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The prevalence and distribution of dental caries in four early medieval non-adult populations of different socioeconomic status from Central Europe

Petra Stránská [a,*], Petr Velemínský [b], Lumír Poláček [c]

[a] Institute of Archaeology of Academy of Sciences of the Czech Republic, Letenská 4, 118 01 Prague 1, Czech Republic
[b] Department of Anthropology, National Museum, Václavské náměstí 68, 115 79 Prague 1, Czech Republic
[c] Institute of Archaeology of Academy of Sciences of the Czech Republic, Královopolská 147, 612 00 Brno, Czech Republic

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ABSTRACT

Objectives: The aim of the study was to map the dental health status in non-adult individuals and to verify whether and how the existence of caries in the non-adult age group is associated with the different socio-economic status of early medieval populations.
Material and methods: We studied the dental remains from the acropolis of the Mikulčice settlement agglomeration, where members of the higher social classes were buried, and from the Mikulčice hinterland. Overall, we evaluated 2544 teeth/3714 alveoli of deciduous dentition and 1938 teeth/2128 alveoli of permanent dentition. We determined the number of individuals with dental caries (i.e., caries frequency index, F-CE) and the proportion of teeth/alveoli with caries/ante-mortem tooth loss (i.e., caries intensity index, I-CE).
Results: We found no statistical significant difference in the F-CE values between the Mikulčice hinterland and the acropolis. In addition, we found no statistically significant difference in the proportion of teeth with carious lesions (I-CE) either in the case of deciduous dentition or in the case of permanent dentition between the hinterland and the acropolis. In the case of permanent dentition, the statistically significant highest proportion of carious lesions (I-CE) was found in Mikulčice I ($p \leq 0.05$). We confirmed an increase in the rate of caries with age.
Conclusions: The level of caries at all of the studied medieval locations was very low. We presume that lifestyle and the associated dietary habits and hygienic practices of the individuals or population groups had a greater influence on dental caries than did the socio-economic status of these individuals.

1. Introduction

Dental diseases represent a valuable source of information regarding the lifestyle,[1] social status,[2–4] diet and nutrition of past populations.[5–7] The structure and composition of dental components ensure the teeth's higher resistance to the effects of taphonomic factors and post-mortem damage. In contrast to bones, teeth are more often preserved undamaged, in their original state.[8,9]

Most researchers have studied dentition only in adult populations.[2–4,6,7,9] Increased interest in the course of

* Corresponding author. Tel.: +420 257014312; fax: +420 257532288.
E-mail address: stranska@arup.cas.cz (P. Stránská).
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ontogenesis of past populations has led to a rise in the number of studies based on non-adult individuals over the past two decades.[10,11] In children, teeth are an especially important source of information; the preservation of their skeletons is often worse than in the case of adults due to their gracile structure, excavation techniques and the manner of their burial, reflecting the cultural customs of past populations.[12,13] The importance of deciduous teeth as a source of information is supported by a number of works that studied the dental health of deciduous teeth in relation to the diet or social status of past populations.[14–17] Maternal milk represents a safe, hygienic and nutritionally balanced diet for very young children and it promotes the development of the child's immune system.[18] A milk-based diet is associated with a lower incidence of caries.[19,20] Weaning and the transition to solid foods represent a risk for the child, due not only to potential nutritional stress or the ingestion of pathogens from contaminated food but also to a higher probability of developing caries.[21,22] Saccharides, especially sucrose, fructose and glucose, play a key role in the development of caries in early childhood. These are present in honey and various sweets.[23,24] The development of caries during the first years of a child's life is influenced by living conditions, dietary habits, hygienic practices and overall care for dentition.[25] The research in recent populations has shown that one of the risk groups is children coming from families of a lower standard of living; in these children, poor hygiene practices have been proven.[26] Other groups include children whose mothers had a genetic predisposition for dental caries occurrence or children suffering from diseases accompanied by a higher predisposition for caries occurrence (e.g., calcium absorption disorder).[27] In addition, there are many possible causes that can lead to enamel development anomalies (e.g. inborn syphilis, endocrine and metabolic diseases and malnutrition).[24] Hypoplastic defects then occur on the teeth, the enamel is thinner and the decay more easily affects the dentition leading to caries.[25,28]

In this study, we evaluate the dental health status, expression and distribution of caries in non-adult individuals from several early medieval populations of different socio-economic origin, living in the same region. The archaeological research at the Great Moravian burial grounds in south Moravia (Czech Republic) has been going on for >50 years, now conducted by the Institute of Archaeology of Academy of Sciences of the Czech Republic in Brno. This research has provided an enormous amount of source material. It includes material from hundreds, exceptionally even thousands, of graves explored at Mikulčice and in the stronghold hinterland. In our study, the human skeletal remains originated from four burial grounds: (a) two 'urban-type' burial grounds from Mikulčice, the power centre of the Great Moravian Empire (Mikulčice I with 82 evaluated individuals and Mikulčice II with 168 evaluated individuals), and (b) two rural burial grounds from the hinterland of the Mikulčice settlement agglomeration (Josefov with 59 evaluated individuals and Prušánky I with 111 evaluated individuals).

The term Great Moravia denotes the West Slavic territorial and political entity existing in the 9th and at the beginning of the 10th centuries to the north of the Middle Danube area. The centre of this state was situated in the area of Moravia (part of today's Czech Republic), Western Slovakia and Lower Austria.[29] Mikulčice was one of the leading Great Moravian centres (Fig. 1). We distinguish between 'urban' burial sites situated in the main (fortified) centres and 'rural' sites spread across the hinterland (Figs. 2–6). Grave finds from the centre demonstrate especially burials of members of higher social strata, whereas the population buried at the rural cemeteries can be considered as part of the middle and lower classes of the Great Moravian society.[30,31]

When defining our aims, we drew from our previous study,[4] which compared the incidence of caries in the adult inhabitants of the Mikulčice centre and its hinterland. The results of that study indicated that socially differentiated

Fig. 1 – Early medieval Central European sites evaluated. (Edited by P. Stránská according to the images available under licence Creative Commons—Author: Petr Graclík and Wikimedia Commons—Author: David Liuzzo.)

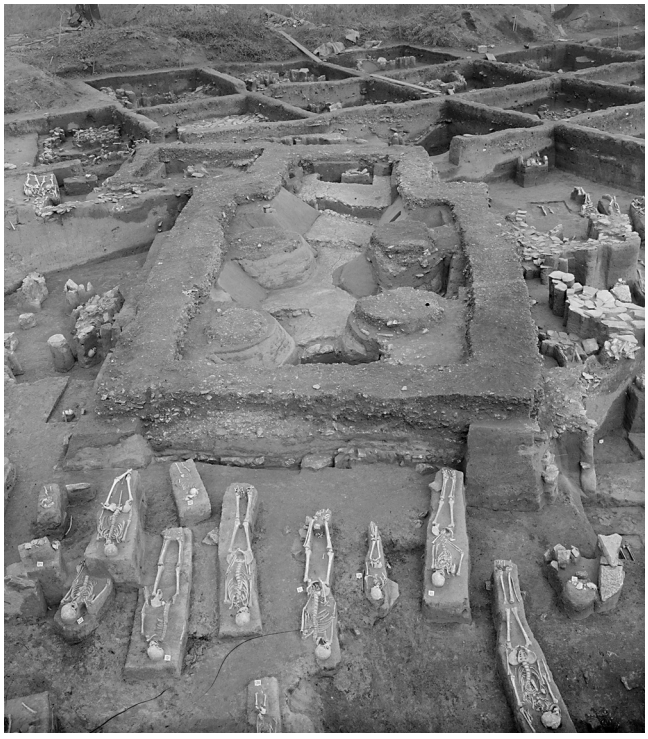

Fig. 2 – Mikulčice, church Nr. 2 on the acropolis. The picture from 1955 showing an overview of the excavation area with skeletal remains in situ.

Fig. 4 – Mikulčice, burial site at the third church on the hilltop settlement (acropolis). The burial site at the church was extensively used for burials, as seen from up to three layers of graves.

groups did not demonstrate any differences in susceptibility to caries at a younger age; significant differences appeared only with increasing age. The population of higher socio-economic status from the Mikulčice castle showed a lower prevalence of caries compared to the rural population. Similarly, a lower prevalence of caries was found in individuals from 'rich' graves in all of the studied burial grounds.

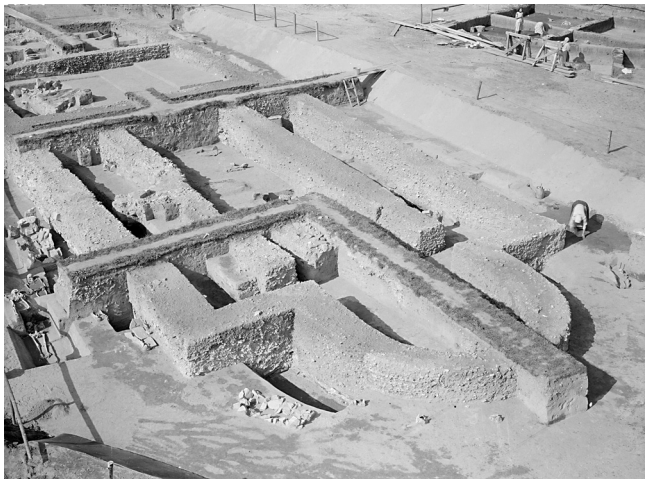

Fig. 3 – Mikulčice, third church on the hilltop settlement (acropolis). Finding of a three-naved basilica in 1957, long shot. The basilica was the biggest and probably also the most important church edifice in the Great Moravia area in the 9th century. In the burial site at the church, >550 graves have been examined.

The aim of the current study was thus to map the dental health status in non-adult individuals and to verify whether and how the existence of caries in the non-adult age group is associated with socio-economic status in early medieval populations. We presumed that the degree of differences would allow us to indirectly infer differences in diet composition, quality and quantity for the individual groups.

The first hypothesis that we tested was the assumption that the prevalence of caries in children up to 6 years of age is related to the high-risk period of weaning and that it would not differ from the other age categories. The second hypothesis we tested was the assumption that caries prevalence in children from localities with different socio-economic characters (central castle vs. rural hinterland) would not differ. Finally, the third hypothesis we tested was the assumption that within the individual burial grounds, the incidence of caries would be the same in individuals with different grave goods, that is, for whom different socio-economic statuses could be presumed. At the same time, we studied whether these two relationships were the same for the non-adult population as well as the adult population.

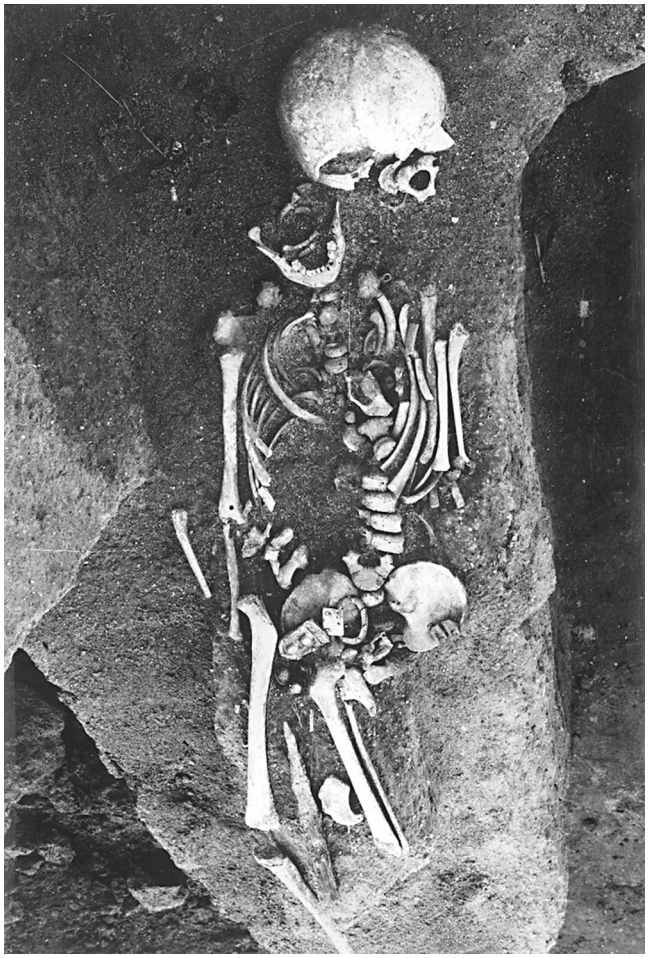

Fig. 5 – Mikulčice, burial site at the second church on the hilltop settlement (acropolis), grave Nr. 100 with rich grave goods. Approximately 3-year-old child with spectacular metal-plated belt, big silver buttons ('gombiks') and iron knife. The gilded silver ending of the belt was on the rear side decorated by an 'orant' figure.

Fig. 6 – Mikulčice, burial site at the third church on the hilltop settlement (acropolis), graves Nr. 257 (right) and 258 (left). Both the children graves lacked any equipment.

2. Material and methods

2.1. *Population samples*

Mikulčice was one of the leading Great Moravian centres—the Mojmir dynasty is assumed to have had its seat there.[32] Historical resources on Great Moravia are a testament to several wars with the Frankish Empire.[29] In spite of the not particularly favourable political situation, the Mikulčice region was a pleasant place to live. Individuals in this time period lived in relatively mild environmental conditions known as the Little Climatic Optimum, which occurred between the 9th and the 12th centuries.[33] The studied territory lies in the warmest region of the Czech Republic. The fortified centre was found on a few islands in the Morava River. As the floodplain apparently did not offer suitable conditions for the cultivation of cereals, the necessary arable land was replaced by the more distant position outside the floodplain. A hypothetical radius of approximately 10 km is considered to be the economic hinterland of the Mikulčice centre. This is based on the estimated size of the agricultural area necessary to cover the cereal consumption required for the subsistence of the power centre's population.[34]

Great Moravian society was marked by great social inequality: the social pyramid with the ruler, principals, nobles and free tenants at the top and the inhabitants in various degrees of dependency. The lowest echelon of the social hierarchy was represented by slaves, that is, paupers and people with no rights. The largest group in the society included 'simple people', members of the village commons who gradually became legally dependent on the ruler, but otherwise remained politically and economically free.[34,35]

However, except for a few cases, the written resources usually do not mention the social structure of Great Moravia. The main source of information on the social structure is archaeology and its findings: settlements (both fortified and unfortified) and burial sites.[32] The grave goods from the Mikulčice acropolis document that members of the higher social classes were predominantly buried at this site. The social elite's presence in the Great Moravian graves is proven by archaeological findings of weapons, horse riding equipment, jewels made of precious metals, etc.[31] The population that was buried in the rural cemeteries can be considered as a part of the middle and lower classes of Great Moravian society; exceptions are represented by members of the local elite warriors with swords.[36] However, the attribution of the individual categories of grave findings to a particular social class is not unproblematic. Not only were the graves equipped based on the wealth of the individual but also other factors played a role, such as the social status of the individual, the socio-economic situation of the community, the influence of the church, local customs and rituals. Thus, the terms 'rich' and 'poor' cannot be so strictly attributed to the graves.[34,36,37]

The Great Moravian burial sites are dated exclusively based on the typological and chronological classification of the grave findings. That is why the dating can only be an estimate. Great Moravia ceased to exist due to an attack by the Hungarians in the beginning of the 10th century (906?). After a certain period of time and to a very limited extent, burials continued to take

place at the central burial grounds, including the church cemeteries. However, these burials gradually subsided, and they finally ended sometime during the first half of the 10th century. These youngest funerals probably belong to the remnants of the population living in the former power centres.[38–40]

The skeletal remains studied originated from four burial grounds: two 'urban type' burial grounds from the Mikulčice acropolis and two 'rural' burial grounds from the hinterland of the Mikulčice settlement agglomeration.

The first burial ground, 'Mikulčice I', was situated around the first and second Mikulčice church. It included 236 individuals, of which 101 were non-adults.[41] The second burial ground, 'Mikulčice II', was located near the third Mikulčice church basilica, the central and largest church within the Mikulčice locality. This site included 566 individuals, of which 213 were non-adults (<19 years).[42]

The human remains from the hinterland of the Mikulčice settlement agglomeration came from two rural burial grounds. These sites included the following: Prušánky I, with 313 individuals, of which 153 were non-adults,[43,44] and Josefov, with 167 individuals, of which 86 were non-adults.[45,46]

The definition of 'rich' graves was based on the classification of Stloukal and Hrubý.[47,48] Based on this classification, we classified the following numbers of graves as 'rich': 41 graves (36.9%) in Prušánky, 17 (23.7%) in Josefov, 23 (28.0%) in Mikulčice I and 36 (21.4%) in Mikulčice II.

2.2. *Palaeodemography indicators*

When evaluating the human skeletal remains, it is possible to estimate only a biological age but not the chronological age of the individual. We divided the non-adult individuals into three age categories, according to the state of dental development. ''Subadult age-at death estimations can be considered more accurate than adult age estimations because of the telescoped time span of human growth relative to the total life span over which age variability is assessed''.[13] The biological age of a non-adult can be determined according to either the teeth mineralisation (dental age) or the ontogenesis of the long bones (bone age). In juveniles, the process of creation of epiphyses, that is, the stage of ossification, is decisive. The dental age is of greater accuracy, as it is less variable in living populations and less influenced by hormones, local environmental factors, nutrition and social factors.[49,50] Therefore, in individuals whose teeth were preserved, the biological age was assessed based on the teeth mineralisation.[51] In individuals whose teeth were not preserved, the biological age was assessed based on the ontogenesis of the long bones of the extremities.[52]

To avoid any terminological ambiguities,[49] instead of using verbal designations (categories such as 'infants' and 'juveniles'), we labelled the age groups with the numerical age range (Table 1). The 0–6-year category was divided into two intervals to cover the breastfeeding period and weaning:

0–6 years (divided into subcategory 0–3 and 3–6): erupting and completely erupted deciduous dentition;
7–14 years: mixed dentition;
15–19 years: completely erupted permanent dentition (except for the third permanent molars).

2.3. *Dental characteristics*

We evaluated all of the preserved deciduous and permanent teeth in non-adult individuals. The minimal number of teeth per individual was seven. We studied the presence of carious lesions and location of caries, as well as the ante-mortem tooth loss (AMTL) (Figs. 7 and 8). Tooth loss was classified as AMTL or post-mortem tooth loss (PMTL). AMTL is defined as the absence of a tooth and the resorptive destruction of the alveolus.[53] The teeth were classified as lost post mortem if the presence of the alveolar socket was clearly evident[16] (Table 2).

The presence of dental caries was examined macroscopically, with the naked eye. Visual determination is the most suitable method available.[54] We took into consideration caries that had disrupted the enamel and where the cavity had a basin-like shape and smooth walls. We did not evaluate the different colouring of the enamel, which may sometimes represent the initial phase of caries.[55,56] We divided the caries cavity into three categories according to the affected site of the tooth: the crown, root or cementum–enamel junction (CEJ) region. We further divided these categories according to the site of the affected dental surfaces: occlusal, approximal, buccal and lingual in premolars and molars and approximal, buccal and lingual in the case of canines and incisors.[6,16,57]

2.4. *Statistical evaluation*

As inter-observer error values when evaluating the presence or absence of caries are usually low,[17,54] we focused on assessing intra-observer error. The dentition of 30 children was macroscopically evaluated twice at an interval of several months. To verify intra-observer error, we calculated the % concordance (%A) according to the formula: $\%A = \frac{(n-n')\times 100}{n}$, where n is the total number of paired observations and n' is the number of discordant observations.

Table 1 – Number of individuals evaluated.

	No. of non-adult individuals				No. of non-adult individuals evaluated			
Age	0–3	3–6	7–14	15–19	0–3	3–6	7–14	15–19
Mikulčice I	37	28	21	15	23	28	20	11
Mikulčice II	61	79	48	25	51	59	39	19
Josefov	44	18	17	7	22	16	16	5
Prušánky	85	33	29	6	51	26	28	6

Fig. 7 – Mikulčice I—Grave Nr. 121. Caries in both deciduous upper first molars (arrows).

Fig. 8 – Mikulčice I—Grave Nr. 108. Caries in permanent lower first molar (arrow).

We used two characteristics to evaluate the caries prevalence—the caries frequency index (F-CE; C = caries, E = extraction) and the caries intensity index (I-CE; C = caries, E = extraction). Both indexes were introduced in the study by Stloukal and Vyhnanek.[58]

The F-CE expresses the percentage of the evaluated individuals who have at least one tooth with a caries or at least one healed alveolus as a result of AMTL.

The I-CE provides information on how many teeth of the total evaluated teeth were affected by caries or lost during life. The index is the sum of two percentages—the percentage of caries-affected teeth out of the total number of preserved teeth and the percentage of healed alveoli out of the total number of preserved alveoli.

We assessed both indicators in relation to age at death, the burial ground and its location within the settlement agglomeration, that is, in relation to the socio-economic status of those buried there ('poor' graves vs. 'rich graves'). This evaluation was carried out independently for the deciduous and permanent dentition.

We used the non-parametric Pearson χ^2 test to test the zero hypothesis. We used the STATISTICA 6.0 program for our calculations.

3. Results

3.1. *The caries expression in relation with the tooth type and caries location*

In general, carious lesions affect molars more often than the incisors, canines or premolars.[1,59] In all of the samples studied, both deciduous and permanent molars were affected most often.

Table 3 shows the percentage of carious lesions of individual deciduous and permanent teeth. Caries of the deciduous anterior teeth was noted in only one child from the Mikulčice II burial ground, in whose case the other teeth were also affected by caries. It may be assumed that either this was a child with a greater predisposition to develop caries (due to genetic factors or any disease) or the child's diet contained more cariogenic substances. An upper central incisor caries is not frequent and can be also attributed to night-feeding practices, where the oral clearance is lower due to reduced salivary secretion during sleep.[60]

No caries occurred on any of the 716 preserved anterior permanent teeth. In the case of deciduous dentition, we did not find any statistically significant differences in caries rates between the teeth of the upper and lower jaw.

Most of the caries affecting permanent dentition occurred on the mandibular teeth, and the difference compared to the maxilla was statistically significant ($p \leq 0.01$).

The locations of caries are listed in Table 4. In all carious teeth, the crowns were most often affected, 87.5% of deciduous dentition and 86.7% of permanent dentition. At the CEJ region, caries occurred in 8.3% of carious deciduous

Table 2 – Archaeological sites evaluated—available paleodental data.

	Deciduous dentition							Permanent dentition						
	TP	TL	TH	TC	AP	PMTL	AMTL	TP	TL	TH	TC	AP	PMTL	AMTL
Mikulčice I	546	13	541	5	931	398	0	370	18	361	9	469	117	0
Mikulčice II	992	43	979	13	1768	819	0	684	34	680	4	910	258	2
Josefov	371	61	367	4	558	248	0	330	20	330	0	366	56	0
Prušánky	635	338	633	2	453	156	0	554	278	552	2	332	56	0
In total	2544	455	2520	24	3714	1621	0	1938	350	1923	15	2077	487	2

TP—teeth present, TL—teeth loose, TH—teeth without caries, TC—teeth with caries, AP—alveoli present (AP = (TP − TL) + PMTL + AMTL), PMTL—teeth lost postmortem, AMTL—teeth lost antemortem.

Table 3 – Caries prevalence of individual teeth.

		Deciduous dentition		
		Teeth present	Carious teeth	% Of carious teeth
Maxilla	i1	115	–	–
	i2	132	1	0.8
	c	194	2	1.0
	m1	373	8	2.1
	m2	387	1	0.3
	In total	1201	12	1.0
Mandible	i1	92	–	–
	i2	147	–	–
	c	221	–	–
	m1	435	5	1.1
	m2	448	7	1.6
	In total	1343	12	0.9
		Permanent dention		
Maxilla	I1	128	–	–
	I2	118	–	–
	C	107	–	–
	P1	102	–	–
	P2	96	–	–
	M1	243	–	–
	M2	116	1	0.9
	M3	49	1	2.0
	In total	959	2	0.2
Mandible	I1	129	–	–
	I2	133	–	–
	C	101	–	–
	P1	99	–	–
	P2	106	3	2.8
	M1	249	7	2.8
	M2	114	3	2.6
	M3	48	–	–
	In total	979	13	1.3

and 13.3% of carious permanent teeth. The root was affected in only a single deciduous tooth. Nevertheless, the tooth was partially damaged. As the cavity was located close to the CEJ region, the caries spread most likely from the crown. Root caries usually occurs in higher age groups in association with parodontopathy. It develops when a section of the tooth is exposed, for example, in association with parodontitis.[61] However, it is sometimes difficult to determine the initial site of the caries, which could have spread to the cement from the CEJ region or even from the crown.[20]

Table 4 – Location of caries.

	No. of caries (% of caries)	
	Deciduous dentition	Permanent dentition
Crown	21 (87.5)	13 (86.7)
Occlusal	5	7
Approximal	15	3
Buccal/lingual		2
Occlusal/approximal		1
Buccal/approximal	1	
CEJ	2 (8.3)	2 (13.3)
Approximal	1	2
Lingual	1	
Radix	1 (4.2)	
In total	24 (100.0)	15 (100.0)

The localisation of caries differed slightly in the case of deciduous and permanent dentition. We evaluated the occlusal surfaces of the molars and premolars (in the case of permanent dentition) in 1643 deciduous and 1222 permanent teeth. As for the approximal surfaces, we counted the incidence of caries as a percentage of 5088 surfaces for deciduous dentition and 3876 surfaces for permanent dentition. In the case of deciduous dentition, caries affected nearly the same percentage of both occlusal (0.3%) and approximal surfaces (0.29%). In the case of permanent dentition, the occlusal surface was predominantly affected (0.57%), with caries affecting the approximal surfaces only sporadically (0.08%). The involvement of buccal and lingual surfaces, as well as more extensive caries affecting several surfaces, was rare (deciduous dentition – two individuals – Mikulčice I and II; permanent dentition – two individuals – Mikulčice I and II).

3.2. *Caries prevalence from the aspect of age and socio-economic status*

3.2.1. *The individuals with caries expression, F-CE*

The number of individuals with at least one carious lesion in relation with age at death is summarised in Table 5. In all of the burial grounds, there was only a small number of non-adult individuals with caries. We did not record any statistically significant difference between the centre (Mikulčice I and II) and the hinterland of the Mikulčice–Valy settlement agglomeration (Josefov and Prušánky).

In the 0–3 year age subcategory, we did not note any children with caries. We found a statistically significant increase in the number of affected individuals at both the Mikulčice burial grounds between the age categories of 0–6 (3–6 years, respectively) and 7–14 years ($p \leq 0.01$) and at the Prušánky burial ground between the age categories of 7–14 and 15–19 years ($p \leq 0.05$).

3.2.2. *The proportion of teeth with carious lesions, I-CE*

These results are shown in Table 6. As mentioned above, the I-CE index is calculated as a sum of two percentages (the percentage of caries-affected teeth and the percentage of healed alveoli in consequence of AMTL). However, the percentage of healed alveoli was only added in the Mikulčice II set, where we found two AMTL. In other sets, no AMTL were recorded.

We confirmed an increase in the rate of caries with age in both deciduous and permanent dentition. At Josefov, we did not find caries in any of the permanent teeth.

The highest I-CE value involving deciduous dentition was found at the Mikulčice II burial ground, followed by Josefov, Mikulčice I and Prušánky, where the individuals demonstrated the lowest values. To avoid the influence of the age profile on the statistical test, we decided to test the difference in caries proportion between the hinterland and the castle only within one age level (7–14 years). We did not find the statistically significant difference between the hinterland and the castle.

Table 5 – The percentage of individuals with dental caries, F-CE.

	Josefov				Prušánky				Mikulčice I				Mikulčice II			
	Intact dentition		Carious dentition		Intact dentition		Carious dentition		Intact dentition		Carious dentition		Intact dentition		Carious dentition	
Age	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
0–3	22	100.00	–	–	25	100.0	–	–	23	100.0	–	–	56	100.0.	–	–
3–6	15	93.30	1	6.70	51	98.10	1	1.90	27	96.30	1	3.70	51	94.10	3	5.90
0–6 together	37	97.36	1	2.63	76	98.70	1	1.29	50	98.03	1	1.96	107	97.27	3	2.72
7–14	14	87.50	2	12.50	27	96.42	1	3.57	16	80.00	4	20.00	33	84.61	6	15.38
15–19	5	100.00	-	–	4	66.66	2	33.33	7	63.63	4	36.36	17	89.47	2	10.52
In total	56	94.91	3	5.08	107	96.4	4	3.6	73	89.02	9	10.97	157	93.45	11	6.54

N—No. of individuals.
%—% of individuals.

The evaluation of permanent dentition produced the following results. The highest I-CE values were recorded in individuals from the burial grounds at Mikulčice I ($p \leq 0.05$), followed by Mikulčice II and Prušánky. To avoid the influence of the age profile on the statistical test, we decided to test the difference in caries proportion between the hinterland and the castle only within one age level (15–19 years). The statistically significant difference was not evident.

3.3. *Caries prevalence in individuals from 'rich' and 'poor' graves*

The evaluation of F-CE and I-CE values in deciduous and permanent dentition did not demonstrate a statistically significant difference between individuals from graves with 'rich' grave goods and individuals buried with 'poor' or without any grave goods at any of the localities. The results are shown in Tables 7 and 8.

4. Discussion

Our study is based on the presumption that dental health status indirectly reflects the living conditions of our ancestors, including the composition, quality and quantity of their diet. Caries frequency, AMTL and inflammatory changes at the site of dental arches, in turn, reflect the state of health. Given the above, we evaluated the incidence of caries in four geographically close early medieval (Great Moravian) populations of different socio-economic status.

Research on the dental health of past populations has its limitations, of which we were well aware when interpreting our results. These limitations include the state of skeletal preservation, different methods of evaluating traits and calculating caries prevalence and different quantitative and qualitative completeness of individual studies.[61–63] The results also may be distorted by the fact that not all post-mortem loss teeth were found during archaeological excavations. For example, Costa[64] deals with the problem of teeth lost post mortem, who proposed a correction factor, which is multiplied by the number of affected teeth by caries. In our opinion, however, inaccurate numbers are replaced by other inaccurate numbers in the mathematical modelling.

Sufficient sample size is important. In our case, we evaluated several hundred teeth from >50 individuals at each burial ground, which, from the aspect of statistical analysis, represents a sufficiently large number. We calculated the percentage of concordance (%A) to verify intra-observer error.[17] We evaluated the dentition in 30 randomly selected individuals twice, at an interval of several months. Identical observations were achieved in 96% of the evaluated teeth. Due to a sufficiently high percentage of concordance, we need not take this error into consideration in the assessment.

No less important is the state of preservation of individual types of teeth. In general, carious lesions affect molars more frequently than front teeth, canines or premolars.[3,65-67] If the assumed distribution of individual types of teeth is incorrect and the molars predominate, the proportion of caries may be significantly artificially increased.[5,20] In the evaluated samples, the distribution of permanent anterior teeth, premolars and molars was similar and, except for minor deviations, corresponded to the data cited for permanent dentition by Hillson[20]: the anterior teeth and molars represented 37.5% each and the premolars represented 25% of the teeth. We may similarly determine the distribution of deciduous teeth: anterior teeth 60% and molars 40%. However, in our samples, there were twice as many molars as anterior teeth. As this discrepancy was the same at all of the localities, it was not necessary to take it into consideration when comparing the caries prevalence between the population groups. A significant predominance of molars was also recorded by Garcin et al.[17] Some researchers evaluate only deciduous molars,[59] while others report overall cariosity along with caries specifically affecting the molars,[12] and others do not report the number of individual types of teeth at all[14,68]. Thus, it is very important to evaluate deciduous and permanent dentition separately, as shown in this study.

When comparing results with other studies, the means of evaluating the compared data must also be taken into consideration. Most studies provide clear and comprehensive information about the methods used to calculate the prevalence of caries.[63] Some authors evaluate caries prevalence jointly in adult and non-adult individuals.[69] The studies with which we compared our results have been selected on the basis of being conducted at similarly dated European localities and reporting the incidence of caries as a percentage of teeth,[12,17,67] or they also recorded the number of affected individuals[57,65,66,68,70].

According to our results, the involvement of the crown predominated (87.5% in the case of deciduous dentition and 86.7% in the case of permanent dentition). Caries was mainly located on the occlusal surfaces. Children's teeth are not

Table 6 – The proportion of teeth with carious lesions, I-CE.

	Deciduous dentition	No. of caries (AMTL)	% of caries (AMTL)	Permanent dentition	No. of caries (AMTL)	% of caries (AMTL)	Deciduous dentition	No. of caries (AMTL	% of caries (AMTL)	Permanent dentition	No. of caries (AMTL)	% of caries (AMTL)
	Josefov						Prušánky					
Age												
0–3	172	–	–	–	–	–	325	–	–	–	–	–
3–6	109	1	0.90	34	–	–	206	1	0.50	69	–	–
0–6 together	281	1	0.35	34	–	–	531	1	0.18	69	–	–
7–14	90	3	3.30	170	–	–	104	1	0.96	331	–	–
15–19	0	–	–	126	–	–	0	–	–	154	2	1.29
Teeth in total	371	4	1.07	330	–	–	635	2	0.31	554	2	0.36
Alveoli in total	558	–	–	366	–	–	453	–	–	332	–	–
I-CE			1.07			–			0.31			0.36
	Mikulčice I						Mikulčice II					
0–3	211	–	–	–	–	–	375	–	–	–	–	–
3–6	241	1	0.41	21	–	–	427	3	0.70	9	–	–
0–6 together	452	1	0.22	21	–	–	802	3	0.37	9	–	–
7–14	94	4	4.25	125	1	0.80	189	10	5.29	321	1	0.31
15–19	0	–	–	224	8	3.57	1	–	–	354	3	0.84
Teeth in total	546	5	0.91	370	9	2.43	992	13	1.31	684	4	0.58
Alveoli in total	931	–	–	469	–	–	1772	–	–	910	2	0.22
I-CE			0.91			2.43			1.31			0.80

Table 7 – I-CE in "rich" and "poor" graves in deciduous dentition.

	Graves	Present	N	No. of caries (AMTL)	% of caries/AMTL	I-CE
Josefov	Rich	Teeth	67	1	1.5	1.5
		Alveoli	90	–	–	
	Poor	Teeth	304	3	1.0	1.0
		Alveoli	468	–	–	
Prušánky	Rich	Teeth	193	1	0.5	0.5
		Alveoli	152	–	–	
	Poor	Teeth	442	1	0.2	0.2
		Alveoli	301	–	–	
Mikulčice I	Rich	Teeth	159	3	1.9	1.9
		Alveoli	229	–	–	
	Poor	Teeth	357	2	0.6	0.6
		Alveoli	701	–	–	
Mikulčice II	Rich	Teeth	278	3	1.1	1.1
		Alveoli	714	–	–	
	Poor	Teeth	389	10	2.6	2.6
		Alveoli	1383	–	–	

N—no. of teeth/alveoli present.

Table 8 – I-CE in "rich" and "poor" graves in permanent dentition.

	Graves	Present	N	No. of caries/AMTL	% of caries/AMTL	I-CE
Josefov	Rich	Teeth	130	–	–	–
		Alveoli	151	–	–	
	Poor	Teeth	180	–	–	–
		Alveoli	215	–	–	
Prušánky	Rich	Teeth	330	1	0.3	0.3
		Alveoli	198	–	–	
	Poor	Teeth	224	1	0.4	0.4
		Alveoli	134	–	–	
Mikulčice I	Rich	Teeth	162	6	3.7	3.7
		Alveoli	190	–	–	
	Poor	Teeth	208	3	1.4	1.4
		Alveoli	281	–	–	
Mikulčice II	Rich	Teeth	195	1	0.5	0.5
		Alveoli	233	–	–	
	Poor	Teeth	489	3	0.6	0.9
		Alveoli	677	2	0.3	

N—no. of teeth/alveoli present.

affected by pronounced abrasion and thus there is sufficient time for caries to develop on the occlusal surface.[9,12,57] However, in contrast to the findings of some authors who mapped the dental health status in non-adult individuals from various early medieval European localities,[12,14,57,68,71] interproximal lesions on deciduous dentition were equally frequent.

Our results indicate that at all of the burial grounds studied the prevalence of caries was relatively low. The F-CE reached 3.6–10.9%. A number of authors cite higher values in non-adult individuals, even at early medieval localities, such as 28–36% in Šebastovce,[14] Děvín[70] or Pohansko[68]. A more frequent experience of caries is quite common at burial grounds dating to the late Middle Ages and modern times, for example, 16–73% in Scotland,[65] Finland[66] or England[72].

The I-CE was also very low at all of the burial grounds, in the case of both deciduous (0.75–2.14%) and permanent dentition (0.0–4.27%). Comparable values of the percentage of carious lesions in deciduous dentition were recorded by Garcin et al.[17] at the burial grounds in Cherbourg (1.3%), Mikulčice–Kostelisko (2.0%) and by Kozaczek[73] in the population of Western Slavs (1.6–3.4%). Comparable values of I-CE in permanent dentition were reported by Bodoriková, Veselá[14] in Šebastovce (3.5%) and by Garcin et al.[17] in Mikulčice (4.3%). Some researchers cite a higher percentage of carious lesions at similarly dated burial grounds, for example, in the deciduous dentition at Šebastovce 4.9%,[14] Bijelo Brdo 6.0–8.7%,[57] in Scotland 4.3%,[12] in Britain 8.6%,[67] and at Děvín 20.0%[70] and in permanent dentition at Děvín 5.7%[70] and Pohansko 6.2%.[68]

We may also define caries as a 'sugar-dependent infectious disease'.[24] However, nutritional status and eating habits have different effects on the susceptibility to caries in deciduous and permanent teeth. High caries prevalence of deciduous dentition is more often associated with overall malnutrition and nutritional stress, which render teeth more sensitive to the development of caries[21]. In children aged 0–6 years, caries is sometimes related to the feeding practices in early childhood (night breastfeeding, night bottle feeding, etc.) and is called 'baby bottle tooth decay', 'nursing caries' or 'night bottle mouth'. This caries occurs on the planes of teeth where the risk of decay is usually low, such as the facial planes of upper incisors and lingual and buccal planes of the upper and

lower molars.[74,75] During the night, oral clearance is lower due to reduced salivary secretion during sleep.[60] In addition, the weaning poses greater risks as to caries occurrence.[21,22] In general, early childhood caries (ECC), as it is called today, is a result of several factors and its aetiology has not been fully examined yet.[76]

The positive significant correlation between a cariogenic diet and a higher incidence of caries applies especially in the case of permanent dentition.[77] Based on our results, we may presume good living conditions and a diet not too rich in cariogenic components, especially in younger children.

Written sources describing the diet and eating habits of children and the educational practices of old Slavs practically do not exist. It is clear that the composition of the diet of small children up to the age of 6 years was similar, regardless of social status. In the middle ages, maternal milk represented the exclusive diet of the youngest children from birth to at least the age of 4–6 months, regardless of socio-economic status and lifestyle; weaning most often occurred around the age of one to 1½ years and sometimes around the age of 2 years, especially among the poorer classes.[78–80] Weaning and transition to solids between the first and third year of life is also supported by studies that analysed stable nitrogen isotopes.[22,81–83] This is related to the fact that the children's deciduous dentition had already erupted and they were able to eat everything. Maternal milk contains only a small amount of cariogenic lactose, and it also includes a number of substances that prevent the demineralisation of hard dental tissues. The milk-based diet was gradually supplemented with a solid component common in society at the time, such as fermentative wheat or rye bread, cereal flat cakes and mash made from millet, barley or oats. Meals were soaked in honey water and bread in chicken or beef broth, and meat was added later on.[84] Our results showed very low caries prevalence in all of the samples from the youngest age category of 0–6 years. We did not find caries in individuals younger than 3 years. It is clear that, while weaning did represent a certain risk to children from the aspect of a higher probability of developing caries, the overall cariosity of dentition remained low during this period. Thus, the assumption that the prevalence of caries from 0 to 6 years would be similar to that in older children was not confirmed.

A number of current studies concur that the caries prevalence in past populations increases with life expectancy.[9,57,61] Given the aetiology of caries and the progressive character of this disease, it is clear that the higher the life expectancy of an individual, the higher the probability of developing caries or of worsening an already present lesion.[24] The trend of an increasing number of affected individuals and an increase in the rate of caries with age, regardless of the type of dentition, was especially evident in children from the burial grounds in the hinterland (F-CE/I-CE: Josefov 0–6 years 2.63/0.35 and 7–14 years 12.5/3.3; Prušánky 0–6 years 1.29/0.18, 7–14 years 3.57/0.96 and 15–19 years 33.3/1.29).

In the Mikulčice centre, the results are not as unequivocal, with differing values for deciduous and permanent dentition. However, the positive correlation between cariosity and age was also manifest here (I-CE deciduous dentition: Mikulčice I 0–6 years 0.22 and 7–14 years 4.25, Mikulčice II 0–6 years 0.37 and 7–14 years 5.29; I-CE permanent dentition: Mikulčice I 7–14 years 0.8 and 15–19 years 3.57, Mikulčice II 7–14 years 0.31 and 15–19 years 0.84). Similar results from medieval populations have been reported by other authors. In Šebastovce, Slovakia,[14] in the infants I (0–6 years) category, the proportion of individuals with carious lesions reached 14.63% and in the infants II (6–14 years) category as much as 40.62%; at the Croatian locality of Bijelo Brdo from the 10th to the 11th century, Vodanovic et al.[57] recorded 14.3% of 6–12-year-old children as affected individuals and as much as 40.0% of those aged 13–20 years.

The problem of such studies is that it is impossible to unequivocally define the connection between socio-economic status, dietary habits and the incidence of caries. On the one hand, many studies concur that the diet of poorer inhabitants and members of the lower social classes in medieval populations was based predominantly on plant sources, such as cereal mash and wheat and rye bread,[9,84,85] which are highly cariogenic food components.[19,20] On the other hand, their diet lacked high amounts of cariogenic sugars and was tougher, which reduced the formation of caries. By contrast, the softer, better prepared meals of the higher classes promoted the formation of caries.[9,61] The diet of the rich and poor mainly differed in terms of preparation rather than composition.[84] Some studies indicate that when rural and more primitive populations adopted the habits and dietary patterns of urban and more developed societies, these populations saw a dramatic increase in the prevalence of caries.[77]

As to F-CE, no statistically significant difference was demonstrated between the Mikulčice hinterland and castle. Garcin et al.,[17] who evaluated the incidence of caries and enamel hypoplasia in the non-adult population of the Mikulčice–Kostelisko burial ground, presume, on the basis of their results, that this population enjoyed good living conditions and was not exposed to any long-term environmental stress. In our previous study involving the dental health of adult individuals,[4] we found a higher proportion of individuals with caries, but the difference between the Mikulčice hinterland and castle was also non-significant (F-CE: Mikulčice–Kostelisko 75.5, Josefov 79.4 and Prušánky 69.2).

As to I-CE, this reached higher values in the centre compared to the hinterland, in the case of both deciduous and permanent dentition but this difference was not statistically significant.

When comparing the caries prevalence between 'rich' and 'poor' graves within the individual localities, we did not find any significant difference. However, the richness of grave goods need not unequivocally reflect the social status attained by the buried individual within society. Especially in Mikulčice, with its great concentration of church burial grounds, offerings could have diminished under the influence of the religious environment.

In adult individuals, we reached the conclusion that the socially differentiated groups of inhabitants did not demonstrate any differences in susceptibility to caries at a younger age, and it was only with increasing age that significant differences emerged.[4] The socio-economically better-off population from Kostelisko was characterised by lower caries prevalence compared to both rural populations. Similarly, lower caries prevalence was found in individuals from 'rich'

graves in all of the burial grounds. These differences may be related not only to the different diet but also to different hygienic practices or practices associated with the 'maintenance' of caries-affected teeth (e.g. extraction of affected teeth).

Our results showed that, in the affected children, caries involved one or two teeth at most. It was only at the two Mikulčice burial grounds that we found two individuals with several affected teeth. An older child (aged 7–14 years) buried at the Mikulčice II burial site had five carious deciduous teeth and the remains of an adolescent aged 15–19 years from the Mikulčice I site had four carious permanent teeth. Both of these individuals significantly influenced the I-CE calculated for these burial grounds. Although no other pathological changes have been found on the skeletal remains of these individuals, they could either have suffered from a disease (such as the calcium absorption disorder, or a disease influencing the salivary secretion and pH or disease which result in a disturbances in amelogenesis) or have been individuals who, within the socially higher group, received somewhat preferential treatment; for example, their diet contained more foods with higher sugar content than was the norm at the time.[65] A similar example of high dental cariosity in a member of the nobility has been reported by O'Sullivan et al.[59] in the case of Anne Mowbray (approximately 13 years old), the bride of Richard Duke of York. Rural inhabitants more often replaced highly cariogenic honey, which was nonetheless a common component of the diet of all social classes and was also given to the youngest children with dried fruits.[80] The overall state of health of the youngest children was also influenced by the state of health and hygienic practices of their mothers or wet nurses.[86–88] However, we are unable to assess these factors satisfactorily. Nonetheless, we presume that the lifestyle of the higher classes of Great Moravia came under Byzantine influence, as documented in the society's material culture.[31] Thus, this could have involved more refined hygienic practices, which would partially compensate the unhealthy dietary habits. It is clear that the diet to which older children and adolescents had access or which they were allowed to consume was closely related to social position.[83]

5. Conclusion

The study deals with the comparison of the dental health conditions of non-adult individuals from four early medieval Great Moravian population samples with similar demographic profile and of different socio-economic status. Our results indicate that the occurrence of caries was relatively low at all of the burial grounds. The number of individuals with caries as well as the proportion of carious teeth increased with age. In the 0–3-year age subcategory, we did not note any children with caries. We did not record any statistically significant difference between the centre and the hinterland.

Except for a few cases, the written resources usually do not mention the social structure of Great Moravia. However, the great social inequality has been proven by several archaeological findings.[35] Furthermore, the different lifestyles of the people living in the centre and in the agricultural hinterland can be inferred from other biological features of the skeleton, such as changes in muscle and ligament insertions (enthesopathy) or the asymmetrical size and shape of the skull.[89–91] Nevertheless, the differences between the socio-economic groups were in all cases less marked than those between the sexes. This fact is further supported by the study conducted by Trefny and Veleminsky[92] examining the prevalence of linear enamel hypoplasia (LEH) in minors from the Mikulčice acropolis and from the hinterland (Prušánky, Josefov). In contrast to what was assumed, it found a significantly higher prevalence of LEH in individuals from the Mikulčice castle than in individuals from the hinterland. It is obvious that in the Great Moravian population it is impossible to unambiguously define the relation between the socio-economic status and living conditions. The results of our study were that the low proportion of individuals with caries and the low percentage of total carious lesions from the burial grounds studied attest to quite favourable living conditions for all groups of people. The presumed different socio-economic status of individuals from the centre and the hinterland manifest neither in the case of younger children nor in the older age. No significant effect of weaning on caries prevalence was demonstrated. It is apparent that both their living conditions and dietary habits did not differ much in the case of children up to the age of 6 years. The occurrence of more affected individuals in older age at the acropolis could be related to the easier access to honey and various sweets for the economically better-situated inhabitants. The superior standard of living of the ruling class of Great Moravia included a diverse diet supplemented by fruits, vegetables, honey, apices, wine, etc.[93]

Unfortunately, in the resources, there is almost no evidence of hygienic measures or practices. However, we assume that the lifestyle of the higher social classes was influenced by the Byzantine Empire. This influence is documented in the society's material culture.[31] It could thus also involve more sound hygienic practices partially compensating the unhealthy eating habits.[34]

We believe that the lifestyle of individuals, or of groups of inhabitants, and the related hygienic practices had a greater influence on caries prevalence than did socio-economic status.

Conflict of interest statement

None.

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Competing interest

None declared.

Ethical approval

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