THE CHRONOLOGY OF TOOTH DEVELOPMENT IN WILD BOAR – A GUIDE TO AGE DETERMINATION OF LINEAR ENAMEL HYPOPLASIA IN PREHISTORIC AND MEDIEVAL PIGS

Ola Magnell[1], Richard Carter[2]
[1]Historical Osteology, Department of Archaeology and Ancient History, Lund University, Sandgatan 1, 223 50 Lund, Sweden: Phone +46(0) 46 2224466; e-mail: ola_magnell@yahoo.com
[2]Sussex Institute, University of Sussex, Falmer, Brighton, BN1 9QQ, England: Phone +44(0) 1273 872956; e-mail: r.j.carter@sussex.ac.uk

Abstract. Linear enamel hypoplasia (LEH) is transverse lines or bands on the enamel of teeth caused by developmental stress during the formation of the tooth crown. LEH has shown to be useful as a stress marker in studies of health conditions in past populations of pigs. The chronology of LEH and the age at which animals of past populations where afflicted by metabolic stress can be determined based on tooth formation. Tooth development in wild boar has been determined based on radiographs of 55 mandibles with known age of death. A user-friendly diagram of tooth development in wild boar has been made for determination of the chronology of LEH in archaeological pigs. The implications of the presented tooth development for the interpretation of chronology of LEH are also discussed.
Key words: linear enamel hypoplasia, tooth development, pigs, wild boar, age determination.

ŠERNŲ DANTŲ FORMAVIMOSI CHRONOLOGIJA: PRIEŠISTORINIŲ IR VIDURAMŽIŲ KIAULIŲ LINIJINĖ EMALIO HIPOPLAZIJA

Ola Magnell[1], Richard Carter[2]
[1]Archeologijos ir senovės istorijos katedra, Lundo universitetas,Lurdas, Švedija tel. +46(0) 46 222 4466; el. paštas: ola_magnell@yahoo.com
[2]Sussexo institutas, Sussexo universitetas, Brightonas, Anglija, tel. +44(0) 1273 87 29 56; El. paštas: r.j.carter@sussex.ac.uk

Santrauka. Linijinė emalio hipoplazija (LEH) – tai skersines linijos arba ruožai ant dantų emalio, susiformavę veikiant stresui danties vainiko formavimosi laikotarpiu. LEH yra naudinga tiriant ankstyvųjų amžių kiaulių populiacijų sveikatos būklę. LEH chronologija ir amžius parodo, ar gyvūnai buvo veikiami streso. Šernų dantų formavimasis buvo analizuojamas rentgenu ištyrus 55 žinomo amžiaus apatinius žandikaulius. Reikšmingos šernų dantų formavimosi diagramos sudarytos nustatant priešistorinių ir viduramžių kiaulių LEH chronologiją. Dantų vystymosi reikšmė interpretuojant LEH chronologiją taip pat aptariama.
Raktažodžiai: linijinė emalio hipoplazija, dantų vystymasis, kiaulė, šernas, amžiaus nustatymas.

Introduction. The tooth formation is a complex and sensitive process. Metabolic stress that cause disturbance of the tooth development can result in linear enamel hypoplasia (LEH), transverse lines or bands on the enamel.

Several different factors may cause LEH, but enamel hypoplasia is usually associated with malnutrition, weaning and infectious diseases (Rose et al., 1985; Hillson, 1996). Since LEH is caused during tooth development it is possible to determine at what age the LEH was formed and when the individual was affected by stress. By analysing the chronology of LEH, the health conditions can be studied for past populations at different ages during development from birth to the formation of the third molar in sub adults.

LEH was described as early as 1746 on teeth of diseased children (Hillson, 1996). The relationship between enamel hypoplasia and health in humans has been investigated in several studies since the 1940´s (Sarnat, Schour, 1941; Dobney, Goodman, 1991).

For some time LEH has been used as a stress marker in physical anthropology and odontological studies of skeletal remains of humans from archaeological sites (Svärdstedt, 1966; Goodman et al., 1980). In analyses of human skeletal remains it has at least been a standard to record and study LEH since the 1990´s (Buikstra, Ubelaker, 1994).

Enamel hypoplasia has been described on the teeth of dogs and sheep since the early 20th century (Mellanby, 1929; Rabkin, 1956). LEH has also occasionally been described on animal teeth from archaeological sites, but it is only recently been used in archaeozoological studies of health conditions of animal populations (Baker, Brothwell, 1980; Dobney, Ervynck 2000)

LEH has shown to be useful as a stress marker in studies of pig domestication. The frequencies of LEH in recent and Mesolithic populations of wild boar are low, while the frequency is higher in Neolithic domestic pigs. This result shows that LEH is a useful proxy indicator of animal husbandry and domestication (Dobney et al., 2004).

Enamel hypoplasia can also be useful in studies of animal husbandry in the past, since LEH can be used for assessment of second farrowing in pigs. Based on the assumption that most enamel hypoplasia is caused by stress during the winter, the age of formation of LEH will differ between animals from spring and autumn farrows. By identifying distributions of LEH it can be assessed if pig teeth originated from a population that had second farrows in the autumn or only in the spring (Ervynck, Dobney, 2002).

In earlier studies of the chronology of LEH in prehistoric and medieval pig populations, no other source for tooth development other than a rather small sample (n= 18) of undernourished recent improved pig breeds has been used (McCance et al, 1961; Dobney, Ervynck, 2000). The tooth development in wild boar has recently been studied in order to estimate age (Carter, Magnell, in Print). The aim of this paper is to present user-friendly diagrams of tooth development in wild boar that may be useful for assessing the chronology of LEH in prehistoric and medieval pig.

Materials and methods. The tooth development has been determined based on radiographs of 55 mandibles from wild boar and cross-breeds of wild and domestic pigs from Poland and Sweden, with known age of death (Table 1).

Table 1. **Age and origin of mandibles of wild boar and hybrids between wild boar and domestic pigs used in this study. B.R.= Breeding Reserves, F.= forests, N.P.= National Park.**

Age (months)	Bialowieza B.R.		Bialowieza F.	Kampinos N.P.	Scania, Sweden	totals
	hybrids	wild boar				
at birth			1			1
2	4					4
3			1			1
5	1	1				2
6	2					2
7	4					4
9		1				1
10				1		1
12	5	2			16	23
18	5	1		2		8
21	1					1
24	1	2		1		4
25		1				1
30	1					1
36	1					1
totals	25	8	2	4	16	55

Figure 1. **Linear enamel hypoplasia (arrows) on a third molar of domestic pig from Iron Age site Uppåkra, Southern Sweden**

The Polish samples come from collections at the Mammal Research Institute in Bialowieza and originate from three populations; free-ranging wild boar tagged as newborn piglets from Kampinos National Park and Bialowieza forest; hybrids between wild boar and domestic pigs, and wild boar from enclosures in breeding reserves of the Mammal Research Institute near Bialowieza.

The Swedish sample is from the collections of the Department of Historical Osteology, Lund University and comprises mandibles of farmed wild boar held in enclosures in Scania.

Tooth development was studied by taking radiographs of the mandibular molariform teeth with x-ray equipment for intra-oral radiography (Figure 2). Radiographs were taken of the right mandible with the exception of a few specimens with damaged crypts where the left side was examined instead. *Kodak* insight dental film (5 x 7 cm) was taped against the lingual side and the x-ray source was placed at 20 cm distance from the buccal side of the mandible.

In order to make it possible to study the complete molar row, usually three overlapping radiographs were taken on each mandible. The exposure varied between 0,16-0,62 s depending on the age of the mandible at standardized settings of power at 63kV and amperage of 8 mA.

Diagrams of tooth chronology in humans worked as models for the figures showing the tooth development in wild boar (Schour, Massler, 1941; Ubelaker, 1987).

The tooth development in boars and sows and in wild boar and hybrids have been analysed based on tooth developmental scores in order to study eventual sexual or populations differences in tooth development. The tooth formation of the molariform dentition has been described in eight stages from formation of crypt, to completion of root, corresponding to different scores. The tooth developmental score of a mandible is assessed by the sum of the scores of the permanent molars (Carter, Magnell, in print).

Figure 2. **Radiograph of crown formation of a M_2 from a wild boar aged 7 months**

Results. The tooth development of the permanent mandibular molariform dentition in wild boar is described in Figures 3 and 4. The formation of the first molar (M1) starts at birth and the formation of the crown is complete at 2-5 months. The first evidence of mineralization of the second molars (M2) is at 2-5 months and the crown formation is complete at 7-9 months. The third molar (M3) is first visible on radiographs at 7-9 months and the mesial crown is complete at 12-18 months, while the distal crown is complete at 18-24 months.

The analysis of the radiographs shows that the formation of the tooth crown in wild boar is not a slow, continuous process. The formation from first evidence of mineralization to completion of large parts of the crown takes place within a few months, while the completion of the crown seems to be a more gradual development over a relatively longer period (figure 3 and figure 4). This is expected since the tooth formation in humans and red deer follows a similar pattern (Chapman, Brown, 1991; Hillson, 1996).

No significant statistical differences in tooth development between males or females and between wild boar and hybrids were observed in this sample (Table 2).

The second and third molars in normal feed recent improved breeds develop a few months earlier than in wild boar, while M1 seems to be formed at the same ages (Table 3). This corresponds to tooth eruption ages. The differences in eruption of M1 are small between wild boar and domestic pig, but eruption of M2, the premolars and especially M3 is generally later in wild boar (Bull, Payne, 1982). The tooth development of M2 and M3 in undernourished recent pigs is a few months delayed in comparison with tooth formation in wild boar (Table 3).

Discussion. The tooth development in wild boar described in this study indicates relatively small variation in tooth formation between males and females and between wild boar and hybrids. However, certain ages are only represented by a few mandibles; only two mandibles at the age of 8-10 months, no specimens between 13-17 months and only one mandible between 19-23 months. This means the stages of tooth development are uncertain in these age intervals and a larger sample would have made it possible to present a more detailed description. For example, in this study it is only possible to show that the crown formation of the anterior cusp of the third molar is completed somewhere between 12-18 months.

Table 2. **Comparison of tooth development scores between males and females respectively wild boar and hybrids between wild and domestic pigs. Tooth developmental scores according to Carter and Magnell (in print)**

	12 months			18 months		
	mean	min-max	n	mean	min-max	n
wild boar	25,3	21-30	18	36,3	35-37	3
hybrids	26,2	24-27	5	35,6	33-37	5
males	25,2	21-30	16	36	35-37	4
females	26,3	24-27	6	35,8	33-37	4

It is proposed that tooth development can be used not only for ageing teeth and LEH of archaeological wild boar, but also of domestic pigs. It could be argued whether modern wild boar is a reliable reference for domestic pigs or not. However, no differences in the tooth development of wild boar and hybrids could be noticed. Therefore it is suggested that tooth development in presented in this study is most likely a more reliable reference to primitive prehistoric and medieval pigs than tooth formation in recent improved breeds of domestic pigs. In most past pig populations cross-breeding with wild boar was fairly common (Lasota-Moskalewska *et al*, 1987; Albarella et al, in print). Secondly, in traditional pig husbandry the animals were often free-ranging and their environment and feeding were probably more similar to wild boar than recent pig keeping in farms.

The fast formation of the upper two thirds of the crowns of the molars within three months has implications for interpreting LEH. Even though the LEH is measured and recorded with detailed precision at 0,05 mm and the height of different enamel hypoplasia on the upper parts of the crown varies between 7 mm, the different LEH are actually formed within a few months. On the other hand, the lower third of the crowns of the molars are formed over a longer period and LEH 1-3 mm apart could be caused at different periods of stress, several months apart.

Table 3. **Tooth development in wild boar compared with normal and undernourished domestic pig (McCance et al, 1961). Age in months**

	Wild boar	Tooth formation		Crown formation complete			Root formation complete	
		Normal	Undernourished	Wild boar	Normal	Undernourished	Wild boar	Normal	Undernourished
M1	*In utero?*	*In utero*	*In utero*	2-5	2-3	2-3	6-7	7-8	13-14
M2	2-5	1-2	3	7-9	6-7	10-11	12-18	12-13	>15
M3	7-12	3-4	10-11	12-18	12-13	>15	38-48	>13	>15
P2	8-12	3-4	3	10-12	9-10	>15	18-21	12-13	>15
P3	6-7	1-2	3	7-12	7-8	13-14	18-21	12-13	>15
P4	5-7	1-2	3	10-12	7-8	13-14	12-18	12-13	>15

The frequency distribution of LEH heights on the anterior cusps of second molars shows in different samples of recent wild boar, Medieval and Neolithic pigs, a clear peak at between 2,5-3,5 mm from the CEJ (cemento-enamel junction) (Dobney et al, 2004). This distance corresponds well to a part of the crown that seems to be formed during a relatively longer period between 5-9 months (Figure 3). This indicates the probability that pigs exposed to stress causing LEH at this height of the crown are higher than on LEH heights above 3,5 mm. The high frequency of LEH at 2,5-3,5 mm from the CEJ may be a consequence of tooth development rather than that the pigs are more frequently affected by stress during the formation of the cervical parts of the crown.

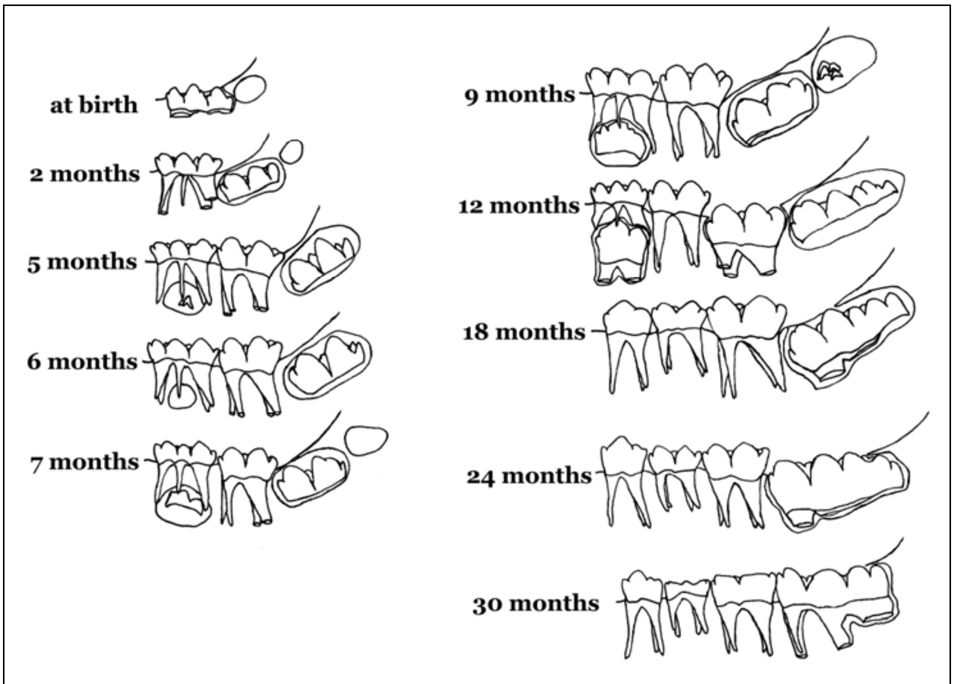

Figure 3. **Tooth development of the permanent mandibular molariform dentition in wild boar based on radiographs of 55 mandibles**

The use of undernourished recent improved pig breeds as a reference for tooth development gives partly different interpretations of the chronology of LEH in comparison with the results presented in this study.

However, the tooth formation of M1 seems to be similar in wild boar and undernourished domestic pigs.

The crown of the second molar appears to be completed two months earlier in wild boar than in undernourished domestic pigs. This has some implications of the interpretation of the high frequency of LEH on the lower third of the second molar in pigs from different archaeological samples, which are assumed to be formed during early winter (Ervynck, Dobney, 2002). Based on the tooth development, presented in this study, this peak in LEH occurs during the autumn, alternatively the farrows of prehistoric pigs were later than assumed. However, as mentioned, the effects of tooth development could also explain the high frequency of LEH on the cervical parts on the second molar. This study shows that the formation of the anterior cusps of the third molar are completed at 18 months of age and not at the assumed 21-24 months (Dobney, Ervynck, 2000). However, the conclusion that most of LEH on the third molars are formed during winter (assuming farrows in spring) seems in agreement with the tooth development presented in this study, despite most of the LEH being formed at 9-12 months of age and not by 21-22 months.

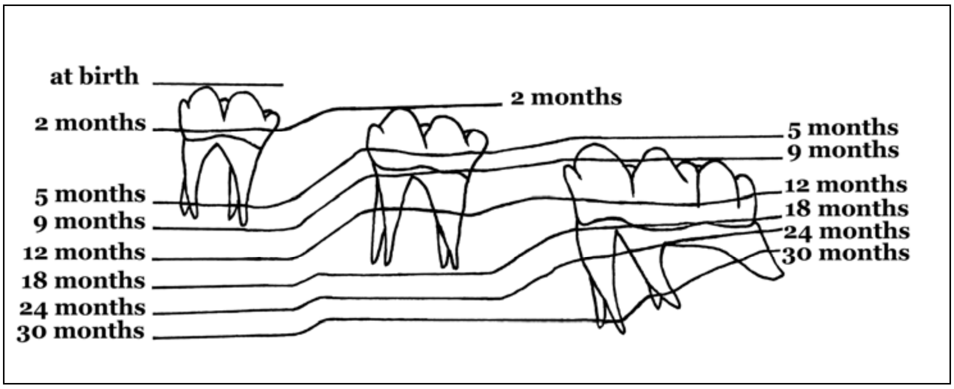

Figure 4. **Tooth development in permanent mandibular molars in wild boar based on radiographs of 55 mandibles**

Conclusions. The tooth development and results presented in this paper raises some problems with analysis and interpretation of LEH in pigs, such as, the implications of the uneven rate of crown formation and different ages for formation of the crowns. The purpose of this paper is not to criticize earlier studies of LEH in pigs, but rather to advocate the importance of analysis of LEH for understanding pig keeping in the past. This has been achieved by presenting diagrams of tooth development in wild boar that may be useful for the assessment of chronology of LEH in future studies.

Acknowledgements. This study was made possible by Christina Lindh and her colleagues at the Department of Oral Radiology, Centre for Oral Health Sciences, Lund University, Malmö, for kindly letting us use their equipment. Elwira Szuma and her colleagues at the Mammal Research Institute in Bialowieza, Poland, deserve thanks for letting us use their collections. We are also thankful to Per-Ola Andersson of the wild game butchery in Sjunkaröd, Sweden, for providing us with mandibles of wild boar.

References

1. Albarella, U., Manconi, F., Vigne, J-D., Dobney, K., Rowley-Conwy, P. Questions for the present, answers for the past? Traditional pig husbandry in Sardinia and Corsica. In: U. Albarella, K. Dobney, A. Ervynck & Rowley-Conwy, P. (eds): Pigs and Humans. 10,000 Years of Interaction. Oxford: Oxford University Press. In Print.
2. Baker, J., Brothwell, D. Animal Diseases in Archaeology. London: Academic Press. 1980.
3. Brown, W. A. B., Chapman, N. G. Age assesment of Red Deer (*Cervus elaphus*): from a scoring scheme based on radiographs of developing permanent molariform teeth. Journal of Zoology. 1991. Vol. 225. P. 85-97.
4. Buikstra, J. E., Ubelaker, D. H. Standards for Data Collection from Human Skeletal Remains. Archaeological Survey Research Series No. 44. Arkansas. 1994.
5. Bull, G., Payne, S. Tooth eruption and epiphysial fusion in pigs and wild boar. In B. Wilson, C. Grigson & S, Payne, (eds): Ageing and Sexing Animal Bones from Archaeological Sites. Oxford: BAR British Series 109. 1982. P. 55-71.
6. Carter, R., Magnell, O. Age estimation of wild boar (*Sus scrofa*) based on molariform mandibular tooth development and its application to seasonality at the Mesolithic site of Ringkloster. In: U. Albarella, K. Dobney, A. Ervynck & Rowley-Conwy, P. (eds): Pigs and Humans. 10,000 Years of Interaction. Oxford: Oxford University Press. In Print. P. 197-217.
7. Dobney, K., Ervynck, A. Interpreting developmental stress in archeological pigs: the chronology of linear enamel hypoplasia. Journal of Archaeological Science. 2000. Vol. 27. P. 597-607.
8. Dobney, K., Ervynck, A., Albarella, U., Rowley-Conwy, P. The chronology and frequency of a stress marker (linear enamel hypoplasia) in recent and archaeological populations of *Sus scrofa* in north-west Europe, and the effects of early domestication. Journal of Zoology. 2004. Vol. 264. P. 197-208.
9. Ervynck, A., Dobney, K. A pig for all seasons? Approaches to the assessment of second farrowing in archaeological pig populations. Archaeofauna. 2002. Vol. 11. P. 7-22.
10. Dobney, K., Goodman, A. Epidemiological Studies of Dental Enamel Hypoplasias in Mexico and Bradford: Their Relevance to Archaeological Skeletal Studies. In: H. Bush & M. Zvelebil (eds): Health in Past Societies. Biocultural Interpretations of Human Skeletal Remains in Archaeological Contexts. BAR International Series 567. 1991.
11. Goodman, A. H., Armelagos, G. J., Rose, J. C. enamel Hypoplasias as Indicators of Stress in Three Prehistoric Populations from Illinois. Human Biology. 1980. Vol. 52. P. 515-528.
12. Hillson, S. Dental Anthropology. Cambridge. 1996.
13. Lasota-Moskalewska A., Kobryn H., Swiezynski K. Changes in the size of domestic and wild pig in the territory of Poland from the Neolithic to the Middle Ages. Acta Theriologica. 1987. Vol.

32. P. 51-81.

14. McCance R. A., Ford E. H. R., Brown W. A. B. Severe undernutrition in growing and adult animals. 7. Development of the skull, jaws and teeth in pigs. British Journal of Nutrition. 1961. Vol. 15. P. 213-224.
15. Mellanby, M. Diet and Teeth: an experimental study. Part I. Dental structure in dogs. Medical Research Council Special Report Series 140. London: H.M.S.O. 1929.
16. Rabkin, S. Comparative alveolr pathology in sheep and goats. Journal of Dental Research. 1956. Vol. 25. P. 513-515.
17. Rose, J. C., Condon, K. W., Goodman, A. H. Diet and Dentition: Developmental Disturbances. In: R. I. Gilbert & J. H. Mielke (eds): The Analysis of Prehistoric Diets. New York: Academic Press. 1985. P. 281-306.
18. Sarnat, B. G., Schour, I. Enamel hypoplasia (chronic enamel aplasia) in relationship to systemic disease: a chronological, morphologic and etiologic classification. Journal of American Dentist Association. 1941. Vol. 28. P. 1989-2000.
19. Schour, I. & Massler, M. 1941. The development of the human dentition. Journal of the American Dental Association. 1941. Vol. 28. P. 1153-1160.
20. Svärdstedt, T. Odontological Aspects of a Medieval Population in the Province of Jämtland/Mid-Sweden. Stockholm. 1966.
21. Ubelaker, D. H. Estimating age at death from immature human skeletons: an overview. Journal of Forensic Sciences. 1987. Vol. 32. P. 1254-1263.