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Periostitis as an Indicator of the Impact of Subadult Stress: An Analysis of Late Antique Sites in Southern Pannonia

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Abstract

Subadult physiological stress and non-specific infectious conditions are key bioarchaeological indicators of health and mortality risk. This study examines the impact of periostitis (PO), along with multiple subadult stress indicators, on adult age at death in Late Antique Southern Pannonia. The sample comprises 400 adults (>15 years) from four archaeological sites (Osijek–Mursa, Vinkovci–Cibalae, Štrbinci–Certissa, and Tekić–Incerum). Previously analyzed for subadult stress, the dataset is reexamined here with a focus on periostitis. Cribra orbitalia (CO) and linear enamel hypoplasia (LEH) were recorded as markers of early-life physiological stress, and their interaction with periostitis was assessed. Age at death was estimated using standard osteological methods based on degenerative skeletal changes, and mean ages at death were compared by sex and combinations of pathological conditions. Periostitis was associated with a reduced mean age at death in both sexes, with a stronger effect in females. The lowest ages at death were observed in individuals exhibiting all three indicators (CO, LEH, PO), suggesting the cumulative effect of multiple stressors. Males showed greater inter-site variability, while the negative impact among females was more consistent. These findings indicate that periostitis, especially when combined with subadult stress markers, is associated with increased mortality risk and highlights sex-specific patterns in long-term survival.

Keywords: periostitis; stress; mortality

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1. Introduction

One of the main goals of bioarchaeology is to reconstruct the overall living conditions and health status of past human populations.

This study was designed to examine how environmental and living conditions influenced the occurrence of subadult stress and how these stress experiences were reflected in adult mortality patterns.

Specifically, the study evaluates periostitis as both an indicator of chronic inflammatory burden and a non-specific marker of physiological stress. It also investigates the relationship between periostitis—either alone or in combination with two commonly used indicators of subadult stress, cribra orbitalia and linear enamel hypoplasia—and mortality patterns among adult males and females.

The main aim is to demonstrate that individuals exhibiting one or more indicators of subadult stress generally had lower life expectancy than those who showed no evidence of such stress markers.

The research material consists of osteological remains collected during long-term archaeological investigations at Late Antique sites in Southern Pannonia, a region that geographically includes present-day northern, or continental, Croatia (Figure 1).

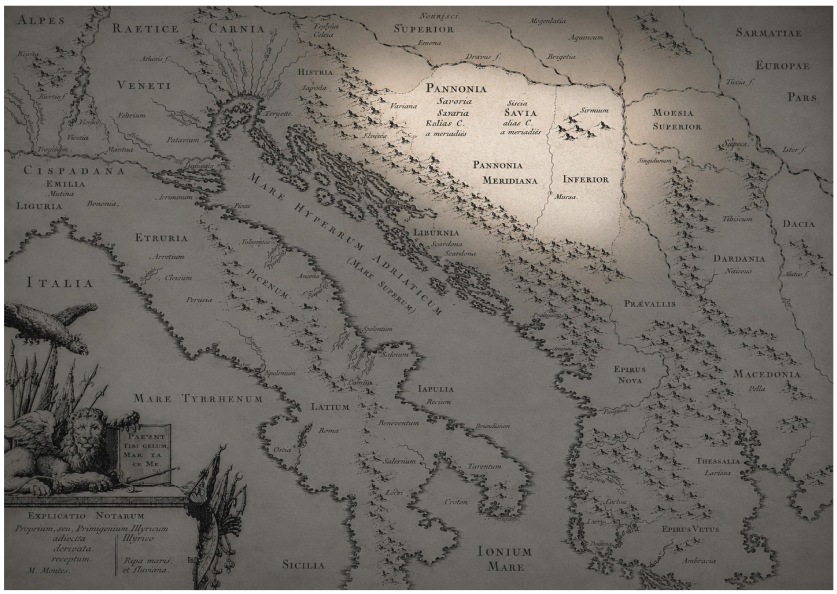


Figure 1. Southern Pannonia. Adapted and reproduced from reference [1] with the author's permission.

The Late Antique period, from AD 379 to 568, was a highly turbulent era for the Roman Empire [1]. During this time, the Western Roman Empire collapsed in AD 476, while the eastern part of the Empire grew stronger. Life in Southern Pannonia during the 4th century was turbulent and demanding due to frequent wars and incursions by barbarian groups into the area of present-day Slavonia [1].

Southern Pannonia was one of the most strategically important regions of the Roman Empire along its northeastern frontier (Figure 1). Geographically, it included the area between the Danube, Drava, Sava, and Una rivers, corresponding largely to present-day continental Croatia, Slavonia, and Syrmia, and underwent several administrative reorganizations during the Roman period [2,3]. Its position on the imperial frontier (limes) gave the region exceptional military, economic, and logistical significance. While some ancient authors described Pannonia as having a harsh climate and limited agricultural potential, other sources emphasized its fertile arable land, pastures, and extensive forests, underscoring its importance to the Roman economy [2,4]. Environmental features such as vast woodlands and marshlands strongly influenced daily life and provided natural defensive barriers for major urban centers, including Mursa and Cibalae [3,4].

During Late Antiquity, Southern Pannonia became a focal point for major political and military developments. As a frontier province, it was repeatedly exposed to incursions by various barbarian groups, including the Huns, Gepids, Ostrogoths, Lombards, and Visigoths, which profoundly affected the region's demographic, social, and economic landscape [2,3]. Numerous military campaigns and battles between Roman emperors, imperial contenders, and barbarian groups occurred within its territory, making Southern Pannonia a key defensive zone of the Western Roman Empire [1–5]. Historical sources describe repeated invasions across the Danube frontier and episodes of large-scale destruction that had lasting consequences for the province and its population [1–5].

At the same time, Southern Pannonia remained highly urbanized and economically integrated, containing important urban centers such as Mursa, Cibalae, Sirmium, and Certissa. Mursa and Cibalae, in particular, occupied strategic positions along major riverine and overland communication routes and served as important administrative, commercial,

and transportation hubs within the Roman provincial system [1–6]. The combination of developed urban infrastructure, frontier location, and frequent military conflicts makes Southern Pannonia an especially valuable region for investigating patterns of population dynamics, health, disease, and human adaptation during Late Antiquity.

Environmental and Living Conditions as Determinants of Health in Late Antique Southern Pannonia

Numerous studies on the health status of archaeological populations emphasize their growing importance in reconstructing past life and examining how human living conditions, environment, and lifestyle influence health [7–10].

The results of this study demonstrate that childhood exposure to adverse environmental and living conditions had long-term consequences. Individuals showing signs of subadult stress experienced significantly lower age at death than those without this pathology, suggesting that physiological stress during childhood continued to affect health and mortality in adulthood. These findings confirm the importance of environmental conditions and health stressors in shaping both individual life histories and overall population health in Late Antique Southern Pannonia. Consequently, these factors may influence the occurrence of indicators of subadult stress that manifest in human skeletal remains [11,12] and dental material [13–16].

One of the most significant changes in lifestyle—the transition to sedentary agricultural communities, a process already recognized in bioarchaeological literature—resulted in reduced dietary diversity, increased exposure to infectious diseases, and elevated physiological stress levels [9–12]. These factors are reflected in skeletal markers such as cribra orbitalia (CO) and linear enamel hypoplasia (LEH), both of which indicate adverse childhood conditions and episodes of physiological stress [10,12,14–16].

The health and survival of individuals in Late Antique Southern Pannonia were likely shaped by a complex interplay of environmental, biological, and socio-cultural factors.

The broader environmental context of Southern Pannonia during Late Antiquity was marked by political instability, military conflicts, and shifting socio-economic conditions. Frequent wars and barbarian incursions into the region of present-day Slavonia created challenging living conditions that likely affected population health and well-being [2,3].

Geographical and ecological conditions may also have influenced disease prevalence. The settlements examined in this study—Mursa, Cibalae, Certissa, and Incerum—were surrounded by extensive marshlands and dense forests [2,3]. These environments provided suitable habitats for bacteria, parasites, and mosquito populations capable of transmitting malaria [17–22]. As a result, environmental conditions may have contributed to higher rates of anemia and the development of cribra orbitalia among the inhabitants of Southern Pannonia [23]. Similar interpretations have been proposed for Roman-period populations in Italy [24] and other historical periods in Croatia [23,25–27].

Population density and settlement organization also likely influenced health outcomes. Sedentary communities concentrated large numbers of individuals in relatively confined spaces, which could lead to reduced food availability and poorer hygienic conditions. These circumstances increased susceptibility to infectious diseases and nutritional deficiencies, both recognized causes of physiological stress and enamel hypoplasia [15,26–33].

Evidence from previous bioarchaeological investigations in Southern Pannonia supports the interpretation that subadult stress was widespread. For example, findings from Tekić revealed high frequencies of stress indicators associated with elevated physiological stress and recurrent infectious diseases [34]. Furthermore, cribra orbitalia, linear enamel hypoplasia, and periostitis have consistently been interpreted as indicators of difficult living conditions, inadequate nutrition, and poor health status in Late Antique populations from

Slavonia [14,34,35]. These conditions may have increased susceptibility to both childhood stress [36] and chronic inflammatory conditions in adulthood. [21,37–40].

Living conditions and health status of Late Antique populations in Slavonia at the sites examined in this study have been extensively investigated by numerous scholars. Research by Croatian authors has focused on a range of diseases, as well as the effects of subadult stress in Osijek and at sites along the limes [41,42], in Štrbinci [43–45], Vinkovci [46], and Tekić [34].

An increasing number of studies have addressed subadult stress among adult individuals during different historical periods in Croatia, from the Late Iron Age to the Middle Ages [35,47–49], and research in other parts of Europe is also growing [50–54]. Research on subadult stress most commonly focuses on the two most frequent indicators—cribra orbitalia and linear enamel hypoplasia—while studies using periostitis as the primary reference point remain considerably fewer.

Periostitis is a pathological condition affecting the external, or periosteal, surface of bone. Non-specific periostitis represents an inflammatory process that occurs as a response of the periosteal surface to non-specific bacterial infections [55], but it may also result from specific trauma, infectious disease, or infection caused by staphylococci and streptococci [56] that spread hematogenously to the bone, as in cases of tuberculosis or syphilis [57,58]. Furthermore, non-specific periostitis may result from localized trauma, venous insufficiency, metabolic diseases such as scurvy or rickets, and numerous other factors [59]. Periostitis develops when infection or trauma stimulates osteoblastic cells in the inner layer of the periosteum; the periosteal portion of the bone responds by forming newly deposited, poorly organized bone that covers the original cortical bone in areas exposed to trauma [56]. Macroscopically, this appears as an irregular accumulation on the periosteal bone surface, with poorly defined margins and generally brown coloration [28].

Periostitis may be generalized, affecting an entire bone or multiple skeletal elements, or localized, restricted to a small and clearly defined part of the bone. Generalized periostitis is usually caused by non-specific or specific infectious diseases, while localized periostitis most often results from trauma or chronic suppurative ulcers [28].

Cribra orbitalia (CO) has proven to be a useful indicator for reconstructing living conditions in archaeological populations [23]. It is commonly considered a consequence of inadequate or insufficient nutrition [8,57,58], poor hygiene, chronic gastrointestinal diseases [59–66], and parasitic infections [23].

Linear enamel hypoplasia (LEH) is recognized as a macroscopic defect on the surface of dental enamel [29,30]. This indicator of subadult physiological disturbance develops as a result of acute, temporally limited stress events most commonly associated with conditions such as starvation, psychological and/or physical trauma [35], deficiencies of vitamins A, C, or D, anemia, and elevated body temperature [36–40].

Bioarchaeological research has demonstrated the value of skeletal health indicators in reconstructing the living conditions of past populations. The transition to sedentary agricultural lifeways has been associated with reduced dietary diversity, increased exposure to infectious diseases, and heightened physiological stress [9,10]. However, the relationship between subadult stress and adult mortality is complex and shaped by the interaction of biological, environmental, and sociocultural factors. Living conditions, nutritional status, disease exposure, hygiene standards, sex-based differences in caregiving practices, and the reproductive burden borne by women all contributed to variation in health and survival within past populations.

2. Materials and Methods

This research was approved by the Research Ethics Committee of the Faculty of Medicine at Josip Juraj Strossmayer University of Osijek at the committee meeting held on 16 July 2012, classification: 602-04/12-08/09 document number: 2158-61-07-12-28.

The sites from which the human skeletal remains originate are:

- Tekić/Treštanovačka Gradina–Incerum, 19 skeletons available

The village of Tekić is located approximately 12 km northeast of Požega. Immediately to the north is the archaeological site of Treštanovačka Gradina, inhabited during the Roman period between the 2nd and 4th centuries AD [34]. According to some interpretations, this site may correspond to Incerum, a settlement recorded in the Antonine Itinerary [34].

Treštanovačka Gradina has attracted scholarly attention since the 18th century, when it was first recognized as an archaeological site. Later excavations identified a Late Antique necropolis with 124 graves containing human skeletal remains. The cemetery was associated with the nearby Roman settlement that occupied the site during antiquity.

The skeletal assemblage examined in this study comes from archaeological campaigns conducted in 1972, 1975, 2004, and 2005. Nineteen individuals were available for anthropological analysis, with preservation ranging from very poor to excellent. Burial practices featured a west–east orientation of the graves, with the deceased placed with their heads toward the west. While single interments predominated, several graves contained the remains of two individuals.

- Osijek–Mursa–northeastern necropolis, 75 skeletons available

The Roman settlement of Mursa, located in present-day Osijek, was situated in the Donji Grad district on the right bank of the Drava River, near a former Celtic-Pannonian settlement inhabited by the Andizetes tribe. Its transformation into an urban center and subsequent expansion are associated with Emperor Hadrian, who granted the settlement the status of a colony in AD 133, after which it became known as Colonia Aelia Mursa [6]. Due to its strategic location at the intersection of major road networks connecting Emona, Sirmium, and Aquincum, as well as its proximity to the navigable Danube route, Mursa became one of the Roman Empire's key trade and transportation hubs.

Mursa continued to develop and urbanize until AD 378, when the Western Goths devastated this part of the Roman Empire, ending its growth as an urban center. Following the Hun incursions into the Syrmian region in AD 441—covering the area between the Drava, Sava, and Danube rivers—the city was further devastated and never regained its former prominence and status [6]. A total of 75 skeletons from the Osijek site, preserved in conditions ranging from good to excellent, were available for anthropological analysis.

- Vinkovci–Cibalae–northern, southern, eastern, and western necropolis, 186 skeletons available

The Roman settlement in the area of modern-day Vinkovci was located along the left bank of the Bosut River and developed on the foundations of an earlier prehistoric settlement in the area of the former Market. After the Roman conquest of Pannonia, Cibalae gradually became an important urban center. At the beginning of the 3rd century, during the reign of Emperor Caracalla, it was granted the status of a colony and became known as Colonia Aurelia Cibalae [1]. Historical sources mention Cibalae until the first half of the 6th century, indicating its long-standing significance as a major trade and transportation hub within the Roman Empire, largely due to its access to an important waterway.

A substantial and well-fortified military camp was located south of the settlement, while the associated necropolises were positioned along the roads leading out of the camp. Among these, the northern necropolis, situated on the route toward Mursa and Sotin

(Cornacum), has been the most thoroughly investigated. Burial practices were diverse, although elite brick-built tombs with flat or gabled roofs predominated. Archaeological excavations also revealed several stone sarcophagi, while individuals buried in simple earthen graves were generally interred in wooden coffins; in a limited number of cases, lead coffins were used as well [1].

The osteological sample from Vinkovci includes individuals recovered from all four necropolises of Cibalae. Most of the material originates from the northern necropolis, while the southern and eastern necropolises contributed four and three skeletons, respectively. An additional burial area yielded only a single skeleton, despite earlier reports of a considerable concentration of graves at that location [1]. In total, 186 skeletons were available for anthropological analysis, with preservation ranging from poor to excellent.

- Štrbinci–Certissa, 120 skeletons available

Štrbinci, located approximately 3 km southeast of present-day Đakovo, is a natural geomorphological unit consisting of two low elevations and a plateau [44]. The site has long been associated with the Roman settlement of Certissa, a locality documented in written sources from the 2nd to the 7th centuries AD. Although Certissa is well attested historically, its precise location remains uncertain.

Archaeological research conducted over several decades has yielded a rich assemblage of Roman-period finds, including artifacts made of metal, glass, bone, and ceramic, as well as building materials such as bricks, plaster, pottery kilns, mosaic tesserae, and fragments of frescoes. Excavations also uncovered elements of both civilian and military equipment, along with jewelry, fibulae, and coins [44].

The burial ground at Štrbinci was characterized exclusively by inhumation burials. Based on their construction, the graves can be categorized as brick-built tombs, simple earth-cut graves, and burials in wooden coffins, the latter identified by numerous nails and preserved wood remains. The anthropological sample from the site consisted of 120 skeletons, whose state of preservation ranged from good to excellent.

All data used in this study originate from the laboratory collection of the Anthropological Centre of the Croatian Academy of Sciences and Arts. The laboratory's analytical procedures are based on previously established methods that are simple, widely accepted, and readily comparable with data from other osteological collections. After cleaning and drying, skeletal remains are documented using standardized forms that include a schematic representation of the human skeleton in anatomical position. Detailed inventories are compiled for each bone, joint, and tooth, recording their presence or absence, as well as any observable degenerative, pathological, or traumatic changes. All completely preserved bones and crania are then subjected to osteometric measurement.

Sex determination was based on primary morphological differences visible in the pelvic structure [67–72], as well as other cranial and postcranial morphological differences [73], including discriminant functions that allowed determination of sex in adult individuals based on the dimensions of the femur [71] and tibia [72].

Age estimation in adult individuals depends on several factors, most of which are degenerative in nature [70]. Age at death was determined based on degenerative changes observed in the pubic symphysis [70,73–75], the degree of obliteration of cranial sutures [70,76], the auricular surface of the ilium [77], changes at the sternal ends of the ribs [70,78,79], and the presence of degenerative changes on the articular surfaces of long bones and vertebrae [70,80]. As a secondary method for age estimation, the degree of fusion of cranial and maxillary sutures was assessed [70], along with degenerative and osteoarthritic changes in the joints of long bones [70,77,79]. In the dentition, the degree of wear on the occlusal surfaces was examined [70], while in long bones, the amount of cortical bone and the density of trabecular bone were compared [70]. All of these changes

generally occur within relatively predictable periods and are most commonly analyzed in five-year intervals [70].

The study sample included only individuals aged 15 years and older who had at least one preserved orbital roof and at least one tooth suitable for the assessment of linear enamel hypoplasia (LEH).

For this study, periostitis was diagnosed only in skeletons in which at least 50% of all long bones (clavicles, humeri, radii, ulnae, femora, tibiae, and fibulae) and cranial bones (frontal, parietal, and occipital) were preserved. All observed cases of periostitis were included in the analysis, regardless of the origin of the trauma or underlying cause that may have triggered the periosteal reaction.

Cribra orbitalia was evaluated in all individuals with at least one preserved orbit. The presence or absence of the lesion was assessed macroscopically under strong illumination, and lesions were further classified as active or healed. Severity was recorded as mild, moderate, or severe following the criteria established by Mittler and Van Gerven [61].

Linear enamel hypoplasia was recorded on the maxillary incisors and on canines from both jaws. These teeth were selected because central incisors and canines are more susceptible to hypoplastic defects than other tooth classes [30]. Additionally, canines have a prolonged developmental period, extending from approximately the fourth month to the sixth year of life [30], making them particularly useful indicators of physiological stress during childhood. Incisors and canines also tend to accumulate less dental calculus than posterior teeth, reducing the likelihood that hypoplastic defects will be obscured by mineralized plaque. Only macroscopically visible linear defects were included in the analysis, and an individual was considered affected by LEH if at least one tooth displayed evidence of the condition.

Statistical Methods

In this work, nonparametric statistical analyses were used to determine the statistical significance of differences in the obtained results. The Kruskal–Wallis test was applied to demonstrate differences in the average age-at-death between males and females, and to demonstrate differences in the frequency of CO and LEH, the χ^2 test was used, with Yates' correction applied when necessary. Statistical significance was set at $p < 0.05$.

3. Results

3.1. Demographic Characteristics of the Entire Sample

Analysis of the total number of adult individuals (Table 1) showed that the complete sample consisted of 400 individuals, with 241 males and 159 females, representing 20.5% more males than females. This ratio deviates from the usual sex ratio observed at Croatian archaeological sites, where the proportion, whether in the continental region or along the coast, is generally approximately equal [27].

Table 1. Number and age-at-death of all adult individuals in the entire observed sample.

	No. (%)	Age-at-Death
Male	241 (60.3%)	37.38 (SD 10,754)
Female	159 (39.7%)	36.46 (SD 9.595)
Total	400	37.01 (SD 10,307)

The estimated age at death for the entire sample (Table 1)—males (37.38 years, SD = 10.75) and females (36.46 years, SD = 9.60)—corresponds with the expected average age at death observed in previously analyzed Late Antique samples in Croatia and

elsewhere. The difference in age at death between males and females is not statistically significant ($p = 0.199$, $\chi^2 = 1.648$). Although this study considers the complete sample, results at the level of individual sites also support this finding: as expected, the number of males at individual sites is either greater than or approximately equal to the number of females.

3.2. Mortality Distribution by Five-Year Intervals

The period between 30 and 45 years of age is considered the time of highest mortality among males at ancient archaeological sites, both in Antiquity in Croatia and in other regions, although the exact reasons for this pattern have not been fully determined. Mortality distribution across the entire sample (Table 2), examined in five-year intervals, shows the highest percentage of mortality within this age range, with the largest number of males—48 out of 191 (21.5%)—dying between 36 and 40 years of age.

Table 2. Distribution by sex and age-at-death in the entire observed sample.

Age	Male		Female		Total *		Cum.%
	No.	%	No.	%	No.	%	
16–20	18	7.5	6	3.8	24	6.0	6.0
21–25	21	8.7	14	8.7	35	8.8	14.8
26–30	24	10.0	26	16.4	50	12.5	27.3
31–35	37	15.4	30	18.9	67	16.7	44.0
36–40	48	19.8	28	17.6	76	19.0	63.0
41–45	39	16.2	28	17.6	67	16.8	79.8
46–50	25	10.4	17	10.7	42	10.4	90.3
51–55	18	7.5	6	3.8	24	6.0	96.3
56–60	8	3.3	1	0.6	9	2.3	98.5
60+	3	1.2	3	1.9	6	1.5	100.0
Sum	241	100.0	159	100.0	400 *	100.0	
Age-at-death-Dx	37.38 (SD 10,754)		36.46 (SD 9459)		37.01 (SD 10,307)		

* Total number of individuals examined in whole sample.

Among females (Table 2), this lower threshold shifts approximately ten years earlier, and the period of highest mortality coincides with the peak reproductive years, between 26 and 40 years of age. In five-year intervals, the largest number of females in the observed sample from Southern Pannonia died between 31 and 35 years of age, accounting for 30 out of 159 individuals.

3.3. Indicators of Subadult Stress

Males (Table 3), 192 males (82.4%) in the sample showed no signs of periostitis, with a mean age at death of 38.34 years. In contrast, 41 males (17.6%) with periostitis had a mean age at death of 33.00 years (±10.301). This indicates that males with periostitis lived, on average, approximately 5.3 years less than males without periosteal changes.

Table 3. Number and age at death for male and female within an observed part of the sample.

		No. (%) *	Age-at-Death
Male	With PO	41 (17.6%)	33,000(SD 8.80)
	Without PO	192 (82.4%)	38,339 (SD 10.89)
Total **		233	
Female	With PO	19 (12.1%)	30,632 (SD 6.28)
	Without PO	138 (87.9%)	37,348 (SD 10.40)
Total **		157	

* Total number and percentage of individuals observed for periostitis. ** Total number of individuals showed signs of periostitis.

A similar pattern was observed among females (Table 3), with an even more pronounced negative effect of periostitis on age at death. In the complete sample, 138 females (87.9%) showed no signs of periostitis, with a mean age at death of 37.348 years. In contrast, 19 females (12.1%) with periostitis had a mean age at death of 30.632 years (±9.581). This indicates that females with periostitis lived, on average, approximately 6.7 years less than females without periosteal changes.

Statistical analysis shows that the difference in age at death between individuals with periostitis and those without is statistically significant in both sexes ($p = 0.001$; $\chi^2 = 11.436$).

When the results of multiple manifestations of subadult stress (Table 4) are examined for the entire sample, the combination of two pathological conditions (CO and LEH) was recorded in 20 individuals (5.0% of the total sample), whose mean age at death was approximately 32.7 years. In the group presenting all three analyzed pathological manifestations (CO, LEH and PO), 14 individuals (3.5% of the total sample) were identified, with a mean age at death of 34.1 years.

Table 4. Number and age at death for male, female observed for multiple manifestations of subadult stress within observed part of sample.

	Male		Female		Total Site *	
PO and CO	1 (2.5%)	33,000 (SD -)	1 (4.5%)	48,000 (SD -)	2 (3.2%)	40.50 (SD 10.61)
PO and LEH	18 (45%)	37,722 (SD 7.37)	8 (36.4%)	34,875 (SD 7.65)	26 (41.9%)	36.85 (SD 7.42)
PO, CO, and LEH	10 (25%)	27,500 (SD 7.21)	4 (18.2%)	26,750 (SD 2.95)	14 (22.6%)	27.29 (SD 6.17)
CO and LEH	11 (27.5%)	33,000 (SD 10.03)	9 (40.9%)	32,444 (SD 7.50)	20 (32.3%)	32.75 (SD 8.76)
Total	40		22		62	

* number and percentage of individuals examined within observed part of sample.

Analysis of the presence of two or three indicators of subadult stress (CO, LEH, and PO) revealed significant differences in the distribution of pathological conditions between males and females in the observed Late Antique population of Southern Pannonia. In the entire sample, 40 males (10% of the total sample) and 22 females (5.5% of total sample) exhibited two or three of the analyzed pathological changes, indicating that males more frequently presented multiple simultaneous indicators of subadult stress compared with females.

When the sexes are analyzed separately (Table 5), healthy males without the analyzed pathological changes had a mean age at death of 38.23 years. Examining the cumulative effect of subadult stressors among males, the following results were obtained:

Table 5. Frequency and estimated age at death between healthy males and females and males and females exhibiting signs of one, two, or three diseases in the overall sample.

		No. (%)	Age-at-Death
Male	With one or more pathologies	152	37.01 (SD 13.27)
	Healthy (Without pathology)	87	38.23 (SD 10.56)
Female	With one or more pathologies	93	34.99 (SD 12.46)
	Healthy (Without any pathology)	63	38.71 (SD 38.71)

- The most common combination was LEH + PO, observed in 18 males (45%), with a mean age at death of 37.72 years.
- The second most frequent combination was CO + LEH, found in 11 males (27.5%), with a mean age at death of 33 years.
- In 10 males (25%), all three pathological changes were present, with a mean age at death of 27.5 years, the lowest value within this group.

Among females, the influence of subadult stress on age at death is more pronounced. Healthy females had a mean age at death of 38.71 years. For females with multiple manifestations of subadult stress, a pattern similar to that observed among males is evident:

- The most frequent combination was CO + LEH, found in 9 females (40.9%), with a mean age at death of 32.44 years.
- The lowest age at death was recorded among females exhibiting all three pathological manifestations, with an average of approximately 26.75 years, nearly 12 years less than healthy females in the sample.
- No female individuals exhibited both PO and CO simultaneously.

When all pathological conditions are considered cumulatively, regardless of whether an individual presents one, two, or three conditions, individuals affected by disease are expected to have a shorter lifespan, and this pattern was also observed in the analyzed sample. Among females, this difference is statistically significant ($\chi^2 = 4.938$; $p = 0.026$). Among males, the difference in age at death is only 1.2 years, and is not statistically significant ($\chi^2 = 0.312$; $p = 0.576$). However, as the result is relatively close to statistical significance, this difference may be interpreted as marginally significant.

The statistical difference between the ages at death of males with CO and PO and females with CO and LEH could not be calculated due to the insufficient number of individuals manifesting signs of these conditions. Apart from these conditions, the difference in survival between males and females presenting two or more analyzed pathological manifestations was not statistically significant (males $\chi^2 = 5.061$, $p = 0.080$; females $\chi^2 = 2.559$, $p = 0.278$).

The statistical difference between the ages at death of males and females presenting at least two pathological manifestations was not statistically significant.

The fact that healthy males and females—individuals who show no signs of any indicator of subadult stress—reached a similar average lifespan suggests a comparable quality of life for both males and females within the analyzed sample.

4. Discussion

4.1. Periostitis as an Independent Factor of Mortality

One of the most significant contributions to this issue is the 2014 study by Sharon N. DeWitte [81], which demonstrated that healed periosteal lesions are associated with a higher probability of survival, while active lesions are linked to an increased risk of mortality. These findings indicate that periostitis does not simply reflect poor health status but may also reflect individual resilience or frailty.

In the present study, periostitis was analyzed as a non-specific indicator of inflammatory and infectious processes, in accordance with definitions found in the literature [27,41,57–59]. The results show that the presence of PO is associated with a lower mean age at death, particularly among females.

Within the analyzed sample, males with PO exhibit a moderately lower age at death compared with males without PO. Among females, however, the pattern is more consistent and pronounced—women with PO consistently show a shorter lifespan compared with women without periosteal changes. This finding suggests that, within the female portion of the population, the presence of chronic or recurring inflammatory processes exerted a stronger influence on long-term survival.

Considering the historical context of Late Antique Southern Pannonia—characterized by warfare, migrations, and general instability [2,23]—periostitis likely reflects a combination of infectious burdens, nutritional stress, and physical trauma, which is consistent with previous research on Late Antique populations in continental Croatia [34,42–48].

Similar results, in which periostitis was recorded more frequently among males than females, have also been reported in other studies [23,81,82].

This pattern is consistent with earlier research demonstrating that periosteal lesions may be associated with an increased risk of mortality [82–84]. In a bioarchaeological context, periostitis is often interpreted as an indicator of increased biological frailty, meaning an increased susceptibility to adverse environmental conditions [82–84].

Although the present results indicate that periostitis is generally associated with a reduced age at death, this relationship should be interpreted with caution. Recent bioarchaeological research has emphasized that skeletal lesions do not necessarily represent poor health alone. As demonstrated by DeWitte [83], periosteal reactions may reflect both biological frailty and survival. Because periosteal new bone formation requires time to develop, individuals exhibiting such lesions must have survived long enough for these skeletal changes to occur. Consequently, some affected individuals may represent a relatively resilient segment of the population rather than simply those experiencing the greatest disease burden. This perspective is particularly relevant when interpreting individuals who exhibit evidence of multiple stress indicators yet attained ages at death comparable to, or in some cases exceeding, those of apparently healthy individuals. In our case, this is particularly relevant for males with combined LEH and PO, whose mean age at death remained relatively high despite evidence of both childhood and adult stress. Therefore, periostitis should be viewed not only as an indicator of chronic inflammation and physiological stress but also as a potential marker of survival following episodes of disease or adversity. This dual interpretation is consistent with the osteological paradox and the heterogeneity of the frailty model proposed by Wood [85].

4.2. Periostitis at Croatian Archaeological Sites

A review of published bioarchaeological research indicates that periostitis appears in the territory of present-day Croatia throughout the entire chronological range from prehistory to the Middle Ages, although with varying prevalence.

In prehistoric populations, periostitis is rare and generally localized. In the Iron Age necropolis at Nadin, six cases were recorded (26.1% of the observed tibiae, rather than explicitly individuals) [86]. The occurrence of periostitis during prehistory in Croatia is generally associated with other indicators of subadult stress.

One primary reason for the relatively low number of cases is the small number of individuals represented by skeletal remains in prehistoric cemeteries, as well as the nature of prehistoric lifestyles [87]. Communities were smaller, more mobile, and dispersed across larger territories, which reduced conditions favorable for the spread of infectious diseases, epidemics, and long-term chronic infections that could leave traces of periostitis on skeletal remains [86]. Prehistoric communities also had a different dietary structure, characterized by a higher proportion of plant-based foods, wild game, and fish. Such a diet may have reduced certain nutritional deficiencies, although in some regions the adoption of agriculture increased the risk of anemia, which can make individuals more susceptible to additional diseases [88].

In historical periods, particularly from Late Antiquity onward, the prevalence of periostitis increases. The greatest rise was documented in the Early Middle Ages, often linked to changes in socio-economic and sanitary conditions. Mario Šlaus, in his 2008 study, compared samples from continental and Adriatic Croatia during the transition from Late Antiquity to the Early Middle Ages [23]. During Late Antiquity, 24–29 individuals (5–6% of the observed sample) exhibited periostitis, while in the Early Middle Ages the proportion was nearly twice as high—45–46 individuals (9–11% of the observed sample). These percentages are consistent with the values obtained in the present research. In contrast, composite samples from continental Croatia show extreme values (85.7% among subadults), confirming that rural populations were often exposed to intense stress [89].

The increase in periostitis prevalence in Early Medieval populations compared to Late Antique populations is interpreted as a consequence of changes in living conditions during this historical transition. The rise in periosteal lesions is attributed to deteriorating general living and hygienic conditions, which in the Early Middle Ages were often poorer than in the more urbanized Late Antique period. Another factor was the shift in settlement patterns, with populations moving from urban centers to smaller, more rural settlements characterized by weaker infrastructure and poorer sanitary conditions [23]. Such environments increased exposure to environmental pathogens commonly associated with poor hygiene, close contact with animals, and limited food resources, thereby raising the risk of bacterial infections capable of causing periosteal reactions on bones.

The author also emphasizes the role of increased physical stress in agrarian communities, where daily activities involved intensive labor and mechanical loading of the skeleton, particularly the lower limbs. An important aspect of interpretation concerns regional differences, as the increase in periostitis is particularly pronounced in Adriatic populations, while continental populations show relatively stable prevalence rates. Additionally, periostitis frequently occurs alongside other non-specific stress markers such as cribra orbitalia and linear enamel hypoplasia, further indicating episodes of nutritional and infectious stress within the population. The combination of these factors suggests that the increase in periostitis reflects an overall deterioration in health status in part of the population during the transition from Late Antiquity to the Early Middle Ages [23].

The reasons outlined above for the increase in the number of affected individuals between these two historical periods apply to all sites and studied populations, as they summarize the main causes of periostitis and, more broadly, subadult stress. Regional and chronological differences in the frequency of periostitis highlight the importance of a contextual approach when interpreting paleopathological findings.

Although this study focuses on adult individuals, when discussing the occurrence of periostitis at Croatian archaeological sites, Koprivno stands out as one of the most extreme examples in Europe [90]. The results from that site primarily concern lesions among children (79.7%, with 33.9% of lesions active at the time of death). The number of adults with periostitis is considerably smaller—only four adult individuals (7.7% of the observed sample), while in a comparative sample from continental Croatia five cases were recorded, representing approximately one quarter of the analyzed individuals. At Nin, the situation is quite different: the prevalence of periostitis among children is approximately 20%, which has been interpreted as a result of better nutritional conditions and access to marine resources [91].

This pattern clearly indicates high childhood mortality and selective survival. Historical sources also point to the presence of infectious diseases such as tuberculosis and typhus, which further explains the high prevalence observed [90].

4.3. Two or More Indicators of Subadult Stress with Emphasis on Periostitis

The relatively large number of males exhibiting signs of two or more analyzed pathological manifestations of subadult stress supports findings by other researchers, namely that periostitis is more frequently observed among males. This may indicate that males who displayed cribra orbitalia (CO) during childhood, due to compromised immunity, were more susceptible to developing non-specific infectious diseases later in life [23,92]. Notably, in this group, the presence of linear enamel hypoplasia (LEH) and periostitis (PO) did not significantly affect age at death. These individuals lived slightly longer than the average age at death for males presenting two or more pathological manifestations. Such a result can logically be explained—or perhaps only be explained—by the osteological paradox, which will be discussed later in this study. The central premise of this concept is that individuals who survived disease during early youth or childhood may have subsequently developed stronger immunity and, despite the presence of pathological markers, could live relatively long lives compared with others, or even as long as healthy individuals.

The mean age at death of females with combinations of the analyzed pathological changes is, on average, three to five years lower than that of females in the entire sample. These results may be explained similarly to those observed among males: the presence of CO during childhood may indicate that the individual was more susceptible to diseases later in life, including the development of non-specific infectious and other diseases, resulting in a shorter expected lifespan.

In other words, individuals who exhibit signs of periostitis may represent the more resilient segment of the population, whereas those who died rapidly from infection often did not live long enough for visible pathological changes to develop on the skeleton. Several authors [17] have mentioned a possible association between periostitis and cribra orbitalia, largely because periostitis is considered a consequence of infectious diseases [40]. Sharon N. DeWitte, in her studies published in 2014, described the influence of active and healed periostitis on individual survival [81] and examined the frequency of periostitis in London following outbreaks of plague [83]. This concept has been further developed through frailty models, in which active lesions are interpreted as indicators of increased mortality risk, whereas healed lesions suggest resilience [81,83].

This perspective may help explain why some individuals with periostitis, particularly males exhibiting both LEH and PO, reached ages at death comparable to those of unaffected individuals. Therefore, the presence of periostitis in this population should not be interpreted solely as evidence of increased frailty but also as a possible indicator of successful survival following episodes of physiological stress.

When the entire sample is divided into healthy and affected individuals—that is, those who show signs of any pathological condition either individually or in any combination—similar results are obtained. When all pathological conditions are considered cumulatively, regardless of whether an individual presents with one, two, or three diseases, affected individuals are expected to have a shorter lifespan, and this pattern was also observed in the analyzed sample. Among females, this difference is statistically significant ($\chi^2 = 4.938$; $p = 0.026$). Among males, the difference in age at death is small, amounting to only 1.2 years, and is not statistically significant ($\chi^2 = 0.312$; $p = 0.576$). However, since the result is relatively close to statistical significance, this difference may be interpreted as marginally significant.

Several studies conducted outside Croatia that have examined the relationship between these two manifestations have produced differing results. A positive correlation between LEH and cribra orbitalia was observed in a composite sample from the Roman-period population of Rimini, Italy [24], and similar findings were reported by Stodder in a subadult sample from Guam in the Mariana Islands [93]. Obertová and Thuzó, in their analysis of a younger population from the medieval site of Borovce in Slovakia, also demonstrated a positive correlation between these two indicators of subadult stress [94]. In Lithuania, a study of a medieval cemetery sample from Vilnius by Jankauskas and colleagues likewise showed a positive relationship between LEH and CO among adult individuals, although no significant difference in frequency between the sexes or connection with periostitis was observed [50].

An increased frequency of linear enamel hypoplasia was observed among individuals who also exhibited cribra orbitalia in the composite Roman-period sample from the archaeological site of Poundbury Camp in England [53]. Stuart-Macadam interpreted the presence of these two manifestations in the Poundbury Camp sample as resulting from weakened immunity in children who did not receive adequate nutrition during growth. Such conditions led to compromised immune systems, making individuals more susceptible to factors producing subadult stress—in this case, cribra orbitalia and linear enamel hypoplasia.

In contrast, some sites have not shown a significant correlation between these two indicators of subadult stress. Such results were recorded in an Avar-period sample from the 8th century by Hungarian researchers Marcik and Bagylas at the cemetery of Makkoserdő near Szeged [95], as well as by Kozak and Krenz-Niedbala in Poland at the medieval site of Kołobrzeg [52]. Similar findings were obtained by Turbón in Spain when analyzing a sample of 1390 individuals from 18 different population groups dating from the Bronze Age to the early twentieth century [96]. Their conclusions indicated that no significant association existed between these two conditions either within individual population groups or across the entire sample. They further suggested that, given their differing etiologies, these two manifestations cannot necessarily be directly linked, since cribra orbitalia develops primarily as a consequence of iron deficiency, whereas linear enamel hypoplasia is associated with deficiencies in vitamin absorption [97].

Analysis of age at death in the entire observed sample of individuals with cribra orbitalia and linear enamel hypoplasia showed that sex does not influence age at death. Several authors [11,63] have also noted a possible association between periostitis and cribra orbitalia, as periostitis is frequently interpreted as a consequence of infectious diseases [11].

4.4. The Influence of Periostitis and Its Combination with CO and LEH on Age at Death for Males and Females

The results of this study confirm that the presence of periostitis (PO), as well as its combination with cribra orbitalia (CO) and linear enamel hypoplasia (LEH), has a measurable effect on the age at death of adult individuals in Late Antique Southern Pannonia. This effect is present in both sexes, but with clearly expressed sex differences.

4.5. Cumulative Effect of Subadult Stress

The most pronounced negative effect on age at death was recorded among individuals presenting all three manifestations (CO, LEH, and PO). This group shows the lowest mean age at death in both sexes.

CO and LEH are widely recognized in the literature as reliable indicators of subadult physiological stress [9,11,18,20,60–66]. Because dental enamel cannot remodel, LEH permanently records episodes of physiological stress during growth [31,33], while healed CO in adults indicates a disorder experienced during childhood [36,53,58,61].

When these indicators of subadult stress are combined with periostitis—which reflects active or chronic pathological processes in adulthood—a pattern of cumulative biological burden emerges. This finding is consistent with the heterogeneity [84] of the frailty model and the concept of the osteological paradox [85].

In this study, males presenting all three manifestations have a considerably lower age at death compared with males presenting only one or two manifestations. However, the decline in age at death is proportionally even more pronounced among females. Females with the combination of CO, LEH, and PO represent the group with the most unfavorable survival pattern in the entire sample.

This finding suggests that the cumulative impact of subadult and adult stress exerted a stronger effect on the female portion of the population.

4.6. Sex Differences in the Impact of Stress on Mortality

The results indicate clear sex differences:

- Periostitis alone has a more pronounced negative effect on age at death among females.
- The combination of periostitis with CO and LEH shows the cumulative effect in both sexes, but the relative impact is stronger among females.
- Males show greater variability between sites, while the pattern among females is more consistent.

These differences may be explained by a combination of biological and sociocultural factors. In Late Antique populations of continental Croatia, women were likely exposed to additional physiological burdens related to reproduction, breastfeeding, and possible nutritional inequality. Under conditions of instability and increased exposure to infectious diseases, such factors may have heightened their susceptibility to the long-term consequences of chronic stress.

Similar interpretations appear in bioarchaeological studies of other European populations [24,50–54], where sex differences in the frequency and consequences of stress markers are explained by the interaction of biological and social structures.

4.7. The Osteological Paradox

The main hypothesis of this study is that the presence of the analyzed pathological manifestations of subadult stress—primarily periostitis (PO), but also in combination with cribra orbitalia (CO) and linear enamel hypoplasia (LEH)—negatively affects individuals' age at death. In other words, individuals presenting one, two, or all three manifestations of subadult stress are expected to have significantly shorter lifespans than those without these manifestations.

The results obtained in this study largely confirm this expectation: in most cases, the presence of periostitis alone, as well as the cumulative effect of two or three manifestations of subadult stress, negatively influences age at death, and these individuals, on average, die earlier than others.

Such a distribution and frequency of disease can be explained by a wide range of factors that may influence the lives of individuals and communities, including sociocultural status, health conditions, and environmental circumstances.

Within the analyzed sample, however, some individuals who exhibited one or more indicators of subadult stress lived significantly longer than average. For example, one female individual presenting both LEH and PO lived 11 years longer than females who did not exhibit any pathological manifestations. This case is notable because it involves one of only two individuals in the observed sample who display both conditions and therefore represents an exception to the general pattern observed in the remaining results.

When examining cases in which individuals with the analyzed pathological changes live significantly longer than apparently healthy individuals, the interpretation becomes far more complex and requires an explanation that goes beyond simply listing pathological markers of subadult stress and other diseases, or drawing conclusions about the health status of individuals or communities solely on the basis of visible or absent pathological changes—that is, merely by counting apparently healthy or diseased individuals. The problem of directly interpreting the health status of individuals and communities based solely on the number of diseased and healthy individuals was addressed by James Wood, George Milner, Henry Harpending, and Kenneth Weiss in their 1992 study [85]. The identification of disease in paleopathology is primarily based on the observation of changes in human skeletal remains. In their pioneering work, Wood and colleagues highlighted the issues of selective mortality and hidden heterogeneity in susceptibility to disease, and they encouraged paleopathologists to consider in their analyses and interpretations of health the phenomenon they termed the "osteological paradox" [85].

The central premise of the osteological paradox is that individuals who died soon after becoming ill did not live long enough for the disease to leave traces on their bones. Conversely, individuals who survived long enough for pathological changes to develop on their bones—and thus become identifiable—may actually have been healthier, or at least more resilient, than those who died shortly after the onset of illness. The osteological paradox is therefore based on two key events in the life of an individual who becomes ill: the onset of disease and the moment of death.

Taking the osteological paradox into account, on one side are individuals who, during osteological analysis, are classified as healthy because they show no visible signs of disease. These individuals may indeed have been healthy, but they may also represent those in poorer overall health who succumbed to disease very rapidly after its onset, before any pathological changes had time to manifest on the bones. For disease manifestations to become visible on bone, an individual must live with the disease long enough for the bone to undergo structural change—something that depends on the type of disease but generally may require approximately three to eight months. Furthermore, it must always be considered that pathological changes may exist at a microscopic level, and an affected individual may have died before these changes became visible to the naked eye during macroscopic analysis [97].

On the other hand, during the analysis of human skeletal remains, individuals who display visible signs of disease are classified as diseased and become the focus of studies related to population mortality analyses, demographic reconstructions, and assessments of the health status of individuals and communities. However, the question remains as to what extent such individuals should truly be considered diseased, given that osteologically visible pathological changes may in some cases remain unchanged for as long as a decade after the onset of disease, while in certain conditions they may never fully remodel [94]. This implies that such individuals possessed sufficiently strong physiological resistance to

withstand disease, and in some cases, even to survive it, with the ultimate cause of death being unrelated to the disease that produced the skeletal lesion.

The osteological paradox lies in the fact that individuals who lived long enough for pathological changes to manifest on their bones may have been healthier than those who died before the disease had the opportunity to produce skeletal changes [85]. In other words, the absence of analyzed pathological changes on bone does not necessarily indicate the absence of disease, whereas the presence of pathological manifestations may, paradoxically, be interpreted as an indicator of relatively good health or resilience [85].

4.8. Some Limitations

Finally, several methodological and interpretive limitations should be acknowledged. In addition to methodological constraints, the analysis of bioarchaeological data is inherently accompanied by interpretive challenges that must be considered when assessing the present findings. The results presented in this study should be evaluated in light of several methodological constraints. One important limitation relates to the relatively small number of individuals represented within certain pathological groups and site samples, which may have reduced the robustness of statistical analyses and limited the ability to detect weaker relationships. This issue is particularly evident when analyzing combinations of stress indicators or site-specific samples, where low frequencies may reduce statistical power and limit the ability to detect significant associations.

In addition, differential preservation of skeletal remains may have influenced the recording of pathological changes, since the identification of cribra orbitalia, linear enamel hypoplasia, and periostitis requires the preservation of particular anatomical structures. Individuals with poorly preserved orbital roofs, dentition, or long bones may therefore be underrepresented in pathological categories, potentially affecting observed frequencies and statistical relationships.

Furthermore, these lesions are widely recognized as non-specific stress markers and may arise from multiple biological and environmental factors. Consequently, although these lesions provide evidence of physiological stress, they do not allow precise identification of the underlying cause, whether nutritional deficiency, infectious disease, parasitic burden, or other stressors.

The interpretation of these findings is further complicated by the osteological paradox, which highlights that individuals exhibiting skeletal lesions may not necessarily represent the least healthy members of a population, but rather those who survived physiological challenges long enough for pathological changes to become visible in the skeleton. Recognizing that skeletal lesions may reflect both increased frailty and successful survival following episodes of physiological stress, the observed associations between pathological lesions and mortality should be interpreted with appropriate caution.

5. Conclusions

The results of this study demonstrate that periostitis is an important bioarchaeological indicator of health status and mortality risk in Late Antique populations of Southern Pannonia. The analysis showed that the presence of periostitis can be associated with a lower mean age at death in both sexes, with the negative effect more pronounced among females. Furthermore, the combination of periostitis with other indicators of subadult stress—cribra orbitalia and linear enamel hypoplasia—indicates the cumulative effect of multiple physiological stressors that further increases mortality risk.

The results support the assumption that episodes of stress experienced during childhood, together with chronic inflammatory processes in adulthood, have long-term consequences for individual survival. The lowest ages at death were recorded among individuals

presenting all three analyzed pathological manifestations, suggesting a strong cumulative effect of biological stress throughout the life course. The observed sex differences further suggest that females in the analyzed populations were more sensitive to the long-term consequences of physiological and environmental stress.

A particular contribution of this study is that periostitis was analyzed as the central analytical component in relation to other indicators of subadult stress. Although cribra orbitalia and linear enamel hypoplasia are relatively common indicators in bioarchaeological research, studies that incorporate periostitis into such analytical frameworks remain considerably less frequent. In this way, the present research contributes to a better understanding of the role of non-specific infectious and inflammatory processes in interpreting health status and mortality patterns in past populations. The presence of skeletal lesions does not necessarily represent poor health alone, as such changes can only develop in individuals who survive long enough for pathological bone remodeling to occur and their presence may reflect both increased frailty and successful survival following episodes of physiological stress. Consequently, the results are best understood as evidence of associations rather than direct causation. The observed relationships therefore likely represent complex interactions between physiological stress, survival, and mortality rather than simple cause-and-effect patterns.

While the present study identified statistically significant associations between certain stress indicators and age-at-death, these relationships should be interpreted cautiously. Cribra orbitalia, linear enamel hypoplasia, and periostitis are non-specific skeletal markers that reflect complex interactions among nutrition, infectious disease, environmental conditions, and individual biological responses. Consequently, the observed patterns should not be viewed as direct evidence of causality. Rather, they suggest that individuals exhibiting these lesions may have experienced greater physiological stress during life, which was associated with differences in mortality patterns. Furthermore, in light of the osteological paradox, skeletal lesions may reflect both increased frailty and survival following episodes of stress or disease, highlighting the need for nuanced interpretation of bioarchaeological data.

Although the results indicate an association between certain stress indicators and reduced age-at-death, these findings should be interpreted within the framework of the Osteological Paradox. The presence of skeletal lesions does not necessarily represent poor health alone, as such changes can only develop in individuals who survive long enough for pathological bone remodeling to occur. Consequently, cribra orbitalia, linear enamel hypoplasia, and periostitis may reflect both increased frailty and biological resilience. The observed relationships therefore likely represent complex interactions between physiological stress, survival, and mortality rather than simple cause-and-effect patterns.

In a broader context, the results of this study provide additional insight into the complex relationships between subadult stress, chronic disease, and long-term survival in Late Antique communities of continental Croatia. They also confirm the importance of an integrated approach in bioarchaeology, in which the combined analysis of multiple stress markers is essential for reconstructing the health and living conditions of past populations.

In the light of broadening of the topic of subadult stress in Antique Panonnia, future research should focus on multidisciplinary approaches by integrating osteological data with isotopic analyses in order to reconstruct dietary patterns and mobility. Paleogenomic approaches could provide additional insight into genetic susceptibility to infectious diseases and physiological stress, while larger comparative datasets from other Late Antique populations would allow a more comprehensive evaluation of regional variability in health and mortality patterns.

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Abbreviations

The following abbreviations are used in this manuscript:

CO	Cribra Orbitalia
LEH	Linear enamel hypoplasia
PO	Periostitis

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