

Temporal Trends in Demographic Profiles and Stress Levels in Medieval (6th–13th Century) Population Samples from Continental Croatia

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Aim. To analyze and compare the demographic profiles and disease frequencies of early (6th-9th century) and late (10th-13th century) medieval skeletal series from continental Croatia.

Methods. Age and sex distributions in three early (n = 277) and six late (n = 175) medieval skeletal series were compared. All skeletons were analyzed for the presence of dental enamel hypoplasia, periostitis, trauma, and presence of Schmorl's depressions in vertebral bodies.

Results. Data collected from the skeletal series suggested significantly higher stress in the late medieval period. This stress may have affected mortality, as evidenced by significantly higher subadult mortality and shorter adult average life span. Men in the late medieval series, in particular, seem to have been under greater stress. They exhibited significantly higher mortality in the 21-25 years age category, and significantly higher frequencies of periosteal lesions, cranial and postcranial trauma, and Schmorl's depressions.

Conclusion. The frequencies of all skeletal indicators of stress increased significantly during the late medieval period. This was accompanied by a significant increase in subadult mortality and shortening of the average life span of adult men and women.

Key words: communicable diseases; Croatia; demography; dental enamel hypoplasia; paleopathology; wounds and injuries

In recent years, there has been increased interest in bioarchaeological research of skeletal series recovered from archaeological sites (1-3). Bioarchaeology is the study of human biological remains within their cultural (archaeological) context. This interdisciplinary field of research developed through the mutual interests of physical anthropologists and archaeologists (4-5). In Croatia, bioarchaeological research focused primarily on problems related to the origin and migrations of the early medieval Croat population (6-9). The pathological changes and demographic profiles of skeletal series from the medieval period in continental Croatia have so far received limited attention. Biological data have been published for the Đakovo phase I skeletal series, but the primary concern in that report was craniometric differentiation between the two burial phases (8). Boljunčić (10-12) reported on the demography and pathology of two small late medieval skeletal series recovered from sites near Virovitica: Zvonimirovo (10,11) and Josipovo (12). Šlaus (13,14) reported on the pathological features of the early medieval Privlaka series (13), and an osteochondroma found in an adult male from the late medieval Lobar site has been published as a case report of a bone tumor recovered from an archaeological series (14). Apart from

these reports, little is known about the demography and pathology of the medieval period in continental Croatia. It was an important period of time, both in terms of political and economic changes, but historical sources are confusing and conflicting.

According to historical data, the early medieval period (6th-9th century) was characterized by mass migrations, political instability, and warfare (15,16). The period began with the death of Atilla in 453, and ended with the destruction of the Avar state by the Franks in 803. During this period, continental Croatia was inhabited by various ethnic groups, including Eastern Goths, Langobards, Gepids, Slavs, and Avars. The latter were themselves a conglomerate of different ethnic groups, including Central Asian populations, Bulgars, Kutrigurs, and the remains of conquered Germanic tribes.

Historical sources for the late medieval period (10th-13th century) indicate an initial period of anarchy in this region, during which sovereignty changed between Hungary and Croatia (16). In 1102, the Hungarian king Koloman defeated the Croatian king Petar Svačić and crowned himself King of Hungary, (continental) Croatia, and Dalmatia. From the archaeological point of view, this period is known as the Bijelo Brdo

Culture (17). This term has been used for over 70 years to designate different types of material remains with common characteristics found in medieval graves from Slovakia, Hungary, Slovenia, continental Croatia, Vojvodina, and western Romania. The name of the culture derives from the eponymous site near Osijek in Croatia. The bearers of the Bijelo Brdo Culture have been identified as Slavs and Hungarians, with the Slav component being heterogeneous and consisting of Slovaks, Bulgars, and Croats (17).

Multivariate statistical analyses of craniometric measurements from medieval archaeological sites in Central Europe (7,9) also attest to the complex political and ethnic interactions in continental Croatia between 6th and 13th century. It is presumed that early medieval Croats migrated to the eastern Adriatic from an area located in northern parts of today's Poland (7). From the 10th to 13th century, this population gradually expanded northward into today's Bosnia and Herzegovina, and the continental part of Croatia (9). This expansion is not mentioned in historical sources and may therefore represent a gradual process. In view of the vagueness of the historical data and the inconclusiveness of the archaeological data, a valid question that can be asked is does biological data indicate that this expansion affected living conditions, or in the broadest sense, quality of life in continental Croatia during the late medieval period? To answer this question, we compared the demographic profiles and disease frequencies between three early medieval and six late medieval skeletal series from continental Croatia. Data were then compiled for two large composite series, an early (6th-9th century) and a late (10th-13th century) medieval series, and the results compared.

Material and Methods

The composite early medieval skeletal series comprised skeletons recovered from the sites of Vinkovci (a Gepid cemetery), and two Avaroslav sites; Stari Jankovci, and Privlaka (Table 1).

Table 1. Dating and number of human skeletons recovered from the sites in Croatia

Site	Dating (AD)	No. of skeletons
Early medieval:		
Vinkovci-Gepid	500-550	34
Stari Jankovci	650-750	62
Privlaka	700-800	181
total		277
Late medieval:		
Đakovo phase I	1050-1242	31
Vinkovci	1050-1300	17
Lobor	1000-1100	11
Ščitarjevo	1000-1300	13
Đelekovec	1000-1300	19
Stenjevec	900-1200	84
total		175

The composite late medieval skeletal series was comprised of skeletons recovered from six sites: Đakovo phase I, Vinkovci, Lobor, Ščitarjevo, Đelekovec, and Stenjevec. Most of the recovered series were relatively small, with 11 to 19 individuals (Table 1). The exceptions were the first phase of the Đakovo cemetery and Stenjevec.

The criteria for determination of sex included pelvic (18) and cranial morphology (19). These criteria generally provide accurate results. From a sample of skeletons of known sex, Meindl et al (20) report a 3% error rate when both the pelvis and skull were evalu-

ated. When these elements were missing, sex was determined by discriminant functions for sexing adult femora from medieval sites in continental Croatia (21) with an accuracy rate of 87% to 95%. No attempt was made to estimate the sex of subadult individuals.

Adult age at death was estimated with as many methods as possible, including ectocranial suture fusion (22), pubic symphysis morphology (23-25), auricular surface morphology (26), and changes at the sternal end of the rib (27,28). In subadults, age at death was estimated on the basis of epiphyseal fusion, diaphyseal lengths, and dental eruption criteria (25,29-31).

The specific disease categories summarized for the two composite series were dental enamel hypoplasia, which is an indicator of subadult stress; non-specific periostitis, which is an indicator of infectious disease; skeletal trauma, including evidence of healed or unhealed fractures; and the presence of Schmorl's depressions in vertebral bodies as an indicator of physical stress on the vertebral column. These categories were chosen for two reasons. First, the pathological conditions comprising these categories are relatively common and leave relatively unambiguous traces in the skeleton. Second, when taken together, these categories create a composite profile of general health and quality of life.

Dental enamel hypoplasia or chronological aplasia is generally defined as any macroscopic defect in the enamel surface (32-34). Hypoplastic defects can range from minor depressions in the enamel surface, with no dentin exposure, to complete disruption of the enamel. These defects appear as band-like depressions (linear enamel hypoplasia) or pits. The causes of the hypoplastic defects are commonly attributed to a variety of factors, including physiological stresses, such as malnutrition, infectious disease, psychological or physical trauma, or other metabolic disruptions (35). Hypoplasias remain visible until the affected enamel is worn away through dental attrition, providing a nearly permanent record of developmental arrest during infancy and early childhood. Whereas the development of enamel hypoplastic defects cannot be attributed to a specific disease or episode in the life of a deceased individual, studies of living children document the association between higher frequencies of hypoplastic defects and poor nutrition and low socioeconomic status (36,37).

Data on enamel hypoplasias were collected for the permanent maxillary central incisors and canines, and permanent mandibular canines. The selection of these teeth categories for study was dictated by the following considerations: 1) central incisors and canines are considered to be more susceptible to stress than other teeth (38); 2) canines have a long developmental period, from around 4 months to 6 years (39); and 3) incisors and canines in general displayed a relatively small amount of dental calculus, which obscured enamel in other teeth. 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 analyzed if the one on the right was missing.

Skeletal evidence for infectious disease was determined by the presence of non-specific periostitis. Periostitis involves inflammation of the periosteum as evidenced by the deposition of new bone on the outer surface of the affected element (40).

Skeletal evidence for trauma was determined by the presence of healed or unhealed fractures.

Schmorl's depressions were used to assess physical stress in the spinal column. Schmorl's depressions are lesions that result from herniation and displacement of intervertebral disc tissue into the adjacent vertebral body (41). The presence of Schmorl's depressions can be idiopathic, or related to a variety of reasons, including certain diseases and congenital factors, which produce a weakening of the subchondral bone and a disruption of the cartilaginous end-plate, and strong compression caused by traumatic injury. However, the most common cause of Schmorl's depressions according to Schmorl and Junghans (41) are degenerative changes associated with ordinary stress on the vertebral column.

Results

Subadults comprised 19.9% of the total sample in the early medieval (Table 2) and 30.2% of the total sample in the late medieval composite series (Table 3) (chi-square=5.85; $p<0.05$). Subadult mortality in

Table 2. Age and sex distribution in the early medieval composite series of human skeletons recovered from the sites in Croatia

Age (years)	No. (%) of individuals who died			
	subadult	women	men	total
Birth-1	6 (10.9)			6 (2.2)
2-5	12 (21.8)			12 (4.4)
6-10	23 (41.8)			23 (8.3)
11-15	14 (25.5)			14 (5.0)
16-20		5 (4.4)	5 (4.5)	10 (3.6)
21-25		18 (16.1)	8 (7.3)	26 (9.4)
26-30		16 (14.3)	16 (14.5)	32 (11.5)
31-35		17 (15.2)	18 (16.4)	35 (12.6)
36-40		12 (10.7)	19 (17.3)	31 (11.2)
41-45		11 (9.8)	16 (14.5)	27 (9.7)
46-50		10 (8.9)	11 (10.0)	21 (7.6)
51-55		10 (8.9)	8 (7.3)	18 (6.5)
56-60		7 (6.3)	4 (3.6)	11 (4.0)
>60		6 (5.4)	5 (4.6)	11 (4.0)
Total	55 (100.0)	112 (100.0)	110 (100.0)	277 (100.0)
Mean age at death ^a		37.9 ± 12.9	38.5 ± 11.4	

^aMean age at death was calculated from median values of each age category (for example, 23 for the age category 21-25), and 65 for the age category >60.

Table 3. Age and sex distribution in the late medieval composite series of human skeletons recovered from the sites in Croatia

Age (years)	No. (%) of individuals who died			
	subadult	women	men	total
Birth-1	7 (13.2)			7 (4.0)
2-5	13 (24.5)			13 (7.4)
6-10	16 (30.2)			16 (9.1)
11-15	17 (32.1)			17 (9.7)
16-20		3 (4.8)	2 (3.3)	5 (2.9)
21-25		11 (17.7)	13 (21.8)	24 (13.7)
26-30		10 (16.2)	3 (5.0)	13 (7.4)
31-35		15 (24.3)	16 (26.7)	31 (17.8)
36-40		5 (8.1)	8 (13.3)	13 (7.4)
41-45		4 (6.4)	11 (18.3)	15 (8.6)
46-50		4 (6.4)	2 (3.3)	6 (3.4)
51-55		6 (9.7)	2 (3.3)	8 (4.6)
56-60		1 (1.6)	1 (1.7)	2 (1.1)
60+		3 (4.8)	2 (3.3)	5 (2.9)
Total	53 (100.0)	62 (100.0)	60 (100.0)	175 (100.0)
Mean age at death ^a		35.6 ± 12.2	35.2 ± 10.7	

^aMean age at death is calculated from median values of each age category (for example, 23 for the age category 21-25), and 65 for the age category >60.

the early and late medieval series was highest in the 6-10 and 11-15 age groups, respectively.

Men and women were evenly represented in both composite series (Tables 2 and 3). Adults from the early medieval composite series lived slightly longer. The average age at death in the early medieval series was 37.9 years for women, and 38.5 years for men. In the late medieval series, adult women lived 35.6 years on average (2.3 years shorter than in the early medieval series), and adult men lived 35.2 years (3.3 years shorter than in the early medieval series). Young adult men particularly seemed to be under greater stress during the late medieval period. The mortality rate of men between 21 and 25 years of age in the late medieval series was significantly higher than in the early medieval series (21.8% vs 7.3%; chi-square = 6.16; df = 1; p < 0.05). Both series were characterized by high mortality in the 16-35 year age group: 37.1% of the total early medieval, and 41.8% of the total late medieval sample died during this interval. Few individuals (40 or 14.4% of the total early medieval se-

ries, and 15 or 8.6% of the total late medieval series) lived to be older than 50 years.

Small sex differences (0.6 and 0.4 years) in average life spans in both series were reflected in similar mortality profiles for men and women. Women aged 21-30 in the early medieval series and those aged 26-35 in the late medieval series were at greatest risk. In both series, men between 31 and 40 years of age were at greatest risk.

In the early medieval composite series, hypoplasias were most frequently recorded in the maxillary canines, followed by mandibular canines, and maxillary central incisors (Table 4). Over a third of the analyzed teeth exhibited hypoplastic defects. In the late medieval composite series, hypoplasias were most frequently recorded in the maxillary central incisors, followed by mandibular and maxillary canines. The total frequency of hypoplasias in the late medieval series was significantly higher than that recorded in the early medieval series (49.2% vs 36.1%; chi-square = 8.86; df = 1; p < 0.01). The frequency of hypoplastic defects in central maxillary incisors was also significantly higher in the late medieval composite series (55.8% vs 31.9%; chi-square = 7.65; df = 1; p < 0.01).

Table 4. Hypoplasia frequencies per individual in the early and late medieval composite series of human skeletons recovered from the sites in Croatia

Tooth	Hypoplasia frequencies per individual in medieval series (No. skeletons ^a /No. hypoplasias ^b /%) ^c	
	early	late
Maxillary incisor 1	119/38/31.9	52/29/55.8 ^d
Maxillary canine	143/55/38.5	57/26/45.6
Mandibular canine	178/66/37.1	80/38/47.5
Total	440/59/36.1	189/93/49.2 ^e

^aNo. of individuals.

^bNumber of teeth with one or more linear enamel hypoplasia (LEH).

^cPercentage of teeth with one or more LEH.

^dp = 0.006 vs early medieval series.

^ep = 0.003 vs early medieval series.

Subadults were poorly represented in both composite series. Only 34 teeth of subadults from the late medieval, and 76 teeth of subadults from the early medieval series were recovered (Table 5). In both composite series, subadults consistently exhibited higher frequencies of hypoplastic defects than adults. Subadults from the late medieval series also consistently exhibited higher frequencies of hypoplastic defects than subadults from the early medieval series. The total frequency of hypoplasias recorded in all subadult teeth from the late medieval series was significantly higher than the frequency recorded in the early medieval series (64.7% or 22/34 vs 42.1% or 32/76; chi-square = 3.93; df = 1; p < 0.05).

No significant differences in hypoplastic defects were recorded in total adult frequencies. A breakdown of the adult samples by sex showed, however, that men from the late medieval series consistently exhibited higher frequencies of hypoplastic defects than men from the early medieval series, whereas in women frequencies were similar. The total frequency of hypoplastic defects in the teeth of men from the late medieval series was significantly higher than the frequency re-

Table 5. Teeth hypoplasia frequencies in the early and late medieval composite series of subadult and adult human skeletons recovered from the sites in Croatia

Tooth	No. skeletons with enamel hypoplasia ^a (%) ^b			
	subadults	all adults	women	men
Early medieval series:				
maxillary incisors 1	9/24 (37.5)	29/95 (30.5)	18/46 (39.1)	11/49 (22.4)
maxillary canines	10/24 (41.7)	45/119 (37.8)	22/62 (35.4)	23/57 (40.3)
mandibular canines	13/28 (46.4)	53/150 (35.3)	26/81 (32.1)	27/69 (39.1)
Late medieval series:				
maxillary incisors 1	9/13 (69.2)	20/39 (51.3)	8/17 (47.1)	12/22 (54.5)
maxillary canines	4/8 (50.0)	22/49 (44.9)	8/22 (36.4)	14/27 (51.8)
mandibular canines	9/13 (69.2)	29/67 (43.3)	8/32 (25.0)	21/35 (60.0)

^aNumber of individuals with one or more linear enamel hypoplasia (LEH)/number of individuals observed.

^bPercentage of individuals with one or more LEH.

Table 6. Mean number of hypoplasias in incisors and canines in the early and late medieval composite series of human skeletons recovered from the sites in Croatia

Tooth	No. (mean ± SD) of hypoplasias in			
	subadults	all adults	women	men
Early medieval series:				
maxillary incisors 1	24 (0.72 ± 0.79)	95 (0.41 ± 0.67)	46 (0.49 ± 0.53)	49 (0.31 ± 0.67)
maxillary canines	24 (0.58 ± 0.65)	119 (0.45 ± 0.61)	62 (0.39 ± 0.61)	57 (0.54 ± 0.75)
mandibular canines	28 (0.79 ± 0.88)	150 (0.51 ± 0.74)	81 (0.34 ± 0.67)	69 (0.60 ± 0.83)
Late medieval series:				
maxillary incisors 1	13 (0.92 ± 0.83)	39 (0.72 ± 0.78)	17 (0.65 ± 0.76)	22 (0.77 ± 0.79)
maxillary canines	8 (0.62 ± 0.70)	49 (0.53 ± 0.64)	22 (0.41 ± 0.58)	27 (0.63 ± 0.67)
mandibular canines	13 (1.00 ± 0.78)	67 (0.58 ± 0.74)	32 (0.28 ± 0.51)	35 (0.86 ± 0.80)

corded in the early medieval series (55.9% or 47/84 vs 34.8% or 61/175; chi-square = 9.53; df = 1; p < 0.01).

The mean number of hypoplasias per tooth followed the same pattern. When the number of defects in each tooth with hypoplasias was averaged for the different groups in the sample, subadults from both composite series had a greater number of defects per tooth than adults, and subadults and men from the late medieval series had a greater number of defects per tooth than subadults and men from the early medieval series (Table 6).

Skeletal evidence for infectious disease was present in subadults and adults. In comparison with adults, subadults in both series showed less resistance to infectious diseases (Table 7). Furthermore, whereas the majority of subadult lesions showed no evidence of healing – 88.9% in the early medieval, and 74.3% in the late medieval series were active at time of death – the same was true for only 11.5% of adults in the early medieval, and 40.0% of adults in the late medieval series (Table 8).

The total frequency of periostitis in the late medieval series was significantly higher than the frequency recorded in the early medieval series (56.2% vs 19.1%; chi-square = 5.85; df = 1; p < 0.05). Differences between subadult (81.2% vs 30.0%; chi-square = 18.38; df = 1; p < 0.01) and total adult frequencies (35.1% vs 17.0%; chi-square = 6.92; df = 1; p < 0.01) were also significant, as were the differences in frequencies for men (40.0% vs 19.4%; chi-square = 3.70; df = 1; p < 0.05).

The total frequency of periosteal lesions active at time of death was also significantly higher in the late medieval series (62.7% vs 31.4%; chi-square = 7.39; df = 1; p < 0.01) (Table 8).

Skeletal evidence of trauma was present in both series. In the early medieval series trauma was almost exclusively found in adults. Only a single fracture, a well-

healed depression fracture on the frontal bone (1/38 or 2.6% of preserved subadult cranial vaults) was recorded in a subadult from Vinkovci. In adults, fractures were recorded in the cranium and postcranium.

Cranial fractures were noted in one woman (1/68 or 1.5% of women with recovered cranial vaults), and 2 men (2/72 or 2.8%). All three fractures were well-healed depression fractures that had not penetrated the inner table of the skull.

Table 7. Periosteal lesions in the early and late medieval composite series of human skeletons recovered from the sites in Croatia

Sex	Periosteal lesion frequencies in medieval series (No. skeletons ^a /No. lesions ^b /%)			p ^d
	early	late		
Subadults	30/9/30.0	48/39/81.2		< 0.001
Women	81/12/14.8	27/8/29.6		–
Men	72/14/19.4	30/12/40.0		0.050
All adults	153/26/17.0	57/20/35.1		0.008
Total	183/35/19.1	105/59/56.2		< 0.001

^aNumber of skeletons sufficiently preserved to evaluate presence of infectious disease.

^bNumber of skeletons affected with periostitis.

^cPercentage of skeletons affected with periostitis.

^dChi-square test.

Table 8. Frequency of occurrence of active periosteal lesions in the early and late medieval composite series of human skeletons recovered from the sites in Croatia

Sex	Periosteal lesion frequencies in medieval series (No. skeletons ^a /No. lesions ^b /%)	
	early	late
Subadults	9/8/88.9	39/29/74.3
Women	12/1/8.3	8/3/37.5
Men	14/2/14.3	12/5/41.7
All adults	26/3/11.5	20/8/40.0
Total	35/11/31.4	59/37/62.7 ^d

^aNumber of skeletons with periostitis.

^bNumber of skeletons with periostitis active at time of death.

^cPercentage of skeletons with periostitis active at time of death.

^dDifference between early and late medieval series significant at p = 0.006; chi square test.

Postcranial fractures of the following bones were recorded: the clavicle, in 2/59 (3.4%) women with recovered clavicles, and 3/66 (4.5%) men with recovered clavicles; humerus, in 1/77 (1.3%) women and 3/73 (4.1%) men; radius, in 2/71 (2.8%) women and 1/69 (1.4%) men; ulna, in 1/69 (1.4%) women and 1/72 (1.4%) men; femur, in 2/80 (2.5%) women; tibia, in 2/71 (2.8%) men; and fibula, in 2/64 (3.1%) men.

In the late medieval composite series skeletal trauma frequencies were higher. In adults, cranial fractures were present in 9/79 (11.4%) complete crania. The sex distribution was uneven, with 6 fractures recorded in men (6/40 preserved crania or 15.0%), and 3 (3/39 or 7.7%) in women. All fractures were healed depression fractures with smooth margins and slightly porous floors. None penetrated the inner table of the skull or exhibited evidence of subsequent infection. The difference between cranial fracture frequencies in men in the early (2.8%) and late (15.0%) medieval series was significant (chi-square = 4.09; $p < 0.05$).

Long bone fractures in women were recorded on the radius (2/39 women with recovered radii or 5.1%), and on the ulna (1/37 or 2.7%). In men, postcranial fractures were noted on the clavicle – 1/30 (3.3%) men with recovered clavicles, humerus (1/36 or 2.8%), radius (4/33 or 12.1%), and ulna (7/50 or 14.0%). Fractures on the midshaft of the ulna were of particular interest. These fractures are considered defensive fractures and occur when an individual covers the face or head with the arm in an attempt to protect themselves from an assailant. The difference between midshaft ulna fracture frequencies in men in the early (1.4%) and late (14.0%) medieval series was significant (chi-square = 5.73; $p < 0.05$).

In the composite late medieval subadult sample only a single fracture was noted, a well healed rib fracture in a 12.5-14.5 year old individual from Šćitarjevo.

The overall frequency of Schmorl's depressions in the early medieval series was 15.7% (112/713) (Tables 9 and 10). Schmorl's defects were more common in thoracic (50/280; 17.9%) than in lumbar (62/433; 14.3%) vertebrae. Adult men in the series exhibited significantly higher frequencies than women (19.7% vs 11.1%; chi-square = 9.33; $p < 0.01$).

The overall frequency of Schmorl's depressions in the late medieval series (171/845; 20.2%) was higher than in the early medieval series (15.7%), with significant difference (chi-square = 5.03; $p < 0.05$). The increase was primarily the result of differences in the subsample of men. Women frequencies were similar: 11.1% in the early and 13.6% in the late medieval series. Men, however, exhibited a significant increase of Schmorl's defects, from 19.7% in the early to 26.8% in the late medieval series (chi-square = 5.22; $p < 0.05$). Thoracic and lumbar vertebrae frequencies in the late medieval series were similar (19.6% and 21.4%, respectively). Adult men in the series exhibited higher frequencies than women (26.8% vs 13.6%); the difference was also significant (chi-square = 22.2; $df = 1$; $p < 0.01$).

Table 9. Schmorl's depressions in the early medieval composite series of human skeletons recovered from the sites in Croatia

Skeletons	Relative number ^a (%) ^b of Schmorl's depressions		
	thoracic	lumbar	total
Women:			
young adult ^c	7/67 (10.4)	13/129 (10.1)	20/196 (10.2)
old adult	0/63 (15.9)	7/74 (9.5)	17/137 (12.4)
total	17/130 (13.1)	20/203 (9.8)	37/333 (11.1)
Men:			
young adult	14/79 (17.7)	20/139 (14.4)	34/218 (15.6)
old adult	19/71 (26.7)	22/91 (24.2)	41/162 (25.3)
total	33/150 (22.0)	42/230 (18.3)	75/380 (19.7)

^aNumber of vertebrae with Schmorl's depressions/number of vertebrae observed.

^bPercentage of vertebrae with Schmorl's depressions.

^cYoung adult – individual aged between 16-35 years; old adult – individual older than 36 years.

Table 10. Schmorl's depressions in the late medieval composite series of human skeletons recovered from the sites in Croatia

Skeletons	Relative number ^a (%) ^b of Schmorl's depressions		
	thoracic	lumbar	total
Women:			
young adult ^c	27/179 (15.1)	14/90 (15.6)	41/269 (15.2)
old adult	9/99 (9.1)	7/52 (13.5)	16/151 (10.6)
total	36/278 (12.9)	21/142 (14.8)	57/420 (13.6)
Men:			
young adult	28/139 (20.1)	18/74 (24.3)	46/213 (21.6)
old adult	44/134 (32.8)	24/78 (30.8)	68/212 (32.1)
total	72/273 (26.4)	42/152 (27.6)	114/425 (26.8)

^aNumber of vertebrae with Schmorl's depressions/number of vertebrae observed.

^bPercentage of vertebrae with Schmorl's depressions.

^cYoung adult – individual aged between 16-35 years; old adult – individual older than 36 years.

Discussion

Analyses of the skeletal series recovered from archaeological sites in continental Croatia offer a valuable insight into the biological history of medieval Croatia. This is an important period of time characterized by numerous changes (political, social, and economic), which had a profound effect on human welfare. The accumulation of osteological data from skeletal collections is therefore an important step, not only for evaluating conclusions from historical, archaeological, and economic sources, but also for expanding empirical evidence not available through these sources.

This study demonstrated that the frequencies of all skeletal indicators of stress analyzed (enamel hypoplasia, skeletal evidence of infectious disease, skeletal evidence of trauma, and skeletal evidence of physical stress) had increased significantly during the late medieval period. This was accompanied by a significant increase in subadult mortality and a shortening of the average life span of adult men and women during the late medieval period.

Analysis of subadult mortality requires cautious interpretation. The significantly higher number of subadults recovered in the late medieval series, and the fact that subadults in all age categories in the late medieval series exhibited higher mortality rates than subadults in the early medieval series can be interpreted as a deterioration of living conditions during the late medieval period. However, one of the most

noticeable demographic similarities in both composite series was the consistent underrepresentation of subadults. Subadults comprised less than 20% of the total sample in the early medieval, and slightly more than 30% of the total sample in the late medieval composite series. The youngest age category, birth to one year, where subadult mortality is typically the highest, comprised only 2.2% of the total sample in the early medieval series. In the late medieval series, this age category comprised 4% of the total sample. To put these numbers into perspective, 28.5% (32/113) individuals died during the first two years of life (our unpublished data). However, subadult underrepresentation is by no means specific only to continental Croatia. The underrepresentation of infants in cemetery samples is a ubiquitous problem. Contributing factors in skeletal series from Croatia include possible differential burial customs for infants and stillborns, and differential burial depths for subadults and adults. Graves for adults were, as a rule, dug deeper than children's graves and thus more likely to remain undisturbed. There is some evidence that that this practice was present in continental Croatia, and it has been documented in neighboring Hungary, in medieval cemeteries from Alattyán-Tulát and Kerpuszta (42). Whatever the reasons, the biased exclusion of subadult individuals in both medieval composite series compromises analysis of subadult mortality trends and precludes meaningful consideration of longevity, survivorship, and life expectancy from birth.

Adult mortality was less ambiguous and comparisons between the two series were consistent with deteriorating living conditions and greater stress in the late medieval period. Both men and women had shorter average life span during the late medieval period. Life span of adult men and women in each series was similar.

Enamel hypoplasia frequencies in the two series showed an increase in subadult stress in the late medieval period. Total, subadult, and men frequencies were significantly higher in the late medieval series. There is a growing body of bioarchaeological evidence associating childhood stress with reduced life expectancy in preindustrial populations (43-46). Undernutrition and infection impair morphological development in children, and impact adult morbidity and mortality through metabolic imprinting and impaired immune response (47). Subadults in both composite skeletal series consistently exhibited higher frequencies of enamel hypoplasia than adults. Furthermore, not only did adults have a lower incidence of hypoplasia, but they also had a smaller number of defects in the teeth affected than individuals who died as children. These data are consistent with the pattern recorded in other skeletal series (43,44,46,48), and strongly suggest that hypoplasias were related to age at death in the archaeological series from Croatia. The enamel hypoplasia data were, therefore, consistent with the observed demographic profiles in the two series and, likewise, suggested greater stress during the late medieval period.

The same observation applies to the presence of infectious disease. Significantly higher frequencies of periosteal lesions were recorded in the late medieval series for subadults, men, and all adults as well as total fre-

quencies. The greatest difference was noted in subadults, where periostitis frequencies increased more than two-fold from the early to the late medieval period. Not only were infectious diseases more common during the late medieval period, but the assessment of the state of lesion showed that infectious diseases might have directly contributed to the increase in mortality.

Trauma frequencies are of particular interest. For some reason, the evident political instability that characterized the early medieval period, causing the destructions of the Gepid and Avar states, did not translate into high frequencies of skeletal trauma. The frequencies, for instance, of cranial trauma in the series were considerably lower than those recorded in Antique (4th century AD) series from Croatia (49,50). Postcranial fracture frequencies were more similar but also low, below 5% for both sexes in all bones analyzed. There is no evidence of "beaten-up" individuals (individuals with several fractures), and the frequencies of defensive "parry" fractures to the ulna were less than 3% for both sexes. The reasons for this apparent lack of skeletal trauma are unclear and open to different interpretations. The late medieval skeletal series was, on the other hand, characterized by high frequencies of skeletal trauma. The increase in total cranial fractures from the early to the late medieval period was five-fold. Frequencies of defensive, midshaft fractures of the ulna also increased five-fold in the late medieval series. The higher frequencies of skeletal trauma in the late medieval series are also consistent with a deterioration of living conditions and greater stress during the late medieval period.

High frequencies of Schmorl's depressions in both series are consistent with heavy physical strain on the vertebral column. Due to the nonspecific nature of this stress indicator, etiological determinations of specific activities are inappropriate. What is, however, clear from the skeletal data is that men in both composite series exhibited significantly higher frequencies of Schmorl's depressions than women, indicating their different activity patterns. There was a significant increase primarily related to frequencies of Schmorl's lesions in men during the late medieval period.

In conclusion, the biological and pathological information collected from the analyzed medieval skeletal series suggest higher stress in the late medieval period. This stress may have affected mortality, as evidenced by greater subadult mortality and shorter adult average life spans in the late medieval series. Men in particular seemed to have been under greater stress in the late medieval series and exhibited significantly higher mortality rates as well as significantly higher frequencies of periosteal lesions, cranial and postcranial trauma, and Schmorl's depressions. Multivariate cranio-metric analyses (9) showed that this coincided with an expansion of early medieval Croat populations from the eastern coast of the Adriatic into modern Bosnia and Herzegovina and continental Croatia. Further research of skeletal series from continental Croatia is necessary to determine if data from these collections confirm this correlation.

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