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Traces of Disease in Cremated Children's Bones: Age and Health in Bronze and Iron Age Communities North and South of the Alps

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A B S T R A C T

Diseases are a constant of the human experience and have been affecting past populations of all periods, including those that practised cremation as a dominant burial rite. This paper focuses specifically on children's health status in the Late Bronze and Iron Age (circa 1500–600 BC) inferred from the osteological analysis of cremated human remains. We have analysed skeletal material from four Croatian (Poljana Križevačka, Slatina, Batina and Sotin) and four Austrian (Franzhausen-Kokoron, Unterradlberg, Inzersdorf, St. Pölten) cemeteries to demonstrate that despite the fragmentation, distortion and selective recovery process of the funerary activities, cremated remains still yield important information on the life and death of children in later European prehistory. Children in the Croatian graveyards were more frequently affected from pathological lesions (38%) than children in the Austrian sample (3%). Cranial porosity, cribra orbitalia, and endocranial lesions dominated, probably related to metabolic diseases such as rickets and scurvy which were noticed primarily in children younger than six years at death. Differences between the Croatian and Austrian samples are likely associated with taphonomic processes as indicated by differences in bone weight and fragmentation size. Since children are the most vulnerable part of communities, a focus on children's morbidity and mortality can elucidate the living conditions of prehistoric societies as a whole.

1. Introduction

Direct evidence for people's health status in the past can be obtained from the macroscopic examination of human skeletons, because, during life, bone reacts to a range of different stress factors. As one of the largest components of society, children need to be included in the analysis to fully understand past societies and their health status, presuming that children actively participated in the social and everyday life of their communities (*e.g.* Kamp, 2001; Sanchez Romero *et al.*, 2012; Lillehammer, 2015).

The burial customs of the Late Bronze Age and Early Iron Age in the southern Carpathian Basin and eastern Austria were predominantly characterised by the cremation of the deceased. The area between the Danube River to the north and the Sava River to the south was part of the Middle Danubian Urnfield culture (Pittioni, 1979; von Schnurbein, 2009; Lochner, 2021). This region displays many regional variations in cremation mortuary practice between the 14th and 9th century BC (Lochner, 2013; 2021; Ložnjak Dizdar *et al.*, 2018; Cavazutti *et al.*, 2022; Sorensen and Rebay-Salisbury, 2023). At this time, children and adults were treated according to similar funerary rites (Ložnjak Dizdar and Rajić Šikanjić, 2020; Lochner, 2021). After they were cremated on a separate pyre in their costume; their cremated remains were placed in an urn. In some phases of the Late Bronze Age, such as the 11th century BC in Croatia and the 10/9th century BC in Lower Austria (Lochner and Hellerschmid, 2009), these urns were sized in proportion to the smaller amount of cremated remains. Sometimes the

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children were accompanied by their personal belongings, such as toys or child-sized vessels.

The analysis of pathological lesions in cremations presents a challenge due to the heightened fragmentation of bones caused by the cremation process, often leading to the destruction of bones with pathological changes (Manifold, 2012; Harving and Lynnerup, 2013). Furthermore, bone response to disease is relatively slow, so in general, bones are only affected by long-term diseases, which manifest over months, years or even decades (Mays, 1998; Lewis, 2017; Buikstra, 2019). Acute infections, which were the main causes of mortality in the past in children, cannot be seen on the skeleton because they do not last long enough to affect the bones and leave traces (Mays, 1998; Waldron, 2009). Consequently, the morbidity of these individuals cannot be determined based on skeletal remains and we focus on bony lesions of chronic diseases to evaluate morbidity and frailty in the past.

The location, characteristics and distribution of marks on bones serve as distinct pathognomonic indicators to identify diseases. In most cases, it is very difficult to determine the specific cause of a particular pathological change because bone, like other tissues, can react in only a few ways (Ragsdale and Lehmer, 2012). Bone reaction to disorders in the body is caused by two types of cells: osteoblasts that create bone and osteoclasts that absorb bone. Accordingly, abnormal/atypical bone is formed in some diseases while it is destroyed in others, forming lytic lesions. Additionally, a large number of diseases include the simultaneous formation and destruction of bone (Roberts and Manchester, 2010; Ortner, 2012). The characteristics of abnormal/atypical bone properties provide key information necessary for the description and diagnosis of all skeletal disorders. The fact that the same change can occur as a result of several diseases and that a certain disease can cause several different changes complicates a differential diagnosis. Relatively specific diagnoses are associated with only a few highly accentuated and specific bone lesions (Ragsdale and Lehmer, 2012). In the majority of cases, skeletal signs are non-specific, indicating that the individual was ill. The exact disease, however, cannot be detected. In light of the osteological paradox (Wood *et al.*, 1992; McFadden and Oxenham, 2020), many children most likely died quickly, of accidents, acute infections and famine, and the skeleton could not remodel in time to be visible in the osteological analysis.

The interconnection between diseases and social actions is even less frequently observable. The skeletal remains of a child from the Early Bronze Age settlement at Schleinbach in Lower Austria are a rare exception: a 5–6-year-old child was found in a pit with traces of a violent death, interpreted as entangled in a chain of events that include an uncontrolled middle ear infection (Rebay-Salisbury *et al.*, 2020).

In this paper, we focus specifically on children's health status inferred from the osteological analysis of cremated human remains. This study aims to evaluate the health status and morbidity rates of children, with a focus on general stress markers, metabolic diseases, and infections. This will provide insights into living conditions and the social status of children north and south of the Alps during the Late Bronze Urnfield culture. Due to the mortuary practice in that period, cremation remains are the only source of information that can give us data on the demography and diseases of the population. Even though it is particularly difficult to identify pathological lesions in cremated remains due to a high degree of bone fragmentation, we cannot overlook the value of the collected data.

2. Methods

The skeletal remains were analysed using standard methods to gather information about the age of the individuals and pathological changes (Brickley and McKinley, 2004; McKinley, 2004). The bone fragments were individually separated into the following anatomical areas: cranium, thorax, pelvis, upper limbs (including the shoulder girdle), lower limbs, and unidentifiable long bone fragments. Bone weight and average and maximal fragmentation size were recorded. Children were identified by age-at-death using dental and skeletal development. Dental formation and eruption were observed according to the London atlas of human tooth development and eruption (AlQahtani, Hector, and Liversidge, 2010). This method quantifies all the stages of dental development (formation, eruption, resorption of the root) from 30 weeks in utero to 23 years of age. The determination of skeletal development included looking at the fusion of secondary ossification centres. The timing of epiphyseal fusion was determined based on the published literature (Schaefer *et al.*, 2008; Cunningham *et al.*, 2016). Whenever possible, the methods complemented each other in estimating age categories. Since there are various problems with the terminology and age categories used in the analysis of individuals younger than 19 years, in this paper we will use the term "child" (Halcrow and Tayles, 2011). Absolute age ranges were divided into the age categories: infans I (0–6 years), infans II (7–12 years), and adolescent (13–19 years). Due to an imprecise age-at-death estimation, some individuals might fall into a range of several age categories and were classified as "child". Sex was not estimated due to the fact that sexually dimorphic features begin to develop during adolescence (Huseynov *et al.*, 2016), and proteomic and genetic methods cannot be applied to cremated remains as all organic compounds are usually combusted. If several individuals were mixed, the MNI was estimated based on the most frequent element and further information that clearly separated two individuals from each other, for instance, sex or age at death.

The material was visually examined to identify any pathological changes in the bones. All available bone fragments were evaluated for pathologies. Lesions were only recorded if they could be pathological lesions identified as of pathological origin to avoid false-positive diagnoses. The shape and location of identified lesions were documented. The research focus relied on childhood stress indicators (*i.e.* cribra orbitalia, porotic hyperostosis), non-specific inflammation/infection (*i.e.* periostitis, osteomyelitis) and observed pathological lesions were grouped accordingly into four categories: endocranial lesions, ectocranial lesions, cribra orbitalia, and periosteal reactions, and infections. As teeth crowns rarely survive the cremation process, further stress markers on the teeth, for example, enamel hypoplasias, could not be evaluated. We selected adults from the same sites as a control group in this study. Our analysis focused solely on the aforementioned categories, without considering age-related diseases such as osteoarthritis.

Endocranial lesions are a term used to describe a set of changes that occur on the inner side of the cranium. Most often they are found on the occipital bone, but can also affect the parietal and frontal bones (Lewis, 2007). Lesions can have several forms: porosity, new bone deposition, vascular impressions, erosions and "hair on end" lesions (Hershkovitz *et al.*, 2002; Lewis, 2004). They are the result of inflammations and haemorrhage caused by different conditions such as infectious meningitis, tuberculosis, syphilis, bone tumours, metabolic diseases and traumatic injuries (Hershkovitz *et al.*, 2002; Lewis, 2004; Kappelman *et al.*, 2008; Janovic *et al.*, 2015; Rohnbogner and Lewis, 2017). In younger children, especially between 3 and 7 years, deposits of new bone are not always pathological and can be considered normal. During that period, there is rapid development of the brain and endocranium causing fibrous bone deposition that is indistinguishable from pathological conditions (Lewis, 2004; Rohnbogner and Lewis, 2017).

Ectocranial lesions are areas of porosity on the outer surface of the cranial vault, resembling orange peel without medullary expansion. They mostly occur on the parietal, occipital and frontal bones (Mann and Hunt, 2005). Some authors associate ectocranial lesions with periods of malnutrition (Stirland, 2013). According to Roberts and Manchester (2005), porosity can be a population-specific normal variation of the cranium but can also be caused by diseases such as scurvy, rickets, inflammatory processes and some tumours.

Porotic hyperostosis – porotic lesions with a widening of the diploe, was classified as an additional pathological lesions (Brickley, 2018). Porotic hyperostosis is commonly observed together with cribra orbitalia, which is an abnormal porosity on the uppermost part of the orbital cavity on the frontal bone (Ortner, 2003; Lewis, 2007). The two most common causes of cribra orbitalia and porotic hyperostosis are iron deficiency anaemia and respiratory diseases (O'Donnell *et al.*, 2020). Certain types of anaemia, such as megaloblastic and haemolytic anaemia, but also inherited types of anaemia (thalassemia and sickle cell anaemia), can lead to cribra orbitalia and porotic hyperostosis (Lewis, 2007; Walker *et al.*, 2009). The frequency of cribra orbitalia is often used as an indicator of the health status and living circumstances of the analysed community. Its appearance points to the presence of poor hygienic conditions, improper nutrition, and infectious diseases (Walker *et al.*, 2009; Kozłowski and Witas, 2012, p.407)

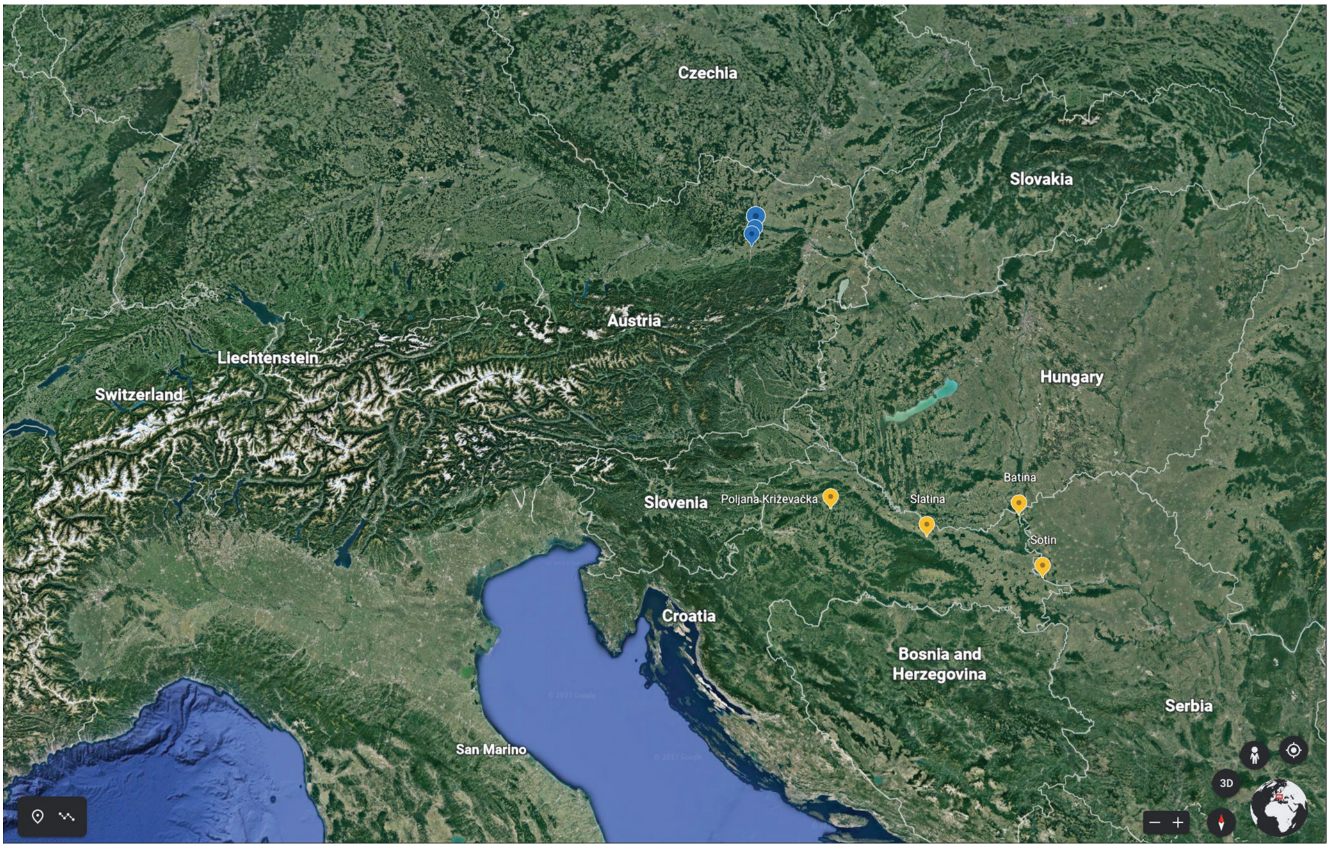

Figure 1. Map of the study region with Austrian (blue) and Croatian (yellow) sites (Base map: Google Landsat/Copernicus, GeoBasis–DE/BKG (©2009).

Periosteal reactions are associated with any number of diseases including scurvy, rickets, haemangiomas, and traumatic injuries, most of which have the root causes of malnutrition and chronic infectious diseases (Wapler *et al.*, 2004; Lewis, 2007). Periosteal reactions are an inflammatory response that produces new bone formation (Weston, 2012). The inflammation can be both localised and systemic. Localised periosteal new bone deposits can be caused by a trauma or local infection, but systemic periosteal reaction formation can also indicate a chronic infectious disease (Weston, 2009; Larsen, 2015; Šlaus, 2021, p. 90). It is used as an indicator of community health: high prevalence within a population is generally indicative of unhealthy living conditions associated with a dense population, poor hygiene and/or poor sanitation practices (Larsen, 2015). Due to the severity of subperiosteal reactions, lesions can have the form of new bone deposition, longitudinal striations or, in severe cases, osteitis and osteomyelitis.

3. Material

3.1 Croatia

For this analysis, we have gathered skeletal material from four cemeteries: Poljana Križevačka, Slatina, Batina and Sotin (Figure 1). We included only individuals who died between birth and 18 years of age, a total of 45 individuals.

Poljana Križevačka in northwestern Croatia is the oldest examined burial ground, dated to the 14th and 13th centuries BC (Ložnjak Dizdar, 2012), where 43 individuals were buried in 50 excavated graves. Out of that number, 14 cremation burials contained subadults with a biological age of 0–18, and four of those exhibited pathological conditions (Premužić, 2016, p.55).

Another cemetery from the Late Bronze Age is Slatina in middle Podravina, dated to the 11th century BC. Excavations uncovered 38 graves with 28 individuals. Out of that number,

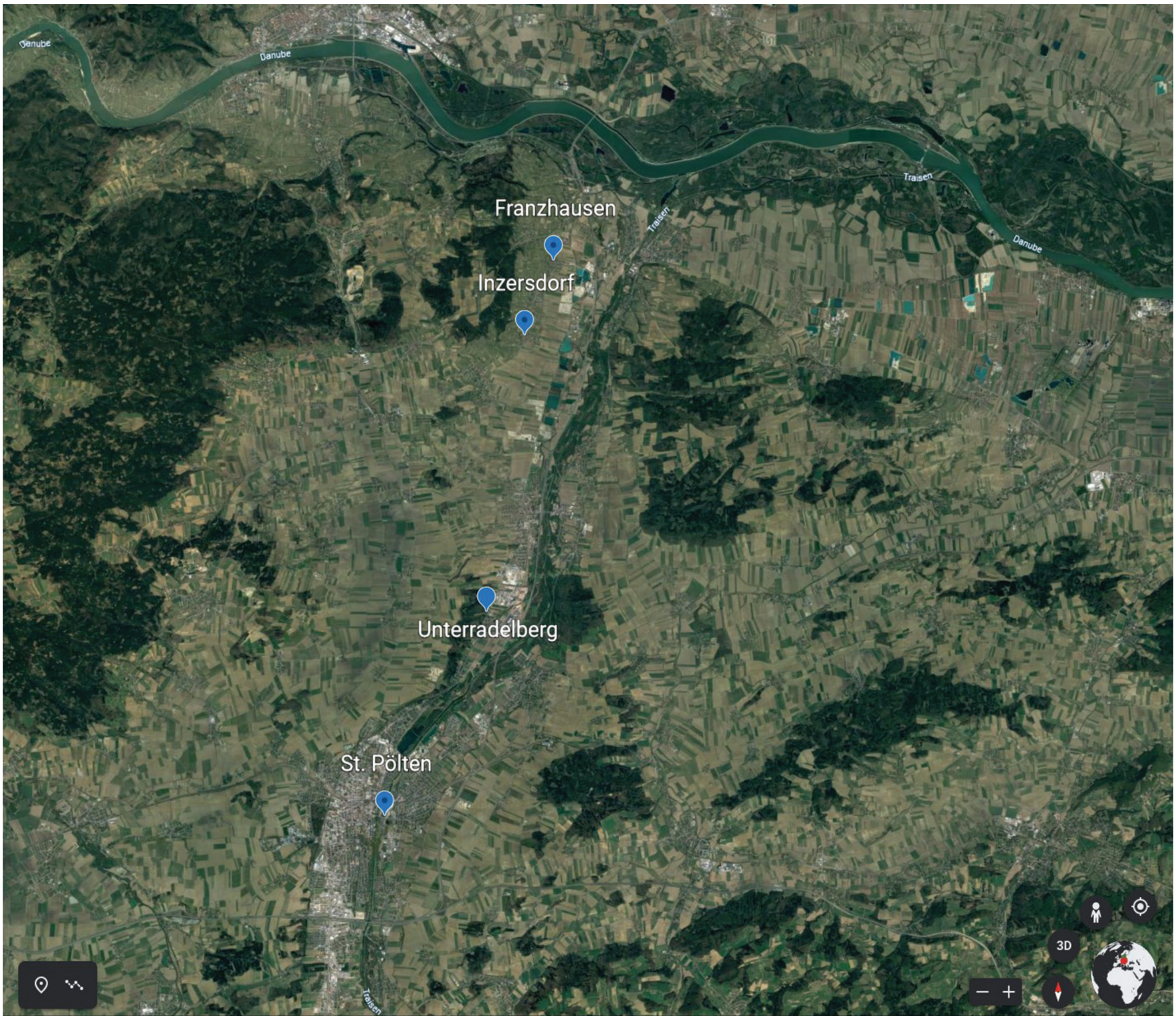

Figure 2. Austrian sites along the Traisen river (Base map: Google 2019).

Table 1. Frequencies of number of observed lesions on single individuals and types of observed lesions in the Croatian and Austrian sample.

Sample	No lesions		Average cremation weight	One lesion		Two or more lesions		Average cremation weight	Maximal fragment size (average)
	n	%	g	n	%	n	%	g	mm
Croatian	28	62.2	317.5	13	28.9	4	8.9	109.1	30.5
Austrian	216	96.9	47	4	1.9	3	1.3	227	46.81

Lesion type

Sample	Ectocranial porosity		Endocranial lesions		Cranial hyperostosis		Cribra orbitalia		Periosteal reactions		Sinusitis	
	n	%	n	%	n	%	n	%	n	%	n	%
Croatian	4	18.2	3	13.6	0	0	3	13.6	12	54.5	0	0
Austrian	3	27.3	2	18.2	1	9.1	2	18.2	2	18.2	1	9.1

12 were children with a biological age of 0–18 years, of which nine had pathological conditions (Ložnjak Dizdar *et al.*, 2018, pp.227, 230–232, Figures 16–17).

Two cemeteries on the Danube were dated to the Late Bronze Age and the beginning of the Early Iron Age. The Batina burial ground in Baranja, dates from the 11th to the 7th century BC, and contains 69 excavated graves (Dizdar *et al.*, 2021). Twenty-six of the graves have been analysed, which contained 29 individuals, including 7 subadults. The child in Grave 53 was found with pathological lesions.

The graves from Sotin in Syrmia date from the 9th to the 7th century BC. A total of 119 graves were excavated (Ložnjak Dizdar, 2019), of which 20 were subject to osteological analysis. Twelve of the 26 discovered individuals were children, three of which showed pathological lesions.

3.2 Austria

Late Bronze Age cemeteries of the Traisen river valley south of the Danube in Lower Austria have recently been subjected to osteological analysis in the framework of the "Unlocking the Secrets of Cremated Human Remains" project. Sites in this study include Unterradlberg, St. Pölten, Inzersdorf and Franzhausen-Kokoron, which are located just a few kilometres from each other and were all recovered in the course of rescue excavations from the 1980s until the present (Figure 2).

Four burial mound complexes dating to the transitional period from the Middle to Late Bronze Age (circa 1500–1250 BC) were investigated at Unterradlberg (Blesl *et al.*, 2002; Blesl and Krumpel, 2003; Krenn-Leeb, 2019; Skerjanz, 2024). Six adults and eight children were identified, showing a complex burial landscape including primary and secondary burials. The children were either buried alongside the adults inside the central grave chambers or around the mound construction. Two of the children showed pathological lesions.

Two late Bronze Age urns of the 14th century BC, recovered from a recent rescue excavation in the city of St. Pölten, were subjected to detailed, multi-disciplinary analyses (Waltenberger *et al.*, 2023). One contained the remains of a female adult, the other of a ten to fifteen-year-old child. Both individuals showed pathological lesions.

The cemetery of Inzersdorf includes a total of 273 scattered cremations and urn burials dating to circa 1200–1000 BC (Lochner, 2013; Fritzl, 2017). A large proportion of individuals, 121 in total, were identified as children, two of which present pathological conditions of the skeleton.

The cemetery of Franzhausen-Kokoron comprises 403 cremation graves dating to circa 1000–800 BC, including five double burials (Lochner and Hellerschmid, 2009; Lochner and Hellerschmid, 2016). At this cemetery, 236 individuals were identified as adults and 93 as children. Three children individuals and 58 adults showed pathological conditions.

4. Results

In the Croatian sample, out of 45 analysed children, 17 (37.8%) presented at least one pathological lesion. Of these, the majority of the individuals (13 individuals, 76.5%) had one lesion, whilst three individuals (17.6%) had two lesions, and there was only one individual (5.9%) with three different types of lesions. In the Austrian sample, pathological lesion were much rarer, affecting seven out of 223 individuals (3.1%). Of these, four individuals showed only one lesion (57.1%), whilst three showed two or more lesions (42.9%; Table 1). Most likely, there was originally a higher frequency of individuals affected by pathological conditions, but differential survival of skeletal elements as a result of the cremation and taphonomic processes resulted in information loss. For instance, individuals without any visible pathological lesions have on average a lower cremation weight (47 g) than individuals with present pathological lesions (227 g). Dividing the samples further into age categories, individuals younger than 6 years were affected more frequently by pathological lesions. In the age category infans II, only one individual was affected by pathological lesions in the Croatian sample (ectocranial porosity; G23 from Poljana). In this age group, in the Austrian sample, three individuals were affected. All three showed multiple lesions. In the adolescent age group, only periostitis could be observed in one individual from Slatina (Croatia; G11). No adolescent individuals were affected in the Austrian sample. See Tables 2–4 for more details.

In the majority of cases, only one change was observed; this includes 13 burials from Croatia and four from Austria. The most frequent lesion was periostitis on long bone fragments, present in 13 individuals from Croatia. The severity of the lesion varied from striation and porosity to new bone formation. In the Austrian sample, active periostitis with fibrous new bone formation was found in two cases (*i.e.* Figure 3). In addition, the individual in grave 567 from Franzhausen–Kokoron had active sinusitis with fibrous new bone formation of the sphenoid sinus (Figure 4).

Endocranial lesions were present in three individuals from the Croatian sample and two from the Austrian sample. Four out of five individuals were younger than 6 years of age. Observed lesions were present in several forms: porosity, new bone deposition, and lytic lesions. In one case, Grave 152 from Inzersdorf, netlike capillary lesions and microporosity were present. In only one case, Grave 5 from Poljana, was it possible to identify the bone as occipital (Figure 7). Endocranial lesions in children are relatively rare, with frequencies reported in various populations ranging from 15% to just a little below 30% (Schultz and Teschler-Nicola, 1989; Cook and Buikstra, 1979; Lewis, 2004; Rohnbogner and Lewis, 2017).

Ectocranial lesions were observed in three individuals from Croatia and four individuals from Austria. The majority exhibited mild porosity, but in one case, Grave 603 from Franzhausen-Kokoron, a pronounced active porotic hyperostosis was present (Figure 5). Three children from Croatia, all younger than 5 years, had cribra orbitalia. The only child of the Austria sample with this kind of lesion was a 10–12-year-old from St. Pölten, which was found with a strongly developed, active cribra orbitalia (stage 3 after Steckel *et al.*, 2006) (Figure 6).

5. Comparison to the adult population

The development of porous lesions is still not completely understood, as studies point toward a complex, multifactorial origin of these lesions (Rivera *et al.*, 2017; Brickley, 2018). Porous lesions predominantly form during childhood but may persist into adulthood if the individual does not die during childhood (Schats, 2021). One can expect that the frequencies of the observed lesions would be less common in the adult sample, or at least, porous lesions would be more frequently healed. However, taking into account the cremation process, which strongly affects the gracile and incompletely calcified children's bones, many lesions may be destroyed and therefore underrepresented in children. Consequently, we compared the frequencies of observed lesions in children to adults in the same populations.

At all four Croatian sites, pathological lesions were observed in only 5.5% of adults. Only three out of four types of lesions were present, and they had a higher incidence in the younger age group. In addition to those four categories, there were also several cases of osteoarthritic changes, fractures and antemortem tooth loss. A possible explanation for the obtained results is an age-related effect, with higher

Table 2. Frequencies of observed number of lesions and lesion type in the age groups infans I, infans II and adolescent in the Croatian sample.

Croatian sites																			
Age category	No lesions		One lesion		Two or more lesions		Lesion type												
							Ectocranial porosity		Endocranial lesions		Cranial hyperostosis		Cribra orbitalia		Periosteal reactions		Sinusitis		
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	
infans I	12	46.1	10	38.5	4	15.4	3	15.8	3	15.8	0	0	3	15.8	10	52.6	0	0	
infans II	9	81.8	2	18.2	0	0	1	50	0	0	0	0	0	0	1	50	0	0	
adolescent	7	87.5	1	12.5	0	0	0	0	0	0	0	0	0	0	1	100	0	0	

Table 3. Frequencies of observed number of lesions and lesion type in the age groups infans I, infans II and adolescent in the Austrian sample.

Austrian sites																		
Age category	No lesions		One lesion		Two or more lesions		Lesion type											
							Ectocranial porosity		Endocranial lesions		Cranial hyperostosis		Cribra orbitalia		Periosteal reactions		Sinusitis	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
infans I	95	96.9	3	3.1	0	0	0	0	0	0	1	33.3	0	0	1	33.3	1	33.3
infans II	54	94.7	0	0	3	5.3	2	40	1	20	0	0	1	20	1	20	0	0
adolescent	21	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4. Pathological conditions observed in the eight sites.

Cemetery	Grave no.	Cremation weight [g]	Age	Pathological changes
Poljana	5	107.7	0–6	endocranial lesions (new bone on one fragment of the occipital)
				ectocranial porosity (one bone fragment)
				periostitis (one long bone fragment)
Poljana	23	565.7	7–10	ectocranial porosity (one bone fragment)
Poljana	36	68.5	1–3	cribra orbitalia (right orbit)
Poljana	38	406.3	0–6	ectocranial porosity (several bone fragments)
Slatina	4	35.70	2–4	endocranial lesions (porosity on several bone fragments, new bone on one fragment)
				periostitis (several long bone fragments)
Slatina	11	44.30	12–16	periostitis (striation on two long bone fragments)
Slatina	13	108.40	3–6	periostitis (striation and new bone on several long bone fragments)
Slatina	15	65.30	1–4	periostitis (porosity on one long bone fragment)
Slatina	17	62.90	2–5	cribra orbitalia (left & right orbit)
				periostitis (porosity on two long bone fragments)
Slatina	28	3.30	0–18	periostitis (porosity on one long bone fragment)
Slatina	31	118.70	0–6	periostitis (porosity on several long bone fragments)
Slatina	34	13.90	0–6	periostitis (new bone on one long bone fragment)
Slatina	38	125.80	2–4	cribra orbitalia (one orbit)
				cranial lesions (porosity on four bone fragments)
Batina	53	108	3–5	endocranial lesions (lytic lesions on one fragment)
Sotin	4	4.4	0–18	periostitis (striation on three long bone fragments)
Sotin	7	14.7	0–18	periostitis (striation on one long bone fragment)
Sotin	8	1.9	7–11 months	periostitis (striation on one long bone fragment)
Unterradlberg	814	412.2	0–18	ectocranial lesions
Unterradlberg	818	34.29	0–6	active periostitis (one neurocranial fragment)
St. Pölten	2	696.37	10–12	cribra orbitalia (severe)
				ectocranial lesions (weak)
				active periostitis (one diaphysis probably humerus)
Inzersdorf	152	37.85	3–9	endocranial lesions (netlike capillary lesions and microporosity)
				cribra orbitalia
Inzersdorf	171	234.34	7–12	endocranial lesions (porosity and new bone formation)
				ectocranial lesions
Franzhausen-Kokoron	567	137.86	0–6	active sinusitis with woven new bone formation of the sphenoid sinus
Franzhausen-Kokoron	603	24.2	0–6	active porotic hyperostosis

Table 5. Frequencies of the cases with pathological lesions in relation to the whole sample size.

Pathological lesion	Croatian sample		Austrian sample	
	Child	Adult	Child	Adult
Endocranial lesions	3 (6.6%)	2 (1.4%)	2 (0.9%)	1 (0.3%)
Ectocranial lesions	3 (6.6%)	5 (3.4%)	4 (1.8%)	19 (5.4%)
Cribra orbitalia	3 (6.6%)	–	1 (0.5%)	3 (0.8%)
Periostitis	13 (28.8%)	2 (1.4%)	2 (0.9%)	5 (1.4%)

Table 6. Pathological lesions observed in comparative sites.

Cemetery	Reference	Pathological changes
Pitten, Austria	Rebay-Salisbury, 2020; Teschler-Nicola, 1985	not observed
Bischofshofen-Pestfriedhof, Austria	Renhart, 2009	cribra orbitalia – 1 child
		cribra cranii – 1 child
Doroslovo, Serbia	Živanović, 2008	not observed
Podbrežje, Slovenia	Thomas, 2021	cranial porosity –1 child (16 years)
		varying diploe thickening – 1child (16 years)
Domašinec, Croatia	Krmpotić and Novak, 2021	healed ectocranial porosity – child (10–16 years)
Belišće, Croatia	Ložnjak Dizdar, 2014	not observed
Dolina, Croatia	Ložnjak Dizdar and Dizdar, 2021	not observed
Statzendorf, Austria	Renhart, 2006	no children

Figure 3. Periosteal reactions in a cranial fragment of the individual from Grave 818 of Unterradlberg (photo by L. Waltenberger).

Figure 4. Woven new bone formation and porosity within the sphenoid sinus of the individual from Grave 567 of Franzhausen-Kokoron is consistent with an active sinusitis (photo by L. Waltenberger).

susceptibility of children to infections and/or dietary deficiency.

Pathological lesions were observed much more frequently in adult individuals from the Austrian sites (20.6%). However, most cases involve osteoarthritic changes in joints and occupational stress-related remodelling of muscle attachments. Looking at the pathological categories in the sample of children, only 8.7 % of the adult individuals showed similar lesions (n=28, Table 5). A chi-squared-test

Figure 5. Active cranial hyperostosis in a child from Franzhausen-Kokoron, Grave 603 (photo by L. Waltenberger).

revealed that of all pathological lesions, only ectocranial lesions are more frequent than expected in the children sample of Austria (p=0.024). There is no difference between the age groups for the remaining pathological lesions. See Table 5 for more details.

6. Discussion

For those cases that have more than one lesion present, a tentative diagnosis of the underlying disease can be made. The 0–6-year-old child from Poljana, Grave 5, had new bone formation on the endocranial surface of the bone, ectocranial porosity on one bone fragment, and porosity on a fragment of a long bone (Figures 7 to 9). The orbitae were not available for evaluation. The simultaneous presence of these three changes might indicate scurvy. Scurvy is a metabolic disease caused by a long-term significant lack of vitamin C in the diet (Brown and Ortner, 2011). Since people take up vitamin C through food such as fresh fruits and vegetables, its deficiency indicates periods of hunger and poor nutrition (Waldron, 2009). In the body, the walls of blood vessels weaken and bleeding occurs. If the bleeding occurs near a bone, the result is increased porosity and a new layer of bone (Brickley and Ives, 2006). Changes caused

Figure 6. Strongly developed cribra orbitalia (stage 3 after Steckel *et al.* 2006) in the child from St. Pölten, Grave 2 (photo by L. Waltenberger).

by scurvy occur on the outer surface of the cranium, orbits, sphenoid bone, upper jaw and scapula, as well as the long bones (Brickley and Ives, 2006; Brown and Ortner, 2011). Symptoms in children usually appear 6 to 10 months after vitamin C has completely or almost disappeared from their diet (Brickley and Ives, 2006). The possible presence of scurvy (endocranial lesions, ectocranial porosity, porosity on long bone fragment) in the child from Grave 5 (Poljana Križevačka 0–5 years) points to unfavourable living conditions for an extended time period, with a diet of low or unsatisfactory quality.

The combination of more than one pathological lesion in five children may be the result of scurvy, even though all these changes can be associated with several other potential diseases. A child younger than 6 years from Grave 4 in Slatina had porosity and new bone formation on the endocranial surface of several skull fragments and porosity on long bone fragments. Cribra orbitalia and porosity on fragments of cranial bones were observed in the child (2–4 years) from Grave 38 from Slatina and Grave 152 (3–9 years) from Inzersdorf. A child from Grave 17 (2–5 years) in Slatina and the child from St. Pölten (10–12 years) had cribra orbitalia on both orbits and porosity on two fragments of long bones. Both endocranial and ectocranial lesions, as well as lesions on the orbital roof, may potentially be associated with scurvy.

All lesions in the Austrian sample, except endocranial lesions, were more frequently observed in adults in comparison to subadults. Ectocranial lesions are three times more common in adults than in subadults. Evidence for healing suggests that ectocranial lesions developed a long time before, probably during childhood (Stuart-Macadam, 1985; Mays, 2018). These individuals survived the stress factors and deficiencies of childhood, whereas many subadults died before the conditions could manifest themselves. Especially at Inzersdorf, with its high number of subadults, this indicates a high mortality rate in this age group, with the individuals dying quickly before skeletal lesions could manifest (osteological paradox; see Wood *et al.*, 1992). Interestingly, endocranial lesions were more common in subadults than in adults, although the numbers were low and non-significant. Bone reactions at the endocranial surface point towards infections as a differential diagnosis in addition to metabolic diseases. Endocranial infections greatly affect the meninges and brain, often leading quickly to death, although chronic forms are known and subadult bone remodels with higher turnover rates than adult bone (Lewis, 2004).

In our sample, the number of observed pathological lesions on juvenile cremated remains in Austria was much lower than on the Croatian sites. One explanation could be bone preservation. The average cremation weight of children with Pathological lesions from Croatian sites was 102.81 g (ranging from 1.9 g to 565.7 g), whereas the average weight of children without pathological lesions was much higher (average: 317.5 g, range: 7.8–920.3 g). The average cremation weight of children with pathological lesions at Austrian sites was 227 g (ranging from 81 g to 696 g), whereas the average weight of cremated bones from subadults without any visible pathological lesions was much lower (average: 47 g, range: 30–62 g). Taphonomic processes likely affect the frequencies of observed pathological lesions in subadult cremated remains. Taphonomy is caused by multiple factors, such as soil chemistry, bone weathering, and bone composition (Stodder, 2008). For instance, the sites in the Traisen Valley were all located in pebble-rich soil, which is not the best for bone preservation. Moreover, most of these graves were very shallow and strongly affected by modern ploughing. Furthermore, funerary practices, the burning process, and the selection of certain elements as *pars pro toto* further affect the condition of burnt and buried bones (Harvig *et al.*, 2012), which affect the anthropological analysis of the fragile juvenile remains and makes general inferences on the health of populations difficult.

Pathological lesions in cremated osteological remains have previously rarely been described in Bronze and Iron Age cemeteries of Central Europe. However, there are several cemeteries, geographically and chronologically close to our samples, for which published anthropological data is available and therefore can be used for comparison. They are: Pitten, Bischofshofen-Pestfriedhof, Doroslovo, Podbrežje, Domašinec, Belišće, Dolina, and Statzendorf (Table 6).

The bi-ritual Middle Bronze Age cemetery of Pitten, Austria (circa 1600–1200 BC, Rebay-Salisbury, 2020), includes 70 inhumations and 135 cremations. Most of the cremations were buried *in situ* and since no selection process took place as part of the funerary ritual, the assemblages of cremated bone are more complete and of greater weight than at other sites (Sørensen and Rebay-Salisbury, 2023). Pathological changes were not observed in any of the 51 children, whereas eight adults were affected (by caries, dental granuloma, porotic hyperostosis, arthropathy and degenerative joint disease, Teschler-Nicola, 1985).

The Late Bronze and Early Iron Age cemetery of Bischofshofen-Pestfriedhof, a western Austrian site (circa 1100–500 BC), comprised 544 cremated individuals from 465 graves. Amongst these, only 22.9% were sub-adults (Renhart, 2009). Two children, one adolescent and five females of reproductive age were found to be affected by

Figure 7. Endocranial lesion on a fragment of the occipital in a child from Grave 5 in Poljana (photo by D. Doračić).

Figure 9. Periostitis on a long bone fragment of a child from Grave 5 in Poljana (photo by D. Doračić).

Figure 8. Ectocranial porosity on a bone fragment of a child from Grave 5 in Poljana (photo by D. Doračić).

cribra orbitalia, and two children, three females and two males were found with porosities on the palate. Cribra cranii was diagnosed in eight females, two males and one child. The dominant presence of traces of deficiency disease in females has been linked to an increased yet unmet need for iron during pregnancy (Renhart, 2009, p.300).

In the cemetery in Doroslovo, in the Bačka region in Serbia, around 180 graves dated from the end of the 12th century BC to the 6th century BC were discovered. Among the analysed 91 individuals were 17 children, but no pathological changes were identified in this age group (Živanović, 2008).

Podbrežje in northeastern Slovenia is a burial ground dating to the 10th century BC in which several children had pathological lesions present. The individual in grave 84 (16 years old), had cranial porosity, while another individual in grave 101 (16 years old) exhibited traces of varying diploe thickening (Thomas, 2021, p.502, App. 1). The observed pathological change was only recorded, without an attempt at a differential diagnosis.

In Domašinec, Donje Međimurje in northern Croatia, a cemetery dating from the 10th to 9th century BC, a case of healed ectocranial porosity was recorded on the bones of the older child/adolescent (10 to 16 years old) from Grave 3. The observed lesion is most often associated with various types of anaemia, parasitism and malnutrition in childhood. Since the observed lesions were healed, the individual survived one or more episodes of physiological stress during childhood. The presence of ectocranial porosity could be related to anaemia caused by parasitism because the marshy environment dominating the area around Domašinec was very suitable for the development and spread of mosquito-borne malaria. Confirmation for this assumption would be a few examples of ectocranial porosity recorded in Podbrežje, indicating that this disorder was widespread in the Late Bronze Age communities in the area (Krmpotić and Novak, 2021, pp. 12 and 16, note 7, Figures 8–9, Plate 1, 8–9). However, the lack of local palaeoenvironmental studies (Kleijne *et al.*, 2020, p.16) that may explain the impact of the environment on the health status of prehistoric communities currently prevents further conclusions.

Excavations at Belišće in lower Podravina found two graves with one individual each, dating to the 9th century BC (Ložnjak Dizdar, 2014), one of them a child aged 5–13 with no pathological changes.

At the Dolina barrow-cemetery in the middle Sava valley, dating to the 9th and 8th century BC (Ložnjak Dizdar and Dizdar, 2021), 8 tumuli with 9 individuals were excavated, which included three children – one aged 2–6 and two children aged 4–7. No pathological lesions were identified in these graves.

Only 16 cremations were preserved of 378 burials at the early Iron Age cemetery of Statzendorf, Lower Austria (circa 800–600 BC), none of which were children or showed any pathological bone changes (Renhart, 2006, p.323).

Despite the fact that pathological changes were not the focus of the comparative studies, skeletal reports indicate that several individuals were affected due to evidence for diploe thickening, healed ectocranial porosity, cribra orbitalia, cribra cranii and porosity on the palate. Unfortunately, when observed, these are usually single lesions that are difficult to diagnose, making comparison impossible.

7. Conclusions

Our analysis has confirmed that pathological lesions are rarely noticed, but present in cremated subadults from Bronze Age Europe. Key factors for the recognition of pathological traces are the preservation of the bones, including the selection of body parts for burying, and possible post-funerary manipulation. A comparison between cremated human remains north and south of the Alps revealed that pathological lesions were less frequent in Bronze Age Austria than in Croatia. One explanation might be taphonomic; urns were typically placed in shallow pits in pebble-rich subsoils in the Traisen Valley, with many graves disturbed by modern ploughing, which resulted in small amounts of preserved bone material. Overall, however, the mortality rate of children is surprisingly high, especially at Inzersdorf with almost 50% of urn burials containing subadults. We cannot exclude the possibility that some of the children died quickly due to acute infection and famine, leaving no time for developing skeletal lesions.

Traces of stress in cremated osteological material were identified in greater numbers in the period from the 14th to the 11th century BC, in Poljana Križevačka in northwestern Croatia and Slatina in Podravina, as well as at St. Pölten in Austria. This might indicate that through time, living conditions might have improved for children and adults.

The majority of changes were identified in the youngest age group, those younger than 6 years, which corresponds to the fact that this is the most vulnerable age group within society. Children under the age of five are the most frequent in the majority of the archaeological populations (Hoppa and Vaupel, 2002; Lewis, 2007). The high childhood mortality generally postulated for the Bronze Age (Harding, 2000, p.377) is often associated with a reduction of immunity and the exposure to pathogens during the weaning process (Katzenberg *et al.*, 1996).

The majority of observed pathological lesions fall into four categories: endocranial lesions, ectocranial lesions, cribra orbitalia, and periostitis. In archaeological populations, all four types of observed changes are fairly typical for children and have common causes, such as poor hygiene, inadequate nourishment, and infectious diseases. Most individuals survived childhood disease and deficiencies and died of other causes later; meningitis may be the only true exception that is potentially visible as endocranial lesions in children's skeletal remains.

The reliance on an agricultural way of life with variable and sometimes inadequate food supplies might affect children the most: if a community was not able to grow enough food for all its members, then food could not be equally available to everyone, and children would usually be most affected by shortages. The variable proportion of children at different sites, the morbidity and mortality of children therefore provide valuable insights into changing and challenging living conditions of past communities.

The limitation of children's skeletal material potentially includes social exclusion from burial grounds and poor preservation, and the primary burial rite of cremation in Late Bronze and Early Iron Age Central Europe adds another obstacle. However, the integration of pathological data of children might help us to reconstruct different life circumstances of prehistoric communities and aid in demographic analyses. New developments in the analysis of cremated human remains, such as understanding vitamin D deficiency through dental thin section analysis (Veselka and Snoeck, 2021), age assessment with tooth cementum annulation (Großkopf and Hummel, 1992; Gocha and Schutkowski, 2013) and further histological studies (Großkopf, 2004) will shed more light on this topic in the future.

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