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Skeletal and dental indicators of health in the late medieval (12th-15th century) population from Nin, southern Croatia

M. Novak[a],*, O. Martinčić[b], D. Strinović[c], M. Šlaus[a,c]

[a]Department of Archaeology, Croatian Academy of Sciences and Arts, Ante Kovačića 5, 10 000 Zagreb, Croatia.
[b]The Miroslav Krleža Institute of Lexicography, Frankopanska 26, 10 000 Zagreb, Croatia.
[c]Department of Forensic Medicine and Criminalistics, School of Medicine, University of Zagreb, Šalata 11, 10 000 Zagreb, Croatia

Abbreviated title: Bioarchaeology of the late medieval Nin

Corresponding author: Dr. Mario Novak, tel.: +385-1-4698238, fax: +385-1-4856211, e-mail: mnovak@hazu.hr

Abstract

A comprehensive bioarchaeological study of the late medieval (12^{th}-15^{th} century) skeletal sample from Nin was carried out in order to test the historically documented hypothesis that during the late medieval period Nin sustained a period of rapid development that resulted in its becoming one of the major urban centers on the eastern Adriatic coast. The analysed pathological changes (alveolar bone disease, dental caries, dental enamel hypoplasia, *cribra orbitalia*, periostitis, tuberculosis, Schmorl's nodes, vertebral osteoarthritis, and bone fractures) indicate a relatively good quality of life for the majority of the population from this late medieval site. A low prevalence of dental pathologies suggests an adequate diet while a low frequency of long bone trauma testifies to a relatively peaceful life for the inhabitants of medieval Nin. Increased urban development during this period resulted in a worsening of sanitary conditions most likely caused by overcrowding, which is reflected in the presence of tuberculosis and the relatively high frequencies of dental enamel hypoplasia and *cribra orbitalia*. An additional health concern for the late medieval inhabitants of Nin may have been the presence of malaria, as recorded in numerous historical sources. Comparison with other Croatian medieval skeletal samples suggests that the inhabitants of late medieval Nin experienced a somewhat better living conditions than their contemporaries from other parts of Croatia.

Introduction

Because osteological and dental human remains preserve a significant amount of biologically relevant information, systematic bioarchaeological studies are of crucial importance for both anthropological and archaeological sciences as they supply answers to questions concerning the effects that the interactive actions of various cultural and biological factors had on the health of different populations in the past. Osteological data provide information on age-at-death, sex, diseases, trauma, and possible causes of death. In some cases, depending on the state of preservation of the recovered remains, osteological attributes can provide important information on the lifestyle and potential occupation of an individual, his/her daily activities, and other socio-biological characteristics.

The late medieval period (12^{th}-16^{th} century CE) in Dalmatia was an extremely turbulent period characterized by significant changes in demography, economy and social structure. It was marked by a significant weakening of the royal Arpad dynasty that ultimately resulted in feudal anarchy. This was accompanied by constant fighting against the Republic of Venice for control over the rich Dalmatian towns, and in later periods by increasingly desperate fighting against Ottoman conquest and rule. Because written sources describing the everyday life of the majority of individuals that inhabited Dalmatia during this period are either rare, or non-existent, bioarchaeological data on mortality patterns, the occurrence and distribution of infectious diseases, and the true risk of trauma and violent death provide the best insight into the lives of these peoples.

To this date, several papers dealing with bioarchaeological studies of late medieval populations (12^{th}-16^{th} centuries) from Dalmatia have been published (Mikić, 1983; Novak, 2011; Novak and Šlaus, 2007, 2012; Rajić Šikanjić and Vlak, 2010a, 2010b; Šlaus, 1996; Šlaus et al., 2012). In conjunction with the results of concomitant historical and archaeological studies these papers have deepened our knowledge of the health status of Dalmatian late medieval populations, in particular populations that inhabited small rural communities, and brought a new understanding of the occurrences of various infectious diseases as well as episodes of deliberate violence. So far, however, little information is available for the quality of life in late medieval urban settings from Dalmatia.

According to available historic sources, the late medieval period was a time of prosperity that was most pronounced in the larger urban centers that developed on the Adriatic coast. Regarding Nin, written sources from the beginning of the 12^{th} century state that it was an independent urban commune with its own statutory privileges. The city became the seat of a bishop, and in 1205 it achieved the status of a royal free city. Its importance is attested by the fact that in 1371 the king Louis I of Anjou summoned a Council of the nobility and citizenry of Dalmatia and Croatia to Nin which he labeled as "our main and royal city of Dalmatia" (Novak, 2001). Nin retained its independence until the beginning of the 15th century when it was incorporated into the Adriatic holdings of the Venetian Republic. From the beginning of the 16th century Nin experienced a period of profound decay caused by continuous Turkish intrusions into Dalmatia. The town was captured by the Turks, and subsequently liberated, on several occasions (in 1537 and 1570), and during these fights it was heavily damaged (particularly in 1646) (e.g. Hrabak, 1986; Traljić, 1969).

As numerous historical documents testify to the rapid development of Nin during the late medieval period the purpose of this analysis is to attempt to verify this hypothesis through a comprehensive bioarchaeological analysis of the late medieval (12th-15th century) skeletal series recovered from the late medieval Nin cemetery. An analysis of the frequencies and distribution of dental and skeletal indicators of stress is carried out in subadults, males and females in order to determine potential greater exposure to stress in specific subgroups of the population, as well as to establish a potential division of labor between males and females. In order to obtain a better insight into the quality of life of the Nin medieval population and to create a broader picture of the health status of medieval Croatian populations, the frequencies of various alveo-dental and skeletal health indicators (caries, alveolar bone disease, *cribra orbitalia*, dental enamel hypoplasia, periostitis, Schmorl's nodes, vertebral osteoarthritis, long bone fractures) recorded in the Nin sample were compared with several other late medieval skeletal series from Croatia (Dugopolje, Koprivno, Rijeka, Zagreb, and Suhopolje). These samples were chosen because of the following reasons: 1) all of them are large enough and well preserved in order to make valid assumptions; 2) they are chronologically and geographically closest to the Nin skeletal sample (late medieval series from the territory of contemporary Croatia); 3) all studies of compared samples were conducted using the same methodology. Although some of the studied series differ in size, all of them are characterized by similar sex and age distribution, and as such are suitable for comparison. This analysis, together with other studies of medieval period skeletal samples from Dalmatia, will enable the creation of a broader bioarchaeological database for the eastern Adriatic coast and its hinterland which will ultimately provide better insight into the quality of life and the living conditions of the medieval populations that inhabited Croatia.

Material and methods

Geographic and archaeological context

The town of Nin is situated on the eastern Adriatic coast, about 15 km north-west of the city of Zadar (Fig. 1). The town is located in a lagoon, in the middle of a shallow bay that opens to the neighboring Dalmatian islands of Vir and Pag. This shallow peninsula, where the Roman town of *Aenona* developed in the 1st century BCE, is oval-shaped, and was connected to the adjacent mainland by a southern isthmus and a bridge on its east side. In 1346 the peninsula was converted into an island. In the hinterland of Nin lies the Ravni Kotari region, rich in woods and arable land, while over the sea-channel to the north stretches the massive Velebit mountain range. This favorable position, and the surrounding fertile lands, enabled Nin to become an urban, cultural and political centre very early during its history (Novak and Maštrović, 1969).

Systematic excavations conducted between 1995 and 2001 by the Archaeological Museum in Zadar and the Museum of Nin Antiquities, in and around the church of St. Anselm in Nin, revealed a complex cemetery with 250 graves that covered a time span from the late antiquity to the early modern period (Kolega, 2001a, 2001b, 2002). Graves dated to the late medieval period (12th-15th century CE) can be divided into three forms: burials in stone tombs covered with thick stone slabs, burials in earthen graves with a simple grave architecture of irregular stones, and burials in crypts. The most characteristic finds in the late medieval graves were earrings (plain circlets, three-jointed circlets, and three-beaded earrings), rings, buttons, and coins (Hungarian and Venetian) (Kolega, 2001a, 2001b, 2002).

The skeletal sample from Nin analyzed in this study consists of 141 skeletons excavated from graves located in the southern part of the St. Anselm church complex, all of which have been reliably dated (through a combination of radiocarbon dating, typological analyses of recovered artifacts, and vertical and horizontal stratigraphy) to the late medieval period (12th-15th century CE). The degree of preservation of the osteological material varies from very poor to very good, with only a few excellently preserved skeletons.

Methods used in the analysis

The anthropological analysis was carried out in the laboratory of the Department of Archaeology of the Croatian Academy of Sciences and Arts in Zagreb. Sex and age-at-death of the recovered individuals were determined using methods described in Buikstra and Ubelaker (1994). No attempt was made to determine the sex of subadults (individuals under

15 years of age). The age of the adults was determined within a five-year range (e.g. 21-25), while the age of subadults was determined within a range of one year.

All skeletons were analyzed for the possible presence of the following pathologic changes: alveolar bone disease, dental caries, dental enamel hypoplasia, *cribra orbitalia*, non-specific periostitis, tuberculosis, Schmorl's nodes, vertebral osteoarthritis, and bone fractures. All pathologies were recorded according to criteria described by Ortner (2003). Most of the pathological changes were calculated by the element (tooth/alveolus/vertebra/long bone), and not by the individual/skeleton due to poor and/or partial preservation of some skeletons.

For the purposes of this analysis, alveolar bone disease was defined as the presence of periodontal or periapical abscesses, or antemortem tooth loss. The presence of caries was diagnosed macroscopically, under strong illumination, with the help of a dental probe. Caries size was classified into four categories according to Metress and Conway (1975): 1) pit or slight fissural start of lesion, 2) lesion covering less than 50% of the tooth's surface, 3) lesion covering over 50% of the tooth's surface, and 4) lesion that has completely destroyed the crown with only the root remaining. The presence of dental enamel hypoplasia was analyzed on the permanent maxillary central incisors and on the permanent maxillary and mandibular canines for the following reasons: 1) central incisors and canines are more susceptible to hypoplastic defects than other teeth (Goodman and Rose, 1990); 2) canines develop and grow for a relatively long time - from the fourth month to the sixth year of life; 3) incisors and canines have the lowest amount of mineralized dental deposits which sometimes may cover the crown of the teeth and prevent determination of the presence of hypoplasia. All skulls with preserved both orbital roofs were macroscopically examined under powerful illumination for the possible presence of *cribra orbitalia*. All observed lesions were classified based on intensity (mild, moderate or severe) and condition (active or healed) at time of death according to criteria proposed by Mensforth et al. (1978), and Mittler and Van Gerven (1994). Non-specific periostitis was diagnosed when two or more skeletal elements exhibited active or healed periostitis - criteria for inclusion in the sample were the presence of at least 50% of all cranial bones and long bones. Spinal tuberculosis was diagnosed based on the presence of: lower thoracic vertebral collapse with kyphosis and fusion coupled with an absence of new bone formation, and normality of the laminae and posterior spinous processes (Aufderheide and Rodriguez-Martin, 1998; Resnick and Niwayama, 1981). The presence of trauma was established by macroscopic analysis that included certification of bilateral asymmetry, angular deformities, the presence of bone calluses and healed depressions, blunt force trauma, cutting and projectile injuries to the skull; only long bones preserved to the extent of at least two thirds of their diaphyses and with all major articular surfaces preserved were analyzed (humerii, radii, ulnae, femora, tibiae and fibulae). Inclusion of cranial elements was dependent on the presence of at least 3/4 of the affected bone.

Some of the described diseases (e.g. dento-alveolar lesions) are age-dependent, i.e. their frequency increases with advanced age. Therefore, when tabulating the data, age was controlled by dividing the sample into two broad categories: young adults (individuals aged between 16 and 35 years) and old adults (individuals older than 36 years). Differences in the frequencies of the analyzed pathological changes between subadults and adults, between two adult age subgroups, and between males and females were evaluated with the Chi-squared test using Yates correction when appropriate. The statistical computer package SPSS 14.0 for Windows was used for all statistical calculations and tests.

Results

Demography

The age and sex distribution of the Nin skeletal sample is presented in Table 1. The sample consists of 141 individuals: 34 subadults (24.1%), 44 females (31.2%), and 63 males (44.7%). The highest mortality in the analyzed series occurs between the ages of 41 and 45 when almost one fifth (19.9%) of all individuals died.

Dento-alveolar lesions

The overall frequency of alveolar bone disease in Nin is 11.0% (188/1710) (Tab. 2). In subadults it was registered in only two cases (2/332 or 0.6%), while in adults it occurs in 13.5% (186/1378) of the observed alveoli. Both sexes from Nin exhibit similar prevalence of this pathology - males 14.0%, and females 12.9%. A considerable increase in alveolar bone disease among older individuals in both sexes is clearly visible - these differences are statistically significant (females $\chi^2=14.182$, $P<0.001$; males $\chi^2=9.43$, $P=0.002$).

Caries is present in 7.9% (63/802) of the analyzed teeth (Tab. 3). Carious lesions were recorded in only one subadult tooth (1/159 or 0.6%), while in adults the lesions occur in 9.6% (62/643) of the analyzed teeth. When the sexes are compared, males exhibit higher frequencies (11.0% vs. 7.6%), without, however, achieving statistical significance. Caries frequency in males is higher in the older age group, but without statistical significance; in females frequencies of caries in both age groups are almost identical. Regarding the caries size, among adults the most frequent are carious lesions graded 1 (22/62 or 35.5%), followed by carious lesions graded 2 (20/62 or 32.3%), then 3 (12/62 or 19.3%) and 4 (8/62 or 12.9%).

Subadult stress

The total frequency of dental enamel hypoplasia in the Nin sample is 44.2% (34/77). Dental enamel hypoplasia was most often recorded on the mandibular canines (52.6% or 20/38), followed by the maxillary canines (40% or 12/30) and maxillary central incisors (22.2% or 2/9). Analysis by sex shows that males exhibit a somewhat higher frequency of hypoplastic defects when compared to females (51.2% vs. 43.5%), but, again, without achieving statistical significance. Two hypoplastic defects are present in only three analyzed teeth, while in all other studied teeth only one hypoplastic defect was recorded.

Cribra orbitalia were registered in 25.5% (14/55) of the analyzed frontal bones (Tab. 4). In subadults they were present in 43.8% (7/16) of analyzed frontal bones, with only one case in the active form at the time of death. Among adults *cribra orbitalia* occur in almost one fifth of cases (17.9% or 7/39) with higher frequency in females compared to males (26.3% vs. 10%), again, without statistical significance. Analysis of intensity of *cribra orbitalia* shows that *cribra orbitalia* in a mild form occur in 71.4% (10/14) of cases, and in moderate form in 28.6% (4/14) of cases.

Specific and non-specific infectious diseases

Periostitis, a non-specific indicator of infectious diseases occurs in 11 of 78 well preserved skeletons (14.1%). One fifth of the well preserved subadult skeletons (20% or 4/20) exhibit periosteal changes, while in adults the frequency of this pathology is 12.1% (7/58). Comparison between the sexes shows that males exhibit three times higher frequencies than females (15.8% or 6/38 vs. 5% or 1/20), without achieving statistical significance. Of the eleven cases of periostitis recorded in the Nin sample seven represent mild, healed forms of periostitis, localized in the area of the lower extremities, primarily on the tibiae and fibulae, while four cases were active at the time of death (one subadult, one female and two males).

A female skeleton buried in grave 17, aged between 31 and 35 years, exhibits pathological changes on the 7th, 8th and 9th thoracic vertebrae that are consistent with tuberculosis (Fig. 2). The process is well healed, and the deformity is preserved by the skeletal ankylosis of the affected vertebrae. The vertebral arches, including the joints and spinous processes, are intact with secondary bony ankylosis between them. The complete destruction of the vertebral bodies of these vertebrae resulted in a sharp-angled kyphosis. No lesions characteristic of tuberculosis were observed on the ribs.

Vertebral lesions (osteoarthritis and Schmorl's nodes)

The total frequency of Schmorl's nodes in the analysed series from Nin is 20% (57/285) (Tab. 5), with higher frequencies recorded in males (23.9% vs. 15.4%), without statistical significance. In both sexes Schmorl's nodes are more prevalent in the thoracic than the lumbar vertebrae. In both males and females frequencies of Schmorl's nodes are higher in the older age groups, without achieving statistical significance.

The frequency of degenerative vertebral osteoarthritis is presented in Table 6 - the overall frequency of this pathology is 18.5% (72/390). Vertebral osteoarthritis is present in 23.4% of male and 12.5% of female vertebrae - this difference is significant (χ^2=6.87, P=0.009). Again, in both males and females frequencies of vertebral osteoarthritis are higher in the older age groups, and in males this difference is statistically significant (χ^2=5.006, P=0.02). In both sexes vertebral osteoarthritis most often occurs in the lumbar vertebrae, followed by the thoracic and cervical vertebrae.

Bone fractures

All of the bone fractures in the Nin skeletal sample were recorded in adults. Long bone injuries are relatively rare - they are present in 7/731 of preserved long bones (1.0%) (Tab. 7). Males exhibit much higher fracture frequencies than females (1.6% or 7/428 vs. 0.0% or 0/303), and this difference is marginally non-significant (χ^2=3.428, P=0.06). The affected skeletal elements include the radius (3/121 or 2.5%), tibia (2/117 or 1.7%), fibula (1/91 or 1.1%), and ulna (1/117 or 0.8%).

Five cranial injuries were observed in two males and three females - all of the recorded cranial traumae were antemortem, shallow, well-healed depressed fractures on the frontal and right parietal bones.

Comparison with other Croatian medieval skeletal samples

The bioarchaeological characteristics of the Nin sample were compared with other contemporary Croatian skeletal samples in order to determine possible differences in stress levels between these communities (Tab. 8). In comparison to Dugopolje the Nin series displays significantly lower frequencies of periostitis (χ^2=10.905, P<0.001); compared to the

Koprivno sample the Nin series exhibits significantly higher frequencies of vertebral osteoarthritis (χ^2=4.631, P=0.03); in comparison to Rijeka the Nin sample exhibits significantly lower frequencies of alveolar bone disease (χ^2=83.26, P<0.001), caries (χ^2=7.21, P=0.007), periostitis (χ^2=23.688, P<0.001) and vertebral osteoarthritis (χ^2=5.966, P=0.01). When data from the Nin series are compared to those from the Zagreb sample it is apparent that the Nin series displays significantly lower frequencies of alveolar bone disease (χ^2=4.675, P=0.03), caries (χ^2=6.492, P=0.01) and periostitis (χ^2=4.517, P=0.03), while at the same time exhibiting significantly higher frequencies of vertebral osteoarthritis (χ^2=8.653, P=0.003). Compared to the Suhopolje sample, Nin exhibits significantly lower frequencies of periostitis (χ^2=5.706, P=0.02), long bone fractures (χ^2=5.106, P=0.02), and significantly higher frequencies of vertebral osteoarthritis (χ^2=13.779, P<0.001).

Discussion

The Nin skeletal series is characterised by an evident under-representation of subadults, especially in the youngest age category - subadults comprise less than one quarter (24.1%) of the total analyzed sample. In most of Croatian late medieval/early modern age skeletal samples these values range between 15% and 25% (e.g. Novak, 2011; Novak and Bedić, 2011; Šlaus, 2002; Šlaus et al., 2007) while in some exceptional cases the percentage of subadult skeletons can rise to as high as 60% (e.g. Novak et al., 2007). Relevant to the under-representation of subadults in the youngest age group, a review of the available literature suggests that this is a widespread phenomenon (e.g. Acsádi and Nemeskéri, 1970; Alesan et al., 1999; Guy et al., 1997; Šlaus, 2006). Guy et al. (1997) noted an under-representation of infants aged between birth and l year in archaeological samples from Hungary (10th-12th centuries CE) and argue that this cannot be explained solely by taphonomic factors, but is most probably the result of a combination of factors, including the type of burial and associated burial practices, and archaeological recovery strategies. Acsádi and Nemeskéri (1970) recorded the under-representation of infants in Hungarian medieval skeletal samples, and argued that as these series were manually recovered that the under-representation of individuals from the youngest age group could have been be the result of poor recovery techniques applied to fragile perinatal infant bones rather than various taphonomic factors. According to the archaeologists that excavated the St. Anselm site, the two most important factors contributing to the under-representation of subadults in Nin are the frequent reuse of the burial site throughout history, and different funeral customs for neonatal deaths and shallower graves of infants aged 0-l years.

The frequencies of oral pathologies, especially caries, in medieval Nin are relatively low and are more similar to frequencies recorded in Croatian antiquity samples than in those from the medieval period. The results of several studies (Novak et al., 2010; Šlaus, 2006, 2008; Šlaus et al., 2011) strongly indicate a deterioration of oral health, i.e. a significant increase of the frequencies of alveo-dental pathologies in the Middle Ages when compared to the antiquity in Croatia, which is explained by a significantly higher dependence on carbohydrates in the medieval diet and more protein in the late antiquity diet (Šlaus et al., 2011). The recorded low prevalence of caries in Nin may, tentatively, be associated with a diet based on fish and other seafood, accessible to the local population. This type of diet, which is relatively rich in proteins, is less favorable to the development of caries, particularly in comparison to diets dependent on cereals rich in carbohydrates that stimulate bacterial growth and the formation of dental plaque. In addition, it is recognized that some species of fish (e.g. anchovies and sardines) are extremely rich in fluoride which protects teeth from caries and bleeding (Konig, 2000; Van Loveren, 2000). About the importance of fishery in the medieval Nin testify archaeological evidence such as the presence of the fish cleaning knives in graves in the early medieval period graveyard at the Nin-Ždrijac site (Belošević, 2007). Besides, “The Statute of the League of the Nin District”, dated to the 15th century (Brajković, 1969), provides numerous detailed regulations and penalties related to fishery, thus witnessing of the importance of fish in the everyday life of the late medieval Nin. Males from Nin exhibit a slightly higher prevalence of caries than females, which is most probably the result of a longer average life span of males (4.5 years). Simply put, males had more time to develop carious lesions and more time for it to progress from a small lesion to a severe problem (Šlaus et al., 1997). Besides, somewhat higher prevalence of caries in males could be a result of differences in behavioral activities such as diet, cultural practices and oral hygiene. Namely, Šlaus et al. (1997) suggested that the higher frequency of caries in younger males in Nova Rača (continental Croatia) is probably caused by their importance in obtaining food through skill-intensive agricultural labor, i.e. young males were selectively buffered from the effects of malnutrition and had more access to limited food resources than young females. The question is, whether and in what extent, this assumption may be applied to the Nin skeletal series.

The low frequencies of alveolar bone diseases recorded in the Nin sample are most probably a result of the low frequencies of caries, as many authors suggest that alveolar bone disease in archaeological series is strongly correlated to carious lesions, along with other pathologies such as periapical osteitis and the accumulation of calculus (e.g. Bonfiglioli et al., 2003; Lukacs, 1989). Additionally, Hillson (1996) reported that gingival inflammation, which results from bacterial plaque, leads to bone resorption and, eventually, tooth loss, i.e. he suggested that insufficient oral hygiene that removes dental plaque may be the basis of future dental loss. However, at the moment it is not possible to assess level of oral hygiene of the late medieval inhabitants of Nin, so this assumption in the case of Nin sample cannot be verified.

Hypoplastic defects can be caused by factors that affect child's growth: inherited and infectious disease, changes in dietary habits, malnutrition, intoxication and others (Pindborg, 1970). The prevalence of dental enamel hypoplasia recorded in the Nin sample closely corresponds to frequencies observed in other late medieval Croatian populations (see Tab. 8), suggesting that a large part of the analyzed sample had, at one time, experienced significant metabolic stress during childhood. Such values are characteristic of communities with sedentary lifestyle and diet primarily based on agriculture (Lanphear, 1990). Specifically, several studies (e.g. Goodman et al., 1980; Wood, 1996) showed that a sudden increase in the frequency of dental enamel hypoplasia occurred during the transition from a hunter-gatherer economy to an economy based on agriculture. It is believed that a sedentary lifestyle, dietary changes, and rapid population growth led to a significant increase in the amount of stress that is reflected in an increasing incidence of hypoplastic defects (Cohen and Armelagos, 1984). It is also possible that a considerable portion of metabolic stress in the late medieval Nin occurred during the weaning period. Namely, some authors (Goodman, 1988; Goodman et al., 1984; Lanphear, 1990) noted that most of the hypoplastic defects in sedentary populations are formed between the first and third year of life, i.e. during the transition from the diet based on the sterile breast milk to the diet rich with microorganisms. However, it is important to stress that serious doubts about this interpretation have been raised (Blakey et al., 1994), and that serious methodological problems related to the age assessment of the defects have been identified (Hodges and Wilkinson, 1990). Additionally, Ritzman et al. (2008) reported that histological studies provide significantly higher age estimates than the commonly used macroscopic methods and this difference is particularly marked in early forming hypoplastic defects. They also suggest that re-evaluation of the methods used to estimate ages of dental enamel hypoplasia formation may be justified.

As previously noted, it was proposed that one of the major causes for the occurrence of dental enamel hypoplasia is infectious diseases. Nevertheless, the low prevalence of indicators of non-specific infectious diseases (periostitis) in the Nin skeletal sample strongly suggests that, at least in the case of late medieval Nin, infectious diseases did not contribute significantly to the occurrence of dental enamel hypoplasia.

Analysis of *cribra orbitalia* frequencies in Nin shows that one quarter of the studied frontal bones exhibits this condition. Some authors (e.g. Angel, 1966; Soren et al., 1995) suggested that porotic hyperostosis and *cribra orbitalia* occur in correlation with hereditary hemolytic anemia (thalassemia and sickle cell anemia) which is usually prevalent in populations where malaria was endemic. In contrast to this, Walker et al. (2009) hypothesize that porotic hyperostosis and many cases of *cribra orbitalia* are a result of megaloblastic anemia acquired by nursing infants through the synergistic effects of depleted maternal vitamin B12 reserves, and unsanitary living conditions that are conducive to additional nutrient losses from gastrointestinal infections around the time of weaning, while *cribra orbitalia* can be attributed to a greater range of causes than porotic hyperostosis (e.g. subperiosteal bleeding associated with a co-deficiency of vitamin C and B12). However, today most authors recognize that *cribra orbitalia* are the result of iron deficiency anemia which is usually defined as a reduction of haemoglobin and haematocrit in the blood below normal levels (e.g. Huss-Ashmore et al., 1982; Mensforth et al., 1978; Mittler and Van Gerven, 1994; Stuart-Macadam, 1985, 1991). Hengen (1971) concluded that iron deficiency anemia is primarily the result of parasitism, while Stuart-Macadam (1992) suggested that this type of anemia is an adjustment of the organism to the disease, and its attempt to exhaust and starve pathogens such as bacteria and viruses that need iron in order to be able to reproduce in the body of the host. Additional factors related to the occurrence of iron deficiency anemia in past populations are poor and inadequate diet, gastrointestinal and parasitic infections (Larsen and Sering, 2000; Reinhard, 1992; Walker, 1986), lead poisoning (Stuart-Macadam, 1991), thalassemia (Ascenzi et al., 1991), changes in dietary habits (Roberts and Manchester, 1995), and diet rich in cereal phytates which lower the absorption of iron in the intestine (Stuart-McAdam, 1992). Additionally, Facchini et al. (1999) and Salvadei et al. (2001) associated the occurrence of active forms of *cribra orbitalia* among subadults with unhealthy ecological systems, i.e. marshy and wooded environment that could be a host for various parasitic infections.

Although there are, as briefly outlined in the preceding paragraph, numerous potential causes for the occurrence of *cribra orbitalia* in the late medieval Nin series, two most common causes appear to be most probable. One concerns unsanitary living conditions, at least for that part of Nin's population that inhabited the overcrowded fortified town which is a direct result of rapid urbanization and population growth in Nin during the late medieval period. This relationship has already been hypothesized by Novak and Šlaus (2010) who registered high frequencies of *cribra orbitalia* and periostitis in the nearby Roman period city of Zadar that was similarly overcrowded. The second possible cause for the occurrence of *cribra orbitalia* in medieval Nin might be the presence of malaria in the region during this period. Historic sources testify that the man-made disruption of the course of the Ričina river which is located on the north-eastern side of town caused silting, a rise in water levels, and consequently the formation of large marshes which in time surrounded the town (Ilakovac, 1995/1996). These marshes were ideal habitats for mosquitoes that transmitted malaria - the disease caused by "bad air" (*male aria*). The deterioration of health caused by the "bad air" disease was one of the reasons for the periodic migrations from Nin, particularly during the early modern period (Ilakovac, 1995/1996). Malaria was not, however, a major concern only in the Nin area because Dalmatia as a Mediterranean region has traditionally been afflicted by malaria. Some authors report (Dugački, 2005), that during the early 20th century some 180,000 people (about one third of the entire population of Dalmatia) suffered from the disease, with the death rate between 43% and 49%. In 1902 the prevalence of the disease in the Nin area was about 80% (Dugački, 2005). Malaria in the Nin area was finally put under control between 1906 and 1909 when the surrounding marshes were drained and a prophylactic medical treatment was applied to the general population (Dugački, 2005).

Studies of populations from different time periods (e.g. Keusch and Farthing, 1986; Mensforth et al., 1978; Scrimshaw et al., 1968) confirmed the synergistic relationship between the occurrence of infectious diseases and poor nutrition, i.e. acutely or chronically undernourished individuals are less resistant to infectious diseases compared to individuals with normal diets. The overall prevalence of periostitis in Nin is low when compared to frequencies reported in other Croatian archaeological series which usually range between 20% and 50%. Not surprisingly therefore, the prevalence of periostitis in children from Nin (20%) is considerably lower than in other skeletal samples from Croatia (e.g. in the early modern age samples such as Koprivno and Torčec these values rise up to 92% (Novak et al., 2007; Novak and Krznar, 2010). Data on the occurrence of periostitis in the Nin sample suggest that the medieval inhabitants of Nin were characterized by relatively strong immune systems enabling them to survive the occurrence of various infectious diseases which is most probably related to the favorable geographic location of Nin with easy access to abundant food resources.

The unequivocal presence of tuberculosis in late medieval Nin is interesting. Tuberculosis is an infectious disease caused by *Mycobacterium tuberculosis* that is most often transmitted through the respiratory system. The primary infection usually starts in the lungs, after which it disseminates by the blood stream to other parts of the body - kidneys, brain and bones. The spine is the most common (in approximately 40% of cases) affected bone element (Aufderheide and Rodriguez-Martin, 1998). The skeleton of an adult female from burial 17 from Nin exhibits lesions characteristic of vertebral tuberculosis: T7, T8 and T9 are collapsed and fused resulting in a sharply angular kyphosis (gibbus); this block is furthermore fused with one superior (T6) and three inferior vertebrae (T10-T12) giving a total of seven fused vertebrae. In pre-antibiotic times sharp angular kyphosis was present in nearly 60% of cases involving spinal tuberculosis (Reinhart, 1932). In the case from Nin differential diagnosis excluded osteomyelitis, vertebral compression fracture, and septic arthritis as possible factors for the noted changes. Osteomyelitis of the spine usually manifests as a destructive lesion of just one vertebra and does not end with ankylosis and kyphosis (Aufderheide and Rodriguez-Martin, 1998). Usually only one vertebra is involved in vertebral compression fractures with angular deformity, and the vertebral body is generally destroyed to a lesser degree (Ortner, 2003). Although septic arthritis often terminates in bony ankylosis and is very similar to tuberculosis arthritis, bone destruction is not that severe as in tuberculosis (Aufderheide and Rodriguez-Martin, 1998). In addition to Nin, only one case of skeletal tuberculosis dated to the late Middle Ages from the territory of the present-day Croatia was registered - an adult female from the town of Rijeka (Šlaus et al., in press). Both cases so far discovered in Croatian skeletal series have, thus, been registered in urban settings characterized by high population density. According to some authors (e.g. Aufderheide and Rodriguez-Martin, 1998; Lindemann, 1999) the most important factors for the emergence of numerous outbreaks of tuberculosis during the late medieval period in Europe were rapid urbanization and population growth during the 15th and 16th centuries, as well as the development of trade that helped to accelerate the spread of the disease. High population density and limited available housing provided the ideal conditions for aerial transmission of the tubercle bacillus causing lung infection (Aufderheide and Rodriguez-Martin, 1998).

Schmorl's nodes in the Nin medieval sample are much more prevalent in males than in females. A recent comprehensive study of vertebral pathologies conducted on two early modern age skeletal samples from Croatia (Novak and Šlaus, 2011) demonstrated a significantly higher prevalence of Schmorl's nodes in males, leading the authors to suggest that the observed sexual dichotomy may be the result of a sexual division of labor where males were engaged in more demanding physical activities, an assumption that was also supported by historical and ethnographic data. An additional conclusion from this study was that Schmorl's nodes were not correlated with increased age (Novak and Šlaus, 2011). Values observed in this analysis are similar to the results recorded by other authors (Stirland and Waldron, 1997; Šlaus, 2000; Üstündağ, 2008) suggesting that Schmorl's nodes can be used as a reliable indicator of activity related stress and different lifestyles in archaeological samples. If the hypothesis suggested by Novak and Šlaus (2011) is applied to the Nin skeletal sample a higher prevalence of Schmorl's nodes in the Nin males was probably a consequence of the different lifestyles between the sexes, i.e. a sexual division of labor where males performed more demanding physical tasks.

The frequency of vertebral osteoarthritis in Nin is higher in comparison to other late medieval Croatian skeletal samples. The main factors influencing the presence and severity of degenerative osteoarthritis in past and modern populations are age, followed by repetitive mechanical loading and movement, and genetic factors (Weiss and Jurmain, 2007). The previously mentioned study conducted by Novak and Šlaus (2011) showed that, unlike Schmorl's nodes, vertebral osteoarthritis is strongly correlated with increased age. Therefore, the differences between Nin and other medieval Croatian communities, as well as the significantly higher frequency of vertebral osteoarthritis in Nin males, could be explained by the relatively long life span of Nin's inhabitants, and the somewhat longer average life span of Nin males in comparison to females (4.5 years). Of course, this hypothesis cannot be confirmed with certainty, as vertebral osteoarthritis can be caused by a wide variety of etiologies. Further research of archaeologically derived skeletal samples is necessary in order to clarify this issue.

The frequency, morphology and location of the recorded long bone fractures in the Nin series strongly suggest a low level of interpersonal violence in this community during the late medieval period. Additional support for this assumption lies in the low frequency of defensive fractures. Ulnar 'parry' fractures have, for instance, frequently been used as an indicator of deliberate violence in a community (for more details see Judd and Roberts, 1999; Smith, 1996). In the Nin series only one ulnar fracture has been recorded. Long bone fractures recorded in the series are typical of those usually related to accidents (e.g. Djurić et al., 2006; Judd, 2004; Russell et al., 2001) such as fractures of radius, tibia, and fibula. The hypothesis of the relatively low risk of deliberate violence in late medieval Nin is further supported by the complete absence of perimortem trauma and trauma inflicted by sharp-edged weapons. Five cranial fractures might suggest sporadic occurrence of deliberate violence of a lesser intensity such as street fights and tavern brawls without fatal consequences, and with the occasional use of blunt weapons.

A comparison of the bioarchaeological characteristics of the Nin series with other Croatian medieval skeletal series shows that the Nin population was characterized by lower prevalences of alveo-dental pathologies, periostitis and long bone fractures than its contemporaries from other medieval communities inhabiting the territory of present-day Croatia. The observed data suggest relatively good living conditions that are possibly a result of the favorable geographical location of Nin that allowed access to adequate food sources (an abundance of seafood and proximity of the fertile fields in the Ravni Kotari region). In addition, its location on an island - surrounded by strong fortifications, allowed for a relatively peaceful life, without major episodes of interpersonal violence. On the negative side, the rapid urbanization of Nin during the late Middle Ages also led to deterioration of sanitary conditions, at least for part of its population, which may have been reflected in the relatively high frequencies of subadult stress indicators (dental enamel hypoplasia and *cribra orbitalia*) and the presence of infectious diseases such as tuberculosis. Additionally, one of the possible causes for the relatively high frequency of *cribra orbitalia* in the Nin series could be the historically documented presence of malaria in the region.

Conclusion

A comprehensive bioarchaeological analysis of human skeletal remains from Nin revealed new details about the living conditions of the medieval inhabitants of this ancient city. Historical data testify to the increased urban development of Nin between the 12th and 15th centuries. The low prevalence of dental pathologies in the skeletal series related to the late medieval component of the Nin cemetery suggest an adequate diet, relatively high in proteins, while the low frequency of bone trauma testifies to the relatively peaceful life of Nin's inhabitants. Increased urban development during this period also had a negative effect on the health of its inhabitants as seen in the relatively high frequencies of dental enamel hypoplasia and *cribra orbitalia* that may have been related to a worsening of sanitary conditions caused by overcrowding, that additionally may have facilitated the emergence of infectious diseases such as tuberculosis.

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Legends to the figures

Figure 1. Map of Croatia with the geographical location of Nin.

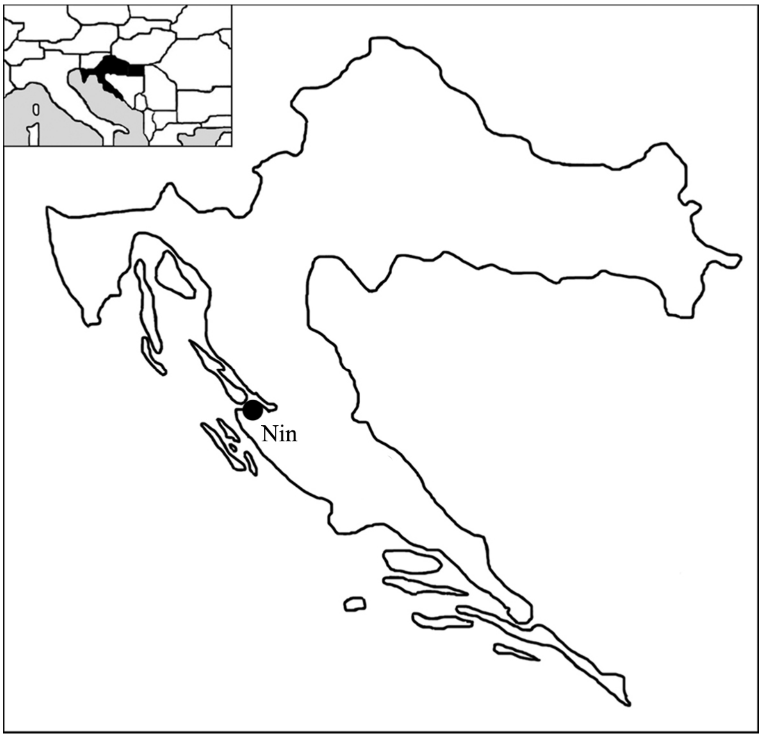

Figure 2. Sharp-angled kyphosis on the thoracic vertebrae as a result of tuberculosis (burial 17, adult female).

Table 1. Age and sex distribution for the Nin sample.

Age	Subadults	Females	Males
0-1	2		
2-5	14		
6-10	14		
11-15	4		
16-20		3	0
21-25		1	1
26-30		3	1
31-35		5	5
36-40		12	14
41-45		9	19
46-50		4	6
51-55		4	10
56-60		3	6
60+		1	1
Total	34	44	63
Mean age at death		x=39.8 sd=10.6	x=44.3 sd=8.4

Table 2. Frequency of alveolar bone disease in the Nin sample.

	Subadults		Females		Males	
	n/N	%	n/N	%	n/N	%
Young adults			0/89	0.0	4/105	3.8
Old adults			75/494	15.2	107/690	15.5
Total	2/332	0.6	75/583	12.9	111/795	14.0

N=total number of examined tooth sockets
n=number of tooth sockets with abscess or antemortem tooth loss

Table 3. Frequency of dental caries in the Nin sample.

	Subadults		Females		Males	
	n/N	%	n/N	%	n/N	%
Young adults			3/39	7.7	5/60	8.3
Old adults			16/212	7.5	38/332	11.4
Total	1/159	0.6	19/251	7.6	43/392	11.0

N=total number of examined teeth
n=number of teeth with carious lesions

Table 4. Frequency of *cribra orbitalia* in the Nin sample.

		Cribra orbitalia		Active lesions	
	N	n1	%	n2	% of n1
Subadults	16	7	43.8	1	14.3
Females	19	5	26.3	0	0.0
Males	20	2	10.0	0	0.0
Total	55	14	25.5	1	4.0

N=total number of examined frontal bones
n1=number of frontal bones with *cribra orbitalia*
n2=number of frontal bones on which the *cribra orbitalia* was active at time of death

Table 5. Frequency of Schmorl's nodes in the Nin sample.

	Thoracic		Lumbar		Total	
	n/N	%	n/N	%	n/N	%
Females						
Young adults	1/5	20.0	0/5	0.0	1/10	10.0
Old adults	15/88	17.0	4/32	12.5	19/120	15.8
Total	16/93	17.2	4/37	10.8	20/130	15.4
Males						
Young adults	1/10	10.0	0/5	0.0	1/15	6.7
Old adults	27/103	26.2	9/37	24.3	36/140	25.7
Total	28/113	24.8	9/42	21.4	37/155	23.9

N=total number of examined vertebrae
n=number of vertebrae with Schmorl's nodes

Table 6. Frequency of degenerative osteoarthritis on the vertebrae in the Nin sample.

	Cervical		Thoracic		Lumbar		Total	
	n/N	%	n/N	%	n/N	%	n/N	%
Females								
Young adults	0/3	0.0	0/5	0.0	0/5	0.0	0/13	0.0
Old adults	1/43	2.3	12/88	12.0	9/32	28.1	22/163	13.5
Total	1/46	2.2	12/93	12.0	9/37	24.3	22/176	12.5
Males								
Young adults	0/4	0.0	0/10	0.0	0/5	0.0	0/19	0.0
Old adults	3/55	5.5	34/103	33.0	13/37	35.1	50/195	25.6
Total	3/59	5.1	34/113	30.1	13/42	31.0	50/214	23.4

N=total number of examined vertebrae
n=number of vertebrae with osteoarthritis

Table 7. Frequency of long bone trauma in the Nin sample.

	N	n	%
Humerus	151	0	0.0
Radius	121	3	2.5
Ulna	117	1	0.8
Femur	134	0	0.0
Tibia	117	2	1.7
Fibula	91	1	1.1
Total	731	7	1.0

N=total number of long bones
n=total number of long bones with trauma

Table 8. Comparison of bioarchaeological characteristics in several Croatian medieval skeletal samples.

	Nin	Dugopolje	Koprivno	Rijeka	Zagreb	Suhopolje
Sample size/datation	141/ 12-15 c.	362/ 14-16 c.	21/ 13-14 c.	115/ 14-18 c.	169/ 14-16 c.	76/ 12-16 c.
Caries	[a]7.9	X	8.8	12.1	[a]11.6	8.4
Alveolar disease	[a]11.0	X	13.5	[a]24.6	[a]13.9	12.8
Enamel hypoplasia	44.2	49.7	47.4	54.8	39.1	41.9
Cribra orbitalia	25.5	33.7	35.0	25.9	32.3	24.0
Periostitis	[a]14.1	[a]34.3	19.0	[a]54.0	[a]26.2	[a]36.4
Schmorl's nodes*	20.0	X	15.6	22.9	26.1	12.2
Vertebral osteoarthritis*	[a]18.5	X	[a]12.3	[a]25.0	[a]12.2	[a]7.2
Long bone fractures*	1.0	1.5	1.9	2.1	1.5	[a]3.3

*only adult individuals were taken into consideration
[a]=significant differences between samples
X=data not available
Dugopolje (Novak and Šlaus, 2007, 2012), Koprivno (Novak, 2011), Rijeka (Šlaus et al., in press), Zagreb (Šlaus et al., 2007), Suhopolje (Novak and Bedić, 2011)