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DOES THE PRESENCE OF HARRIS LINES AFFECT THE FINAL STATURE IN A MEDIEVAL POPULATION?

ABSTRACT: Previous studies on Harris lines (HL) have investigated the relationship between their occurrence and the length of bones and, in consequence, stature. They have often produced discrepant results. By using a new method of categorisation of individuals – in terms of HL presence – we wanted to determine, which period in the ontogenesis is the most susceptible one and when the burden of stress has the most significant effect in terms of either retarding or arresting the longitudinal growth of the bones, which can affect an individual's final stature. We measured four long bones (the femur, tibia, humerus, and radius) of 109 female and 111 male skeletons from the medieval burial ground in Cedynia, Poland. Roentgenograms of the tibiae were also taken and examined. The stature of the individuals under study was reconstructed using regression equations for the four long bones. We demonstrated that there were no differences between the length of the tibiae in individuals with and without Harris lines. The examination of the remaining types of long bones corroborated the result obtained for the tibiae. No differences in length were noted between these bones in individuals with Harris lines and individuals in whom Harris lines were not identified. Both for the incidence of disturbances expressed by the number of HLs, and for the age at which the presence of HLs was noted, no relationship with final adult stature was found for either sex. The results seem to indicate that Harris lines are merely a discreet record of an adverse impact from the external environment, having no relationship with the final realisation of phenotypic traits expressed as the length of the bones and stature.

KEY WORDS: Harris lines – Adult stature – Medieval time

INTRODUCTION

Researchers' interest in the role of environmental factors shaping various morphological traits in prehistoric populations is still growing. These studies are also important for the investigation of the effect of environmental factors on the biological condition of an individual in modern populations. If we have a description of an adult individual's morphological structure we may reconstruct the conditions under which the formation of various skeletal traits took place, by using markers of morphological response to living conditions (such as Harris lines) (Formicola, Holt 2007, Nowak, Piontek 2002b).

We would like this paper to be a direct reference to the work by Papagergopoulou *et al.* (2011) and at the same time a supplement to our own research results published in 2001 and 2002 (Nowak, Piontek 2002a, Piontek *et al.* 2001). In our database we have medieval bone material, examined radiologically for the presence of Harris lines (HL), similar in quantitative terms to those at the disposal of the Swiss researcher's team. In our previous studies we analysed the effect of the presence of Harris lines on the length of adult individuals' bones. The analysis was based on the classical method of assessment of HL formation (Byers 1991) and on methods of line frequency calculation from

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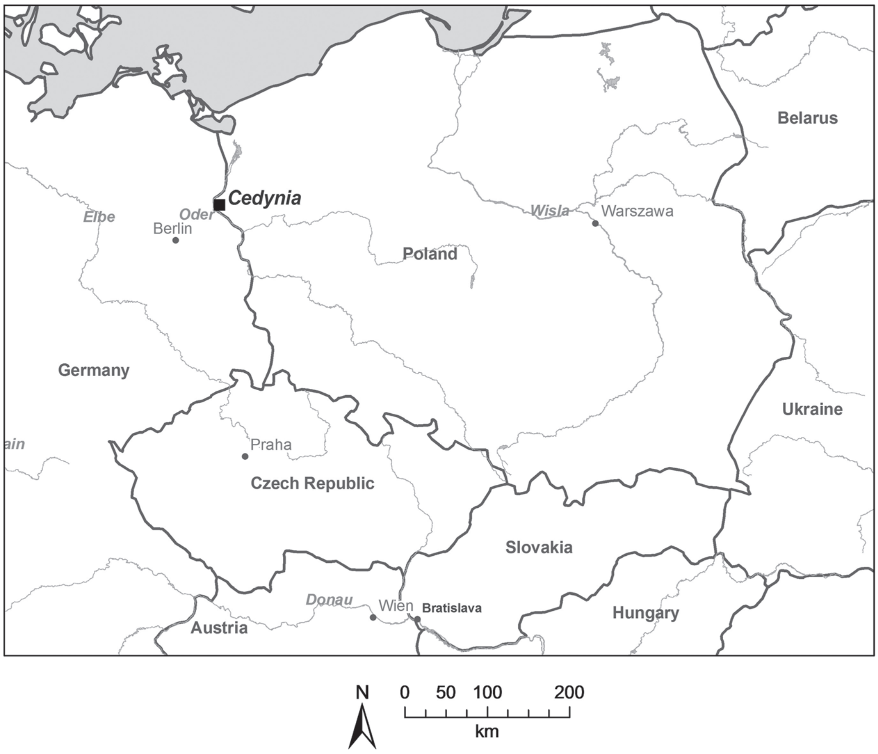


FIGURE 1. Map showing the location of the Cedynia cemetery.

the number of disturbances recorded in the roentgenogram. Like many other researchers (Mays 1995, McHenry1968, Papagergopoulou *et al.* 2011, Wells 1967) we found no statistically significant correlation between the length of the tibia and the frequency of HL occurrence. We welcomed with interest the launching of computer tools for semi-automatic analysis of HL occurrence (Suter *et al.* 2008). However, before we use these tools in our own studies we decided to make another attempt at confirming results previously obtained with the same methods, but this time categorising our individuals in a new way – according to the presence of morphological markers of disturbances. This new way of classification is discussed more extensively in the material and methods section.

Harris (1926), and later also other researchers, arrived at a conclusion, that the transverse lines occurring in the metaphyseal parts of human long bones, may be a source of interesting information on the phenomena of biological development on both individual and population level (Gejvall 1963, Goodman *et al.* 1984, Martin, Armelagos 1979, Wells 1967). In the anthropological literature attempts have been made to sum up the previous findings and results of research on the role of stress factors (living conditions) in prehistoric, historic and modern populations, presented by Cohen and Armelagos (1984), Larsen (1987), Goodman *et al.* (1988), Armelagos and Goodman (1992), Piontek *et al.* (2001), Nowak, Piontek (2002a, b), Papagergopoulou *et al.* (2011).

Harris lines are formed as a specific reaction of an organism to non-specific environmental stress. The impact of extra- and paragenetic factors on bone growth may be compared to signposts which an individual may but does not have to make use of. However, the proper direction and pace of development depend by no means on the individual's will but on his ability to adapt to external environment conditions affecting growth and development. It is not always the case that the impact of adverse environmental factors must result in diversion from the appropriate developmental track for a given individual, which means that the individual can compensate for the effects of these disturbances in periods of improved conditions, and upon reaching biological maturity he is no different from individuals who had no Harris lines. In light of the above, we posed the following research question: which period in the life of an individual is the most susceptible one and when do the disturbances have a significant effect on bones, retarding or arresting their longitudinal growth, which may have a bearing on the individual's final adult stature?

MATERIAL AND METHODS

The research material consisted of four long bones (femur, tibia, humerus, and radius) and of roentgenograms of the tibiae of 109 females and 111 males from the medieval burial ground in Cedynia, Poland (50 km south of the city of Szczecin, Poland, *Figure 1*). The cemetery was discovered in 1966 on a hill situated approximately 200 m north east of an early mediaeval castle. It was used in three stages and it is dated to the period from the end of the 10th century till the first half of the 14th century (Malinowska-Łazarczyk 1982). Skeletons of adult individuals from the Cedynia burial ground were the basis for detailed reconstruction and description of the biological status and socio-economic structure of the population (Mucha 1987, Mucha, Piontek 1983).

The bone material was analysed radiologically for the presence and age of formation of Harris lines on the tibiae (Byers 1991), and anthropometrically according to the Martin and Saller (1957) technique and instrumentarium. To determine the sex and age at death of the skeletons, estimation methods recommended in a report prepared by a group of European anthropologists (Ferembach *et al.* 1979, 1980) and American standards (Buikstra, Ubelaker 1994), were used. In the determination of the sex of individuals, methods based on tibia morphology were also applied (Holland 1991, Iscan, Miller-Shaivitz 1984). The age of the individuals under study was estimated using analysis of the degree of dental crown attrition (Ubelaker 1994) and the intensity of changes taking place on the surface of the pubic symphysis (Todd 1920). These methods were broadly described in the papers of Van Gerven and Armelagos (1983) and Piontek and Weber (1990). Only adult individuals with age at death falling into the 19 to 40 years age category were examined.

From the database, we selected individuals with no HL, individuals having HLs formed only in the period from 0 to 6 years of age, from 7 to 11 years of age, and with lines formed after the 11th year of age. These periods are important from the point of view of developmental changes taking place (Bogdanowicz 1966) but also because they coincide with growth hormone secretion peaks, the first of which is observed after the 7th year of age and the second one around the 10th–11th year of age (Reiter, Rosenfeld 1998). In order to differentiate the power of the impact of adverse environmental factors on an organism in successive ontogenetic periods we assumed that an individual can be classified into a group of individuals affected by disturbances within a given age band if he/she had more than two lines formed in that period. In the male group we found no individuals with Harris lines formed only between 0 and 6 years of age. Hence, individuals with two and more lines present were classified into this age band and they were not classified into the next age category of Harris line formation. The number of these individuals proved to be small not only because of our arbitrary assumption but also due to the fact that Harris lines formed in early childhood tend to vanish in adult individuals as a result of bone tissue remodelling. The same procedure had to be applied for successive HL formation age groups, in both sexes. Individuals with two and more Harris lines formed at the age from 7 to 11 years were included into the 7 to 11 age category providing they had no lines formed at a later age. The remaining individuals were included into the 11 plus category (with Harris lines formed past the 11th year of age). In the female group there were no individuals meeting the condition of having two or more HLs formed after the age of 11 years, therefore we assumed (in accordance with the earlier assumptions) that female development was not disturbed after the onset of puberty.

The stature of the studied individuals was reconstructed using regression equations for four long bones proposed by Pearson (Rösing 1988, after Pearson 1899). We chose Pearson's method because it is commonly used in the studies of prehistoric populations in central Europe. The principal advantage of this approach proved to be the orientation towards prehistoric and early-medieval skeletons untouched by the effects of secular acceleration.

The mean bone length across age categories of HL formation were compared using one-way ANOVA. The relationship between number of HL and stature and between age of HL formation and stature was evaluated by the Spearman rank correlation coefficient. Statistical analyses were carried out using STATISTICA 7.0.

RESULTS

Descriptive statistics showed that the mean number of Harris lines is highest for the 7–11 years age band (*Figure 2*), both for females (4.7 HL) (*Table 1*) and for males (3.9 HL) (*Table 2*). An analysis of the greatest length of the tibia within the group of individuals with Harris lines within the group of individuals with Harris lines and within the group without Harris lines, demonstrated absence of differences in mean tibia length in females (344.3 mm for bones with no HL and 344.5 mm for bone with HL formed at the age of 7–11 years present) (*Table 3*). Also in the male group, in which we had individuals affected by disturbances after the 11th year of age, no statistically significant differences were found (381.5 mm was noted for bones with no Harris lines and 383.4 mm for bones with identified Harris lines formed at the period at which they were most frequent, i.e., at 7 to 11 years of age) (*Table 4*). In order to check whether the results obtained were not valid only for the tibiae, one-way ANOVA of the mean length of other examined bones of the skeleton was carried out for HL occurrence in individual ontogenetic periods (*Tables 3, 4*). Despite potential differences in growth dynamics of the studied bones, no relationship was found between final bone length

TABLE 1. Mean number of Harris lines in selected categories of age of their formation (females).

Age of HL formation	*N*	Mean	SD
Lack of HL	31	n.a.	n.a.
0–6 years	28	3.1	1.2
7–11 years	50	4.7	1.4
Total	109	2.9	2.2

TABLE 2. Mean number of Harris lines in selected categories of age of their formation (males).

Age of HL formation	*N*	Mean	SD
Lack of HL	40	n.a.	n.a.
0–6 years	22	2.6	0.8
7–11 years	40	3.9	1.6
Above 11 years	9	2.3	0.7
Total	111	2.1	1.9

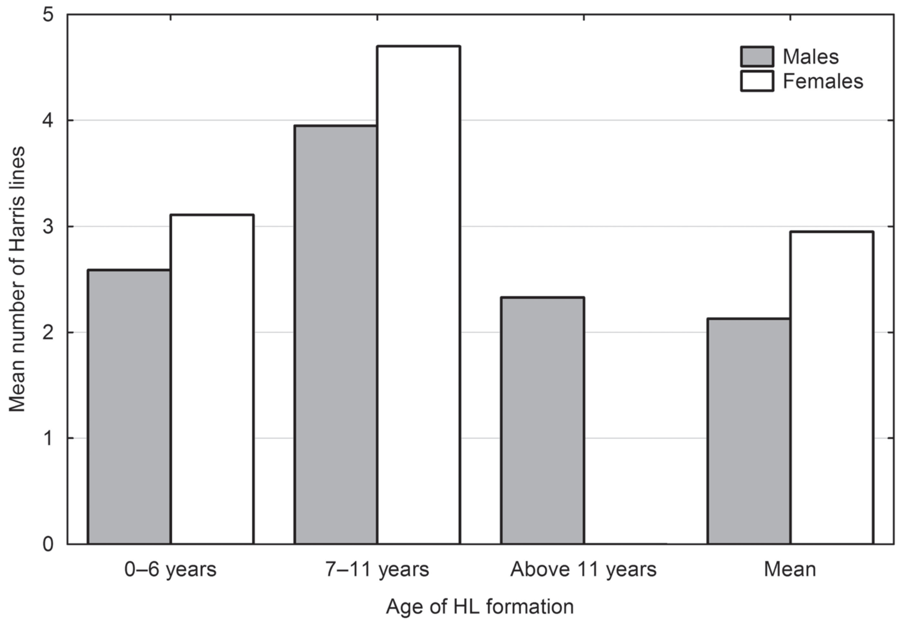


FIGURE 2. Mean number of Harris lines in selected categories of age of their formation.

TABLE 3. Mean length of four bones at individuals without Harris lines (HL) and with Harris lines in selected categories of age of their formation (females). ANOVA: test of no statistical relationship between length of bone and presence of Harris lines.

	Tibia (M1a)			Femur (M1)			Humerus (M1)			Radius (M1)		
Age of HL formation	***N***	**Mean**	**SD**	***N***	**Mean**	**SD**	***N***	**Mean**	**SD**	***N***	**Mean**	**SD**
Lack of HL	31	344.3	13.2	25	422.1	21.2	20	303.1	18.6	23	227.2	12.5
0–6 years	28	344.8	13.0	22	422.7	20.1	20	305.2	15.6	25	229.4	10.6
7–11 years	50	344.5	14.2	41	420.7	16.9	32	306.9	12.4	36	228.1	10.4
P-value (ANOVA)		0.991			0.917			0.685			0.794	

TABLE 4. Mean length of four bones at individuals without Harris lines (HL) and with Harris lines in selected categories of age of their formation (males). ANOVA: test of no statistical relationship between length of bone and presence of Harris lines.

	Tibia (M1a)			Femur (M1)			Humerus (M1)			Radius (M1)		
Age of HL formation	***N***	**Mean**	**SD**	***N***	**Mean**	**SD**	***N***	**Mean**	**SD**	***N***	**Mean**	**SD**
Lack of HL	40	381.5	14.7	35	458.8	18.3	32	335.9	12.7	35	252.6	12.2
0–6 years	22	378.6	14.4	20	457.0	20.2	19	332.5	11.6	19	251.6	9.4
7–11 years	40	383.4	14.4	34	464.6	17.6	32	339.1	14.5	38	253.9	11.9
Above 11 years	9	385.8	12.0	8	461.7	16.7	8	334.7	14.5	7	256.7	11.0
P-value (ANOVA)		0.526			0.443			0.380			0.740	

TABLE 5. Spearman's rank correlation (r_s) between number of Harris lines (HL) and age of Harris lines formation and stature estimated from the length of four bones in females.

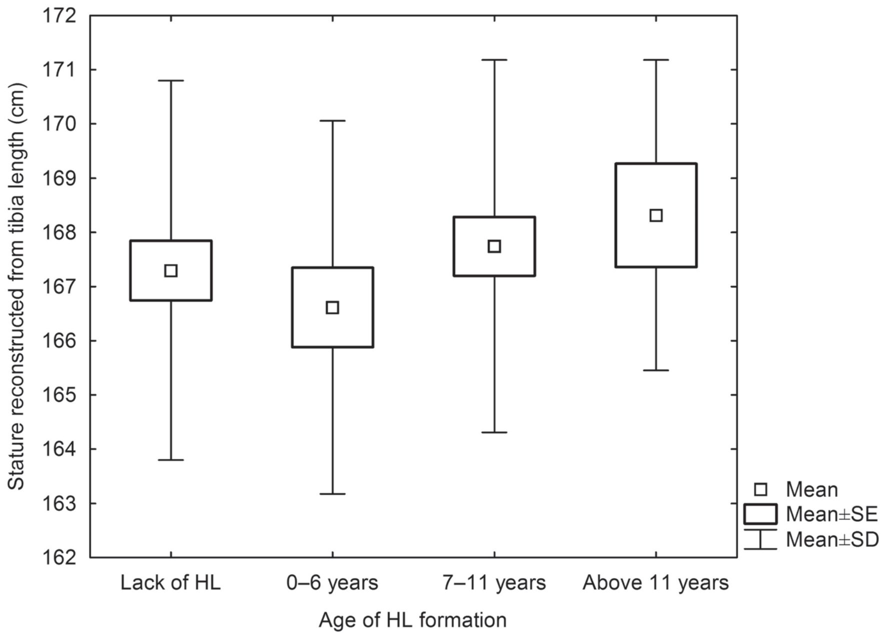
		Number of HL		Age of HL formation	
Body height based on	***N***	r_s	**P-value**	r_s	**P-value**
Tibia	109	–0.05	0.640	0.03	0.791
Femur	88	–0.06	0.559	–0.05	0.635
Humerus	72	0.01	0.956	0.13	0.264
Radius	84	–0.06	0.575	0.04	0.695

TABLE 6. Spearman's rank correlation (r_s) between number of Harris lines (HL) and age of Harris lines formation and stature estimated from the length of four bones in males.

		Number of HL		Age of HL formation	
Body height based on	***N***	r_s	**P-value**	r_s	**P-value**
Tibia	111	0.05	0.581	0.10	0.252
Femur	97	0.07	0.495	0.10	0.326
Humerus	91	–0.02	0.872	0.02	0.834
Radius	99	0.01	0.910	0.05	0.557

FIGURE 3. Mean stature reconstructed from the length of tibia in selected categories of the age of Harris lines (HL) formation (females).

FIGURE 4. Mean stature reconstructed from the length of tibia in selected categories of the age of Harris lines (HL) formation (males).



and the age of formation and the number of Harris lines present, in both sexes. The obtained results were finally verified by Spearman's rank correlation analysis for the reconstructed stature, as related to the number of Harris lines and separated categories of the age of their formation *(Table 5* for females and *Table 6* for males*)*. No correlation was found between the intensity of occurrence of the disturbances expressed in the number of HL present and the noted age of their formation, and the final stature in both sexes. The additional graphical presentation highlights the lack of correlation between the mean stature and the age of HL formation *(Figures 3, 4)*.

DISCUSSION

Based on the results obtained, we can conclude that when examining skeletons of adult individuals for the presence of morphological stress markers and for their effect on the development of bones and of an individual, we cannot state which period is of the greatest individual susceptibility to environmental stress (Alfonso-Durruty 2011, McEwan *et al.* 2005). In the medieval population we studied from Cedynia, the individuals with Harris lines in separate categories of ontogenetic age did not differ from individuals with no Harris lines in terms of bone length and stature.

The authors of previous studies do not present a uniform stance with regard to the correlation between the frequency of HL occurrence and final adult stature. Although Goodman and Clark (1981) found that in the population from Dickson Mounds adult males with longer tibiae had a greater number of transverse lines than individuals with medium bone length, the results of other studies, for instance by McHenry (1968), demonstrate the opposite: more lines were present on shorter bones. Also, there is an opinion prevalent in the literature that individuals whose growth was regularly disturbed during the progressive ontogenesis period can adapt to hard conditions and that in these individuals the process of longitudinal growth of bones is only retarded, which does not have to be reflected in their final adult stature (McHenry 1968). The only studies in which a clear correlation between the stature and presence of Harris lines was actually found are studies of living children in Guatemala (Acheson *et al.* 1974, Blanco *et al.* 1974), where research material was radically different from prehistoric bone material.

The results of our research proved to be the same as those obtained by the team of Swiss researchers headed by Papagergopoulou (Papagergopoulou *et al.* 2011). In that study, based also on medieval and quantitatively similar material, no correlation was found between the number of transverse lines and the length of the tibia and no effect of the frequency of their occurrence on the ultimate stature of adult individuals was noted. We are inclined to agree with the interpretation of the results obtained by our Swiss colleagues who saw the reasons of absence of this seemingly obvious relationship in bone remodelling processes and in hormonal regulation of the growth process.

CONCLUSIONS

In the adult individuals we examined, the earliest lines formed could have vanished in successive stages of progressive ontogenesis, and hence not all longitudinal bone growth disruption episodes are recorded in a roentgenogram. In turn, distribution of the age of formation of Harris lines, which shows that the greatest number of the lines are formed at ages from 7 to 11 years, and smaller and declining numbers are formed after the 11^{th} year of age, may be related to growth hormone secretion peaks (Reiter, Rosenfeld 1998). It seems that, although in studying child skeletons identification of Harris lines may be a tool helpful in understanding environmentally conditioned ontological patterns (Cooke 2010), in adult individuals we can only note slowing down of the growth process. Successive periods in the lives of the studied individuals who had survived periods of disruption caused by environmental factors, could progress along the previously realised and genetically predetermined development track. In such case, Harris lines are only a discrete record of an adverse impact of external environment, unrelated to the final realisation of phenotypic traits expressed as the length of the bones and body stature (Alfonso-Durruty 2011, Wright, Yoder 2003).

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