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# Harris lines of the tibia across centuries: a comparison of two populations, medieval and contemporary in Central Europe

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**Abstract** *Objective:* To determine the incidence of Harris lines in two medieval populations which inhabited the Canton of Berne, in Central Switzerland, and to compare the results with those of a contemporary population living in the same geographical area. A simplified method is described for measuring the age of the individual at the time of formation of Harris lines, with possible future applications. *Design and patients:* Radiographs of 112 well-preserved tibiae of skeletons of two medieval populations from the eighth to fifteenth centuries were reviewed for the incidence of Harris lines. The results were compared with those of 138 current patients living in the same geographic location in Central Switzerland. Age and gender of the medieval individual were determined using known anthropological methods. Age of bone at the time of formation of Harris lines was estimated according to the method of Maat. *Results:* Harris lines were found in 88 of 112 (80%) of the examined medieval skeletons and in 28 of 138 (20%) of the living individuals. Higher incidences of Harris lines were found at the age of 2 years and at ages between 8 and 12 years in both populations. No gender difference was found regarding the incidence of Harris lines. In both populations the occurrence of Harris lines was associated with certain diseases such as degenerative bone disease, trauma, osteoporosis, rheumatoid arthritis, peripheral vascular diseases, rickets and bony deformities. *Conclusion:* A high incidence of Harris lines was found in the medieval population, perhaps reflecting difficult living and hygienic conditions, but also the poor care and neglect of the children population. Measuring the age of the individual at the time of formation of Harris lines is simple and may have future clinical applications in the paediatric population for medico-legal purposes. The application of Harris lines as a marker in follow-up of osteoporosis may need further evaluation.

**Keywords** Harris lines · Physiological stress · Paleopathology · Long bones · Growth arrest lines

## Introduction

Harris transverse lines are horizontally oriented trabeculae that cross the medullary cavity at right angles to the normal longitudinally directed trabecular structure [1, 2, 3]. They are formed in the metaphysis of growing long bones parallel to the epiphyseal plate and appear later in the diaphysis as the length of bone increases with growth. Harris lines are seen in a variety of bones, but most researchers agree that the greatest number of Harris lines can be found in the distal end of the tibia; therefore, this bone was considered to be the most suitable for assessing the incidence of Harris lines [4, 5, 6, 7].

These lines are called Harris growth arrest lines because they were first described by Henry A. Harris in 1931 [1].

Park et al. called these lines, the "recovery lines", indicating a period of new bone formation after a period of inhibited growth of bone [2, 3].

Histologically these bands are composed initially of differentiated chondroblastic and osteoblastic cells and later appear as a thickened, transversely oriented, interconnected trabecular networks [1, 2, 3].

The precise aetiology of Harris lines is varied and controversial. Some researchers triggered their occurrence experimentally by inducing infection or malnutrition in rats and pigs [1, 2, 8]. Harris Lines were described in association with malnutrition in prehistoric populations [1, 2, 3, 6, 8, 9, 10, 11]; therefore, they were used as an indicator of health status and malnutrition in paleopathological studies.

Harris lines have also been described in association with childhood diseases such as measles, whooping cough and chicken pox [9, 12, 13], trauma [14] and psychological stress [15]. Harris Lines are described to be seen frequently in the long bones of adults with osteoporosis [15, 16].

This study was undertaken to determine the incidence of Harris lines in two medieval populations, in comparison with a contemporary population living in the same geographical area.

**Fig. 1 A** A photograph demonstrates an example of one of the medieval skeletons from Oberbueren. Female 25–30 years of age. She was buried in this position with semiflexion of the knees due to severe congenital dysplasia of the hip joints

## Materials and methods

### Medieval population

The skeletal remains were exhumed from two burial sites (Unterseen and Oberbueren; Fig. 1), in the Canton of Berne, in Central Switzerland [17].

The skeletal material from Unterseen dates from the thirteenth to fifteenth centuries. Unterseen is a small city located between Lake Brienz and Lake Thun. It was a favourable meeting point for trade, business and transport. This mountainous city was not suitable for cattle breeding or agriculture and very susceptible to flooding due to the surrounding lakes. Hygienic conditions were poor in this crowded city influenced by lack of appropriate sewage disposal.

The skeletons were excavated from Unterseen Church and represent middle and upper class populations because it was expensive to be buried inside a church at that time [17].

The skeletal material exhumed from Oberbueren dates from the eighth to eleventh centuries (Fig. 1). The inhabitants of this village were simple farmers, who settled in the plains near the city of Berne [18]. They had a mainly vegetable-based diet with relatively little consumption of meat. The daily contact with sheep and cattle made these people more prone to worm and parasitic infestations.

Medieval children in general did not always receive adequate nutrition and familial care, and they were the last to be allowed to sit at the dinner table [17, 18].

A total of 112 well-preserved skeletons were included in this study: 95 adults (53 males and 42 females; mean age 44 years) and 17 children.

Determination of age and gender of the medieval populations was performed using the methods established in physical anthropology. The age of the medieval children was estimated according to the degree of eruption and mineralization of teeth, epiphyseal fusion and length of long bones [19, 20, 21, 22].

In the medieval adults, age determination was performed according to the dental crown attrition, changes of the symphysis pubis, and the degree of obliteration of cranial sutures [19, 20, 21, 22].

For gender determination a methodological approach was used whereby the degree of development of the numerous bones of cranium and pelvis was assessed as well as the epiphyseal width and length of long bones [19, 20, 22].

Anteroposterior radiographs of well-preserved medieval tibiae were performed.

### Contemporary population

A retrospective examination of the radiographs of the lower limb was performed in 138 patients: 118 adults (66 males and 52 females; mean age 52 years) and 20 children.

The contemporary population included in this study represents inhabitants in the Canton of Berne. Only the Swiss citizens were considered. The radiographs date the period between January and December 2001.

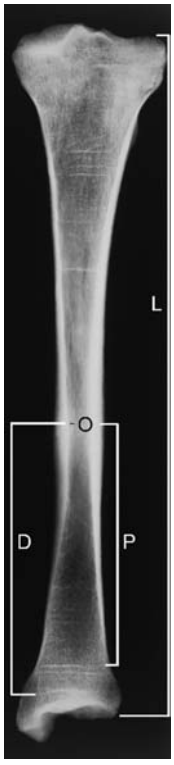


**Fig. 2** An example of one of the medieval tibiae shows the way to measure the age of the individual at the time of the formation of a Harris line. *O* represents the Position of the ossification centre, *P* represents the distance between a Harris line and the ossification centre *O*, expressed as a percentage

The adults attended the orthopaedic department either complaining of joint pain or with a history of trauma. The children population attended the paediatric department and indications for radiography were history of trauma, the suspicion of rickets or a deformity of a lower limb.

The clinical data and history of diseases were gathered from the hospital computerised patient management records and based on records of the orthopaedic and paediatric department as well as maternal recall. No direct questioning of the adult patients or the mothers regarding the paediatric populations was performed.

The distal end of the tibia was considered to be the most suitable for the assessment of Harris lines [4, 5, 6, 7]. Only those lines which extended to at least one-quarter across the width of the shaft were considered representative [10, 23].

The radiographs of the tibiae were examined with the naked eye, and the number of Harris lines was counted by two observers in consensus: a musculoskeletal radiologist and a well-trained physician of the Institute of Historical Medicine.

Estimation of the age of the individual at the time of formation of Harris lines was performed using the method of Maat [5], which includes the following steps (Fig. 2):

1. Measurement of the tibial length (L) on the radiograph, which represents the distance between distal and proximal articular surfaces.
2. Determination of the level of primary ossification centre (O) at 43% of the tibial length measured from the distal articular surface [5].
3. Measurement of the distal diaphyseal length (D), which represents the distance between the primary ossification centre and the epiphyseal line.
4. Measurement of the distance between the primary ossification centre and Harris line (p), and this distance is expressed as a percentage of the distal diaphyseal length.
5. Determination of the age of the individual at the time of formation of Harris line according to the table of Maat [5] (Table 1).

**Table 1** Table of Maat for measuring the age of the individual at the time of formation of Harris line. (From [5])

| Age (year–month) | Adult distal diaphysis length (%) | |
|---|---|---|
| | Male | Female |
| 0–2 | 18.15 | 20.18 |
| –4 | 20.99 | 23.15 |
| –6 | 23.44 | 25.57 |
| 1–0 | 25.60 | 31.05 |
| –6 | 33.02 | 35.67 |
| 2–0 | 36.75 | 39.65 |
| –6 | 40.04 | 43.25 |
| 3–0 | 42.94 | 46.42 |
| –6 | 45.65 | 49.42 |
| 4–0 | 48.22 | 52.33 |
| –6 | 50.72 | 55.13 |
| 5–0 | 53.09 | 57.84 |
| –6 | 55.41 | 60.43 |
| 6–0 | 57.67 | 62.94 |
| –6 | 59.85 | 65.45 |
| 7–0 | 62.01 | 67.93 |
| –6 | 64.17 | 70.38 |
| 8–0 | 66.30 | 72.80 |
| –6 | 68.43 | 75.23 |
| 9–0 | 70.51 | 77.65 |
| –6 | 72.58 | 80.07 |
| 10–0 | 74.64 | 82.43 |
| –6 | 76.66 | 84.77 |
| 11–0 | 78.66 | 87.25 |
| –6 | 80.66 | 89.90 |
| 12–0 | 82.66 | 92.78 |
| –6 | 85.36 | 93.67 |
| 13–0 | 87.85 | 95.34 |
| –6 | 90.63 | 96.91 |
| 14–0 | 92.84 | 98.18 |
| –6 | 94.82 | 99.16 |
| 15–0 | 96.44 | 99.65 |
| –6 | 97.84 | 99.87 |
| 16–0 | 98.77 | 100.00 |
| –6 | 99.35 | – |
| 17–0 | 99.70 | – |
| –6 | 99.88 | – |
| 18–0 | 100.00 | – |

## Results

### Medieval population

Harris lines were found in 71 of 95 (80%) adults and in 17 of 17 (100%) children. The average number of Harris lines per individual ranged between 2 and 12 lines. The largest number of lines was 9 in adults and 12 in children.


**Fig. 3** **A** Anthropology specimen (Oberbueren): male, 40–48 years of age. Harris lines are seen in the distal diaphysis of the tibia (*arrows*). No other pathologies were found. **B** Anthropology specimen (Unterseen): 9–11 years old child. Many Harris lines are seen (*arrows*). The location of the lines in the metaphysis suggests that the lines were probably formed shortly before death


**Fig. 4** **A** A contemporary 30 years old male patient with rheumatoid arthritis. Harris lines are seen in the distal part of the left tibia (*arrows*). The radiograph was requested because of a history of trauma. **B** A contemporary 11 years old child. Two Harris lines are seen in the distal part of the left tibia. According to the tables of Maat these lines are formed at ages of 4 and 10 years respectively

Regarding the incidence of Harris lines, no differences were found between the two medieval populations of Oberbueren and Unterseen.

The age of the medieval adults was estimated: in 50% the age was less than 40 years, in 30% ranged between 40 and 60 years (Fig. 3A), and only 20% of medieval adults reached 60 years of age.

Among medieval children, 10% were at age of 1 year, 20% at age of 5 years and the remainder between 5 and 19 years of age (Fig. 3B).

In the medieval adults with Harris lines, other skeletal pathologies were seen such as osteoarthritis (mostly of the knee joint) in 35 of 71 (50%) of cases, fractures (mostly of the lower limb) in 6 of 71 (10%) of cases, bone osteopaenia with diaphyseal bowing of the lower limb in 3 of 71 (5%) of cases.

In the medieval children signs of nutritional deficiencies, such as porotic hyperostosis and dental enamel changes, were found in many cases.

## Contemporary population

Harris lines were found in 24 of 118 (20%) of contemporary adults, and in 4 of 20 (20%) of contemporary children. The highest number of Harris lines was 7 in adults and 10 in children.

In the contemporary adults with Harris lines, the age was above 50 years in 16 of 24 patients (66%), between 40 and 50 years (Fig. 4A) in 6 of 24 (25%) and below 40 years in 2 of 24 (8%) cases. In the contemporary children with Harris lines, the age in 2 of 4 (50%) was between 2 and 4 years, and between 8 and 11 years in 2 of 4 (50%) cases (Fig. 4B).

In the contemporary adults, Harris lines accompanied osteoarthritis of the knee in 10 of 24 (41%) of cases, a fracture of the lower limb in 5 of 24 (20%) of cases, osteoporosis in 4 of 24 (16%) of cases, peripheral vascular disease in 3 of 24 (12%) of cases and rheumatoid arthritis in 2 of 24 (8%) cases.

In the contemporary children, Harris lines accompanied rickets in 2 of 4 (50%) of cases, congenital hypoplasia of the lower limb in 1 of 4 (25%) of cases and congenital genu valgum in 1 of 4 (25%) of cases. The two children with rickets 2 of 4 (50%) have had a very stressful family situation due to separation of the parents, and the diagnosis of rickets was established after the age of 2 years.

In both medieval and contemporary populations a high incidence of Harris lines was found at the ages between 8 and 12 years, and in the contemporary group a small rise in the incidence of Harris lines was found at the age of 2 years (Fig. 5).

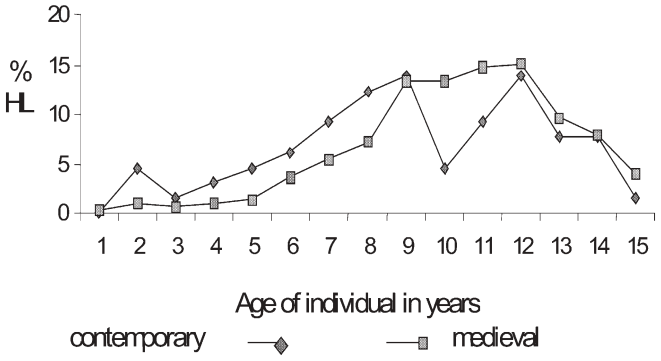


**Fig. 5** This diagram shows two peaks of high incidences of Harris lines in the contemporary population: the first peak is at the age of two years, which represents the mean age at which weaning occurs. The second peak is seen at ages between 9 and 12 years, which probably correspond to the growth spurt which accompanies this period of age

No lines were found below the age of 1 year. No gender differences regarding the incidence of Harris lines were found in either population.

## Discussion

A high incidence of Harris Lines was found in both medieval populations which may reflect some degree of malnutrition (protein deficiency) and/or unhealthy living conditions. The presence of Harris lines in the medieval children might also reflect a poor familial care of children as described in the medieval societies [1, 2, 3, 6, 9].

In the contemporary adults, no information was obtained about the nutritional and health status in the childhood period; therefore, the influence of this period on the formation of Harris lines could not be assessed. In the contemporary children, two had signs of rickets which may have influenced the formation of Harris lines.

Some studies showed an increased incidence of Harris lines in the medieval females, maybe because they received less familial care than males during the period of growth [23, 24]. Other studies showed higher incidences of Harris lines in boys, possibly because they shared with their parents the responsibility for earning and were therefore more susceptible to stress than their sisters [8, 10]. In the present study no gender difference was found regarding the incidence of Harris lines in both medieval and contemporary populations.

Some authors found two peaks of high incidence of Harris lines, the first peak at the age of 2 years, and the second peak at ages between 9 and 12 years [6, 7]. The first peak at the age of 2 years may be attributed to the age at which weaning occurs, as well as a high incidence of early childhood diseases, such as measles and whooping cough. Weaning deprives the child from a source of nutrients and natural antibodies from the nursing mother, leaving the child susceptible to malnutrition, bacterial infections and diarrhoea [6, 7, 8]. The increased incidence of Harris lines at ages between 9 and 12 years might perhaps correlate with the stress of a growth spurt that accompanies this age period [10, 23].

In our study, we found a small rise in the incidence of Harris lines at the age of 2 years and a high incidence of Harris lines at the ages between 9 and 12 years.

Some studies showed that Harris lines may disappear over time as part of an active remodelling of living bone [3, 4, 6, 9, 25, 26]. In a prospective study, Hummert and Van Gerven [6] found that Harris lines did not persist after a time period of 10 years. Garn and Schwager [4] noted a decline in the percentage of individuals with Harris lines in the adult population after the age of 51 years.

In our study, in more than 50% of the contemporary adults and 20% of medieval adults, the mean age was more than 50 years. This may suggest that in the adult population Harris lines might have developed later in life, not related to the childhood period.

Garn and Schwager [4] reported a statistically significant association between trauma and the appearance of new transverse lines. Five of the contemporary adults and six of the medieval adults with Harris lines had a history or evidence of trauma and fracture, mostly of the lower limb.

The relation between psychological stress and the occurrence of Harris lines was mentioned by Sonntag and Comstock [15]. In two of the contemporary children with Harris lines, an additional family stress was found due to the separation of the parents.

Biomechanical stress, such as osseous deformity, was also mentioned in association with Harris lines. Presumably the formation of Harris lines here is a response of the bone to a prolonged mechanical stress [14]. In our study the highest number of Harris lines in the contemporary population was ten in a child with congenital genua valga. Harris lines were seen in both legs (right 4 and left 6).

Harris lines were also described to be seen frequently in the long bones of adults with osteoporosis [14, 15, 16]. They are formed as a reinforcement reaction of the body to osteopaenic bone. Four cases of the contemporary adults had established osteoporosis and the radiograph was requested to exclude fractures and other pathologies.

## Conclusion

In conclusion, the apparently high incidence of Harris lines in the medieval populations, particularly in medieval children, may reflect malnutrition, unhealthy living conditions and poor familial care that might have contributed to a high morbidity and mortality rates.

Measuring the age of the individual at the time of formation of Harris lines is feasible and may have po-

tential uses in paediatric radiology, e.g. as a marker for nutritional deficiency or for medico-legal or forensic purposes.

The role of Harris lines as a radiological tool in the follow-up of osteoporosis needs further evaluation.

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