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Anthropology

The incidence of Harris lines in the non-adult Great Moravian population of Mikulčice (Czech Republic) with reference to social position

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Abstract. Harris lines (HL), the markers of temporary arrest in longitudinal bone growth, have been observed since the 1930's (e.g. Harris 1931). Although much research has concentrated on the causes of HL development, its aetiology is still not well understood. HL are generally considered to be a reaction to a pathological condition or nutritional deficiency. An analysis of HL was performed on 132 non-adults buried at the Great Moravian settlement at Mikulčice-Valy (Czech Republic). These marks were assessed on three long bones – the femur, the tibia and the humerus. The highest incidence of HL was observed in the 0–3 years age group. No statistically significant differences in the occurrence of HL were proved between groups of individuals of higher or lower social status.

■ **Harris lines, long bones of extremities, Middle Ages, Great Moravian population, grave goods**

INTRODUCTION

Harris lines (HL) are transverse sclerotic layers in the spongiose bone tissue. They form mainly in the metaphyseal parts of long bones as a layer parallel to the epiphyseal disc (Hummert et Van Greven 1985). They proceed upright on the bone shaft and cross it either partially or totally.

It is possible to observe HL on a longitudinal section of the bone or on X-ray images; the latter is more useful because as a method it is less invasive.

HL are expressed as the result of unspecific stress undergone during ontogenesis. The temporary interruption or total arrest of bone growth leads to formation of HL during ontogenesis. Subsequent bone growth regeneration is important for HL development (Steinbock 1976). The aetiology of HL development includes many factors (Vyhnánek et Stloukal 1991).

The inheritance of HL has never been proved, but may be a consequence of earlier studies (Sontag et Comstock 1938).

Differential degrees of intensity in HL have been observed. It is supposed that HL intensity reflects the severity and duration of the causal stress. Although many studies have considered the causes of HL development, the aetiology of the latter is still unclear.

Different form of nutritional stress (starving) is presented as the major cause of HL development. A lack of proteins and vitamins may arrest bone growth (Park et Richter 1953).

HL have also been recorded after acute diseases (e.g. childhood infectious diseases such as measles, parotis, etc.), anaemias or poisoning by heavy metals, especially lead or phosphorus (Huges et al. 1996). Some authors even see psychical or environmental deprivation (Sonntag et Comstock 1938) as a cause of HL, but this could simply be the associated factor of physical and physiological stress.

The relationship between HL formation and disease is another of the problems under study. It has been suggested that HL directly reflect all serious diseases, but such dependence has been proved in only around 25 % of the cases (Gindhart 1969, Garn et al. 1968).

The causes of HL development have mainly been studied in animals, given the opportunities for easier control of experimental conditions. Skeletal remains, whether archaeological or from recent medical practice, also provide material appropriate for the study of HL. Such collections are not, however, suitable for the study of the causes of the development of HL, and the research using skeletal remains is therefore restricted to the study of the incidence of HL in a population. HL are not practical use in clinical medicine.

These transverse lines are above all an interesting and important indicator of the state of health of past populations (Wells 1967). Thanks to the supposed correlation between the number of lines and living conditions, it is possible to deduce a better or worse standard of living on the part of our ancestors. The authors' own work is based on this assumption.

In addition to studying HL as markers of the general state of health in a population, it is possible to estimate the age of the development of HL from their position on the bone shaft (e.g. Hunt et Hatch 1981), i.e. the age at which the individual underwent the non-specific stress.

There are, however, relatively great difficulties to be overcome in the investigation of HL. The remodelling of the internal bone structure in adults and the subsequent resorption of the lines is a negative factor that reduces the opportunities for using HL. It is for this reason that the study of HL concentrates on non-adult populations. Furthermore, according to most studies HL development peaks in childhood, too. The material selected for this study was from non-adult individuals for these reasons.

MATERIALS

The bone material on which the study was conducted came from the medieval (Middle "Hillfort" period) settlement agglomeration at Mikulčice-Valy, which dates to the 9th and 10th centuries. This site was a Great Moravian ("Hillfort" period) enclosure sited on the lowlands (fluvial plain) of the river Morava in the Czech Republic. Mikulčice is regarded as having been one of the potential centres of Great Moravia.

Systematic archaeological research began at the site as early as in 1954, and continued uninterrupted until the 1990's. Over this period some 2 500 skeletons were discovered; given this number, the location is one of the largest Early Medieval archaeological sites in Europe.

HL were evaluated on 132 non-adult individuals of indeterminate sex. All of the individuals studied had at least two long bones well preserved; the requirement for well preserved bones is still the basic limiting factor for any further research.

Table 1 summarises how many single long bones and how many pairs of such bones were usable for the study. Overall there were 115 individuals with at least one well-preserved femur, 75 with at least one well-preserved tibia and 102 with at least one well-preserved humerus (Table 1).

Fig. 1. Harris lines on an X-ray image of tibia.

		N	
	individuals	bones	pairs
Femur	115	199	84
Tibie	75	122	48
Humerus	102	167	65

Table 1. Number of individuals under study by single bones.

METHODS

The selection of the bones for HL analysis was carried out using several standards. A non-adult population was the basic requirement. Next it was necessary to have at least two well-preserved long bones with undisturbed compact tissue. (Intact compact tissue is a protection against the interruption and disturbance of the spongiose tissue architecture). Although it is evident from earlier studies that the tibia is the optimal bone for HL investigation, the femur and humerus were also studied for comparison.

The selected bones were X-rayed under the following conditions: focal distance: 110 cm; range ca. 50 mA, ca. 1.25 mAs; time: 0.03 s, ca. 46 kV. To ensure precision the evaluation X-rays were made in two projections – anterioposterior and mediolateral. This method results in a reduction of observer error (see e.g. Vyhnánek et Stloukal 1991). The occurrence of HL can be evaluated from the long section of the bone, but attempts were made to avoid using such an invasive method.

The X-ray image was digitised using a Microtek ScanMaker 64000XL scanner and SilverFast 4 software. The assignment as such, line counts and measuring the distance of HL from the end of diaphysis was conducted using Sigma Scan Image Pro 6.0 image analysis software.

For the evaluation proper, the method of Goodman and Clark (1981) was employed, this requiring that the line be visible by the naked eye and extend at least 1/4 of the width of the diaphysis. The intensity of HL was also observed. In order to minimise the observer error, only two types of lines were distinguished: weak and strong.

To ensure the greatest possible reliability of interpretation the evaluation was conducted three times for each bone. For calculation of interpersonal error (Friedman ANOVA based on median identity) each tibia was measured four times by different people. Statistical analysis was conducted using Statistica 6.0 software.

The second part of the study concentrated on estimating the ages at which HL developed. The method used was that described by Byers (1991), according to which several measurements must be known. Because only non-adults were included in the study there would have been no purpose in carrying out corrections of the metaphyseal lines on bones with connected epiphyses. The measurements such as bone and epiphysis length were not used; only the total diaphysis length, measured from the most proximal to the most distal points, were used for calculations, along with the measurements of HL distance from nearer end of the diaphysis.

Byers' method is based on these two measurements and is applicable to all types of long bones. Further, it allows the temporal distribution of HL development to be observed. The calculation as such is based on equations originating in the same measurements (a modification of Byers' method for non-adult populations: see Velemínský 2000).

The data acquired are a percentual rake-off bone length at the level of the observed lines. These results are necessary to attain an ontogenetic model for the long bones, i.e. for deduction of the "proper" period of HL development. This study employed ontogenetic tables drawn up specifically for the Great Moravian population (Stloukal et

Table 2. Occurrence of HL on particular long bones.

HL	Fe		Ti		Hu	
	N	%	N	%	N	%
absence	53	45.2	8	10.7	97	95.1
presence	62	54.8	67	89.3	5	4.9
total	115	100.0	75	100.0	102	100.0

Hanáková 1978). Regression analysis was used to provide a statistical assessment of the irregular distribution of HL by age.

The aim of the next stage was to find correlations between the standard of living and the number of HL present in this ancestral population. Standard of living was considered in respect of grave goods and the location of the relevant grave in the context of the entire Mikulčice settlement. A higher social status was attributed to individuals buried within the inner stronghold (93 of 132 skeletons), and thus a higher standard of living than those individuals from the lower ward (39 of 132 skeletons).

The 9th century is associated with the beginning of the Christianisation of this region, which in turn led to the abandonment of older pagan customs such as the leaving of grave gifts for the deceased. Grave goods are therefore not such a good indicator of social status as previously. Nevertheless, it might be supposed that those with poor grave goods and those buried in the lower ward had a lower standard of living, and a higher number of HL might thus be expected, and vice versa.

The division of individuals by grave accoutrements was conducted using two methods:

I. that of Unzeitigová (2000):

Group 1: graves with jewellery, weapons, etc.

Group 2: graves with items of everyday use (knives, utensils, pots, etc.)

Group 3: graves with no grave goods

II. that of Stloukal (1970) and Velemínský (2000):

Group 1: graves with swords, spurs, axes, and/or gold, silver and bronze articles

Group 2: graves with no grave goods, or graves with knives and/or small iron, pottery or glass items.

To verify the hypothesis the chi-quadrat test was used.

RESULTS

Nearly 70 % of the skeletons (92 individuals) studied had at least one HL, while 40 had none. The occurrence of HL in single bones (irrespective of the number of bones) is shown in Table 2 (Fig. 2).

As expected, the highest occurrence of HL was recorded on tibia. Only 50 % of the individuals had at least one HL on the femur, and HL appeared on the humerus in no more than 5 % of the cases.

Basic statistics also confirms the tibia to be the bone most afflicted with HL. The median for the tibia is 3, for the femur 1 and for the humerus 0 (Table 3). The situation is similar for the man. The greatest number of HL found on a single bone was 8 – again, on a tibia.

In terms of the distribution of the age of HL development, there is an apparent decline in the formation of new lines with increasing age (Fig. 3). The greatest number of lines developed at between 1 and 3 years of age (on all types of bones), and over 40 % of all of the lines observed formed in this period.

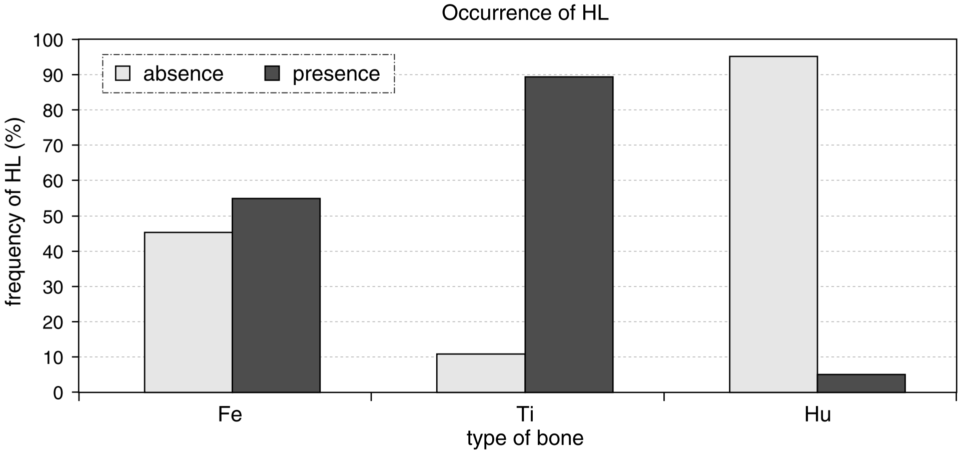


Fig. 2. Occurrence of HL on particular long bones.

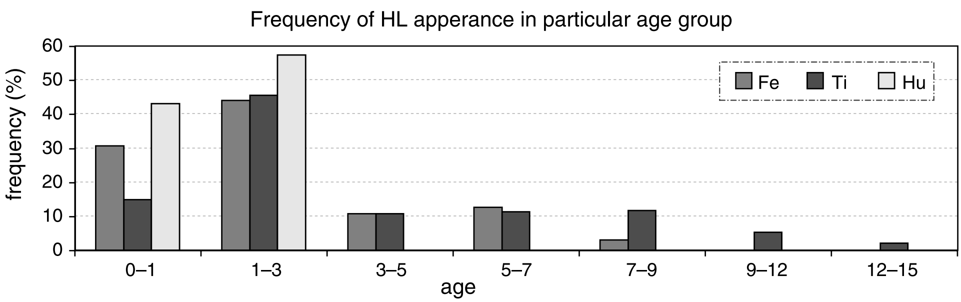


Fig. 3. Distribution of HL by age of HL formation.

The statistical correlation between HL and age is also apparent from the subsequent regression curve (Figs 4–6).

The interpersonal and intrapersonal measurement errors were determined by Friedman ANOVA (about the identity of the medians). The null hypothesis could not be refuted on even one occasion. The method used to assess the lines may thus be regarded as objective and the deviations as statistically insignificant.

The irregular distribution of HL among individuals buried in the inner or lower wards were tested using chi-quadrat statistics, with comparison of the expected and observed frequencies.

Because the null hypothesis could be refuted neither at the (=0.01 nor (=0.05 level the assumption of a higher HL occurrence in the cemeteries of the lower ward could not be validated (Fig. 7).

The distribution of HL according to grave goods was tested using the same statistical methods. The null hypothesis, supposing an irregular distribution of HL by categories of grave goods, could not be rejected until the level of (=0.9; this level is quite high, and is therefore not greatly statistically significant. A detailed characterisation of HL distribution for particular categories of grave goods is given in Table 4 (Figs 8–9).

Table 3. Basic statistical characteristics of occurrence of HL.

	Femur	Tibie	Humerus
Valid N	115.0	75.0	102.0
Mean	0.9	2.9	0.1
Standard error	0.1	0.2	0.0
Median	1.0	3.0	0.0
Mode	0.0	2.0	0.0
Standard Deviation	1.1	2.0	0.3
Variance	1.3	4.1	0.1
Skewness	1.5	0.6	5.0
Range	6.0	8.0	2.0
Minimum	0.0	0.0	0.0
Maximum	6.0	8.0	2.0
Total	105.0	218.0	7.0
Frequency	53.0	17.0	97.0
Lower	0.0	1.0	0.0
Upper	1.0	4.0	0.0

Table 4. Occurrence of HL as regards grave goods.

grave equipment	N of ind. with HL	total individuals	% ind. with HL
1. group	14	20	70.0
2. group	13	17	76.5
3. group	65	95	68.4
1. group	18	25	72.0
2. group	74	107	69.2

CONCLUSIONS AND DISCUSSION

Harris lines were found in approximately 70 % of the individuals in the assemblage of non-adults from Mikulčice, irrespective of the numbers of lines or types of bones studied.

This research has confirmed that the highest occurrence of HL is on the tibia (89.3 % of individuals with HL), and that this is therefore the most appropriate bone for the study of transverse lines – as demonstrated in earlier studies (Gindhart 1969, Huges 1996, Ubelaker 1996, 1998, Vyhnánek et al. 1986). HL occurrence on other types of long bones is relatively poor, and they appear in only 54.8 % of individuals on the femur and just 4.9 % of individuals on the humerus.

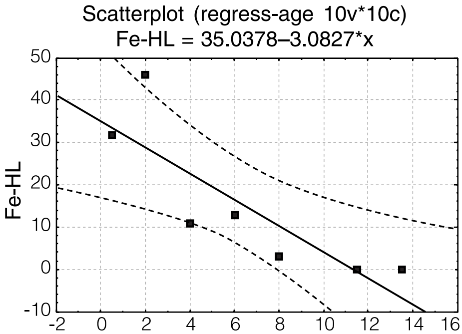
The different occurrence of HL implies different sensitivity and resistance of the various long bones relative to the same stress event (e.g. starvation). More precisely, there may be different thresholds of sensitivity. For example, non-specific stress must probably impact longer and with greater intensity to cause the formation of HL on the femur than is true for the tibia. For the humerus the threshold is set higher, and the intensity of the stress must therefore be greater to have an effect. It is possible to put the higher sensitivity of the long bones of the lower limbs into the context of the fact of their higher biomechanical stress in comparison to the long bones of the upper extremities.

From this perspective the higher sensitivity of the tibia is less well explicable. Although the tibia is a supporting bone of the shank, the femur is a load bearing bone due to the weight of the body, and apart from its mechanical function it is of essential importance for walking as well (e.g. Dylevský et al. 2000). The hip joint is thus the most stressed joint in the human body.

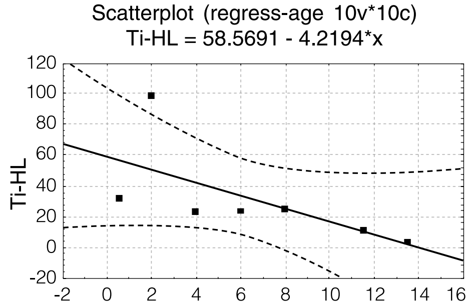
The plurality of the HL on the tibia indicates that their development is probably caused by apparently unimportant, momentary incidents (diseases with fever?).

Earlier observations of HL in (geographically or temporally) similar populations are virtually non-existent; there are just five comparable studies conducted on tibia. The frequency of HL occurrence on tibia observed in this study did not differ in principle from that in any of the earlier studies.

At the Mikulčice-Kostelisko cemetery, Czech Republic (an assemblage including



age: Fe-HL: r^2 = 0.7087; r = -0,8418, p = 0.0175;
y = 35.0377698 - 3.08273381*x



age: Ti-HL: r^2 = 0.4192; r = -0.6475, p = 0.1159;
y = 58.5691161 - 4.21942446*x

age: Hu-HL: r^2 = 0.5552; r = -0.7451, p = 0.0546;
y = 2.33016444 - 0.226618705*x

Figs 4–6. Regression analyses of the incident dependence between occurrence and age among femur (4), tibia (5) and humerus (6).

adults), 86.7 % individuals were recorded as having HL (Velemínský 2000), as were 80 % of the individuals from the Josefov cemetery (Stránská et. al. 2002), 85 % of individuals at Cedynia in Poland (Piontek et al. 2001) – or 68 % where only infants were studied (Jersynska 1991) – and 81 % of the non-adult individuals from the Churches of St James and St Christopher at Wroclaw in Poland (Gronkiewicz et al. 2001). Analogous occurrences have also been recorded in assemblages both geographically distant and of different date (e.g. Manzi et al. 1989).

It is interesting that in a recent collection of Slovak men with a mean age of 67.3 (49–88) years, who had personally experienced the Second World War, Harris lines were observed in the tibia of just 22 % of individuals. The authors believe this condition to be influenced by line resorption in adulthood (Vyhnánek et Stloukal 1991).

HL occurrence is most often recorded in the distal parts of the tibia. This may be supposed to be a consequence of the greater stress on the distal parts of the bone during movement. Fractures of the bone are not so important for HL development, being just one of the influential stress factors according to clinical studies. This can be verified by the symmetrical position of the lines on the bones of the left and right sides; the presence of asymmetrical lines (on the bones of only one side) is rare (see e.g. Velemínský 2000, Stránská et al. 2002, Zítková 2003).

As regards the age at which Harris lines form, the greater number were found to have appeared during the 1st to 3rd year of life. This high occurrence of lines may be con-

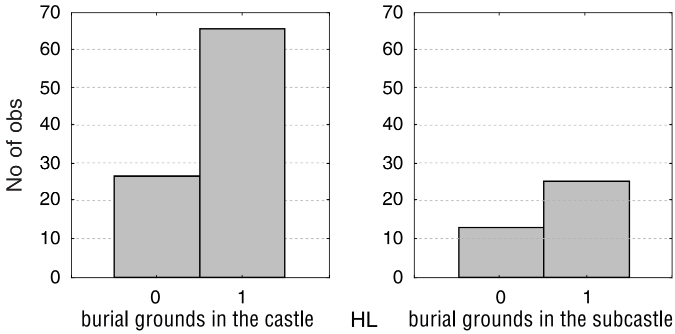


Fig. 7. Distribution of HL by cemeteries of castle and subcastle Table 5: Categorisation of HL occurrence by character of grave equipment.

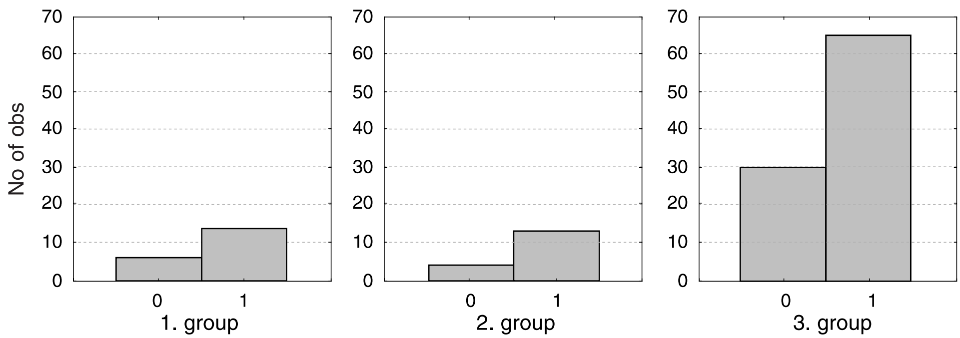


Fig. 8. Distribution of HL by grave goods – the classification according to Unzeitigová (2000).

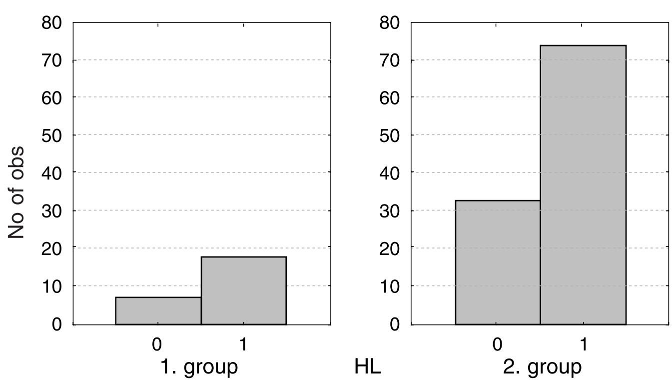


Fig. 9. Distribution of HL by grave goods – the classification according to Stloukal (1970).

nected to the so-called "weaning hypothesis", according to which HL can also develop as a manifestation of a change in the quality of diet after weaning ceases (Lewis et Roberts 1997). This theory, together with the common results of other research, validates the presumption that the majority of lines form in childhood (infancy), generally before 11 years (Hatch 1983). While the studies of Goodman et Clark (1981), Gindhart (1969), Carli-Thiele (1996) or Stránská et al. (2002) present very similar results – the highest number of HL developing in the first to fourth years – the peak of new line formation according to Jerzynska et Nowak (1996), Piontek et al. (2001) and Velemínský (2000) is in the period from 6–12 years of age.

To deduce the age at which HL develops, Byers (1991) has created an ontogenetic model of percentual length increments for the particular long bones (separately for boys and girls). This method arises from a compilation of the results of four earlier ontogenetic studies (those of Anderson, Green 1948, Maresh 1955, Anderson et al. 1963, Gindhart 1973). The authors naturally accept that it is most advantageous to work with an "ontogenetic conversion table" based on a geographically and temporally identical population, i.e. from the Great Moravian period, in their study. From this point of view the study of Stloukal and Hanáková (1978) is practically perfect, as it considers the growth of the long bones in the limbs of the Great Moravian population. The aim of this work was to attempt an assessment of bone age according to the lengths of the long bones. Given that the accuracy of tooth age assessment, particularly in the infants II age category, varies within a 2-year interval at least, it is necessary to consider analogous intervals in the growth increase of limb bones. Such research does not consider the sexual differences in bone ontogenesis. (There was still no reliable method for determining the sex of a non-adult skeleton at this time, and in the 1970's no sex determinations were carried out). The results of this study were therefore used to estimate age, taking account, of course, of the growth disproportionality of the proximal and distal parts of the long bones. In the tibia, for example, a 1.75 multiple of the distance of the HL from the proximal end was deducted from the total length of the diaphysis (or 2.33x the distance of the HL from the distal end). The estimation of the age of HL formation was made from the varying scope of the long bone length in the appropriate ontogenetic period, i.e. the developing of HL was classed into intervals of 3 years.

The expected relationship between social status, characterised by grave locations and richness of grave goods, and number of lines was not proved. The differences between the selected groups were not statistically significant. It is possible that these results arise from the regular distribution of HL at the cemeteries of the inner and lower wards, there having been only minimal differences in the standard of living of the individuals buried in the inner or lower wards, or from the low number of the well-preserved skeletons from the lower ward. Another reason may lie in the initial Christianisation of the Great Moravian region at the time, which meant a change in the types and quantities of grave goods and in the richness of offerings (see e.g. Stloukal et Vyhnánek 1976).

In conclusion it may be remarked that this project has confirmed that the highest occurrence of HL is in the long bones of the lower limbs, and in particular on the tibia. HL develop, however, as a consequence of the disruption of long bone ontogenesis (temporary arrest of their growth), and it may thus be concluded that in Great Moravian Mikulčice four children out of every five suffered a growth disturbance of the tibia. The HL incidence on the humerus was negligible. HL occur more often on the distal parts of the bones than on the proximal.

More information may be derived from the frequency of lines occurring only on one bone, from the intensity of the lines and from the period in which the lines developed, than is possible from a solitary individual occurrence of HL. It is logical to presume that a more intensive line was formed under the influence of a more intensive stress factor. There is, however, the chance that the existing lines might by obliterated: finding no lines on the skeleton of a 50-year old does not allow the assumption that there had never been any lines. It is appropriate, therefore, to associate the aforementioned marks with other characteristics indicative of the optimality of living conditions and state of health (such as enamel hypoplasia, cribra orbitalia).

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