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Prevalence of dental caries in the Late Neolithic and Early Bronze Age populations from Żerniki Górne (Poland)

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ABSTRACT: The aim of the studies is to describe the prevalence and distribution of dental caries in two populations from Żerniki Górne (Poland). The first population represented the Corded Ware Culture (CWC) (2550–2350 BC), and the second population belonged to the Trzciniec Culture (TC) (1300–1000 BC). While the TC is identified with a typically agricultural strategy, the CWC culture strategy is still debatable. Two types of strategies are indicated in the CWC, either a mixed or typical agricultural economy.
A total of 110 adults were examined, of which 29 represented the CWC and 81 belonged to the TC. A total of 1132 permanent teeth were examined (CWC 379, TC 753).
Of the 110 individuals, 54 individuals had dental caries (CWC 19/29, 66%; TC 35/81, 43%). In the CWC, 68% (13/19) of males and 60% (6/10) of females had dental caries. In the younger period (TC), the percentage of dental caries among males was little higher (45%) than among females (41%). Dental caries was identified in 13% (50/379) of the teeth from the CWC. In the TC, the percentage of affected teeth were similar (11%, 82/753). The most common location of caries in all the chronological periods were the approximal and cemento-enamel junction [CEJ] surfaces. Caries on the occlusal surface was much less frequent. If we assume that an important cause of the development of dental caries is a high-carbohydrate diet, we can conclude that a similar prevalence of teeth affected by caries and it locations indicate a similar management strategy in both populations.

KEY WORDS: Żerniki Górne, dental; caries, CWC, TC

Introduction

Dental caries is one of the most widely presented oral pathological conditions in bioarchaeological collections (Stránská et al. 2015; Yanko et al. 2017). Although dental caries has a multifactorial etiology, such as poor oral hygiene, the chemi-

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cal composition of saliva, and enamel defects, it seems that the type of diet plays the most influentual role in the development of caries (e.g. Nyvad 2008). Currently, the strong correlation between a carbohydrate-rich diet and dental caries is widely accepted (Sheiham and James 2015; Feldens et al. 2019). Fermentable carbohydrates, especially sucrose, are not only substrates for bacterial metabolism but also stimulate bacterial growth in dental plaque. Therefore, consumption of carbohydrate-rich products leads to the development of dental caries (e.g. Marsh and Nyvad 2008). It means that, since in historical populations there was a significant frequency of dental caries, it can be concluded that their diet would have contained significant components of carbohydrate-rich products. This interpretation can be related not only to the typical agricultural populations (e.g. Watson 2008) but also to earlier chronological periods before the invention of refined sugar (e.g. Tayles et al. 2020). Some studies of European Mesolithic foragers from Sicily (Borgognini-Tarli and Reppeto 1985), Portugal (Lubell et al. 1994), and Latvia (Antanaitis-Jacobs et al. 2009) showed a high prevalence of carious lesions, and this fact has been linked to the consumption of cariogenic non-agricultural food (i.e., honey or fruits, which are sweet). Thus, analyses of dental caries can be useful in reconstructing dietary changes in bioarchaeological records. In this scope, the frequency and distribution of dental caries may enable researchers to identify socioeconomic changes through different historical periods.

The aim of the present study was to describe the prevalence and distribution of dental caries in two populations from Żerniki Górne (Poland). The first population is dated to the late Neolithic period (2550–2350 BC) and represented the Corded Ware Culture (CWC). The second population is dated to the early Bronze period (1300–1000 BC) and belonged to the Trzciniec Culture (TC). The aim of our study was to ascertain whether a change in the intensity of dental caries was observable between the two successive cultures. While the TC is identified with a typically agricultural strategy, the CWC strategy is still debatable. The two types of strategies were identified in the CWC, either a mixed or typical agricultural economy. Therefore, if the prevalence of dental caries was similar in both cultures, it can be assumed that the economy was also based on a similar agricultural strategy.

Material

Archaeological background

Żerniki Górne is a village situated in southeastern Poland, on the plateau of Loess in the Busko-Zdrój district ($50^{0}28'$N $20^{0}48'$E) (Fig.1). In the late Neolithic period, a CWC burial ground was established there. Later on, a cemetery was founded (Kempisty 1978). The people of the latter culture built a mound that dominates the immediate vicinity. The site was excavated for six seasons (1965–1976). Due to its size, the CWC burial ground is, so far, a unique facility in Poland. It consists of 63 human graves, in which 77 individuals are buried, and one animal grave (a burial of two horses). The CWC represents the last part of the Stone Age. The ^{14}C analysis allowed us to date the cemetery between 2550 and 2350 BC (Kempisty and Włodarczyk

Fig. 1. Location of Żerniki Górne

1996; Wierzbicki 1999). The TC is a younger culture on the site in Żerniki Górne. In total, 15 collective graves were established, with a minimum of 173 buried individuals. The majority of graves were not distributed in a regular fashion. The newest ^{14}C analyses showed that the graves from the TC can be dated between from 1300 BC and 1000 BC (Makarowicz el at. 2021).

The lifestyle of the CWC period is still the subject of controversy, because the CWC settlement is not well-known. Generally, researchers propose two hypotheses. The first hypothesis stipulates that the people of the CWC relied on a mixed or semi-nomadic economy. This lifestyle included farming, pasturing, and hunting (Gleń-Haduch 1995; Piontek 1999; Krenz-Niedbała 2014). It is possible that hunting for animals along the way compensated for losses of pasture animals and resultant food shortages. The small number of remains of pigs further strengthens the hypothesis of a wandering lifestyle (Kruk 1980; Kruk and Milisauskas 1999). In the second hypothesis, the economy of the CWC was based on typical agriculture, suggesting that these were predominantly sedentary communities. Archaeobotanical research confirms the presence of barley seeds (*Hordeum vulgaris*), wheat grains (*Triticum monococum*), oats (*Avensa* sp.), lentils (*Lens esculenta*), and peas (*Pisum sativium*) (Tunia 1986; Kruk and Milisauskas 1999). Still, it is hard to decide explicitly which of these hypotheses is more reliable. The TC is associated with a typical agricultural and settlement lifestyle (Gleń-Haduch 1995; Kardow and Machnik 1997). Archaeozoological research has proved that the people of the TC bred animals and were involved in farming (remains of corn and signs of plowing), hunting, and gathering (accumulation of seashells and turtle hulls).

Dental material

The present study was limited to adults only. A total of 110 adults were examined, of which 29 represented the CWC (males: 19, females: 10) and 81 belonged to the TC (males: 49, females: 32). A total of 1132 permanent teeth were examined, of which 379 belonged to the CWC (males: 261, females: 118) and 753 represented the TC (males: 439, females: 314).

The material from Żerniki Górne was incomplete, and bone elements of the maxilla and mandible often lacked delicate alveolar processes. Therefore, it was not possible to assess which teeth were lost antemortem because of caries. Consequently, in one case, it was difficult to estimate how many teeth were lost because of carious lesions, and in a number of other cases, this analysis was omitted. Hence, only the available permanent teeth were analyzed.

Methods

Dental studies

The sex of individuals was assessed according to commonly accepted anthropological methods (e.g. Brooks and Suchey 1990; Buikstra and Ubelaker 1994). The diagnosis of dental caries was carried out through the following visual and radiographic techniques:

1. Visual observation of the dental caries was conducted with the help of a 3x dental magnifying glass and a sharp dental probe. Visual inspection was performed under a direct dental unit light.
2. We used radiographic techniques for diagnosis, and for this task, a portable X-ray machine (EZX-60, Edlen Imaging, USA) was used.

The intensity of dental caries (i.e., the number of teeth affected by caries) was calculated based on the proportional correction factor (PCF) derived from Erdal and Duyar (1999, 2003). Since tooth classes (anterior or posterior) have a different morphology, the anterior teeth are usually lost more frequently (e.g., during postmortem deposition) than the posterior teeth. The PCF provides caries rates of anterior and posterior teeth according to their appropriate numbers: three-eighths for anterior and five-eighths for posterior teeth multiplied by the number of caries observed. The PCF method was chosen because of significant fragmentation and fracturing of the material from Żerniki Górne.

The location of carious lesions (approximal, cemento-enamel junction [*CEJ*], root, and incisal/occlusal) were considered and analyzed. When more than one surface was affected, each was analyzed separately.

The diagnosis of dental caries is often conditioned from dental wear. Therefore, the relationship between the degree of dental wear and presence of carious lesions was correlated. The scores for dental wear were based on the scale proposed by Smith (1984). The stages of dental wear were grouped into three according to the degree of dentin exposure. The following categories of dental wear were identified: wear facets that are i) invisible or very small (Smith's scale No. 1–3); ii) moderately advanced (Smith's scale No. 4–5); and iii) highly advanced (Smith's scale No. 6–8).

Statistical methods

The chi-squared test was used to analyze the differences in the intensity of caries. Since the number of individuals is not a large group, the Fisher's exact test for small-sized samples was used. To evaluate the correlation between dental caries and surface wear, we used Spearman's rank correlation coefficient. Statistical analyses were performed using the R Project for Statistical Computing (http://www.R-project.org. 2013). Differences with $p \leq 0.05$ were considered statistically significant.

Results

Of the 110 individuals, 54 individuals had dental caries (CWC 19/29, 66%; TC 35/81, 43%). This means that as many as 49% of individuals had affected teeth. Dental caries was identified in 13% (50/379) of the teeth from the CWC. In the TC, the percentage of affected teeth were similar (11%, 82/753). The differences between the chronological periods were not statistically significant (Table 1).

On the anterior teeth, along with subsequent historical periods, an increase in the intensity of dental caries was noted. On the posterior teeth, a similar increase in the intensity of dental caries was noted between the CWC and TC (0.06 vs. 0.08). However, the observed differences were not statistically significant (Table 1).

Differences in the frequency of dental caries between the sexes were not noted in the population studied. In the older period (CWC), 68% (13/19) of males and 60% (6/10) of females had dental caries. In the younger period (TC), the percentage of dental caries among males was little higher (45%) than among females (41%). However, statistically significant differences between the sexes were not noticed (Table 1).

Dental caries may occur on anatomically different parts of the tooth. Thus, the analyses considered the location of the caries on the crown, root, and functionally active surfaces. Both in the CWC and TC, dental caries was most often

Table 1. Frequency of dental caries and intensity of teeth affected by carious lesions.

	Individuals					Teeth				
Period	Total	Sex		p#	OR (CI)	Total	anterior*	posterior*	p	χ^2
CWC	19/29 (66%)	F	6/10 (60%)	0.6981	0.70 (0.11, 4.72)	50/379 (13%)	0/107	50/272 (0.06)	–	–
		M	13/19 (68%)							
TC	35/81 (43%)	F	13/32 (41%)	0.8194	0.84 (0.31, 2.26)	82/753 (11%)	12/223 (0.03)	70/530 (0.08)	0.0025	9.1
		M	22/49 (45%)							
p	0.0649					0.2978	–	0.0657		
χ^2	3.4					1.0	–	3.3		

Fisher's exact test for count data; *according PCF.

Fig. 2. Occlusal and approximal caries detected in the individuals from Żerniki Górne

Table 2. Location of dental caries on different tooth surfaces

Period	root	CEJ	approximal	occlusion	p	χ^2
CWC	11/50 (22%)	22/50 (44%)	29/50 (58%)	21/50 (42%)	0.0350	13.6
TC	25/82 (30%)	37/82 (45%)	61/82 (74%)	21/82 (26%)	0.0001	48.1
p	0.3894	1	0.077	0.077		
χ^2	0.7	0	3.1	3.1		

Table 3. Prevalence of dental caries and stages of dental wear

Period/Stages of dental wear	Total					Anterior			Posterior		
	1	2	3	p	r_s	1	2	3	1	2	3
CWC	30/50 60%	17/50 34%	3/50 6%	0.594	−0.015	0	0	0	30/50 60%	17/50 34%	3/50 6%
TC	62/82 76%	12/82 15%	8/82 10%	0.169	−0.040	8/12 67%	3/12 25%	1/12 8%	54/70 77%	9/70 13%	7/70 10%

1 – invisible or small amount of wear, 2 – moderate wear, and 3 – highly advanced wear.

diagnosed on the approximal surfaces (58% and 74%, respectively) and CEJ (44% and 45%, respectively). The lowest frequency of dental caries was observed in the CWC on the root and on the occlusal surface in the TC. These differences turned out to be statistically significant (Table 2) (Fig. 2).

In all chronological periods, it was observed that, with advancement of dental wear, the prevalence of dental caries decreased. However, the Spearman's rank correlation coefficient did not detect any statistically significant differences (Table 3).

Discussion

Careful analysis and interpretation of the intensity of dental caries can assist in understanding the adaptation strategies of past populations. In this context, the transition from hunting and gathering to farming is usually characterized by an increase in the frequency of teeth affected by caries (e.g. Zvelebil and Dolukhanov 1991; Karsten et al. 2015). An increase in the prevalence of dental caries is associated with a diet based on a high-carbohydrate diet. Such a diet promotes the development of colonies of cariogenic bacteria and, as a consequence, leads to the demineralization of enamel and the development of dental caries. At the same time, the diet of hunter-gatherers was significantly diversified, and the percentage of meat products was significant (Larsen 1995; Eshed et al. 2006). Some studies (Dawes 1970; Silverstone et al. 1981; Zabokova-Bilbilova et al. 2012) have proven that high-protein diets reduce the acidity of the saliva and, in this way, neutralize the decalcifying acids that cariogenic bacteria produce. As a result, such a diet protects the enamel from demineralization and reduces the development of dental caries.

In the dental analysis of Żerniki Górne, no differences were found between the CWC and TC in the prevalence of dental caries (13% vs. 11%). As mentioned previously, the TC was identified with a typical agricultural economy. This is indicated both by botanical and zoological research (Gleń-Haduch 1995; Kardow and Machnik 1997).

However, there is no consensus among scientists about the adaptation strategy of the CWC dated to the Late Neolithic period. A mixed strategy is indicated, which assumes both the use of small agricultural areas and gathering combined with hunting or typical agriculture (Tunia 1986; Kruk and Milisauskas 1999). If we assume that an important cause of the development of dental caries is a high-carbohydrate diet, we can conclude that a similar prevalence of teeth affected by caries indicates a similar management strategy in both populations. It means that both populations based their adaptation strategies on an agricultural economy. Also, other early agricultural populations from Levant (Eshed et al. 2006), Italy (Formicola 1987), and Thailand (Pietrusewsky and Douglas 2002), as well as the Żerniki Górne population, show a similar level of teeth affected by caries. Turner (1979) estimated the following average frequencies of teeth affected by caries: 1.7% for foraging populations, 4.8% for mixed foraging-farming populations, and 8.6% for fully agricultural populations.

The above thesis also seems to find additional confirmation in other odontological research. The odontological studies conducted on the population from Żerniki Górne in terms of the prevalence of enamel hypoplasia also showed no significant differences between the CWC and TC populations (Tomczyk et al. 2012). Generally, the increase of enamel hypoplasia can be explained by the "invention" of the sedentary way of life. Agricultural farming leads to complete dependence on cultivated agricultural areas. Therefore, even small nutritional deficiencies can interfere with the development of enamel. Moreover, the sedentary way of life resulted in a higher population density. This created favorable conditions for the development of pathogens that cause various diseases, which manifest in enamel hypoplasia (Skinner and Goodman1992; Guatelli-Steinberg 2016). The lack of significant differences in the severity of enamel hypoplasia can be interpreted as the type of economy of these two populations not being significantly different from each other.

The prevalence of dental caries was lower in anterior teeth, while it was higher in the posterior teeth. Similar trends in the prevalence of dental caries increasing from anterior to posterior dentation were also observed in other studies (e.g. Vodanovic et al. 2005). This fact is due to the different morphologies of the anterior and posterior teeth, along with the additional protection of the anterior teeth through tongue movements and the functioning of the sublingual and submandibular salivary glands.

The relationship between the incidence of dental caries and sex is still debatable. The fact is that a greater frequency of caries is observed in the teeth of female individuals compared to that of male individuals, but this is not a rule (e.g. Kwiatkowska 2005; Watson 2008). A significant frequency of dental caries in females is explained by a different strategy of obtaining food. In such groups, males would have often obtained their food by hunting, so a large proportion of their diet consisted of animal protein. In addition, the number of meals during the day, due to hunting, was kept to a minimum in men. Alternatively, the diet of women, while harvesting, generally included plants (fruits, seeds, roots, and tubers) rich in carbohydrates (e.g. Larsen 1991). There is no lack of interpretation of the link between the more frequent incidence of dental caries among

pregnant women, which generates biochemical changes, and the composition of saliva (e.g. Lukacs and Largaespada 2006). In the studied population from the CWC period, higher dental caries was observed among males. This means that eating habits, possibly also oral hygiene, was significantly different between males and females. However, it cannot be ruled out that such results were influenced by a small group of individuals.

Research on dental caries in modern and historical populations concerns not only the frequency but also its location. It is generally assumed that dental caries located on the cervical surfaces and/or on the root are identified as a result of eating poorly processed and fibrous food, which remains in the interdental spaces. Food debris, remaining in the interdental and paracervical spaces, becomes a good location for the deposition of plaque, which in turn leads to periodontal disease and gum recession (Meinl et al. 2010). On the other hand, infections on approximal and occlusal surfaces most often result from a well-processed diet that is rich in simple sugars (Greene et al. 2005). In the populations from Żerniki Górne, the most common location of caries in all the chronological periods were the approximal and CEJ surfaces. Caries on the occlusal surface was much less frequent. Although, it was observed that the frequency of dental caries decreases with the increase of occlusal dental wear, this relationship did not show statistical significance.

Conclusion

The presented study of two populations from Żerniki Górne show significant similarity in terms of the presence of dental caries. However, some methodological reservations should be kept in mind. Dental caries is a multifactorial disease, thus, it can be misleading to interpret its severity solely by the quality of the diet. This is why we often interpret diet together with physicochemical tests. In the case of population from Żerniki Górne, these tests should still be performed. Second, the distinction between an agricultural and mixed economy may not always be "clearly" reflected in the odontological material. It results, for example, from the state of preservation of the material or a small research group. Therefore, the obtained results should be confronted with subsequent tests.

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The Authors' contributions

JT designed the research, interpreted the results, and wrote the paper. MZ and PR performed statistical analyses. The final version of the paper was approved by all authors.

Conflict of interests

The authors declare that there is no conflict of interest.

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