Linear Enamel Hypoplasia in an Early Medieval Population of Great Moravia

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Hypoplastic enamel defects represent the disruption of the enamel matrix secretion during the growth of the tooth crown, which is related to a generalized growth disturbance. The aim of the study was to assess the frequency and timing of the linear enamel hypoplasias (LEH) in two early medieval Great Moravian population samples (9th-10th century A.D.) with different socio-economic statuses. Permanent dentitions of 99 children from the cemeteries in the Mikulčice settlement agglomerations and 64 children from the rural cemeteries in the surrounding area were examined. The age of examined individuals ranged from approximately 5 to 12 years. The timing of LEH was estimated in upper and lower canines by measuring the distance of the LEH from the cemento-enamel junction (CEJ). The LEH-CEJ distance was converted to age using the mean crown heights of the upper and lower canines in the examined samples and the sequence and timing of canine crowns formation in the recent Czech population. We observed no significant differences between the Mikulčice and Mikulčice-Hinterland groups in mean age at LEH formation. The earliest onset of LEH in the pooled sample occurred most commonly at around 3.5 years of life, ranging from 2.0 to 4.75 years. Similar results were observed in individuals with a single LEH. In individuals with two LEH, we obtained a mean age of 3.5 years for the first LEH and 4.2 years for the second LEH.

Key words: Early Middle Age – Great Moravia – linear enamel hypoplasia – timing of linear enamel hypoplasia

1. Introduction

Hypoplastic enamel defects are the manifestations of a defect in teeth mineralisation, more precisely of a defect in the development of enamel (amelogenesis) that leads to the reduction of its strength. The cause of this is a disorder of basal cells responsible for the formation of enamel-ameloblasts. This is thus a case of systemic disruption during the secretory phase of enamel development (e.g. Guatelli-Steinberg 2003). The aetiology of these defects is not completely clear. Most frequently, they are associated with inadequate nutrition or illness suffered during the development of dentition (e.g. Goodman/Rose 1990). Generally, enamel defects associated with systemic metabolic stress, rather than with genetic or traumatic causes, are referred to as "developmental" defects and are indicative of non-specific physiological stress during childhood (e.g. Lovell/Dawson 2003; Boldsen 2005; King/ Humphrey/Hillson 2005). As in contrast to bone tissue enamel is a definitive tissue that cannot be re-modelled, it represents a chronological record of strain and stress endured by a child during the period when the crowns develop (e.g. Skinner/Goodman 1992).

Enamel defects may have various characteristics – most frequently they take the form of continuous/discontinuous horizontal grooves

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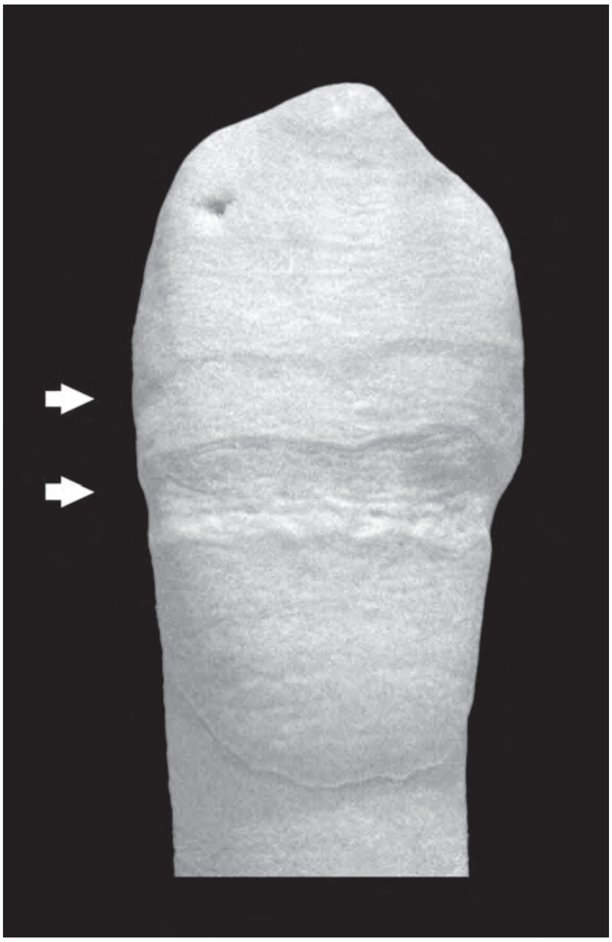

Fig. 1. Linear enamel hypoplasia on the lower left canine. The earliest stress episode can be observed as pit-type hypoplasia. The second and third stress episodes is distinctly manifested as LEH (arrows).

transversing the crown (so-called linear enamel hypoplasia; LEH); on the other hand these defects may involve a single pit or several pits that merely follow the horizontal line or are arranged irregularly (Fig. 1). These may appear on the lingual or facial tooth surface or may circumscribe the tooth. The aetiological and micro-structural differences between the different types of hypoplastic lesions are not well understood (Lovell/Dawson 2003).

All types of teeth may be affected. Individual teeth, though, differ in their sensitivity to stress, which is contingent to the geometry of their crowns. The position of the given tooth within the dental arch also plays an important role. According to research (e.g. Goodman/Rose 1990), the teeth of the anterior section of the arch (incisors, canines) are more susceptible to the development of defects. Posterior teeth have a higher limit threshold for ameloblast disruption (e.g. Goodman/Armelagos 1985; Wright 1997).

The first type of defect listed above, i.e. LEH, is most frequently studied and monitored. This sign is evaluated mainly in the case of incisors and canines of permanent and deciduous dentition. Some researchers prefer the canines of the lower jaw because of their longer developmental period and concurrently their more frequent preservation and relatively inferior abrasion (e.g. Cunha/Umbelino 1995).

In teeth, we may also observe so-called hypo-calcification. This – in contrast to hypoplasia – results in enamel of lower quality due to a systemic insult during the mineralisation phase of enamel development (Lovell/Dawson 2003). This means that hypoplasia and hypo-calcification are linked to a disturbance occurring during a specific phase of enamel development and are associated with a unique process of defect creation.

The location of the LEH on the surface of enamel – its distance from the cemento-enamel junction – and the height of the crown enable one to roughly calculate when it developed, i.e. to determine the age of the child during the period when its organism was "under stress" (e.g. Goodman et al. 1988). This is conditional to knowing the mineralisation chronology of the given crown. Applying this method, which was developed using a recent population, to an archaeological population logically presumes that the dental developmental model in the past was similar to the standards of today. This means that the speed of dental development is consistent among individuals and populations, and that the variability of tooth size does not affect the age-associated determination of hypoplasia (e.g. Lewis/ Roberts 1997). The standards used to determine the period of crown development termination and its height should be the same as those standards employed for determination of age, i.e. for reconstruction of the mortality profile of a studied population. Naturally, dental abrasion of the occlusal dental surfaces that reduces the height of crowns represents the limiting factor for estimation of the period when a hypoplastic defect occurred (Fig. 2).

As shown by previous studies, most defects develop between the 2nd and 4th year of life (e.g. Obertová 2005). This is thus a period when the child in certain societies (hunter-gatherer) abandons a natural diet, is no longer suckled (e.g. Corruccini/Handler/Jakobi 1985; Coppa et al. 1995). The so-called "weaning hypothesis" is based on this event, which may be the cause of defective dental mineralisation. This theory, though, does not correspond to research results, whereby mothers weaned their children in their first year of life, yet the highest frequency of defects occurred in the period between the age of three and four. This "delayed incidence" may be partially explained by the disappearance of maternal antibodies from the child's organism as late as one year after weaning, when the child's own immune system, or rather its acquired adaptive component, is not as yet fully functioning. Nonetheless, it is very probable that environmental conditions also play an important role in the development of hypoplastic defects. This mainly applies to children between the 2nd and 4th year of life (e.g. Goodman/Rose 1990).

Tens, even hundreds of studies have in the past twenty years been devoted to hypoplastic enamel defects. Apart from research studying the chronology of the development of these defects, i.e. the period during which the organism is exposed to stress-related growth-disruptive events (e.g. Goodman et al. 1988; Saunders/Keenleyside 1999) and the difference in their incidence within the dental arch and upper and lower jaws (e.g. Reid/Dean 2000; Lovell/Dawson 2003), there also exist studies that focus on methods and means of evaluation (e.g. Guatelli-Steinberg 2003; Martin et al 2007; Ritzman/Baker/Schwarz 2008). A large group is represented by works attempting to document the frequency of enamel defects in various prehistoric or historical populations (e.g. Palubeckaitë 2001; Jarošová 2005; FitzGerald et al. 2006). Other works have studied the relationship between the frequency of defects and various diseases (e.g. Boldsen 2005). The influence of sex on the incidence of this trait has also been evaluated (e.g. Boldsen 1997; Saunders/Keenleyside 1999). Finally, there also exist studies that investigate whether the incidence of these defects reflects the different social status of individuals (e.g. Cucina/Iscan 1997; Palubeckaitë/Jankauskas/Boldsen 2002; King/Humphrey/Hillson 2005; Boldsen 2007), the geographical (e.g. Wood 1996) or chronological (e.g. Cucina 2002) distinctness of population groups. Verification of the effect of social status on the incidence of enamel defects was also one of the aims of our study.

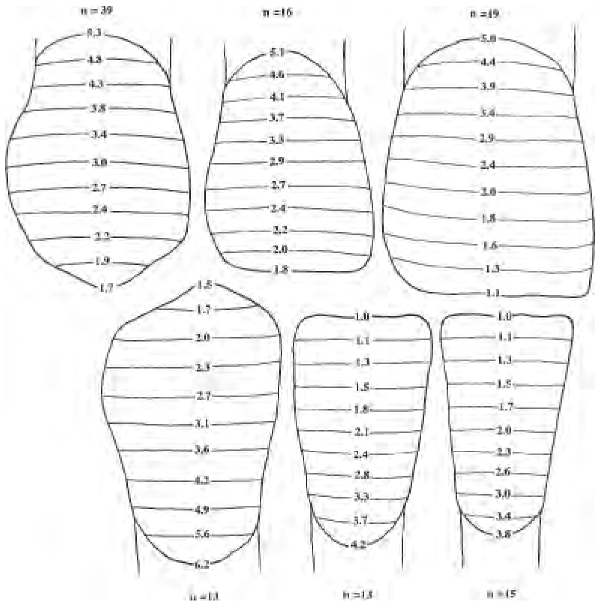

Fig. 2. Timing of anterior tooth growth. The right anterior quadrant of the mouth is depicted as when viewed clinically by an observer. Each height of each type of tooth is divided into 10 equally spaced zones. The age when enamel appears at the incisal edge is considered to be coincident with the completion of cuspal enamel. The age at completion of each zone of surface enamel formation is shown in years to one decimal place (Reid/Dean 2000).

The aim of the study was to assess the frequency and timing of linear enamel hypoplasias (LEH) in two early medieval Great Moravian population samples (9th-10th century A.D.) with different socio-economic status.

2. Material

The permanent dentition sample consisted of the dental remains of 163 individuals from the following archaeological sites:

The Settlement Agglomeration of Mikulčice (M group), presumed to be a centre of the Great Moravian Empire in the 9th-10th century A.D. Skeletal remains of about two thousand individuals have been excavated here so far. LEH were scored in 67 individuals from the castle area and in 32 individuals from the sub-castle area. Based on the archaeological excavations, it can be concluded that members of the higher social classes of the Great Moravian empire (warriors, priests) were buried here.

The Rural Hinterland of Mikulčice (MH group) is represented by two cemeteries in the area surrounding the Mikulčice settlement – Prušánky and Josefov. LEH were scored in 41 individuals from the Prušánky I cemetery and in 23 individuals from the Josefov cemetery. In contrast to the Mikulčice site, the poor equipment of graves indicated the rural character of this population.

Only teeth free of attrition and abrasion, with completed crown development and sufficiently well preserved to allow examination of the crown surface were included. The age of the examined individuals ranged from approximately five to 12 years.

3. Methods

The presence or absence of LEH was recorded by visual examination of the enamel surface under an oblique spotlight. An individual was regarded to be free of LEH if at least two anterior permanent teeth from that individual were available for examination and none of them exhibited LEH. If at least two anterior permanent teeth exhibited LEH that could be matched chronologically, the individual was considered to be LEH-positive. Defects not matched chronologically in at least two frontal teeth were not considered to be LEH.

In the upper and lower canines, the distance of the occlusal border of the LEH from the cemento-enamel junction (CEJ) was measured using a thin-point digital Mitutoyo sliding calliper. Mean crown heights of the upper and lower canines were also determined in unworn, largely unerupted specimens. The sequence of the upper and lower canine crown formation in the examined sample was determined by matching the unerupted canine crowns of the given individual according to the LEH. In most cases, lower canines exhibited a slightly earlier onset and later completion of crown development than upper canines. The age at LEH formation was then estimated using the mean crown heights of the upper and lower canines in the examined samples and the timing of canine crown formation as given in three different developmental charts (Table 1).

There is only one mineralisation chart available for the recent Czech population (Handzel 1996). In this study, the timing of crown development was determined using the position of enamel hypoplasia on the crown surface and the corresponding periods of tetracycline usage stated in the patient's medical record. Probably the most recent developmental chart, that of Reid/Dean (2000), was developed and based on the histological examination of extracted unworn anterior teeth. This chart was modified according to the sequence of upper and lower canine crown formation in the studied sample. To avoid systematic error in the mineralisation standard, we tested the sequence of upper and lower canine crown formation using three developmental charts.

4. Results

The incidence and frequency of LEH are given in Table 2. The prevalence of LEH was higher in the M group: 76.8% individuals had one or more linear enamel hypoplasia. The chi-square test showed a significant difference between the two groups ($p<0.05$).

Both the M and MH groups were characterised by a relatively low number of defects per individual. The majority of individuals had one or two LEH, five individuals exhibited three LEH and four LEH were observed only in one individual.

Table 1. Developmental charts used for estimating age at LEH formation.

		Developmental Age		Regression Equations
		at cusp	at CEJ	
Reid and Dean (2000)	Upper canine	1.7	5.3	-0.336x + 5.3
	Lower canine	1.5	6.2	-0.420x + 6.2
Reid and Dean (2000) modified	Upper canine	1.7	5.3	-0.336x + 5.3
	Lower canine	1.5	5.5	-0.357x + 5.5
Handzel (1996)	Upper canine	0.9	3.8	-0.271x + 3.8
	Lower canine	0.6	4.2	-0.322x + 4.2

Table 2. Incidence and frequency of LEH in the examined samples.

	Individuals Affected	Individuals Examined	%	Chi-square	p
Mikulčice settlement	76	99	76.8		
Rural hinterland	40	64	62.5	3.86	0.049
Total	116	163	71.2		

Table 3. Mean crown heights of the upper and lower canines in the examined sample.

	Crown height	SD	N	Range
Upper canine	10.80	1.05	57	8.50 - 12.89
Lower canine	11.21	0.88	52	9.75 - 13.00

Table 4. Mean age at LEH formation in individuals with single LEH in both upper and lower canines.
* indicates 5% level of significance

		Mean Age	SD	N	Diff.	Range	t
Reid and Dean (2000)	Upper canine	3.54	0.77				
	Lower canine	3.85	0.86	18	-0.31	-0.69 - 0.07	-7.09 *
Reid and Dean (2000) modified	Upper canine	3.54	0.77				
	Lower canine	3.55	0.75	18	-0.01	-0.29 - 0.28	-0.34
Handzel (1996)	Upper canine	2.38	0.62				
	Lower canine	2.40	0.66	18	-0.02	-0.29 - 0.26	-0.57

Table 5. Mean age at LEH formation in individuals with single and two LEH, mean age at the earliest LEH formation.

		Mean Age	SD	N	Range
Subjects with single LEH		3.77	0.67	38	2.00 - 4.75
Subjects with two LEH	first LEH	3.48	0.50	21	2.54 - 4.34
	second LEH	4.16	0.43	21	3.46 - 5.01
Earliest LEH observed		3.64	0.64	59	2.00 - 4.75

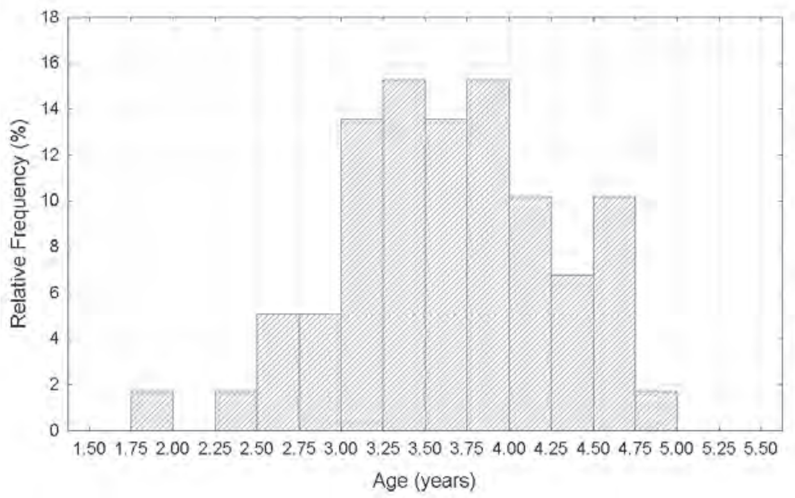

Fig. 3. Chronological distribution of the earliest LEH in each individual (individuals with one or more LEH included).

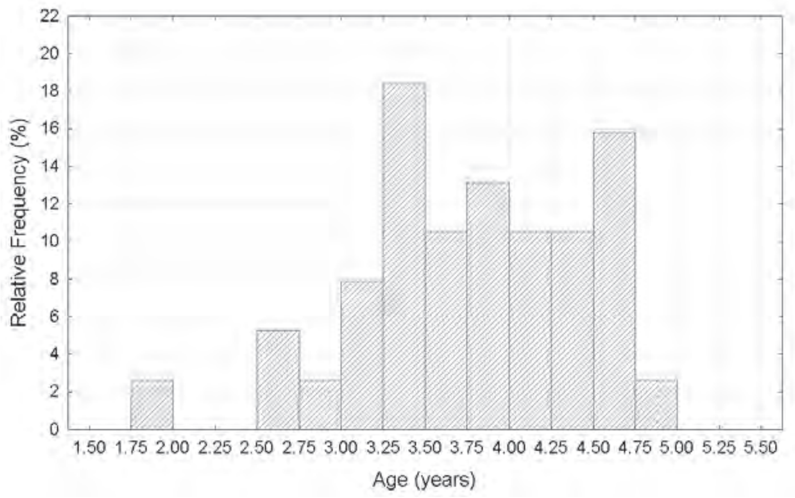

Fig. 4. Chronological distribution of LEH in individuals with single LEH.

There were no significant differences in mean crown heights between the two groups and therefore, the data was pooled (Table 3). In individuals whose upper and lower canines exhibited one chronologically matched LEH, Student's t-test was used to verify the timing of the upper and lower canine crown formation as given in the three mineralisation charts (Table 4). Mean ages at LEH formation in upper and lower canines should ideally be identical.

The J. HANDZEL mineralisation chart (1996) performed well in the test. We obtained identical mean ages at LEH formation in upper and lower canines. However, this chart gave extremely low age values for cuspal enamel completion and also rather low age values for crown completion as compared to other mineralisation schemes. Therefore, it has been omitted from this study.

Using the REID/DEAN developmental chart (2000), we found that the timing of upper and lower canine crown formation did not match the sequence of upper and lower canine development observed in the examined sample. The mean age at LEH formation in lower canines was about 0.3 years greater than in the case of upper canines. Therefore, this mineralisation chart was modified according to the sequence of upper and lower canine crown formation in the studied sample. Completion of lower canine crown formation was shifted from 6.2 years to 5.5 years. Using this modified chart, we obtained identical mean ages at LEH formation in upper and lower canines.

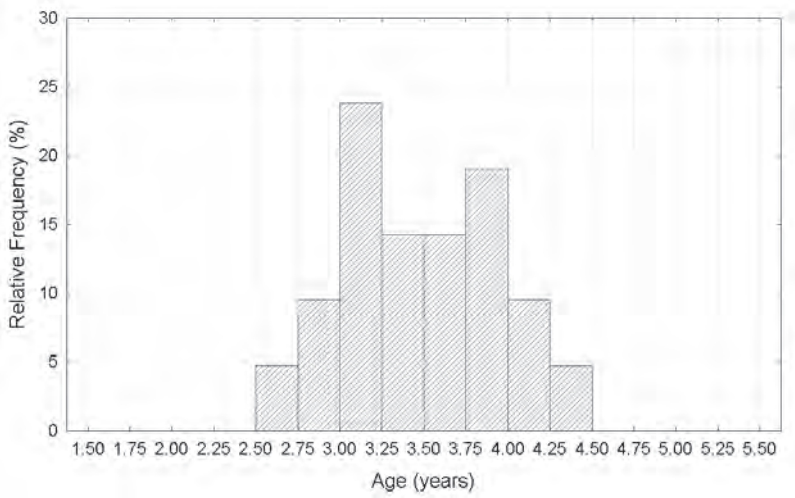

Fig. 5a. Chronological distribution of LEH in individuals with two LEH (first LEH).

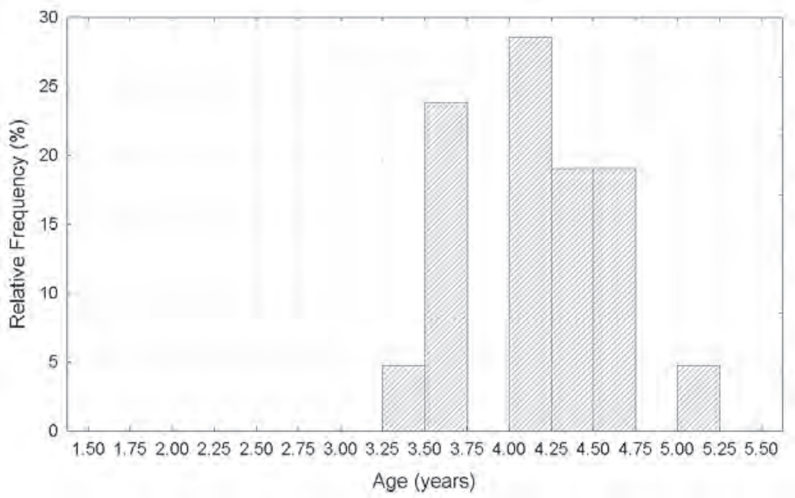

Fig. 5b. Chronological distribution of LEH in individuals with two LEH (second LEH).

We observed no significant differences between the M and MH groups in mean age at LEH formation, therefore, the data was pooled (Table 5). The earliest onset of LEH in the pooled sample occurred most commonly at around 3.5 years of life, ranging from 2.0 to 4.75 years (Fig. 3). Similar results were observed in individuals with a single LEH (Fig. 4). In individuals with two LEH, we obtained a mean age of 3.5 years for the first LEH and 4.2 years for the second LEH (Fig. 5).

5. Discussion

The prevalence of LEH in the M and MH groups was found to be comparable to the frequencies reported in medieval samples. It could be argued that rigorous criteria for selection of teeth biased the sample towards younger individuals, resulting in overestimation of the frequency of LEH. But we presume that only teeth free of attrition and abrasion can provide reliable evidence of stressful events. Subtle LEH involving only few perikymata cannot be easily identified in older individuals due to the rapid abrasion of the enamel surface in prehistoric populations. Another issue is the frequent occurrence of calculus and adherent deposits that cover the cervical enamel on the buccal surfaces of frontal teeth. This can result in underestimation of LEH prevalence.

Although the severity of LEH has not been scored yet, it can be concluded that predominantly mild to moderate degrees of LEH occurred in both groups. Differences between the M and MH group in the prevalence of LEH are surprising. Previous anthropological studies confirmed that the higher social classes of the Great Moravian Empire (i.e. subjects with better living conditions) were buried at Mikulčice-castle. On the contrary, the cemeteries of the sub-castle and the hinterland of Mikulčice were probably the burial sites of the poorer social classes. Josefov, for instance, was very likely to have been the cemetery of the rural population only. Therefore, we presume that the MH group experienced more stress during childhood.

Since many studies of historical and contemporary populations have confirmed a relationship between poor nutrition and a higher incidence of LEH, we would expect the rural MH group to show a higher frequency of LEH. But the opposite is true. The well-situated M population exhibited a significantly higher frequency of LEH. Palubeckaitë/Jankauskas/Boldsen (2002) observed a similar situation in their analysis of LEH in Danish and Lithuanian late medieval samples.

Using multiple teeth (typically the upper first incisor and lower canine) to obtain the age at LEH formation, some studies have shown two different peak ages of stress in a single population. Although such differences could most likely be attributed to a systematic error in the mineralisation standard, some authors have suggested a different susceptibility of individual teeth to stress.

There is no reason to assume that one episode of stress will produce LEH at two different ages. But it is also clear that different inter- and intradental susceptibilities to stress exist in human dentition. For instance, in two teeth developing at the same time, one stressful event can perceptibly manifest as LEH in one tooth only. In the second tooth, LEH can be much less obvious or not present at all. In the studied sample, we observed such differences in both adjacent and opposite teeth.

It has been well documented that a considerable part of the upper and lower canine crown formation is not expressed on the crown surface. A combination of lower first incisors and canines is often used to obtain an estimation of the age at LEH formation, as this covers the period from approximately 1 to 5.5 years of life. However, there still remain two main difficulties associated with the use of multiple teeth: correct crown formation timing of the teeth studied and the nonlinear nature of dental growth.

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