161/106	65.8	103/77	74.8	147/93	63.3	172/93	54.1

LA, Late Antique samples; EM, Early Medieval samples; O, number of individuals observed; A, number of individuals with LEH.

TABLE 5. The frequency and distribution of periostitis in the analyzed series

	Continental LA		Continental EM		Adriatic LA		Adriatic EM	
Age (years)/sex	O/A	%	O/A	%	O/A	%	O/A	%
0.0–0.9	1/1	100.0	1/0	0.0	6/5	83.3	6/4	66.7
1.0–3.9	3/1	33.3	2/2	100.0	9/6	66.7	13/5	38.5
4.0–9.9	16/6	37.5	14/5	35.7	33/12	36.4	31/10	32.3
10.0–14.9	12/3	25.0	13/1	7.7	12/6	50.0	14/5	35.7
All subadults	32/11	34.4	30/8	26.7	60/29	48.3	64/24	37.5
Females 15–29	18/1	5.6	34/2	5.9	21/4	19.0	16/6	37.5
Females 30–44	40/3	7.5	26/3	11.5	36/4	11.1	48/5	10.4
Females 45+	14/1	7.1	14/1	7.1	13/0	0.0	35/1	2.9
All females	72/5	6.9	74/6	8.1	70/8	11.4	99/12	12.1
Males 15–29	21/1	4.8	18/4	22.2	11/2	18.2	13/6	46.2
Males 30–44	34/4	11.8	40/5	12.5	42/3	7.1	53/12	22.6
Males 45+	23/1	4.3	12/1	8.3	24/3	12.5	34/6	17.6
All males	78/6	7.7	70/10	14.3	77/8	10.4	100/24	24.0
All adults	150/11	7.3	144/16	11.1	147/16	10.9	199/36	18.1

LA, Late Antique samples; EM, Early Medieval samples; O, number of individuals observed; A, number of individuals with periostitis.

dition ranges from slight pitting, to severe sieve like lesions with considerable diploic expansion. Total cribra orbitalia frequencies range from 19.7% (43/218) in the continental part of the EM series to 32.5% (93/286) in the Adriatic part of the EM series. In all series subadult frequencies are significantly ($P < 0.001$) higher than adult frequencies with χ^2 values ranging from 21.09 in the Adriatic part of the LA series, to 42.76 in the Adriatic part of the EM series. Active cases of cribra orbitalia in subadults are most frequent in the 1.0–3.9 years age category, and at the level of the complete subadult sample ($n = 126$), there is a significant association between active lesions and younger age categories ($\chi^2 = 8.93$, df $= 2$, $P = 0.011$).

Adult frequencies range from 11.9% in the continental part of the EM series to 20.7% in the Adriatic part of the EM series. No significant sex differences are noted. In both sexes higher cribra orbitalia frequencies are significantly associated with younger age categories ($n = 368$; $\chi^2 = 11.20$, df $= 2$, $P = 0.004$ for females, and $n = 371$; $\chi^2 = 8.45$, df $= 2$, $P = 0.015$ for males).

LEH. LEH frequencies are presented in Table 4. Total frequencies range from 54.1% in the Adriatic part of the EM series, to 74.8% in the continental part of the EM series. No significant sex differences are noted in any of the analyzed series. At the level of the complete adult sample ($n = 583$) higher LEH frequencies are significantly associated with younger age categories ($\chi^2 = 8.77$, df $= 2$, $P = 0.012$), although when the sample is analyzed by sex, this general age effect holds true only for females ($n = 293$; $\chi^2 = 12.24$, df $= 2$, $P = 0.002$). Males show a uniform frequency of LEH lesions that is not biased towards younger age categories ($n = 290$; $\chi^2 = 1.45$, df $= 2$, $P = 0.485$).

Periostitis. The frequencies of nonspecific periostitis by sex and age are presented in Table 5. In order of diminishing frequency, periostitis in subadults was recorded in the tibia, femur, radius, ulna, and humerus. In the adult sample periostitis was noted on the tibia and femur. Total periostitis frequencies range from 12.1% (22/182) in the continental part of the LA series to 22.8% (60/263) in the Adriatic part of the EM series. In all series subadult frequencies are significantly ($P < 0.05$) higher than adult frequencies with χ^2 values ranging from 3.83 in the continental part of the EM series, to 15.69 in the continental part of the LA series. Periostitis frequencies in subadults are highest in the 0.0–0.9 years age category, and at the level of the complete subadult sample ($n = 186$) there is a significant association between nonspecific periostitis, and younger age categories ($\chi^2 = 10.65$, df $= 3$, $P = 0.014$).

Adult frequencies range from 7.3% in the continental part of the LA series to 18.1% in the Adriatic part of the EM series. Male and female frequencies are similar in all series except in the Adriatic part of the EM series where males (24.0%) exhibit an almost twice as high frequency as females (12.1%; $\chi^2 = 3.97$, df $= 1$, $P = 0.046$).

TABLE 6. The frequency and distribution of trauma in the analyzed series

	Continental LA		Continental EM		Adriatic LA		Adriatic EM	
Age (years)/sex	O/A	%	O/A	%	O/A	%	O/A	%
Females 15–29	18/0	0.0	35/3	8.6	21/0	0.0	17/2	11.8
Females 30–44	39/3	7.7	27/5	18.5	38/11	28.9	48/8	16.7
Females 45+	13/4	30.8	13/4	30.8	15/5	33.3	35/10	28.6
All females	70/7	10.0	75/12	16.0	74/16	21.6	100/20	20.0
Males 15–29	20/5	25.0	19/3	15.8	11/2	18.2	13/3	23.1
Males 30–44	36/6	16.7	39/7	17.9	43/19	44.2	53/24	45.3
Males 45+	24/12	50.0	12/5	41.7	24/7	29.2	34/26	76.5
All males	80/23	28.8	70/15	21.4	78/28	35.9	100/53	53.0
All adults	150/30	20.0	145/27	18.6	152/44	28.9	200/73	36.5

LA, Late Antique samples; EM, Early Medieval samples; O, number of individuals observed; A, number of individuals with trauma.

TABLE 7. The frequency and distribution of trauma by anatomical segment

	Continental LA		Continental EM		Adriatic LA		Adriatic EM	
	O/T	%	O/T	%	O/T	%	O/T	%
Females								
Cranium	70/2	2.8	75/1	1.3	74/2	2.7	100/12	12.0
Upper extremity	70/3	4.3	75/8	10.7	74/9	12.2	100/5	5.0
Lower extremity	70/2	2.8	75/3	4.0	74/6	8.1	100/3	3.0
N/A	70/7	10.0	75/12	16.0	74/16[a]	21.6	100/20	20.0
Males								
Cranium	80/12	15.0	70/4	5.7	78/11	14.1	100/28	28.0
Upper extremity	80/6	7.5	70/7	10.0	78/10	12.8	100/19	19.0
Lower extremity	80/5	6.2	70/7	10.0	78/9	11.5	100/11	11.0
N/A	80/23	28.8	70/15[b]	21.4	78/28[c]	35.9	100/53[d]	53.0

LA, Late Antique samples; EM, Early Medieval samples; O, number of individuals with the required anatomical segment preserved; T, number of trauma in the anatomical segment; N, number of individuals observed; A, number of individuals with trauma.
[a] Total number of trauma (17) is larger than number of individuals affected (16) because one female sustained multiple trauma in different anatomical segments.
[b] Total number of trauma (18) is larger than number of individuals affected (15) because three males sustained multiple trauma in different anatomical segments.
[c] Total number of trauma (30) is larger than number of individuals affected (28) because two males sustained multiple trauma in different anatomical segments.
[d] Total number of trauma (58) is larger than number of individuals affected (53) because five males sustained multiple trauma in different anatomical segments.

A marginally not significant association between higher periostitis frequencies and younger age categories is noted in the complete adult sample ($n = 640$; $\chi^2 = 5.76$, df = 2, $P = 0.056$).

Trauma. Trauma frequencies tabulated by individual are presented in Table 6, those by anatomical segment in Table 7. No traumas were noted in any of the recovered subadult remains. Total adult frequencies range from 18.6% in the continental part of the EM series, to 36.5% in the Adriatic part of the EM series. Males exhibit higher frequencies of trauma than females in all of the analyzed series, but statistical significance is reached only in the continental part of the LA series ($\chi^2 = 7.07$, df = 1, $P = 0.004$), and the Adriatic part of the EM series ($\chi^2 = 22.09$, df = 1, $P < 0.001$). A significant association ($P < 0.03$) between higher trauma frequencies and older age categories is noted in all four series.

Analyses by anatomical segment show that at the level of complete samples, the most frequent location of trauma in females is in the upper extremities (7.8% or 25/319), in males in the cranium (16.8% or 55/328).

Nine individuals (9/647 or 1.4% of the total adult sample) exhibited one or more perimortem trauma. The trauma were noted in six males from the Adriatic component of the EM series, one female from the continental component of the EM series, one male from the continental component of the EM series, and one male from the continental component of the LA series. All were

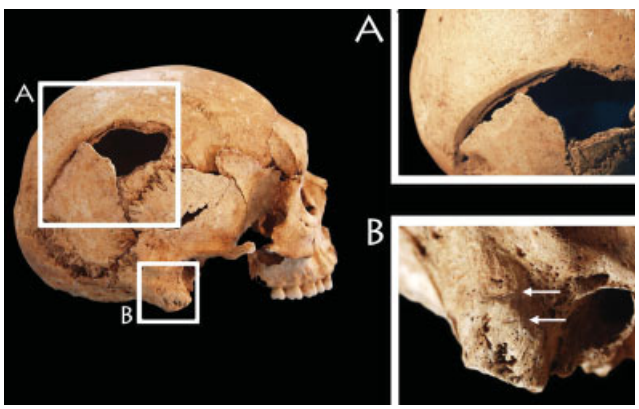

Fig. 2. Skull of 30–44 years old male from Šibenik exhibiting three perimortem injuries. **A**: sword cut to the right parietal and superior part of the occipital bone that penetrated the endocranium, (**B**) two parallel, superficial cuts to the right mastoideus. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

TABLE 8. The frequency and distribution of co–occurrences of osteological and dental markers of health in the analyzed series

	Continental LA		Continental EM		Adriatic LA		Adriatic EM	
Age/sex	O/A	%	O/A	%	O/A	%	O/A	%
Crib. Orbit. & LEH								
Females	51/7	13.7	41/9	22.0	43/4	9.3	42/12	28.6
Males	55/10	18.2	36/7	19.4	50/6	12.0	51/8	15.7
Crib. Orbit. & periostitis								
Subadults	11/8	72.7	8/6	75.0	29/9	31.0	24/16	66.7
Females	5/0	0.0	6/2	33.3	8/2	25.0	12/3	25.0
Males	6/1	16.7	10/1	10.0	8/0	0.0	24/11	45.8
Crib. Orbit. & trauma								
Females	7/0	0.0	12/2	16.7	16/2	12.5	20/4	20.0
Males	23/1	4.3	15/2	13.3	28/2	7.1	53/12	22.6
LEH & periostitis								
Females	42/2	4.8	37/3	8.1	34/4	11.8	39/7	17.9
Males	47/5	10.6	31/5	16.1	43/3	7.0	51/12	23.5
LEH & trauma								
Females	42/5	11.9	39/5	12.8	36/8	22.2	40/8	20.0
Males	49/13	26.5	32/7	21.9	44/16	36.4	51/25	49.0
Trauma & periostitis								
Females	7/0	0.0	10/1	10.0	14/2	14.3	20/2	10.0
Males	21/2	9.5	15/2	13.3	27/4	14.8	53/11	20.8

LA, Late Antique samples; EM, Early Medieval samples; O, number of individuals observed; A, number of individuals with co–occurrence of various markers of health.

inflicted by sharp-edged instruments. Figure 2 presents the skull of a 30 to 44-years-old male from the Šibenik sample that is typical of the type of perimortem trauma recorded in the analyzed series. This individual exhibits a 101 mm long perimortem fracture in the right parietal, and superior part of the occipital bone that appears to have been inflicted by a sword. The characteristic polished appearance of the superior margin of the wound suggests that the injury was delivered by an assailant standing behind the victim, with the motion of the blade moving from superior to inferior. This individual also exhibits two short (8 and 5 mm long, respectively), parallel, superficial cuts to the right mastoideus, and a cut in the superior surface of the right clavicle near the lateral third of the bone (not pictured).

Co-occurrences of markers of health

The co-occurrences of the analyzed markers of health for the analyzed series are presented in Table 8. A total of 523 skeletons from both the LA, and EM period were sufficiently preserved to allow analyses of all skeletal and dental markers. Only one skeleton (1/523 or 0.2%), belonging to a 30 to 44-years-old male from the EM Croat site Velim on the Adriatic coast has all four markers of stress present. Similarly, very small percentages of individuals exhibit the presence of three markers of stress. The simultaneous presence of cribra orbitalia, LEH, and periostitis was recorded in 9/523 (1.7%) skeletons (two from the LA, and seven from the EM series), the simultaneous presence of cribra orbitalia, LEH, and trauma was recorded in 14/523 (2.7%) skeletons (two from the LA, and twelve from the EM series), while the simultaneous presence of LEH, periostitis, and trauma was recorded in 9/523 (1.7%) skeletons (two from the LA, and seven from the EM series).

In contrast to this, total frequencies for the simultaneous occurrences of cribra orbitalia and LEH in the analyzed series range from 10.7% to 21.5%, for the co-occurrence of cribra orbitalia and periostitis from 24.4% to 50.0%, for the co-occurrence of cribra orbitalia and trauma from 3.3% to 21.9%, for the co-occurrence of LEH and periostitis from 7.9% to 21.1%, for the co-occurrence of LEH and trauma from 16.9% to 36.3%, and for the co-occurrence of trauma and periostitis from 7.1% to 17.8%. In five of the six analyzed co-occurrences, highest frequencies are noted in the Adriatic part of the EM series.

No sex differences are noted in any of the analyzed series, with the exception of the simultaneous occurrence of LEH and trauma, which is significantly higher in males from the Adriatic part of the EM series ($\chi^2 = 6.96$, df = 1, $P = 0.008$).

In two of the six analyzed co-occurrences there is a significant association at the level of the total sample between higher frequencies of the analyzed co-occurrences, and younger age categories. Such associations are noted for the simultaneous occurrences of cribra orbitalia and LEH in adults ($n = 369$; $\chi^2 = 10.62$, df = 2, $P = 0.005$), and the simultaneous occurrences of cribra orbitalia and periostitis in adults ($n = 79$; $\chi^2 = 14.24$, df = 2, $P = 0.001$).

Comparisons between the series

Comparisons in the frequencies of individual markers of health, and their various co-occurrences, between the analyzed series are presented in Table 9. Comparisons between the continental and Adriatic regions of the LA series, undertaken to evaluate the effect that the differential ecological features in Croatia had on the quality of life show that, in terms of the analyzed markers of health, these series are substantially the same. Only one difference was noted—a significantly higher frequency of the co-occurrence of cribra orbitalia and periostitis in subadults in continental Croatia (72.7% compared to 31.0% in the Adriatic part of Croatia). These results, therefore, suggest that the different ecological features of continental and Adriatic Croatia did not significantly affect the health of the populations that inhabited them.

Analysis of health at the transition from the LA to the EM period in Croatia suggests a complex process. In con-

TABLE 9. Comparisons of individual and co–occurrence of markers of health in the analyzed series

	Late Antique Continental vs. Adriatic			Continental Croatia LA vs. EM			Adriatic Croatia LA vs. EM		
Osteological or dental feature	*N*	χ^2	*P*	*N*	χ^2	*P*	*N*	χ^2	*P*
Individual features									
Cribra orbitalia in subadults	111	2.122	0.145	87	0.000	1.000	155	6.973	0.008**
Active Crib. Orbit in subadults	53	0.765	0.382	47	2.465	0.116	79	0.167	0.683
Cribra orbitalia in all adults	359	0.044	0.833	363	0.086	0.769	376	4.302	0.038**
Cribra orbitalia in females	177	0.424	0.515	182	0.080	0.778	186	0.192	0.661
Cribra orbitalia in males	182	1.369	0.242	181	0.798	0.372	190	5.320	0.021**
LEH in all adults	308	0.124	0.725	264	1.949	0.163	319	2.392	0.122
LEH in females	151	0.001	0.980	135	1.947	0.163	158	2.419	0.120
LEH in males	157	0.114	0.735	129	0.138	0.710	161	0.152	0.696
Periostitis in subadults	92	1.135	0.287	62	0.146	0.702	124	1.075	0.300
Periostitis in all adults	297	1.133	0.287	294	0.845	0.358	346	2.897	0.089
Periostitis in females	142	0.404	0.525	146	0.000	1.000	169	0.000	1.000
Periostitis in males	155	0.093	0.760	148	1.050	0.306	177	4.561	0.033**
Trauma in all adults	302	2.801	0.094	295	0.023	0.879	352	1.893	0.169
Trauma in females	144	2.806	0.094	145	0.678	0.410	174	0.005	0.943
Trauma in males	158	0.625	0.429	150	0.706	0.401	178	4.502	0.034**
Co-occurrence of features									
Crib. Orbit. & LEH									
Females	94	0.117	0.732	92	0.574	0.449	85	3.979	0.046**
Males	105	0.370	0.543	91	0.000	1.000	101	0.062	0.804
Crib. Orbit. & periostitis									
Subadults	40	4.095	0.043*	19	0.000	1.000	53	5.337	0.021**
Females	13	0.181	0.671	11	0.413	0.521	20	0.000	1.000
Males	14	0.022	0.881	16	0.000	1.000	32	3.740	0.053**
Crib. Orbit. & trauma									
Females	23	0.031	0.861	19	0.135	0.714	36	0.023	0.881
Males	51	0.000	1.000	38	0.151	0.698	81	2.090	0.148
LEH & periostitis									
Females	76	0.487	0.485	79	0.021	0.884	75	0.102	0.750
Males	90	0.057	0.811	78	0.132	0.716	94	3.612	0.057**
LEH & trauma									
Females	78	0.836	0.361	81	0.000	1.000	76	0.000	1.000
Males	93	0.637	0.425	81	0.045	0.833	95	1.994	0.158
Trauma & periostitis									
Females	21	0.069	0.793	17	0.000	1.000	34	0.000	1.000
Males	48	0.012	0.912	36	0.000	1.000	80	0.116	0.733

LA, Late Antique samples; EM, Early Medieval samples; *N*, number of individuals observed.
* Higher frequency in the continental part of Croatia.
** All differences between the Late Antique and Early Medieval series in Adriatic Croatia are the result of significantly higher frequencies in the Early Medieval period.

tinental Croatia there appears to have been no significant discontinuity in the quality of life. In contrast to this, comparisons in the Adriatic part of Croatia show a significant deterioration of living conditions with the transition to the medieval period. Nine of the 28 analyzed categories show significantly higher frequencies in the EM series. Furthermore, the deterioration of living conditions appears to be primarily affecting subadults and males. In comparison to the LA series, the EM series in Adriatic Croatia has significantly higher frequencies of cribra orbitalia in subadults and males, higher frequencies of periostitis and trauma in males, higher frequencies of the co-occurrence of cribra orbitalia and periostitis in subadults and males, and higher frequencies of the co-occurrence of LEH and periostitis in males. In this context it is also relevant to note that six of the nine recorded perimortem trauma were noted in males from the Adriatic component of the EM series. The high frequencies of periostitis in males from the Adriatic component of the EM series may also have been caused by higher trauma frequencies. The one change noted in females is a significantly higher frequency of the co-occurrence of cribra orbitalia and LEH in the Early Medieval period.

DISCUSSION

The lack of differences between the continental and Adriatic parts of the LA series suggest similar levels of stress in these, ecologically different, settings. Several reasons may be responsible for this.

The most important is that all of the skeletal material comprising the LA series comes from moderate to large urban centers. All of these centers were built in a standardized manner (Vitruvius, 1999), with high emphasis on public sanitation. When necessary, fresh drinking water was brought by aqueducts (from as far away as 14 km in *Sirmium*), and distributed throughout the town with lead or clay pipes. Both types of pipes have been recovered in Vinkovci (Iskra-Janošić, 2001). The problem of waste disposal was dealt with by constructing elaborate sewers, the remains of which have been recovered in Osijek, Vinkovci, and Zadar. The high levels of public sanitation in these centers may be responsible for

the uniform and, in comparison to the EM series, relatively low frequencies of cribra orbitalia, LEH, and periostitis.

Cribra orbitalia has been associated with three clinical expressions of acquired anemia: acquired iron-deficiency anemia, the anemia of chronic disease, and megaloblastic anemia (Dallman et al., 1980; Cook, 1990; Stuart-Macadam, 1992; Beck, 1991; Kent et al., 1994; Sullivan, 2005). Differentiating between them, even in clinical settings, is a complex process. In bioarchaeological analyses it is dependent on abundant and detailed historical and archaeological contexts (Sullivan, 2005)—data that are not available for the analyzed Croatian series. Common, however, to these clinical expressions of acquired anemia are high parasite loads and acute bacterial or viral diseases (in acquired iron-deficiency anemia and megaloblastic anemia), and chronic bacterial or viral diseases (in the anemia of chronic disease). Clinical and epidemiological studies have associated LEH with a wide variety of systemic diseases, neonatal disturbances and nutritional deficiencies with among them, importantly, parasitism (Suckling et al., 1986), and infectious diseases (Pindborg, 1982). Nonspecific periostitis results from bacterial infection (Ortner, 2003). The similar frequencies of all individual markers of health, and the majority of the co-occurrences of markers of health in the two LA series, suggest uniform living conditions with high hygienic standards and low incidences of acute and chronic infectious diseases. In this context it is relevant to point out that no instances of tuberculosis or leprosy were noted in Late Antique series from Croatia (Šlaus, 2006).

Cultural practices were also uniform in the LA series, including those pertaining to the onset of weaning. Both Soranus (98–117 AD) and Galen (130–200 AD) suggest the gradual introduction of solid foods after the age of 6 months, and complete weaning at about 3 years of age. This advice on infant feeding appears to have been followed through the entire Empire. This is relevant because weaning stress has been implicated in the development of LEH (Corruccini et al., 1985; Moggi-Cecchi et al., 1994). It is, however, important to note that 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 and Wilkinson, 1990). However, even without these problems, it seems likely that weaning stress did not significantly affect LEH frequencies in the analyzed series as Early Medieval literature on infant feeding reflected the ideas of Soranus and Galen (Fildes, 1986). Both the foods and times of weaning were similar from the 3rd to 9th c. AD in continental Croatia suggesting that factors other than weaning stress were responsible for the differences between LEH frequencies.

An additional reason for the lack of differences between the two LA series concerns the fact that the Romans were, through elaborate and well-developed trading networks, precisely informed of the ecological features and resources of these parts of Croatia, even before they were incorporated into the Roman Empire (Strabo, 1969). Following their military subjugation, exploitation of these resources continued in much the same way as it had before the arrival of the Romans.

Analysis of the distribution of trauma by anatomical segment, in the continental and Adriatic components of the LA series, show high frequencies of trauma to the upper extremities in females, and high frequencies of trauma to the cranium in males. In conjunction with the fact that no perimortem trauma were recorded in females from the LA series, while one perimortem trauma was noted in a male from the continental component of the LA series, these data suggest that the causes of trauma in females were primarily accidents incurred during daily activities, while an important cause of trauma in males was interpersonal violence.

The similar frequencies of traumas in the continental and Adriatic components of the LA series are interesting. Total frequencies are, in fact, higher in the Adriatic (28.9%) than in the continental (20.0%) part of Croatia, indicating that proximity to a, by all historical accounts (Mócsy, 1974; Goldstein, 1995) volatile fortified border, did not elevate trauma frequencies.

Comparisons between the complete LA and EM samples show a general trend of worsening living conditions during the Medieval period, although, as is evident from Table 9, this trend obscures important geographical variation in the frequencies and distributions of the analyzed markers of health. Analyses between the continental components of the analyzed series show no significant change in living conditions with the transition to the Medieval period, while comparisons between the Adriatic components indicate a significant deterioration in the quality of life.

The increased frequencies of individual markers of health conform well to the increased frequencies of the co-occurrences of different markers of health in the Adriatic component of the EM series. This suggest that the causative agents behind the worsening living conditions during the Medieval period most likely were: (a) increased parasite loads (suggested by the significantly higher frequencies of cribra orbitalia, LEH, and the co-occurrence of cribra orbitalia and LEH); (b) higher frequencies of acute and chronic infectious disease (suggested by the significantly higher frequencies of periostitis, and the co-occurrences of cribra orbitalia and periostitis, and LEH and periostitis); and (c) higher trauma frequencies.

The reasons why these changes were so pronounced in the Adriatic part of Croatia, and totally absent in the continental part of Croatia are complex and not completely clear. The following factors may have contributed.

The first is that the EM series consists exclusively of individuals recovered from small village cemeteries. Differences between the LA and EM series, therefore, result not only from the cultural, social and religious changes that followed the fall of the Western Roman Empire, but also because of differences between urban and rural lifestyles. The second factor relates to the continuity or discontinuity in the exploitation of the available resources with the transition to the Medieval period, while the third factor concerns the political and military environment that the newly arrived ethic groups inhabited.

The last factor is easily evaluated in continental Croatia. Following brief and successful campaigns against the Gepids and Lombards, Avar-slav tribes occupied continental Croatia in 569 AD. In military terms Avar-slavs completely dominated their neighbors, exacting in tribute from the Byzantine Empire at least 27 tons of gold (Kovačević, 1963). Following an unsuccessful attempt to capture Constantinople in 626 AD their military dominance declined, but they remained a significant force until their subjugations by the Franks in 803 AD. The political and military situation in continental Croatia during the early medieval period appears to have been stable and peaceful, which explains the low trauma frequencies—total adult frequencies in continental Croatia are, in fact, lower in the EM than in the LA series. Anal-

ysis of the distribution of trauma by anatomical segment supports this hypothesis, and suggests that interpersonal violence contributed little to total trauma frequencies. In comparison to individuals from the other analyzed subsamples, both females and males from the continental component of the EM series exhibit the lowest frequencies of cranial trauma. This is also the only male subsample in which the highest frequency of trauma, by anatomical segment, was not recorded in the cranium.

In terms of the differences between the urban lifestyle of the LA period, and the rural lifestyle of the EM period in continental Croatia, trauma frequencies in females correspond to the pattern of higher fracture frequencies in rural than in urban communities noted by Judd and Roberts (1999)—although in this data set differences in trauma frequencies tabulated by individual are not significant ($\chi^2 = 0.678$, df = 1, $P = 0.410$). In the male subsample from continental Croatia, total trauma frequencies are higher in the LA series, although this primarily appears to be related to the high frequencies of cranial fractures in males from urban LA sites.

Concerning continuity or discontinuity in the exploitation of resources, available historical sources suggest that Gepid and Avar-slav tribes migrated to continental Croatia from an, as yet, unidentified area in modern Byelorussia or Ukraine (Lipták, 1983; Goldstein, 1995). The ecological features of these regions—the predominantly flat terrain with abundant rivers, and mild/moderate continental climate are similar to those of continental Croatia. It, therefore, seems likely that the ethnic groups inhabiting continental Croatia in the EM period continued exploiting the same resources they depended on in their ancestral homelands.

The absence of significant differences in the frequencies of cribra orbitalia, LEH, and nonspecific periostitis—caused by the change from urban to rural living conditions, is somewhat surprising. Sanitation levels in the small medieval villages in continental Croatia must have been lower than in the large Roman urban centers. At the descriptive level, data from the analyzed series support this. Thus, while cribra orbitalia frequencies in the series are similar, LEH and adult periostitis frequencies are higher in the EM series. More importantly, the frequencies of the co-occurrences of the analyzed markers of health are consistently—in 11/13 analyzed categories, higher in the EM series. The fact, however, that none of these differences approaches statistical significance suggests continuity in the levels of parasite loads and incidences of acute and chronic infectious diseases in continental Croatia from the 3rd to 9th centuries AD suggesting, perhaps, that the lower population densities that are associated with rural lifestyles, may have offset the reduced sanitation levels.

The change from urban to rural living conditions did, however, significantly impact the health of the Early Medieval inhabitants of Adriatic Croatia. Subadult and male cribra orbitalia frequencies are significantly higher in the EM series, as is the frequency of periostitis in males. Similarly, the co-occurrences of cribra orbitalia and LEH, cribra orbitalia and periostitis, and LEH and periostitis, are all significantly higher in the Adriatic component of the EM series. The two categories primarily affected by the deterioration of living conditions during the Medieval period were subadults and males.

The high cribra orbitalia frequencies in subadults are not surprising. Subadults are particularly vulnerable to the development of anemia because of a combination of factors including high subadult iron requirements, low amounts of iron in breast milk, and weaning diets rich in carbohydrates that contain phosphorus and phytates which inhibit intestinal absorption of iron, and compromise immunity (Mensforth et al., 1978; Morris, 1987). Weaning also significantly increases exposure of subadults to a wide variety of gastrointestinal pathogens that cause weanling diarrhea. This diarrhea inhibits a child's appetite, and increases metabolic loss of essential nutrients including iron with the result that a child can become anemic despite a diet containing sufficient amounts of iron and other essential nutrients (Gordon et al., 1963; Mittler and Van Gerven, 1994).

Sex differences in adult cribra orbitalia frequencies, suggesting differential exposure to factors that resulted in anemia among boys and girls, have also been reported, although their interpretation is more problematic. Some authors (Cybulski, 1977; Stuart-Macadam, 1985; Šlaus, 2000; Sullivan, 2005) report higher frequencies of cribra orbitalia in women, particularly young women of reproductive age. On the basis of her analysis of adult skeletal material from the medieval Gilbertine Priory of St. Andrew in York, Sullivan (2005) argues that the high iron-demands of menstruation, pregnancy and lactation led to higher frequencies of chronic iron-deficiency anemia in women. In the Adriatic component of the EM series cribra orbitalia frequencies are higher in males, but the difference is not significant. The significant increase of cribra orbitalia frequencies in comparison to the LA series is, however, also associated with significantly higher frequencies of periostitis, and the co-occurrence of cribra orbitalia and periostitis in males. These data may indicate that there was a sex-specific biocultural vulnerability of males during the Medieval period towards developing illnesses linked to anemia or, alternatively, that anemia during childhood adversely affected the immunocompetence of males making them more susceptible to infectious disease later in life. The severity of the experience suffered by males from the Adriatic component of the EM series can be gauged by the fact that the presence of cribra orbitalia, and the simultaneous presence of cribra orbitalia and periostitis in this sub-sample, are both significantly associated with younger age categories ($\chi^2 = 8.93$, df = 2, $P = 0.011$ and $\chi^2 = 8.56$, df = 2, $P = 0.014$, respectively). Whatever the reasons, the collected data clearly show that significantly higher parasite loads, and higher frequencies of acute and chronic infectious disease, were present in Adriatic Croatia during the Early Medieval period. In this context it is relevant to note that six of the seven cases of tuberculosis or leprosy noted in the EM series were recorded in the Adriatic subsample (Šlaus, 2006).

Concerning continuity or discontinuity in the exploitation of available resources, historical sources state that Croats migrated to the Adriatic coast from an area that encompasses lands in modern southern Poland, eastern Slovakia and western Ukraine (Šišić, 1925; Goldstein, 1995). The ecological features of these regions are vastly different to the Mediterranean, which is characterized by few arable fields, karst formations, and a general absence of surface water. Wheat and barely are hard to cultivate in this environment, and the lack of open grasslands prohibits extensive horse and cattle breeding. These reasons may have pushed the Croats towards exploiting the Adriatic Sea. However, for whatever reasons, possibly because they lacked the knowledge and necessary skills, as neither was required in their ances-

TABLE 10. Comparisons between Croatian and other Late Antique and Early Medieval samples from Europe

	CO subadults (%)	CO adults (%)	LEH adults (%)	Periostitis adults (%)	Trauma adults (%)
Late Antique sites					
Lucus Feroniae, Italy 2–4 c. AD	65.4	19.4	82.0		
Rimini, Italy 2–4 c. AD	100.0	30.8			
Ravenna, Italy 1–4 c. AD	62.5	59.3			
Quadrella, Italy 1–4 c. AD		22.9	95.2	61.1[a]	
Isola Sacra, Italy 1–3 c. AD			81.0		
Poundbury Camp, England 4 c. AD	36.4	26.0	37.5		
Croatian sample, 3–5 c. AD (this study)	44.9	12.8	64.6	9.1	24.5
Medieval sites					
Vicenne; Italy 6–8 c. AD		18.7	100.0	52.2[a]	
Selvicciola, Italy 7 c. AD	73.7	23.5	75.0		
Wurttenberg, 5–9 c. AD	68.7	37.5			
Composite English rural sample, 10–13 c. AD					15.5
Composite English urban sample, 10–17 c. AD					5.2
Composite Serbian sample, 11–19 c. AD					3.8
Croatian sample, 6–9 c. AD (this study)	58.9	16.6	61.8	15.2	29.0

All frequencies are per individual; CO, cribra orbitalia; LEH, linear enamel hypoplasia.
[a] Only tibial periostitis.

tral homeland, Croats did not exploit the available marine resource. Analyses of faunal remains recovered from several refuse pits located in the three analyzed Croat sites (Šibenik, Radašinovci, and Velim) show no evidence of fish bones or shellfish. Similarly, no fishhooks or other implements that could be associated with fishing were recovered as grave goods in the analyzed cemeteries (Krnčević, 2000; Jurić, 2003, 2004). Stable isotope analysis from skeletons recovered from these sites are currently being undertaken to see whether the results support the theory of low intakes of marine food in EM Croat populations.

Instead, as is clearly evident from numerous historical sources (Šišić, 1925; Klaić, 1972; Goldstein, 1995), Croats turned to piracy. This led to numerous conflicts with the rapidly developing Venetians, as well as with Saracens who started infiltrating the Adriatic Sea from the middle of the 9th century AD. These conflicts may be responsible for the high total trauma frequencies, as well as for the high frequencies of cranial, and perimortem trauma recorded in males from the Adriatic component of the EM series.

To put data from the LA to EM transition in Croatia into a broader geographical frame, results from the Croatian series were compared to other Roman Imperial, and Middle Ages series from Italy (Manzi et al., 1999; Salvadei et al., 2001; Bonfiglioli et al., 2003; Facchini et al., 2004; Belcastro et al., 2007), Serbia (Djurić et al., 2006), Germany (Hengen, 1971), and England (Stuart-Macadam, 1985; Judd and Roberts, 1999). The results, presented in Table 10, show that cribra orbitalia frequencies in Croatia were slightly lower than in other parts of Europe (with the exception of subadult frequencies in Poundbury Camp, England), while adult LEH frequencies are intermediate—higher than those recorded in England, but lower than the frequencies in Italy. Little comparative data was available for periostitis and trauma comparisons.

Interpretation of the collected data also need to take into account issues identified by Wood et al. (1992) collectively termed as the "osteological paradox." These authors have suggested that aggregate demographic and epidemiological measures are useless for understanding individual experiences because of issues related to heterogeneous individual frailty, and the fact that individuals with pathological lesions such as cribra orbitalia could, in fact, be showing stamina and survivorship in the face of biological stress, while individuals without lesions may be showing weakness because they lacked the physical means to cope with the stress and thus died before developing skeletal manifestations that could identify their suffering. The best way to tackle these important interpretative difficulties is to identify various subpopulations that may have been exposed to stress more often than others, and take advantage of all of the available historical, archaeological and ethnographic data (Sullivan, 2005). In this analysis, the available archaeological data do suggest that all of the analyzed individuals belonged to a single social category—osteological material from the obviously elite Late Antique graves was not available because of looting, while the newly arrived ethnic groups had yet to undergo significant social stratification. Analyzing the populations by age and sex showed that subadults and males from the Adriatic component of the EM series experienced significantly higher level of stress than subadults and males from the Adriatic component of the LA series. In view of the available historical and archaeological evidence—the destruction or abandonment of large urban centers coupled with the arrival of new ethnic groups, the change to a rural lifestyle, the frequent conflicts with Venetians and Saracens, and the presence of infectious diseases such as leprosy and tuberculosis, it is hard to develop a realistic scenario in which these individuals were, in fact, better off than their peers in the LA series. Furthermore, while this analysis was not designed to deal with issues of heterogeneous individual frailty, it is relevant to point out that, at the level of the complete analyzed sample, higher frequencies of cribra orbitalia, LEH, and periostitis are significantly associated with younger age categories. The same applies to the co-occurrences of cribra orbitalia and LEH, cribra orbitalia and periostitis, and LEH and periostitis. These results mirror those from numerous other studies (for instance Cook and Buikstra, 1979; Simpson et al., 1990; Mittler and Van Gerven, 1994; Duray, 1996; Sullivan, 2005) that suggest that childhood stress results not in increased resilience, but in biological damage that reduces adult longevity.

In conclusion, the purpose of this study was to evaluate the transition from the Late Antique to the Early Medieval period in Croatia from the standpoint of population biology, and to compare the results of these analyses with the available historical and archaeological data to test the hypothesis that the transition was catastrophic. An additional objective was to try to determine whether the transition was a uniform process, or differentially affected the past inhabitants of Croatia because of various local considerations.

Data collected from two large composite series from Croatia show that the transition from the Late Antique to the Early Medieval period was not a uniform process, but differentially affected the past inhabitants of Croatia because of local cultural, socio-economical, or political factors. In the continental part of Croatia there seems to have been substantial continuity in the levels of parasite loads and incidences of acute and chronic infectious diseases from the 3rd to 9th centuries AD, while relatively low trauma frequencies, coupled with low frequencies of cranial and perimortem trauma, suggest a stable and peaceful political and military environment. In contrast to this, populations that inhabited the Adriatic part of Croatia show a clear discontinuity from the biological point of view, and an evident, and significant deterioration of living conditions during the Early Medieval period. Parasite loads significantly increased, as did the frequencies of acute and chronic infectious disease, while the significant increase of trauma frequencies, particularly those to the cranium, and the presence of perimortem trauma inflicted by sharp-edged weapons, suggests high risks of interpersonal violence. The collected data also show that the worsening living conditions did not equally affect all segments of the population. Subadults and males in the Adriatic part of Croatia were exposed to greater stress then females. Identification of the factors responsible for this is a challenge that needs to be resolved in future studies.

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