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ABSTRACT In the Central European context, the 9th and 10th centuries are well known for rapid cultural and societal changes concerning the development of the economic and political structures of states as well as the adoption of Christianity. A bioarchaeological study based on a subadult skeletal series was conducted to tackle the impact of these changes on infant and young child feeding practices and, consequently, their health in both urban and rural populations. Data on growth and frequency of nonspecific stress indicators of a subadult group aged 0–6 years were analyzed. A subsample of 41 individuals was selected for nitrogen and carbon isotope analyses, applying an intra-individual sampling strategy (bone vs. tooth). The isotopic results attest to a mosaic of food behaviors. In the urban sample, some children may have been weaned during their second year of life, while some others may have still been consuming breast milk substantially up to 4–5 years of age. By contrast, data from the rural sample show more homogeneity, with a gradual cessation of breastfeeding starting after the age of 2 years. Several factors are suggested which may have been responsible for applied weaning strategies. There is no evidence that observed weaning strategies affected the level of biological stress which the urban subadult population had to face compared with the rural subadult population. Am J Phys Anthropol 155:635–651, 2014. © 2014 Wiley Periodicals, Inc.

The period of weaning is associated with some of the main changes facing a child during the first years of life. The duration of exclusive breastfeeding, the timing and circumstances of the introduction of complementary food, and finally the cessation of breastfeeding have great potential to immediately affect the growth and health of an infant or child (Wilson et al., 2006; Kramer and Kakuma, 2009; Lamberti et al., 2011) as well as influence its development and future health, and physical well-being in the long term (McDade, 2005; Demmelmair et al., 2006; Haines and Kintner, 2008; Palou and Pico, 2009). The optimal timing of weaning is still largely discussed in terms of the so-called "weanling's dilemma" (Lutter, 1992): the choice between the known protective effect of exclusive breastfeeding against infectious morbidity, and the insufficiency of breast milk alone to satisfy the infant's energy and micronutrient (e.g., iron) requirements beyond a certain age (McDade and Worthman, 1998; Foote and Marriott, 2003; Wilson et al., 2006; Fewtrell et al., 2007; Kramer and Kakuma, 2009). While modern recommendations suggest that the optimal length of time for exclusive breastfeeding to be at most 6 months (WHO, 2002; Fewtrell et al., 2007; Kramer and Kakuma, 2009), the benefits of continuation of partial breastfeeding during the first 2 years of life has also been demonstrated (Prentice, 1991; Lamberti et al., 2011).

Infant feeding practices are highly variable, with the age of weaning adjusted to different environmental, cultural, and economic contexts (Fildes, 1995). The level of environmental risk may affect parental investment decisions, including breastfeeding and weaning of a child, parental effort being inversely associated with episodes of extreme stress such as famine and warfare. Parental effort also shows a quadratic association with pathogen stress, increasing as pathogen stress rises to moderate levels, but decreasing at higher levels (Quinlan, 2007). Economic or subsistence strategies that employ mothers away from the household or that expose them to a heavy workload in a tough environment can also adversely affect the duration of breastfeeding (Thorvaldsen, 2008;

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Nitsch et al., 2011). Moreover, there are cultural background factors, including medical, religious, and sexual ideas, that influence women's beliefs about optimal feeding practices (Fildes, 1995; Thorvaldsen, 2008; Yovsi and Keller, 2008). The adaptation of breastfeeding patterns to this external environment can lead to infant feeding practices that do not meet the infant's physiological needs and threaten its health, growth, and development (Fildes, 1995).

This enormous plasticity in weaning practices and its consequences, along with the development of new research methods on bone chemistry (Katzenberg et al., 1996), has attracted the attention of bioarchaeologists. Since the pioneering work of Katzenberg et al. (1996), which highlighted the utility of combining the isotopic results with osteological information, this approach is often used to determine the impact of infant and child nutrition and especially weaning practices on mortality (Schurr, 1997; Williams et al., 2005; Pearson et al., 2010; Howcroft et al., 2012) and morbidity (Prowse et al., 2008; Mays, 2010) patterns of specific populations. This study applies this approach to an early medieval, Great Moravian sample, representing a population from a stressful period of rapid cultural and social change (Poláček, 2008; Macháček, 2010).

INFANT DIET AND STABLE ISOTOPE ANALYSES OF CARBON AND NITROGEN

Nitrogen and carbon stable isotope ratios circulate in the biosphere through plants and animals. At each stage of the food chain, heavier isotopes are discriminated against, resulting in $\delta^{15}N$ and $\delta^{13}C$ values that are 3‰–5‰ and 1‰ heavier at each step, a phenomenon termed the "trophic level effect" (DeNiro and Epstein, 1978; DeNiro and Epstein, 1981; Minagawa and Wada, 1984; Schoeninger and De Niro, 1984; Ambrose and Norr, 1993).

At birth, the isotopic composition of a newborn's tissues is similar to those of the mother (Fogel et al., 1989). Once breastfeeding starts, infants derive their nutrition from their mother's protein, and due to the trophic level effect, they exhibit an elevation of both $\delta^{13}C$ and $\delta^{15}N$ above maternal values. The isotopic values of tissues formed during the weaning process drops continuously with decreasing breast milk intake (Fogel et al., 1989; Fuller et al., 2006). According to Fuller et al. (2006), the $\delta^{13}C$ values decline to maternal levels more rapidly than the $\delta^{15}N$ values, so that they can track the introduction of the first solid foods into the diet, whereas $\delta^{15}N$ values better reflect the length of breast milk consumption.

To examine potential intra-population variability in the duration of breastfeeding, we undertook a strategy of intra-individual sampling, which is to determine the feeding status of each infant (Eerkens et al., 2011; Waters-Rist et al., 2011). This approach has become increasingly common, taking samples from different mineralized tissues (Herrscher, 2003, 2013; Howcroft et al., 2012), from different parts of bone (Waters-Rist et al., 2011), or from serial sections of dental tissues (Fuller et al., 2003; Eerkens et al., 2011; Howcroft et al., 2012). This enables preservation of dietary information from different periods of an individual's life. Bone undergoes constant turnover, such that its isotopic composition reflects the average diet for some period before death. The length of this period is dependent on the bone turnover rate, and consequently is highly variable and affected by different factors such as sex, nutritional status, physical activity and especially the age of an individual (Martin and Armelagos, 1985; Seibel, 2003; Hedges et al., 2007). By contrast, dentine and enamel do not remodel, so their isotopic composition retains information regarding diet at the period of tooth development throughout life (Balasse et al., 1999; Richards et al., 2002). Therefore, once breastfeeding has started, the $\delta^{15}N$ of newly formed dental tissues reflects the full trophic level effect in a short time after the onset of breastfeeding, while the bone $\delta^{15}N$ increases gradually along with the growth of bone and replacement of prenatally developed tissue. During weaning, for the same reason, the dental $\delta^{15}N$ value drops much more rapidly to adult values (Herrscher, 2003). In our study, samples were taken from the bone at the mandibular border and from the apical end of the developing dental root, in which isotopic compositions reflect the diet immediately before death (with regard to a certain indeterminable period that the metabolic nitrogen pool takes to equilibrate with the diet) (Balasse et al., 2001).

With this approach, it is possible to estimate the nutritional status of a specific child on the basis of the relative nitrogen isotopic differences between tooth and bone samples (Δ^{15}Nt-b). A positive Δ^{15}Nt-b (higher $\delta^{15}N$ in tooth) suggests that the particular child was breastfed up to its time of death, a negative value (higher $\delta^{15}N$ in bone) indicates that weaning took place sometime before. However, it is necessary to recognize that: 1) weaning is not an abrupt change, but a continuous process starting with the first introduction of supplementary food and ending with the complete cessation of breastfeeding (Wilson et al., 2006; Pearson et al., 2010), and 2) using this sampling strategy, we are not able to distinguish these two exact moments of the child's life, so that our terms "breastfed" and "weaned" have to be interpreted with caution rather in the sense of "child still consuming breast milk substantially" and "child whose milk consumption decreased substantially."

HISTORICAL PERSPECTIVES AND AIMS OF THE STUDY

The era of the Great Moravian Empire (9th to beginning of 10th century AD) is a crucial period in the history of Central Europe, where the basis of the first Slavic state formation occurred (Fig. 1). The rapid development of the proto-state structure along with Christianization which extended into Moravia no later than the beginning of the 9th century, brought profound change to Moravian society. The introduction of the first urban centers brought new lifestyles to previously rural and tribal communities, while political consolidation encouraged increased socio-economic stratification of society (Poláček, 2008; Macháček, 2010; Herold, 2012).

Our understanding of how the above mentioned changes affected child care and how subadults responded to it is very limited. The timing of weaning with all its health, demographic, and others consequences has been, up to now, completely unknown in this population. It has not been possible for bioarchaeologists to study the impact of these changes in the lives and health of the Great Moravian inhabitants through direct comparison with pre-Great Moravian populations due to the cremation rite, which was widespread in this territory until the turn of the 8th and 9th centuries (Klanica, 1990; Měřínský, 2006). Therefore, an alternative approach to the study of this issue has been undertaken

Fig. 1. Extension of Great Moravia and neighboring European empires in the latter third of the 9th century and the location of Mikulčice center, modified according to Poulík (1975) and Havelková et al. (2010).

in many anthropological studies (Trefný and Velemínský, 2008; Velemínský et al., 2009; Garcin et al., 2010; Havelková et al., 2010): a comparison of population samples of newly formed urban centers and those from rural sites. The rural sites are presumed to maintain an agricultural character, and the progress of Christianization as well as other societal changes were likely more gradual. In addition, strong foreign cultural influence is not supposed to be present in the rural environment.

This study aimed to explore potential differences in infant feeding practices between these two groups. Taking into account the early stage of urban formation (Poláček, 2008), one may hypothesize a shortening of the period of breastfeeding in the urban population due to the more rapid introduction of Christian taboos (Thorvaldsen, 2008). Consequently, potential differences in weaning strategies could be linked to differences in growth and health of infants and young children between samples of the urban and rural Great Moravian populations.

MATERIAL AND METHODS

Material

The skeletal material came from three sites that are all located at the core of the Great Moravian state formation in the south-eastern tip of the today's Czech Republic (Fig. 1). The urban population sample comes from the Mikulčice settlement complex. Both the rural sites (Josefov and Prušánky) are located in an area of presumed hinterland that provided agricultural products to the growing Mikulčice center (Poláček, 2008).

Mikulčice. The agglomeration of the settlement complex in Mikulčice merged the attributes of a military fortress with those of an early urban formation. It is believed to be one of the prominent power centers of the Great Moravian Empire as well as an important center of Christianity in this territory (Poulík, 1970; Poláček, 2008).

The settlement complex consisted of the fortified center (including *acropolis* and the bailey), and a suburb, which gradually grew around the fortified core (Poláček and Marek, 1995; Poláček, 2008).

Archaeological research at Mikulčice has been going on for over 50 years. More than 2500 graves have been uncovered, both in the suburbs and the *acropolis*, dated to the 9th and the first third of the 10th century. The presence of elites of Great Moravian society is supported by the findings of graves (apparently dynastic) in the main church premises and the concentration of richly equipped graves (Poláček and Marek, 1995; Poláček, 2008).

In this study, attention was paid to the subadult population buried at the *acropolis*, which is thought to be a residential area of the privileged class. In regards to the preservation of skeletal material, the individuals from all cemeteries within the acropolis were considered as one unit, neglecting potential slight temporal differences in the use of particular burial sites within the 9th century.

Josefov. This site, situated 7 km from Mikulčice center, is considered to be an example of a "poorer" rural Great Moravian burial site. During the excavation in 1957–1962, a total of 171 graves with the skeletal remains of 178 individuals were uncovered. The majority of the graves contained grave goods, typically a simple inventory (especially ceramics) with a less distinctive evidence of social stratification (Klíma, 2007; Poláček, 2008).

Prušánky I. The site Prušánky I is located 9.5 km from Mikulčice. Over the course of a number of excavations, a total of 376 graves were uncovered. According to the grave goods, the social stratification seems to be slightly higher than is the case of Josefov (Klanica, 2006).

A total of 144 individuals from the area of the Mikulčice castle, and another 158 individuals from rural cemeteries (Josefov and Prušánky), whose age at death was estimated to be less than 6 years, were included in the study. Whereas health investigations were conducted on the whole sample of subadults; for the isotopic study, 23 individuals from Mikulčice and 18 from Josefov were chosen. In the case of Josefov, the samples were taken from all the individuals whose state of preservation enabled sampling. In the case of Mikulčice, the subsample was selected to distribute the age classes and individuals with different quality of grave goods as equally as possible. The low state of preservation of skeletal material precluded the performance of stable isotope analysis on the sample from Prušánky.

Methods

Age-at-death estimation. Age-at-death estimates were obtained using the dental ageing method developed by Liversidge et al. (1998). In several cases, where this method was not applicable, the standards published by Moorrees et al. (1963) tabulated by Smith (1991) were used.

Isotopic analysis. At least 50 mg of tooth dentine was sampled from the tip of the developing dental root at stage $R_{1/4}$ $-\mathrm{Ap}_{1/2}$, after Smith (1991). The samples were taken from different tooth types, regarding the age-at-death. Where possible, the first or second deciduous molar was sampled. From the youngest individuals with insufficiently developed roots of molars, canines or incisors were used. In some of these cases, two teeth had to be sampled to obtain a sufficient amount of dentine. Additionally, 80 mg of mandibular bone of each individual was sampled. Due to the intra-individual variability in the root dentine formation rate between both different teeth and different developmental stages within a single tooth (Dean, 2007; Dean and Vesey, 2008), our dentine samples may represent slightly different periods of time. This, however, does not affect the results of our study, where the values of "most recent" (dentine) and "some period prior to death" (bone) samples are compared.

Collagen extraction proceeded according to the Longin (1971) method, modified by Bocherens (1992). Elemental analyses were performed on a Europa Scientific EA elemental analyzer connected to a Europa Scientific 20-20 IRMS for the carbon and nitrogen isotopes analysis at Iso-Analytical Limited, Crewe (UK). The uncertainty of isotopic measurements calculated on different standard replicates (IA-R042, IA-R045, IA-R046 and IA-R05, IA-R06) was less than 0.1‰ for both nitrogen and carbon. A feeding status through Δ^{15}Nt-b was considered as a threshold for significance if the value was more than 0.4‰. This value is considered adequate in the light of the measurement precision as well as the stochastic isotopic variation reported by other studies (~0.3‰) (Chisholm, 1989; Katzenberg and Lovell, 1999). The children with a Δ^{15}Nt-b value higher than 0.4 were regarded as "breastfed," those with a Δ^{15}Nt-b value lower than −0.4 as "weaned."

Morphological analysis. To evaluate the effect of the urban/rural residency on health and physical well-being, the presence of *cribra orbitalia*, porotic hyperostosis, and endocranial lesions were evaluated macroscopically. The precise etiology of these skeletal lesions is not completely understood (Lewis, 2004; Wapler et al., 2004; Walker et al., 2009), but despite this fact, they are routinely used in studies of child morbidity as non-specific indicators of stress (e.g., Larsen, 1997; Bennike et al., 2005; Lewis, 2010, 2013; Gowland and Western, 2012). The presence of *cribra orbitalia* and porotic hyperostosis were noted, according to the scheme developed by Nathan and Haas (1966). However, for statistical analysis, the stage of lesion was not considered and all cases were counted as "Present." Some previous work on the topic (e.g., Bennike et al., 2005; Lewis, 2013) has considered the "Grade a" lesions to be: 1) too mild to represent serious health problems, and 2) easily mistaken for post-mortem changes. Therefore, the statistical analysis was performed also for modified datasets (where just Grades b and c were considered pathological). The presence of endocranial lesions were evaluated according to the criteria proposed by Lewis (2004), but again, the type of lesion was not considered for statistical analyses. Because Lewis suggests rapid growth to be a complicating factor in the youngest individuals, the statistical tests were repeated, removing all individuals up to 1 year of age from the analysis. Additionally, growth was compared in children of differing residency types. It is well known that lower height for age and slowed maturation in a given population are associated with malnutrition, disease, and physiological stress (Eveleth and Tanner, 1990; Larsen, 1997). Diaphyseal length, antero-posterior (AP) and medio-lateral (ML) diameter at the midshaft of femur, tibia and humerus were measured to monitor both endochondral and appositional growth (Mays et al., 2009).

Statistical analysis. To establish a potential difference in weaning strategies between the two subgroups of the Great Moravian population, simple and multiple logistic regressions, and the subsequent Wald test, were performed to evaluate the effect of age (median age) and type of residency on the presence of breastfed/

TABLE 1. Collagen preservation data

	Tooth				Bone			
Site and individual number[a]	Yield (%)	%C	%N	C:N	Yield (%)	%C	%N	C:N
MIK 1	16.4	39.8	14.4	3.2	15.9	38.3	13.6	3.3
MIK 2	11.2	41.3	15.1	3.2	13.5	40.0	14.2	3.3
MIK 3	20.5	36.6	13.3	3.2	17.2	39.1	14.2	3.2
MIK 4	19.5	38.9	14.1	3.2	14.0	39.7	14.3	3.2
MIK 5	22.1	33.3	12.0	3.2	13.9	36.7	13.2	3.2
MIK 6	9.7	36.7	13.2	3.2	17.0	39.0	14.0	3.2
MIK 7	23.0	35.1	12.7	3.2	15.6	39.3	14.3	3.2
MIK 8	11.2	35.4	12.7	3.2	13.3	40.4	14.5	3.2
MIK 9	21.8	36.3	12.9	3.3	16.1	37.1	13.2	3.3
MIK 10	12.4	34.2	12.2	3.3	14.7	38.1	13.5	3.3
MIK 11	12.7	39.4	13.9	3.3	17.6	38.4	13.4	3.3
MIK 12	19.8	38.0	13.6	3.2	17.9	39.0	13.8	3.3
MIK 13	4.5	33.5	12.0	3.2	5.6	38.5	14.0	3.2
MIK 14	4.8	30.8	10.8	3.3	8.7	37.4	13.4	3.2
MIK 15	21.7	42.2	15.2	3.2	18.4	40.1	14.4	3.2
MIK 16	22.4	38.1	13.3	3.3	18.2	35.6	12.7	3.2
MIK 17	4.3	30.8	11.0	3.2	11.8	38.4	13.8	3.2
MIK 18	20.9	35.1	12.6	3.2	18.6	34.4	12.3	3.2
MIK 19	20.0	32.9	11.8	3.2	17.6	34.4	12.3	3.3
MIK 20	5.3	32.3	11.5	3.2	16.2	37.9	13.5	3.2
MIK 21	21.5	35.9	12.9	3.2	12.6	33.4	12.0	3.2
MIK 22	19.6	35.0	12.7	3.2	19.8	39.9	14.4	3.2
MIK 23	20.8	38.7	14.0	3.2	18.5	39.6	14.2	3.2
JOS 2	22.9	37.3	13.3	3.3	17.8	37.2	13.5	3.2
JOS 3	21.7	40.6	14.3	3.3	20.2	42.2	15.0	3.3
JOS 4	3.6	35.4	11.7	3.5	5.9	40.4	13.6	3.5
JOS 5	18.2	40.7	14.8	3.2	13.3	37.8	13.2	3.3
JOS 6	14.2	37.9	13.2	3.3	10.5	39.0	13.6	3.3
JOS 7	21.4	33.5	11.9	3.3	11.9	39.3	13.7	3.3
JOS 8	18.1	41.1	14.8	3.2	17.3	34.9	12.4	3.3
JOS 9	19.4	39.1	14.1	3.2	17.9	42.5	15.0	3.3
JOS 10	21.6	36.3	13.1	3.2	22.5	36.4	13.2	3.2
JOS 11	18.5	39.1	14.1	3.2	17.4	39.8	14.3	3.2
JOS 12	19.8	38.6	13.9	3.2	15.2	39.9	14.3	3.2
JOS 13	13.9	42.6	15.4	3.2	16.5	39.0	13.9	3.3
JOS 14	17.7	39.8	14.3	3.2	17.7	37.7	13.5	3.2
JOS 15	23.3	35.0	12.4	3.3	17.5	34.3	12.0	3.3
JOS 16	7.6	32.2	11.5	3.3	17.7	41.3	14.8	3.2
JOS 17	12.1	39.5	14.1	3.2	18.8	41.3	14.7	3.3
JOS 18	18.8	41.2	14.7	3.2	10.0	40.8	14.4	3.3
JOS 20	18.7	40.8	14.8	3.2	19.9	42.1	15.1	3.2

[a] JOS, Josefov; MIK, Mikulčice.

weaned status. The consideration of age in multiple regression permits the adjustment of the results for this variable. Moreover, the interaction between age and type of residency has been tested to determine if the potential age-related trends are similarly apparent in the both subsamples. In the case of data regarding the presence of non-specific stress indicators, the same type of analysis was used: simple and multiple logistic regressions taking into account the median age. To evaluate the influence of the type of residency on the growth in different skeletal dimensions, the method developed by Mays et al. (2009) was applied: a polynomial regression for each of the dependent variables (bone length, AP or ML) on dental age was fitted. This procedure enabled investigation of the differences in bone dimensions between urban and rural individuals, controlling for the effect of dental age by carrying out the analysis of the regressions' standardized residuals. Since these did not meet a normal distribution, the urban and rural differences were verified by a nonparametric test, the Wilcoxon test for independent data. The analysis was performed by the Statistica v7.0 and the SAS/STAT® software v12.1.

RESULTS AND DISCUSSION

Isotopic results

Data quality. All the samples met the criteria for good collagen preservation (DeNiro, 1985; van Klinken, 1999) (Table 1). All samples had an elemental compositions range from 30.8 to 42.6 wt% for carbon (mean ± 1σ' equals 37.1 ± 3.2 for tooth samples; 38.6 ± 2.2 for bone samples) and from 10.8 to 15.4 wt% for nitrogen (13.3 ± 1.2 for tooth; 13.7 ± 0.8 for bone). Their C:N ratios (ranging from 3.2 to 3.5) were compatible with well preserved collagen and the collagen yield was in all cases higher than 1%. Several times, the collagen yield was surprisingly high (20%–22%) but acceptable considering the proportionally higher collagen content in the subadult bone (Baker et al., 1946; Waters-Rist et al., 2011).

TABLE 2. $\delta^{13}C$, $\delta^{15}N$ and their intra-individual differences with estimated feeding status

Site and individual number[a]	Dental age (years)	Sampled tooth[b]	$\delta^{13}C$ Tooth	$\delta^{13}C$ Bone	Δ^{13}Ct-b[c]	$\delta^{15}N$ Tooth	$\delta^{15}N$ Bone	Δ^{15}Nt-b[c]	Estimated feeding status[d]
MIK 1	0.4–0.8	dm1	−18.4	−18.2	−0.2	14.8	14.0	**0.8**	**Breastfed**
MIK 2	0.9–1.3	dc	−14.2	−15.4	**1.1**	15.0	13.7	**1.4**	**Breastfed**
MIK 3	0.7–1.1	di1, di2	−14.5	−15.6	**1.1**	17.9	16.6	**1.3**	**Breastfed**
MIK 4	1.3–1.7	dm1	−18.2	−17.9	−0.3	12.3	13.2	**−0.9**	**Weaned**
MIK 5	1.3–1.7	di2 (2x)	−17.9	−18.2	0.3	13.0	12.4	**0.7**	**Breastfed**
MIK 6	1.8–2.2	dm1	−17.5	−17.6	0.2	13.1	12.9	0.2	**ND**
MIK 7	1.7–2.1	dm1	−16.7	−16.6	−0.1	14.7	14.5	0.2	**ND**
MIK 8	1.1–1.5	dm1	−16.8	−17.2	0.4	19.2	18.6	**0.6**	**Breastfed**
MIK 9	1.9–2.3	dm2	−17.7	−17.4	−0.3	12.1	12.9	**−0.7**	**Weaned**
MIK 10	2.4–2.8	dc (2x)	−16.8	−17.8	1.0	11.5	10.7	**0.9**	**Breastfed**
MIK 11	2.6–3.0	dm2	−15.4	−15.3	−0.1	11.9	11.3	**0.6**	**Breastfed**
MIK 12	2.3–2.7	dm2	−16.9	−17.5	**0.6**	12.6	12.4	0.2	**ND**
MIK 13	2.5–2.9	dc (2x)	−16.9	−17.2	0.3	12.2	12.3	−0.2	**ND**
MIK 14	3.5–3.9	dm2	−17.6	−17.9	0.3	11.5	11.8	−0.3	**ND**
MIK 15	2.2–2.6	dm2	−17.3	−17.5	0.2	12.6	11.7	**0.9**	**Breastfed**
MIK 16	2.8–3.2	dm2	−17.5	−17.3	−0.2	11.7	11.7	0.0	**ND**
MIK 17	3.0–3.4	dm2	−18.3	−18.8	**0.5**	12.7	12.7	−0.1	**ND**
MIK 18	3.8–4.2	dm2	−17.6	−17.9	0.3	12.4	11.8	**0.5**	**Breastfed**
MIK 19	4.3–5.5	dm2	−17.9	−17.1	**−0.9**	11.4	12.1	**−0.8**	**Weaned**
MIK 20	3.3–3.7	dm2	−14.9	−16.2	**1.2**	11.3	10.9	0.3	**ND**
MIK 21	4.1–4.5	dm2	−18.5	−18.7	0.3	12.0	11.6	**0.5**	**Breastfed**
MIK 22	3.0–3.4	dm2	−17.5	−17.7	0.1	11.6	10.9	**0.7**	**Breastfed**
MIK 23	5.0–5.4	dm2	−18.8	−18.7	−0.1	11.2	10.9	0.2	**ND**
JOS 2	1.1–1.5	di1, di2	−14.7	−14.9	0.2	13.4	11.8	**1.6**	**Breastfed**
JOS 3	0.8–1.2	di1, di2	−16.8	−17.0	0.2	13.5	12.5	**1.0**	**Breastfed**
JOS 4	1.2–1.6	dm1	−16.8	−17.1	0.3	11.4	11.1	0.3	**ND**
JOS 5	1.1–1.5	di2 (2x)	−15.7	−16.3	**0.6**	14.1	12.7	**1.4**	**Breastfed**
JOS 6	1.6–2.0	dm1	−16.4	−16.3	−0.1	15.0	13.5	**1.5**	**Breastfed**
JOS 7	1.9–2.3	dm1	−17.0	−17.8	**0.8**	13.0	12.5	**0.5**	**Breastfed**
JOS 8	2.4–2.8	dc	−16.3	−16.3	0.0	12.6	12.8	−0.2	**ND**
JOS 9	1.8–2.2	dm1	−17.3	−17.8	**0.5**	11.1	10.5	**0.5**	**Breastfed**
JOS 10	2.3–3.7	dm2	−16.0	−16.2	0.2	11.6	11.0	**0.7**	**Breastfed**
JOS 11	2.0–2.4	dm1	−16.6	−17.0	0.4	12.6	11.7	**0.9**	**Breastfed**
JOS 12	2.6–3.0	dm2	−16.8	−17.1	0.3	12.9	12.9	0.0	**ND**
JOS 13	1.9–2.3	dm2	−17.1	−16.7	−0.4	12.4	12.5	−0.1	**ND**
JOS 14	2.5–2.9	dm2	−18.0	−18.7	0.7	12.2	11.3	**0.9**	**Breastfed**
JOS 15	2.5–2.9	dm2	−17.4	−16.2	**−1.2**	13.2	14.0	**−0.8**	**Weaned**
JOS 16	2.7–3.1	dm2	−17.7	−17.6	−0.1	10.1	10.8	**−0.7**	**Weaned**
JOS 17	3.1–3.5	dm2	−17.3	−17.5	0.2	11.2	10.9	0.3	**ND**
JOS 18	3.4–3.8	dm2	−18.1	−18.5	0.4	10.6	10.5	0.1	**ND**
JOS 20	4.8–5.6	M1	−18.1	−18.1	0.0	10.5	9.9	**0.6**	**?**[e]

[a] JOS, Josefov; MIK, Mikulčice.
[b] di1, di2 = first, second deciduous incisor; dc = deciduous canine; dm1, dm2 = first, second deciduous molar; M1 = first permanent molar.
[c] Relative difference between tooth and bone; significant (>±0.4) differences in bold font.
[d] Based on Δ^{15}Nt-b; ND, no significant isotopic difference.
[e] In the case of JOS 20, the feeding status was not estimated due to its unexpected isotopic values (for more details see Results and Discussion).

Stable nitrogen isotopes. Based on the criteria described earlier (Δ^{15}Nt-b > ±0.4), the feeding status was estimated in 25 cases (14 urban, 11 rural) of a total number of 41 individuals (Table 2). These results reveal a great variability in the age of dietary change within the Great Moravian population.

In the rural population sample of Josefov, nearly all children under 2 years (using the median dental age) had a Δ^{15}Nt-b value higher than 0.4‰, which suggests that they were breastfed substantially (Fig. 2). During the third year of life a strong decrease in the Δ^{15}Nt-b value was observed. The youngest children were weaned at this age, while some others were still consuming a substantial proportion of breast milk. Due to the low number of individuals aged between 3 and 5 years, we were not able to distinguish when exactly the process of weaning was completed among this rural community. However, Δ^{15}Nt-b data from the Josefov sample showed one clear pattern of weaning, beginning after the age of 2 and completed probably during the fourth year of life.

The only exception from this trend is represented by the oldest individual from the entire sample (JOS20, aged 4.8–5.6 years), whose Δ^{15}Nt-b value corresponds to a diet substantially based on breast milk. This is highly unlikely, taking into account the age of JOS20 as well as the fact that its $\delta^{15}N$ value were some of the lowest in the whole sample (the lowest in bone). Potential causes of these unexpected values will be discussed later. However, this outlier was excluded from the statistical analysis (Fig. 2).

In the urban sample of Mikulčice, greater variability in children's' diet was observed. The youngest children were weaned during their second year of life. And, according to the isotopic results, some others may have

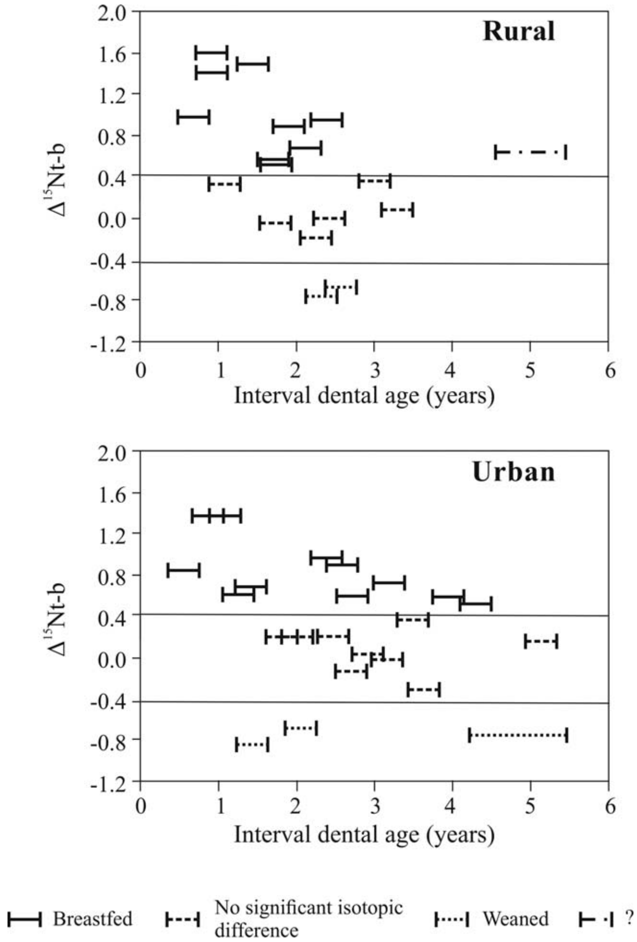


Fig. 2. Relative nitrogen isotopic differences between the tooth dentin and bone samples (Δ^{15}Nt-b) in the rural (Josefov) and urban (Mikulčice) part of the Great Moravian population. Δ^{15}Nt-b > 0.4 interpreted as breastfed, Δ^{15}Nt-b < -0.4 interpreted as weaned, Δ^{15}Nt-b $\in [-0.4, 0.4]$ interpreted as undetermined feeding status; age = median dental age in years.

still been consuming breast milk substantially at the age of 4 years (Fig. 2). This prolonged period of substantial consumption of breast milk in a portion of a population is surprising but not exceptional. In studies of both archaeological evidence (Herrscher, 2003, 2005; Waters-Rist et al., 2011) and current practices (Moffat, 2001; Sellen, 2001; Simondon et al., 2001; Kennedy, 2005), populations could be found with examples of prolonged breastfeeding during the third or fourth year of life. In some cases, the age at complete cessation of breastfeeding was reported to be more than 6 years (Dettwyler, 2004). Also historical sources mention examples of populations where the age of weaning (at least the recommended) was as high as three or even 6 years (Fildes, 1995; Piovanetti, 2001).

Stable carbon isotopes. According to Fuller et al. (2006) a slight trophic level effect in δ^{13}C values (+1‰) is also observable in breastfed infants. Subsequently, during weaning, carbon isotopic values show a more rapid decrease to the adult mean than δ^{15}N values, which led Fuller et al. (2006) to declare δ^{13}C to be a good indicator for detection of the first introduction of

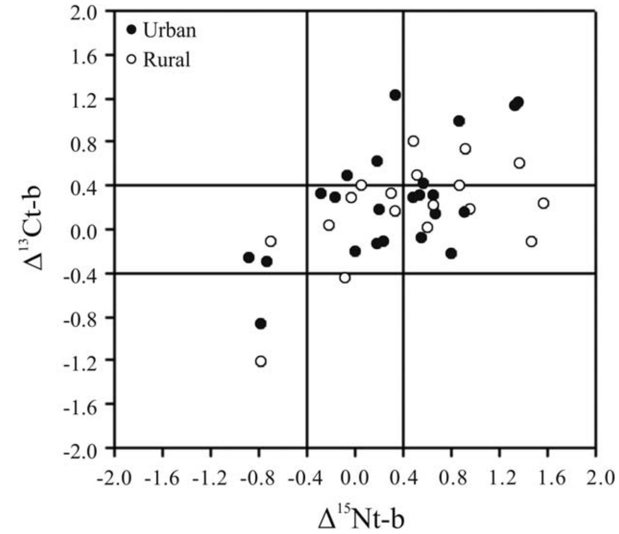


Fig. 3. Δ^{13}Ct-b in relation to Δ^{15}Nt-b in the rural (Josefov) and urban (Mikulčice) parts of the Great Moravian population.

supplementary food into a diet. In our sample, however, we do not see any clear pattern of decreasing Δ^{13}Ct-b, which could be attributed to weaning. In some cases, the values were more positive or negative (±1.2‰) than is generally attributed to the trophic level effect of exclusive breastfeeding (Fig. 3). These results suggest the existence of others factors that could play a role in carbon isotopic variability in our sample of Great Moravian children. From the individual values, the most interesting is a group of children (N = 3, all coming from the urban context) with highly increased Δ^{13}Ct-b, which would be consistent with exclusive breastfeeding. However, a non-significant Δ^{15}Nt-b value for these children precludes such an interpretation. This shift in Δ^{13}Ct-b may reflect the introduction of a new ^{13}C enriched food source into the diet of these children. This new dietary item was introduced into a diet of a portion of the Great Moravian population between 2 and 4 years of age, and was probably based on millet or on the milk of animals fed with it.

In the related literature, the absence of any evidence of a trophic level shift in δ^{13}C attributable to lactation is quite common (e.g., Herrscher, 2003; Waters-Rist et al., 2011; Howcroft et al., 2014). Other studies were inconclusive (Dupras and Tocheri, 2007; Eerkens et al., 2011; Howcroft et al., 2012; Haydock et al., 2013), often with some individuals supporting and others contradicting this scenario. Use of isotopically distinct weaning foods (such as those based on C_4 plants), or alternatively, annual or seasonal variation in the carbon isotopic composition of the mothers' diet, and therefore of breastmilk, could blur a small trophic level effect of lactation in δ^{13}C.

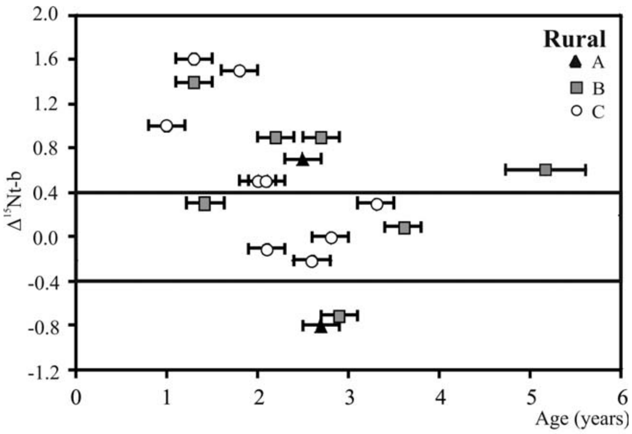
Intra-population variability in feeding practices

Multiple logistic regression analysis was used to evaluate the relationship between the breastfed/weaned status and the type of residency adjusted by age (Table 3). No significant association appears between the breastfed/weaned status and residency (P = 0.902). These results suggest that there were not any norms for the optimal duration of breastfeeding applied specifically

TABLE 3. Factors associated with the weaned status (vs. breastfed status): simple and multiple logistic regressions[a]

Explanatory variables		N	Simple regression OR	95% CI	*P* Wald	Multiple regression Adjusted OR	95% CI	*P* Wald	*P* Interaction[b]
Type of residency	Urban	14	1.00			1.00			0.284
	Rural	11	0.82	0.11–5.99	0.841	1.15	0.13–10.12	0.902	
Age, (continuous)		25	1.83	0.81–4.65	0.134	1.86	0.70–4.92	0.211	

[a] OR, odds ratio; CI, confidence interval; *P*, *P*-value.
[b] p Wald of the interaction age * type of residency.



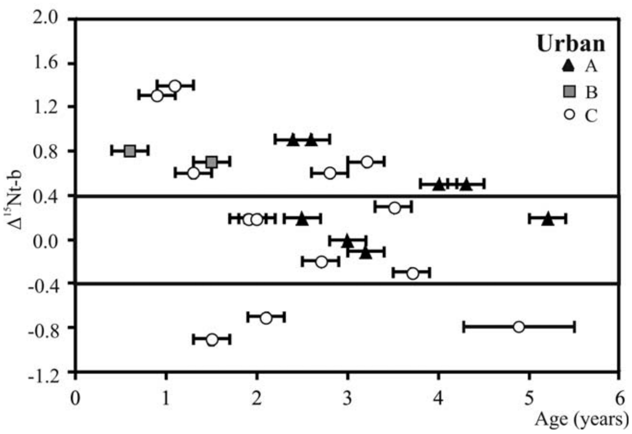


Fig. 4. Δ^{15}Nt-b according to the grave goods in the rural (Josefov) and urban (Mikulčice) part of Great Moravian population. **A** = graves with weapons, gold, silver or bronze objects; **B** = graves with objects of daily use; **C** = without grave goods.

in urban or rural populations. However, from a biological point of view, the greater variability in weaning behavior observed in the urban sample is a notable phenomenon.

The greater diversity in the duration of breastfeeding, observed especially in the urban sample, could have several causes. First, because of the role of Mikulčice as an important center of Christianity (Poláček, 2008), Christian rules may have been adopted more quickly and the pressure to abide by them could be higher in Mikulčice, in comparison with the rural areas. These new rules and taboos clearly influenced family life and child care (Thorvaldsen, 2008). For example, the 9th century dated document *The Responses of Pope Nicholas I to the Questions of the Bulgars* (dated 866) recommends sexual abstinence during the entire period of breastfeeding (Bartoňková et al., 1971). The influence of these new prescriptions could lead at least some women in Mikulčice to the abandonment of the established norm when the weaning of their children was at issue. Nonetheless, the above-mentioned document does not specify any recommendations for duration of breastfeeding (Bartoňková et al., 1971). If there were any rules postulated by the church in the Great Moravian context, they remain completely unknown to us.

Second, even if no direct information on residential mobility in the Great Moravian population is available, looking at the character of the Mikulčice settlement as well as historical circumstances (Poláček, 2008), we can suppose some level of immigration. The retention of traditional infant feeding practices in migrating families is documented by historical sources (from industrializing or industrialized populations) even despite basic changes in living conditions, which these families must have faced (Fildes, 1995). So, the presence of potential "nonlocals" adhering to the infant feeding practices traditional in their place of origin could have contributed to the observed diversity.

Third, despite the assumption that the studied area of the *acropolis* is a residential area of the privileged class, the cemeteries were probably used by members of the middle and lower society as well (Bigoni et al., 2013). These socio-economically distinct groups within the Mikulčice population could apply different weaning strategies. In fact, both of the individuals who were still breastfed substantially by the age 4–5 are believed to be of high socio-economic status, based on their rich grave goods with metal objects, including gold jewelry. By contrast, the children that were weaned before the age of 2 were buried without any grave goods. On the other hand, the rural sample shows no evidence of any relationship between diet and social status (Fig. 4). However, to perform the statistical analysis of potential socio-economic differences, more individuals would have to be sampled. Moreover, when considering the effect of socio-economic status on the age of weaning, we have to keep in mind: 1) the impact of the age factor, because the presence as well as number and luxury of grave goods correlates with the age at death (Stloukal, 1970); and 2) differences in the grave goods ("richness") need not only reflect different social conditions of the respective individuals, but also, for example, different degrees of Christianization. It is probable that the proportion of pre-Christian customs, including the burial of gifts with the dead, receded during the 9th century under the influence of Church prohibition (Poláček, 2008).

And finally while environmental context as well as cultural beliefs about breastfeeding are relevant, the individual decision of mothers to wean could be modified by a number reasons specific for each case: bad health of the mother, onset of the next pregnancy, problems with

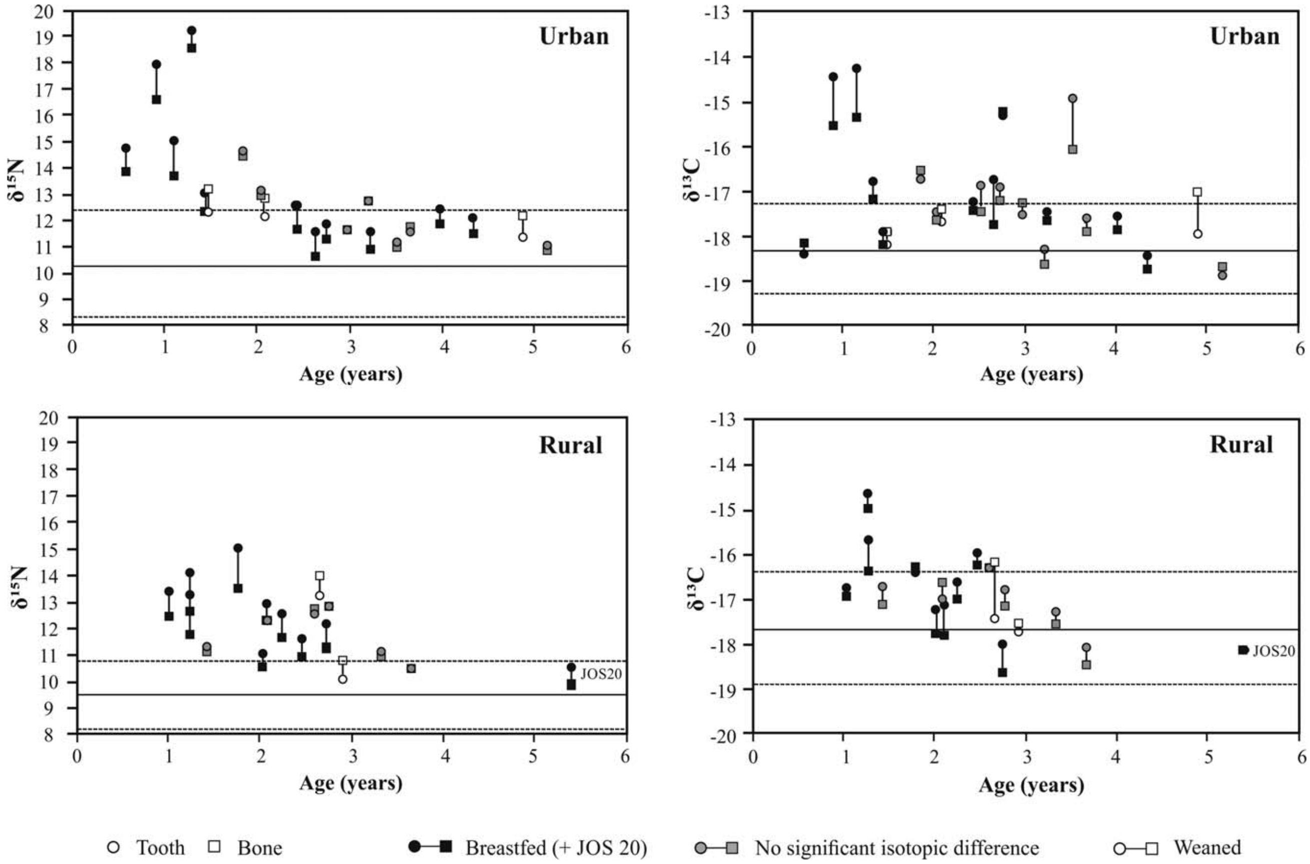


Fig. 5. The $\delta^{15}N$ and $\delta^{13}C$ values of subadult individuals plotted against the age at death and according to whether the sample was derived from bone or dentine. The three horizontal lines represent the adult female mean (*solid line*) and two standard deviations above and below this mean (*dashed lines*). Individual JOS20 (discussed in the text) is labeled.

TABLE 4. Age distribution and prevalence of stress indicators by age category

	Age distribution		Cribra orbitalia[b]		Porotic hyperostosis[b]		Endocranial lesions[c]	
Age[a] (years)	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
0.0–2.0	52	56	16(6)/38	9(1)/15	7(2)/23	1(0)/12	15/32 (12/22)	9/16 (6/11)
2.1–4.0	53	46	23(7)/31	14(4)/19	3(3)/24	1(0)/11	6/30	5/14
4.1–6.0	11	9	1 (0)/6	4(1)/6	0(0)/5	0(0)/4	1/7	0/4
Subadults	28	47	5(2)/8	5(3)/7	0(0)/2	0(0)/2	2/6	2/7
Total	**144**	**158**	**45(15)/83**	**32(9)/47**	**10(5)/54**	**2(0)/29**	**24/75 (21/65)**	**16/41 (13/36)**
First occurence[d]			1.0 (1.0)	0.8 (1.4)	1.0 (1.3)	1.2 (–)	0.9	0.8

[a] For the purposes of sample description the individuals were divided into age groups. Individuals without recovered teeth, whose age could be estimated using growth and skeletal maturity (Stloukal and Hanakova, 1978; Scheuer and Black, 2000) were classified as subadults (0.0–6.0) without further specification.
[b] No. of cases with present lesion (Grade b + c in parentheses)/number of individuals with bone element present.
[c] Number of cases with present lesion/number of individuals with bone element present (older than 1 year in parentheses).
[d] Age of the youngest child with observed lesion (years); in the case of cribra orbitalia and porotic hyperstosis Grade b + c in parentheses.

breastfeeding and infant suckling, mother's assessments of their children's nutritional needs, and economic or subsistence needs requiring the mother to return to work, are only some of the reasons that could motivate women to wean contrary to the generally accepted norm (Panter-Brick, 1992; Gray, 1995; Moffat, 2001; Simondon et al., 2001). Additionally, breastfeeding is ceased abruptly in case of death of the mother (Simondon et al., 2001). By contrast, mothers tend to prolong breastfeeding when there is food shortage in the household, when they are trying to avoid another pregnancy, or when their infants are weak, malnourished or sick. The infant health status may be an extremely important factor when analyzing non-survivors (Mulder-Sibanda and Sibanda-Mulder, 1999; Sellen and Smay, 2001; Simondon et al., 2001). Moreover, there are examples from historical populations in which breast milk was regarded as a beneficial food for the sick and weak, both adults and children (Salmon, 1994). However, we do not have any indication that this practice took place in the Great

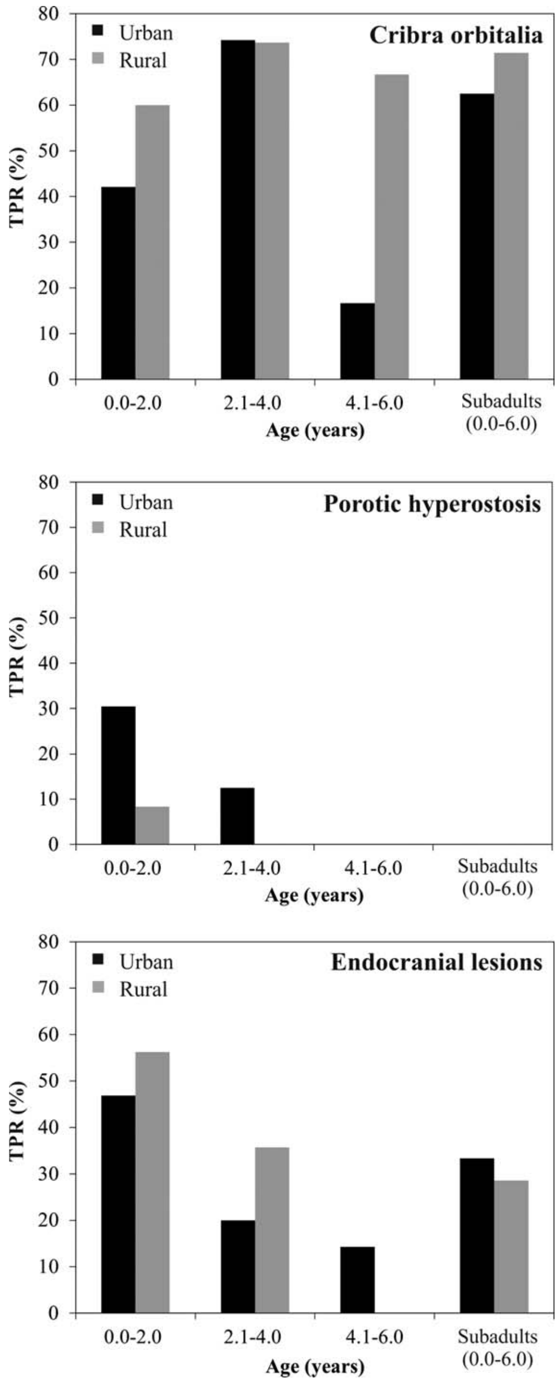


Fig. 6. True prevalence rate (TPR; % individuals with bone element present) of stress indicators in the urban and rural sample by age category.

Moravian population and we are not sure if it was important and lasting enough to affect the isotopic values. Most of these factors are beyond our control with archaeological populations, or their evaluation would require the study of a much larger skeletal collection in an excellent state of preservation. Working on subadult populations, we were not able to consider the potential effect of the sex of the infant affecting the age of weaning through differential parental investment (Jayachandran and Kuziemko, 2011).

The main limitation of our study lies in the fact that the exact time necessary for recording of the new nutritional regime in the isotopic composition of human dental and bone tissues is not known (Herrscher, 2003). In addition, there is a lack of certainty regarding how long the metabolic nitrogen pool takes to equilibrate with the diet (Balasse et al., 2001), and the bone turnover rate in the area of the mandibular base and time required under the regime of breastfeeding to balance the δ^{15}N value in bone to those in the tooth dentine. This results in a relatively high number of individuals (15/41) whose feeding status we were not able to determine because it was impossible to be precise regarding the causes of their insignificant Δ^{15}Nt-b.

Despite this limitation, the actual isotopic data of Great Moravians subadults, as well as those of their potential mothers (Fig. 5) still affirm the choice of the intra-individual sampling strategy. While the actual female isotopic data are going to be published elsewhere (Kaupová et al., 2014), from the view on their basic statistics (10.28‰ $\pm$ 1.0‰, n = 20 for the urban sample; 9.46‰ $\pm$ 0.73‰, n = 20 for the rural sample) it is clear that the greater variability of female isotopic values (especially in the urban sample) precludes the use of the range of mean $\pm$ 2SD (covering $\approx$95% of female variation) as a criteria for the determination of feeding status. In the urban sample, this range is as broad as 4‰, which is at least equal to the full trophic level effect of exclusive breastfeeding. Accordingly, plotting δ^{15}N of dentine and/or bone samples against dental age would lead to the misinterpretation of the feeding status of children nursed by mothers with low nitrogen isotopic values, which would be erroneously determined as weaned. This would be the case, for example, for individuals MIK18 (aged 3.8–4.2 years) and MIK21 (aged 4.1–4.5 years) who—while interpreted as substantially breastfed based on Δ^{15}Nt-b—are bordering the female group variability.

Moreover, especially in the rural population, it is not possible to observe any clear trend of decreasing δ^{15}N attributable to the weaning process: before 3 years of age, the data are highly variable. The remaining 3 (!) cases aged more than three years are located within or at least on the border of the female group variability, but they all—with the exception of JOS20 bone sample—fall within the variability of the younger group. Although the difference between younger (<2 years) and older (more than 2 years) individuals is more notable in the urban sample, even here we find individuals aged 2 years or less bordering the female group variability and being isotopically comparable with the older group. It is also interesting that we miss at all the children (even among those interpreted as weaned or undetermined) with isotopic values located in the lower half of female isotopic variation. This may suggest that either a certain minor proportion of their protein was still derived from breast milk or that their living conditions were more buffered with the post-weaning diet less variable in ^{15}N and on average enriched in animal protein and/or fish, when compared with adult females (but see also the discussion concerning potential non-dietary sources of the observed variability).

For carbon, especially in the urban population sample, actual isotopic data do not reveal any trends attributable to breastfeeding and weaning behavior. This is well in accordance with conclusions derived from intra-individual results (for more details see the above discussion on carbon results).

TABLE 5. Factors associated with the presence (vs. absence) of non-specific stress indicators: simple and multiple logistic regressions[a]

Explanatory variables		N	Simple regression			Multiple regression			
			OR	95% CI	P Wald	Adjusted OR*	95% CI	P Wald	P interaction[b]
Cribra orbitalia									
Type of residency	Urban	75	1.00	0.22–4.05	0.145	1,00	0.79–3.97	0.165	0.282
	Rural	40	1.82			1.77			
Age (continuous)		115	1.17	0.85–1.62	0.335	1.15	0.83–1.60	0.394	
Porotic hyperostosis									
Type of residency	Urban	52	1.00	0.07–1.66	0.181	1.00	0.06–1.62	0.168	0.520
	Rural	27	0.34			0.32			
Age (continuous)		79	0.62	0.34–1.14	0.123	0.62	0.32–1.13	0.117	
Endocranial lesions									
Type of residency	Urban	69	1.00	0.64–3.50	0.354	1.00	0.63–3.72	0.344	0.653
	Rural	34	1.50			1.53			
Age (continuous)		103	0.60	0.40–0.89	**0.011**	0.60	0.40–0.89	**0.010**	

[a] OR, odds ratio; CI, confidence interval; *P*, *P* value.
[b] *P* Wald of the Interaction age * type of residency.

Additionally, the use of the female population mean brings another potential pitfall: Fuller and colleagues (Fuller et al., 2004, 2005) have clearly demonstrated the effect of pregnancy on isotopic data. Although little is known about the nature and extent of isotopic shifts among mothers associated with lactation (Reitsema, 2013), there are some indications from non-human animal ecology that lactation may engender stable isotope shifts in mothers as well (Jenkins et al., 2001; Polischuk et al., 2001; Kurle, 2002; Habran et al., 2010; Reitsema, 2012). Because the turnover rate of adult compact bone is quite low (Hedges et al., 2007), the bone samples reflect a mean isotopic signal for at least the last decade of individuaĺs live (in the case of ribs). This may potentially blur any of the short term effects of either pregnancy (Nitsch et al., 2010) or lactation. Moreover, special dietary rules may be imposed on young women in different cultures in relation to their pregnancy or lactation (Baumslag, 1987). To conclude this part, we cannot be sure that the isotopic values observed in female ribs are the same as at the time they had nursed their babies, which makes the use of adult females as a comparative group disputable.

To mention the other potential limitations of our study, we also have to consider the possible interference of our results by the difference in the age composition between subsamples. In our study, the rural sample had a lower mean age (2.4 years) than the urban (2.7 years). This difference was not statistically significant (Wilcoxon test: $P = 0.393$) and moreover all performed statistical operations controlled for the age effect. However, taking into account the low number of individuals aged 3–5 years in the Josefov sample, the potential effect of different age composition cannot be excluded.

The non-dietary factors involved in changes in δ^{15}N values recorded in tissues should also be considered. Indeed, studies conducted on adult individuals agree on the fact that physiological stress related to the protein turnover process (osteopenia, anorexia) may increase δ^{15}N values in tissues (Katzenberg and Lovell, 1999; Fuller et al., 2005; Mekota et al., 2006). For subadults, however, the impact of stress has not been fully explained. Based on the results from control feeding experiments, Ambrose (2002) proposes that while nutritional stress after maturation may occasion a tissue loss with a consecutive isotopic effect, a subadult organism undergoing a period of nutritional stress may slow their growth rate rather than resort to tissue catabolism. Kempster et al. (2007) verified that under a biologically meaningful level of nutritional stress (with the measurable impact on physiology, growth and development at multiple scales) there was no effect of the feeding regime on either δ^{15}N or δ^{13}C values in any tissue of growing song sparrows. Williams et al. (2007) mention the potentially competing influence of positive nitrogen balance during growth (widely discussed by Waters-Rist and Katzenberg, 2010).

For humans, no study has yet demonstrated that enrichment in ^{15}N in children's tissue could be related to other non-dietary factors. Two studies conducted on subadults show neither the change in δ^{15}N values during growth from early to late adolescence (Waters-Rist and Katzenberg, 2010) nor a linear correlation between δ^{15}N values for children's hair and protein metabolism (de Luca et al., 2012). On the other hand monitored studies of breastfed/bottle-fed babies and their mothers have proved the relation between ^{15}N enrichment and breastfeeding (Fogel et al., 1989; Fuller et al., 2006).

Theoretically, some of these non-nutritional factors may well explain the aforementioned unexpected isotopic values of the JOS20 individual (4.8–5.6 years, Δ^{15}Nt-b = 0.6). However, when the health status of JOS20 was considered, this child does not appear to be stunted, and of the three evaluated nonspecific stress indicators, only *cribra orbitalia* was present (Figs. 7 and 8), which is absolutely insufficient (especially when taking into account the high prevalence of this pathological lesion, present in 68% of the evaluated individuals from the rural sample) to ascribe observed values unambiguously to the stress event. Additionally, this case was scored as Grade a, which according some authors (Bennike et al., 2005), is considered too mild to represent serious health problems. Alternatively this child may have increased the consumption of high trophic level food shortly before death. In the case of urban individuals that were interpreted to be still breastfed at the age of four, these alternative explanations are less probable, because their Δ^{15}Nt-b values were not extraordinary high but follow a general pattern in this population (Fig. 2). They are close to the level of significance, which is in accordance

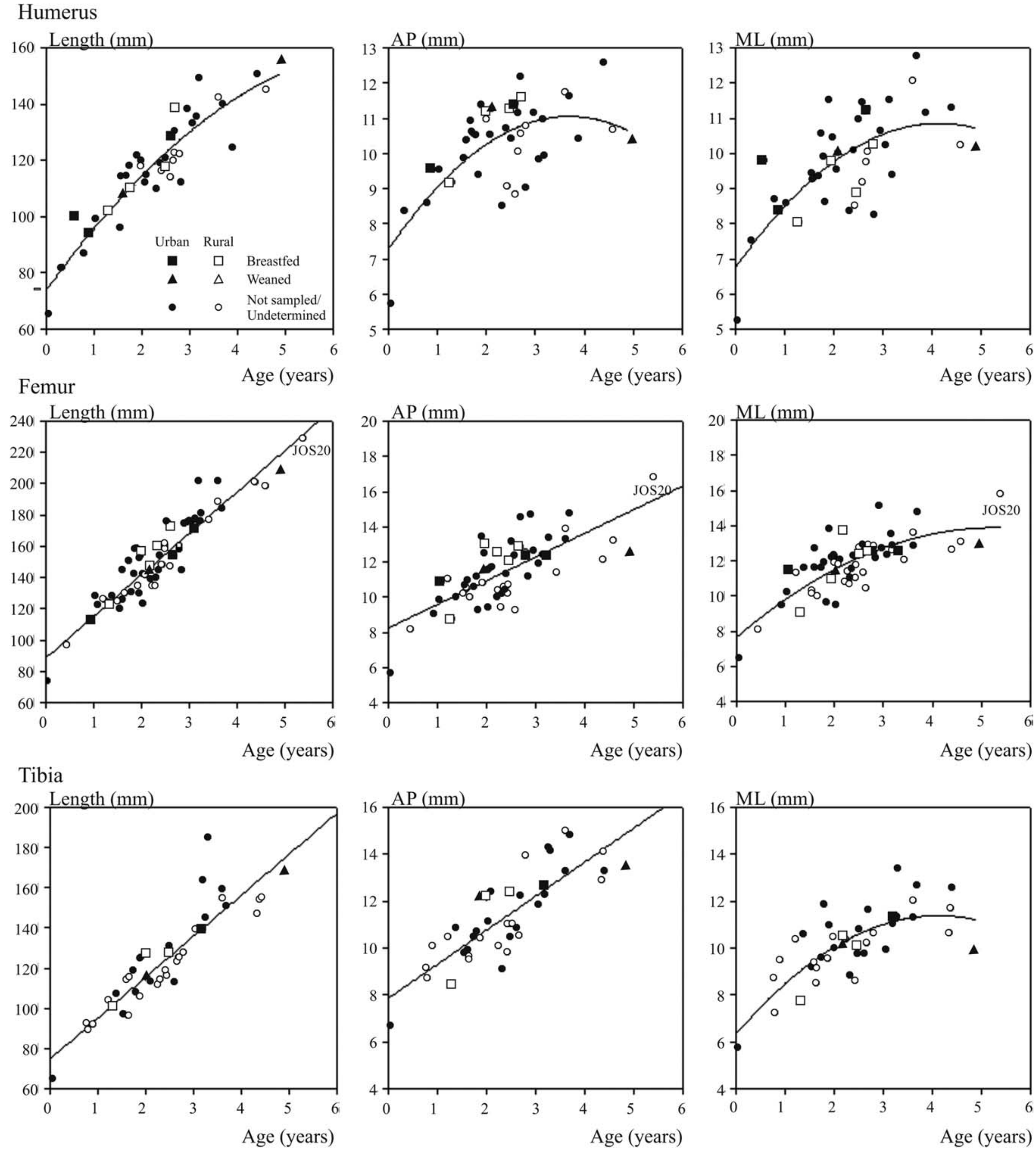


Fig. 7. Lineal regressions or second order polynomials for bone dimensions on dental age according to the urban versus rural place of residence and suggested feeding status. AP, ML = antero-posterior, medio-lateral diameter at the midshaft; age = median dental age in years.

with a scenario of prolonged breastfeeding, since a substantial proportion of bone had been formed under this nutritional regime. Nevertheless, low skeletal preservation precluded the osteological examination of these two individuals. Moreover, no information is available on the types of weaning food consumed by Great Moravian children. While there is wide variation exhibited between cultures in the types of supplementary foods consumed during weaning (e.g., Sellen and Smay, 2001) often including ^{15}N highly enriched foodstuff, such as fish; the diet of Great Moravian children would have to be really specific (taking into account a central European context) in its quantity to compensate or even surpass the effect of the cessation of breastfeeding.

TABLE 6. Regression equations for bone dimensions upon dental age[a]

	Length	AP	ML
Humerus	HL = 73.78 + 23.64 (age) − 1.62 (age)^2	AP = 7.26 + 2.05 (age) − 0.28 (age)^2	ML = 6.75 + 1.98 (age) − 0.23 (age)^2
Femur	FL = 88.57 + 26.52 (age)	AP = 8.23 + 1.35 (age)	ML = 7.63 + 2.38 (age) − 0.23 (age)^2
Tibia	TL = 74.76 + 20.38 (age)	AP = 7.86 + 1.45 (age)	ML = 6.32 + 2.46(age) − 0.30(age)^2

[a] HL, FL, TL, length of humerus, femur, tibia; AP, ML, antero-posterior, medio-lateral diameter at the midschaft; age, median dental age in years; all bone dimensions in mm.

TABLE 7. The effect of type of residency on the standardized residuals of the polynomial regression on biometric measures upon dental age[a]

		Urban			Rural			
		N	Mean	s.d	*N*	Mean	s.d.	*P*[b]
Humerus	Length	31	0.06	1.01	10	−0.19	0.89	0.219
	AP	30	0.10	0.98	10	−0.31	0.94	0.268
	ML	31	0.17	0.98	10	−0.52	0.80	**0.020**
Femur	Length	36	0.14	1.10	22	−0.24	0.73	0.197
	AP	36	0.11	0.98	22	−0.19	1.01	0.365
	ML	36	0.17	0.98	22	−0.28	0.95	**0.034**
Tibia	Length	23	0.19	1.15	18	−0.24	0.68	0.293
	AP	23	0.03	0.97	18	−0.03	1.03	0.703
	ML	23	0.14	1.03	18	−0.19	0.86	0.287

[a] AP, ML, antero-posterior, medio-lateral diameter at the midschaft.
[b] Wilcoxon test for independent data.

Weaning strategies in relation to health

If one accepts weaning to be a period of a high risk of biological stress in the lives of Great Moravian children, one may suppose the above described differences in weaning strategies could result in observable differences in growth and health between an urban and rural population sample. Taking into account the isotopic results in the rural population of Josefov, one may expect a peak in mortality and incidence of stress indicators after the age of 2 years, while in the urban sample of Mikulčice more homogenous distribution of the palaeopathological data would be expected due to the higher differentiation in weaning practices, with potentially higher morbidity and mortality in the older age induced by a nutrition shortage due to prolonged breastfeeding (Pearson et al., 2010).

Comparing the prevalence of *cribra orbitalia*, porotic hyperostosis and endocranial lesions (see Table 4 and Fig. 6 for the prevalence and the age of the first occurrence in the sample), logistic regression analysis was used to evaluate the relation between each of the three lesions and the type of residency.

Neither the results of the simple regressions nor those of the multiple regression, adjusted on median age variable (Table 5), reveal any significant relation between the prevalence of stress indicators and the type of residency. Nonetheless, the presence of endocranial lesions is negatively associated with an increase of median age (OR = 0.60, P = 0.010). This means that the probability of endocranial lesion decreased when the age increased, as expected based on the results of previous studies (Lewis, 2004, 2010). However, the trend of decreasing prevalence of endocranial lesions with increasing age did not differ significantly according to the type of residency (Interaction Age * Type of residency: P = 0.653). The use of alternative scoring for the presence of *cribra orbitalia* or exclusion of individuals younger than one year in the case of endocranial lesions did not change the results of the statistical tests significantly. In the case of porotic hyperostosis, our data did not enable repetition of the statistical test.

However, rural children seemed slightly shorter in comparison with urban children in all bone dimensions (Fig. 7), according to their age at death, the analysis of the standardized residuals of the polynomial regression (Tables 6 and 7) shows significant differences only for medio-lateral diameter of the humerus and femur (respectively, P = 0.020 and P = 0.034), which is not sufficient to prove any systematic and significant difference in growth between these two groups of the Great Moravian population.

Based on these results, the breastfeeding practices observed with isotope data are not reflected in the health status of both population groups. In the literature, both situations are described, either the breastfeeding duration could explain the patterns of health or mortality (Mays, 2010; Pearson et al., 2010), or there is non-causative relationship between weaning age and health and/or demographic trends in a population (Schurr, 1997; Howcroft et al., 2012), which suggests that the level of biological risk connected with the weaning varied among archaeological populations (Pearson et al., 2010). In the Great Moravian population, where the first children were weaned during the second year of life, probably a great majority of children benefited from all of the advantages of prolonged breastfeeding. By contrast, applying our sampling strategy, it is not possible to determine exactly the age of first introduction of supplementary food, which surely took place sometime before the substantial decrease in breast milk consumption, which we were able to track. This supplementary food may have protected children from potential nutritional imbalances, which could threaten the health of those that were breastfed exclusively for a long time.

And finally, two other explanations are worth mentioning. On one hand, the proportion of children weaned

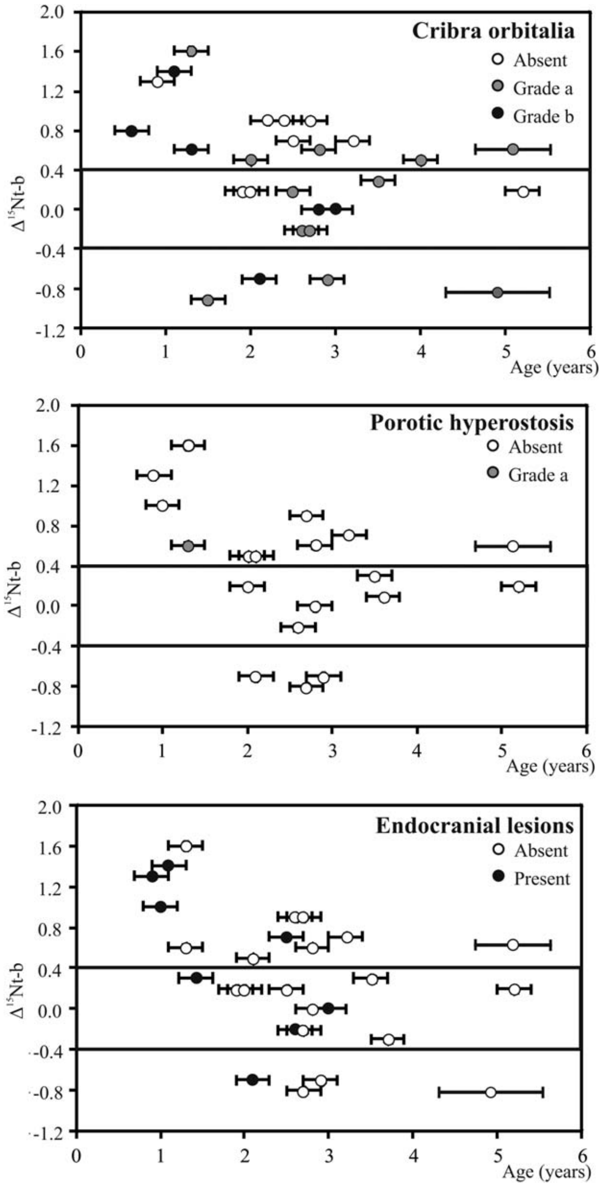


Fig. 8. Δ^{15}Nt-b according to the presence of non-specific stress indicators (for both urban and rural samples).

both early and late was too low to affect the general health of the urban population in comparison with a rural one, especially when taking into account the multifactorial origin of non-specific stress indicators, as well as growth faltering (Lewis, 2007). On the other hand, considering the osteological paradox (Wood et al., 1992), the recording of bone lesions consecutively to physiological stress may present a different timetable than the recording of dietary modifications due to the premature death of children.

At the individual level (Fig. 8), the low number of individuals (especially those interpreted as "weaned") and their state of preservation make the assessment of any relationship between diet and health status difficult. *Cribra orbitalia* were observed in all weaned children ($N = 4$), but they show a high prevalence among other groups (breastfed and undetermined) as well. When we focus solely on Grade b, affected individuals are present in all dietary groups. Porotic hyperostosis was observed just in one case (Grade a), which makes any evaluation of the relation to the dietary status impossible. Most of the cases of endocranial lesions were observed in the "breastfed" group. However, most of these cases are the youngest individuals (<2 years old), where a non-pathological origin cannot be excluded (Lewis, 2004). When these individuals are not considered, the remaining four cases are again distributed among all three dietary groups. Regrettably, our data did not permit any statistical analysis. Based on these data, any of the dietary groups appears to be more buffered against biological stress. Due to the low number of "weaned" individuals with measurable bone dimensions (Fig. 7), it was impossible to describe the relationship between diet and potential stunting. For all these reasons, it is not possible to determine any relevant relation between breastfeeding practices and health status for Great Moravian children.

CONCLUSION

Analysis of dietary behaviors and health status of subadults within three archaeological sites from Great Moravian period indicated subtle patterns. One could see in our results that there was not only one norm for the duration of breastfeeding established in the Great Moravian population. Nonetheless, the data from the urban sample of Mikulčice are more variable when compared with the rural sample, with both early weaning and prolonged breastfeeding being observed. That would suggest the existence of some culturally based ideals for breastfeeding and weaning behavior. However, if these ideals existed, they were likely multiple and related to the different rates of cultural and social change in different groups in Great Moravian society. The results of our study confirm the necessity of using an intraindividual sampling strategy to detect different trends in weaning behavior within the population and to understand the relationship between social structure and the socio-biological phenomenon of weaning.

There is no evidence that observed weaning strategies affected the level of biological stress, which urban subadult population must have faced respective to rural subadult population. This finding, as well as the observation of great intra-population variability in weaning behavior observed in our sample, lead us to urge caution when interpreting child morbidity and demographic trends in past populations.

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