

DOI : 10.1002/(ISSN)1099-1212
ISSN (print) : 1047-482X
ISSN (electronic) : 1099-1212
ID (product) : OA
Title (main) : International Journal of Osteoarchaeology
Title (short) : Int J Osteoarchaeol
DOI : 10.1002/oa.v9999.9999
Copyright (publisher) : © 2019 John Wiley & Sons, Ltd.
Numbering (journalVolume) : 9999
Numbering (journalIssue) : 9999
CoverDate : 2019
DOI : 10.1002/oa.2830
ID (unit) : OA2830
ID (society) : OA-19-0033.R1
Count (pageTotal) : 1
Title (articleCategory) : RESEARCH ARTICLE
Title (tocHeading1) : RESEARCH ARTICLES
Copyright (publisher) : © 2019 John Wiley & Sons, Ltd.
Event (manuscriptReceived) : 2019-03-05
Event (manuscriptRevised) : 2019-10-11
Event (manuscriptAccepted) : 2019-10-12
Event (xmlCreated) : 2019-12-12 (SPi Global)
Numbering (pageFirst) : n/a
Numbering (pageLast) : n/a

SelfCitationGroup : Minozzi S, Caldarini C, Pantano W, di Giannantonio S, Catalano P, Giuffra V. Enamel hypoplasia and health conditions through social status in the Roman Imperial Age (First to third centuries, Rome, Italy). *Int J Osteoarchaeol*. 2019. <https://doi.org/10.1002/oa.2830>

Link (toTypesetVersion) : <file:oa2830.pdf>
Link (toAuthorManuscriptVersion) : file:oa2830_am.pdf

Short Authors: Minozzi et al.

Enamel hypoplasia and health conditions through social status in the Roman Imperial Age (First to third centuries, Rome, Italy)

Simona<<Query: AUTHOR: Please verify that the linked ORCID identifiers are correct for each author. Ans: I have verified>><<Query: AUTHOR: Please confirm that forenames/given names (blue) and surnames/family names (vermilion) have been identified correctly. Ans: I have verified and they are correct>> Minozzi¹, Carla Caldarini², Walter Pantano², Stefania di Giannantonio², Paola Catalano², **Valentina** Giuffra^{*1}

¹ Division of Paleopathology, Department of Translational Research and New Technologies in Medicine and Surgery, University of Pisa, Pisa, Italy

² Service of Anthropology, Special Superintendence for Archaeology, Arts and Landscape Heritage of Rome, Roma, Italy

Valentina Giuffra: ✉ valentina.giuffra@unipi.it

*Correspondence to:

Correspondence

Valentina Giuffra, Division of Paleopathology, Department of Translational Research and New Technologies in Medicine and Surgery, University of Pisa, Via Roma 57, 56126, Pisa, Italy.

Email: valentina.giuffra@unipi.it

FundRef Name	FundRef Organization Name	Funding Number
2015 PRIN Ministerial Project “Diseases, Health and Lifestyles in Rome: from the Empire to the Early Middle Age”		prot. 2015PJ7H3K, 2015PJ7H3K

Abstract

Dental enamel hypoplasia, a deficit in enamel matrix formation, occurs in childhood and in utero as a result of survived nutritional deficiencies/diseases. Examination of hypoplastic lesions in ancient skeletal remains provides an excellent index of developmental stress levels in the past. In this research, linear enamel hypoplasia (LEH) was detected to investigate the relation between social status, health, and nutritional conditions of the Romans during the Imperial Age. LEH was scored in 3,105 permanent teeth of 177 individuals found in two large necropolises in Rome (Italy), dating back to first to third centuries AD. Both sites are located near the ancient city centre, and the presence of different grave typologies, with monumental mausoleums and simple tombs, testifies the presence of stratified social classes. LEH was observed in the whole dentition. Statistically significant differences were found in all the parameters considered, mostly in anterior dentition. Frequencies of the teeth and of the individuals affected were higher in the lower than in the upper class, in both sexes and ages, whereas male/female or adult/subadult differences were not statistically significant. The mean number of events for individuals was also higher in the lower class. Chronological distribution of age at onset of the stressful events seems to be social status related.

The study of two subsamples with different subsistence patterns in the same population allowed us to detect a relationship between LEH and social status in Imperial Rome, indicating that the socially advantaged group enjoyed better health in this past population.

Keywords: developmental stress; enamel defect; LEH; Roman Imperial Age; social class

1 INTRODUCTION

Developmental enamel defects receive significant attention in the anthropological and paleopathological literature for their relationship with diseases and nutritional factors. For this reason, the bioarchaeological analysis of enamel hypoplasia is routinely performed to evaluate the health and living conditions in ancient populations (Goodman & Rose, 1990; Rose, Condon, & Goodman, 1985). Enamel hypoplasia, a defect occurring during enamel formation in childhood, is caused by the interruption of amelogenesis, the enamel

matrix formation resulting from an insult that stops enamel apposition on the crown. Linear enamel hypoplasia (LEH) is identified as horizontal lines or grooves along the outer surface of the tooth crown that mark the points at which enamel growth was stopped. This defect is reported in short episodes of non-specific stress such as childhood illnesses or nutritional deficiencies, and because enamel does not remodel, it provides a permanent and excellent developmental stress level index (Goodman & Rose, 1990; 1991; Guatelli-Steinberg & Lukacs, 1999; Hillson, 1996; Hillson & Bond, 1997; Larsen, 1997).

Many studies have focussed on the relationship between enamel defects and living conditions, highlighting differences in the prevalence of enamel defects among social groups, subsistence strategies, health status, and nutritional deficiencies in past and present populations (Armstrong, 1969; Cucina, 2002; Goodman & Rose, 1990; Griffin & Donlon, 2007; Rose, Armstrong, & Lallo, 1978; Rudney, 1983; Swärdstedt, 1966). Different methods can be used to identify LEH on enamel surface: macroscopic standard approach visible to the naked eyes, or microscopic techniques using electronic microscopy or other sophisticated instruments. Comparisons between macroscopic and microscopic examination have demonstrated that the latter method permits to detect the enamel defects with greater sensitivity and precision. However, microscopy is time-consuming and requires expensive analytical tools that have proved to be impractical for the observation of large samples (Hassett, 2014), as in this case.

Researches focused on the relation between LEH and social status have mainly regarded early modern populations. For example, Lanphear (1990) found a high prevalence of LEH in a 19th-century low socio-economic status population, whereas Nakayama (2016) identified a lower prevalence and smaller number of LEH per tooth in the higher social status of a Japanese population from 18th to 19th centuries. Lower frequencies of LEH in upper social classes were also observed in a 19th century Canadian skeletal sample (Saunders & Keenleyside, 1999), in Danish and Lithuanian late medieval/early modern samples (Palubeckaitė, Jankauskas, & Boldsen, 2002), and in a British medieval population (Miszkievicz, 2012).

Studies of contemporary children living under poverty conditions provided evidence of nutritional deficiency associated with LEH formation (Jelliffe & Jelliffe, 1971; May, Goodman, & Meindl, 1993; Sweeney, Cabrera, Urrtia, & Mata, 1969). However, many other factors can be involved in the onset of enamel hypoplasia, such as infectious diseases, childhood fevers, and weaning problems (Guatelli-Steinberg & Lukacs, 1999).

The purpose of this study is to investigate the relation between social status, health, and nutritional conditions of the Romans during the Imperial Age, by evaluating the prevalence and distribution of dental enamel defects. The availability of a large sample of skeletal remains from two large necropolises brought to light in Rome (Italy) permitted to evaluate LEH in the entire permanent dentition of almost 200 individuals belonging to different social statuses. Unlike previous studies, this paper explores concomitantly many parameters, such as LEH, distribution per teeth and per individuals, mean LEH number in each dental category and in individuals, and chronological distribution of LEH, and it offers an interesting example of the relation between LEH and social status in Imperial Rome.

During the Empire, Rome was a highly hierarchical and class-conscious society with wealthy upper classes, constituted by the senatorial and equestrian classes, and the poor lower classes, represented by plebeians, freedmen, and slaves. In the archaeological sites in which the skeletal remains were found, the archaeological data suggest the presence of different social classes in the city. These were in large part composed by Roman citizens and traders belonging to the middle/upper classes and slaves and *liberti* (slaves who had been manumitted) belonging to the lower classes (Buccellato, Catalano, & Musco, 2008; Musco, Catalano, Caspio, Pantano, & Killgrove, 2008).

2 MATERIAL AND METHODS

2.1 Roman necropolises

Our study was performed in two Roman necropolises from the Imperial Age (first to third centuries AD), in which it was possible to identify individuals belonging to the middle/upper and lower social classes on the basis of funerary structures and grave goods: the Collatina and the Casal Bertone necropolises (Figure 1).

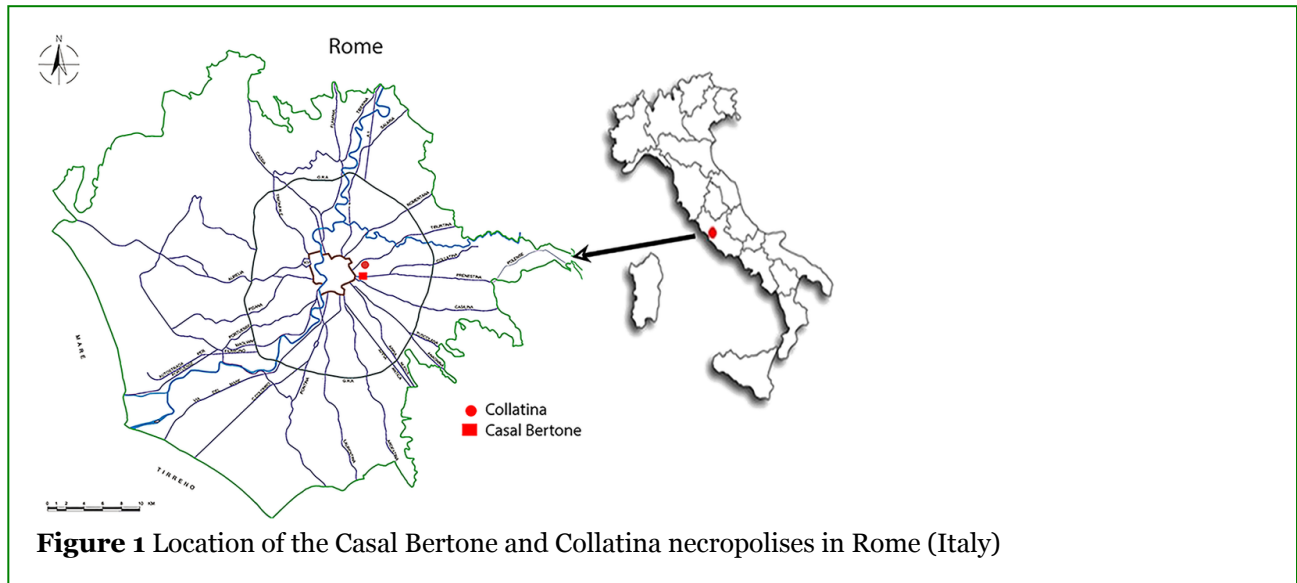


Figure 1 Location of the Casal Bertone and Collatina necropolises in Rome (Italy)

The Collatina necropolis, placed in the eastern part of modern Rome, is the largest funerary area of the Imperial Age (first to third centuries AD). It is close to the Urbe, with 2,749 burials of different typologies: great monumental tombs, inhumation graves, and cremation burials (Buccellato, Catalano, & Musco, et al., 2008; Catalano, 2015). The Casal Bertone necropolis is placed in eastern Rome, at a distance of 4 km from the Collatina necropolis (Figure 1). Archaeological excavations brought to light a funerary area including 302 tombs, and a number of residential and productive buildings dating back to between the second and third centuries AD (Musco, Catalano, Caspio, Pantano, & Killgrove, et al., 2008). The two necropolises are situated outside the ancient city, along the Via Collatina, an important ancient commercial road of the Roman Imperial Age.

2.2 Selected individuals

The classification of the examined population into different social classes was based on burial and other mortuary evidence types. Individuals buried in great monumental tombs, such as Mausoleums, and in privileged areas of the necropolises, identifiable as funerary enclosures with complex tombs, such as brick structures (*formae*) and *sarcophagi*, were considered to belong to the middle/upper class samples. These burials, sometimes pillaged in ancient times, have returned precious grave goods (rings, necklaces, gold earrings, etc.).

By contrast, individuals buried in simple graves excavated in the ground or located in poor areas of the necropolises with no cover and grave goods were selected for inclusion in the lower class sample. In the necropolis of Collatina, these tombs are mainly concentrated in a high density area, where the graves sometimes intersect each other, testifying a chaotic and unplanned use of the funerary space (Buccellato, Catalano, & Musco, et al., 2008).

A similar number of individuals was selected for each necropolis and for each social status, with observable teeth for enamel hypoplasia. Dental enamel hypoplasia was counted in 1299 permanent teeth of 73 human skeletal remains from the Collatina necropolis and 1806 teeth of 104 skeletons from Casal Bertone, of both sexes and of different ages. Only individuals over 6 years of age were analysed because this is the age in which the crown of all the anterior teeth is complete, and this reduces the effect that the osteological paradox (Wood,

Milner, Harpending, & Weiss, 1992) might have on the interpretation of the data, because the individuals had survived the most vulnerable phase of life.

Table 1a shows the biological profiles of the two samples. The data for enamel hypoplasia obtained from the two necropolises were analysed together by dividing the individuals into two social classes. This approach was supported by the similar archaeological and chronological context and by the close proximity of the two sites. Table 1b shows the distribution of sex and age for the two class samples. The chi-squared test applied to each age range did not find any significant differences between the two classes.

Table 1a Biological profiles of the selected individuals from the two necropolises

	Number of individuals				Number of teeth			
	Females	Males	Subadults	Total	Females	Males	Subadults	Total
Collatina								
Lower class	11	14	10	35	259	272	221	752
Upper class	22	15	1	38	335	206	6	547
C. Bertone								
Lower class	16	26	18	63	347	455	355	1157
Upper class	13	10	18	41	219	156	274	649

Table 1b Distribution of sex and age in the two social classes

Age	Lower class				Upper class			
	Females	Males	ND	Total	Females	Males	ND	Total
6-12	0	0	14	14	0	0	13	13
13-18	0	0	14	14	0	0	6	6
19-34	18	17	0	35	22	5	0	27
35-55	9	23	0	32	13	20	0	33
Total	27	40	28	95	35	25	19	79

2.3 Methods

Age at death in adults was assessed by using several indicators such as dental wear, ectocranial suture closure, and modification of pubic symphysis and auricular surface of the os coxae (Buikstra & Ubelaker, 1994; Lovejoy, 1985; Meindl & Lovejoy, 1985). In subadults, age at death was estimated on the basis of dental development (Alqahtani, Hector, & Liversidge, 2010; Ubelaker, 1989), size of bones, and fusion of epiphyses and diaphyses (Schaefer, Black, & Scheuer, 2008; Scheuer & Black, 2000; Ubelaker, 1989). Sex was determined according to the standard osteological procedures recommended by Acsádi and Nemeskéri (1970) and Ferembach, Schwidetzky, and Stloukal (1980).

Enamel defects were observed and scored in the permanent dentition with a 3× magnification lens. Teeth with severe attrition (having over one third of the crown missing) were excluded from the analysis, as well as teeth covered by calculus deposits; only linear enamel hypoplasia was analysed (LEH). An individual was considered observable only if at least three anterior teeth belonging to different dental categories (I1, I2, C, independently of side or jaw) were observable (Manzi, Salvadei, Vienna, & Passarello, 1999). An individual was considered affected by LEH only when at least two different tooth types (e.g., RI1 and LC1) in the anterior dentition were affected. The number and type of teeth observed within a dentition were similar, and the age at onset of the stressful event in each individual was evaluated by matching the defects observed in all the anterior and premolar teeth available. In the observable individuals, the posterior dentition was scored, and the molars were only considered to calculate the mean number of defects and the prevalence of teeth affected.

The distance of each line from the cemento-enamel junction to the upper limit of each defect was measured to the nearest 0.01 mm by means of a digital caliper. Age at onset of the stressful event was calculated by regression equations proposed by Goodman and Rose (1990) and was applied to LEH in the anterior dentition and in the premolars. The defects matched on different tooth types were considered as the result of an identical stress event when they were included in a 3-month-age range. The number of stress episodes per individual was determined on this basis.

Reid and Dean (2000, 2006) proposed a new and more accurate method to detect LEH ageing defects. The authors developed a decile chart of anterior tooth enamel growth, which took into account the population variations in crown height and the non-linear enamel growth rate during tooth formation. This method does not provide any indication for premolar teeth, and as also observed by Cares Henriquez and Oxenham (2019), it is time-consuming and has precision and replicability problems. Moreover, a comparison of the age of LEH formation between the Reid and Dean's (2000, 2006) method and the Goodman and Rose's regression equations (1990) found significant differences ranging from 1 to 4 months (Martin, Guatelli-Steinberg, Sciulli, & Walker, 2008; Ritzman, Baker, & Schwartz, 2008). This difference would not be meaningful with regard to LEH age formation in the two social classes because, in this case, we would need to evaluate the prevalence and distribution of the occurrence of stressful events in 1-year-age ranges, rather than to determine the precise time of defect formation.

LEH was scored in two degrees: slight hypoplasia, a discernible line, when the line was visible to the naked eyes—the measurement could be taken symmetrically in the same left and right teeth (when they were both present)—and moderate hypoplasia, a clear groove, when the line could be felt with a fingernail. LEH was scored by three authors (S. M., C. C., and W. P.) together and separately until full agreement was reached. LEH was scored in “blind mode” without knowing the provenance of the skeletons. For each dental category, the mean LEH number was calculated as the ratio between the number of lines and teeth affected for each tooth type.

The statistical significance for data comparison was evaluated by the chi-squared test performed by STATA 13.0 software.

3 RESULTS

The severity of all the LEH observed is prevalently slight in both social classes: 93.6% in the lower class and 92.7% in the upper class. Tables 2a and 2b show the distribution of teeth affected by LEH in age range and sex, and in each dental category, in both the lower and upper class samples. The general prevalence is relatively high: Half of all the teeth presents one or more defects, with no significant differences between maxilla and mandible. In the whole dentition, the frequency of the affected teeth is twice as much in the lower class (60.2%) than in the upper class (33.2%). The most sensitive teeth to enamel hypoplasia and therefore those most capable of recording the phenomenon are the central incisors and canines, in particular the central maxillary incisor (70.9%) and the mandibular canine (81.3%). The mean LEH number (ratio between number of events and teeth affected) is higher in the lower than in the upper class of all dental categories. Central maxillary incisors and mandibular canines show a higher mean LEH number with respect to the other dental types.

Table 2 a: Distribution of LEH in age ranges and in each dental category in the upper class

Upper class		Maxilla									Mandible								
		I1	I2	C	P3	P4	M1	M2	M3	tot MX	I1	I2	C	P3	P4	M1	M2	M3	tot MD
Females 19–34 years (n = 22)	LEH number	26	17	29	12	2	3	3	4	96	11	13	32	4	5	5	7	2	79
	Teeth affected	14	12	14	8	2	3	3	4	60	7	8	17	3	4	5	5	2	51
	Teeth observed	24	24	28	29	26	28	27	16	202	16	21	24	25	23	29	30	17	185
Females 35–55 years (n = 13)	LEH number	3	4	11	7	5	2	1	1	34	6	9	20	2	6	2	2	0	47
	Teeth affected	2	2	7	4	2	2	1	1	21	4	6	12	2	5	2	2	0	33
	Teeth observed	8	8	11	14	12	9	14	5	81	9	12	14	11	14	10	12	6	88
Males 19–34 years (n = 5)	LEH number	6	4	8	4	4	1	1	3	31	5	9	11	5	5	4	3	5	47
	Teeth affected	2	2	5	3	3	1	1	3	20	3	4	5	4	3	4	3	5	31
	Teeth observed	2	2	5	3	7	6	8	6	39	5	8	7	5	6	8	8	7	54
Males 35–55 years (n = 20)	LEH number	25	21	30	4	4	2	5	1	92	3	7	37	9	4	0	1	0	61
	Teeth affected	11	10	13	3	4	1	5	1	48	2	4	14	8	3	0	1	0	32
	Teeth observed	15	16	18	13	18	18	18	8	124	18	14	24	22	21	17	14	15	145
Subadults 6–12 years (n = 13)	LEH number	13	12	12	2	2	1	0	1	43	14	14	32	7	3	3	0	0	73
	Teeth affected	6	6	6	2	2	1	0	1	24	9	8	13	4	2	2	0	0	38
	Teeth observed	11	10	8	12	8	14	10	1	74	18	14	16	13	11	17	13	0	102
Subadults 13–18 years (n = 6)	LEH number	3	2	14	1	4	5	1	0	30	3	7	16	7	4	2	5	0	44
	Teeth affected	2	1	6	1	2	3	1	0	16	2	4	7	5	2	2	3	0	25
	Teeth observed	3	3	10	4	6	8	8	0	42	7	8	9	10	9	8	10	1	62
Total upper class	Teeth affected	37	33	51	21	15	11	11	10	189	27	34	68	26	19	15	14	7	210
	Teeth observed	63	63	80	75	77	83	85	36	562	73	77	94	86	84	89	87	46	636
	% Teeth affected	58.7	52.4	63.8	28.0	19.5	13.3	12.9	27.8	33.6	37.0	44.2	72.3	30.2	22.6	16.9	16.1	15.2	33.0
	LEH number	76	60	104	30	21	14	11	10	326	42	59	148	34	27	16	18	7	351
	LEH mean number*	2.1	1.8	2.0	1.4	1.4	1.3	1.0	1.0	1.7	1.6	1.7	2.2	1.3	1.4	1.1	1.3	1.0	1.7

* LEH mean number: ratio between the number of LEH and teeth affected in each tooth category

Table 2 b: Distribution of LEH in age ranges and in each dental category in the lower class

Lower class		Maxilla									Mandible								
		I1	I2	C	P3	P4	M1	M2	M3	tot MX	I1	I2	C	P3	P4	M1	M2	M3	tot MD
Females 19–34 years (n = 18)	LEH number	44	44	54	34	25	24	17	11	253	38	38	63	33	28	18	22	7	247
	Teeth affected	19	20	23	18	16	15	10	8	129	17	16	28	20	18	13	18	6	136
	Teeth observed	26	28	28	27	26	25	28	10	198	27	25	30	32	31	29	28	19	221
Females 35–55 years (n = 9)	LEH number	5	12	23	17	7	6	6	5	81	19	25	35	18	12	11	4	3	127
	Teeth affected	3	7	8	9	5	4	4	4	44	10	10	14	11	8	4	3	3	63
	Teeth observed	9	11	13	12	9	7	9	6	76	13	14	17	17	12	13	15	10	111
Males 19–34 years (n = 17)	LEH number	17	24	33	12	11	7	10	5	119	12	17	38	27	13	5	8	5	125
	Teeth affected	9	12	17	8	7	5	7	4	69	5	7	16	14	9	5	5	3	64
	Teeth observed	15	22	24	18	23	18	23	9	152	17	17	22	28	27	21	28	16	176
Males 35–55 years (n = 23)	LEH number	51	30	65	28	17	25	24	7	247	27	51	90	45	26	19	26	13	297
	Teeth affected	23	17	24	16	14	17	14	5	130	13	23	33	29	18	14	18	13	161
	Teeth observed	24	21	27	26	22	22	20	18	180	13	25	35	37	29	24	31	25	219
Subadults 6–12 years (n = 14)	LEH number	28	17	15	3	0	23	1	2	89	22	35	14	1	2	20	0	0	94
	Teeth affected	14	9	11	3	0	12	1	2	52	13	14	8	1	2	9	0	0	47
	Teeth observed	18	19	14	13	10	22	12	3	111	20	21	13	12	10	20	10	3	109
Subadults 13–18 years (n = 14)	LEH number	57	43	66	33	22	21	22	8	272	21	23	59	22	19	20	11	2	177
	Teeth affected	23	20	26	22	14	17	16	6	144	10	13	23	14	12	12	7	1	92
	Teeth observed	25	23	26	24	22	24	26	8	178	15	19	23	23	23	20	22	4	149
Total lower class	Teeth affected	91	85	109	76	56	70	52	29	568	68	83	122	89	67	57	51	26	563
	Teeth observed	117	124	132	120	112	118	118	54	895	105	121	140	149	132	127	134	77	985
	% Teeth affected	77.8	68.5	82.6	63.3	50.0	59.3	44.1	53.7	63.5	64.8	68.6	87.1	59.7	50.8	44.9	38.1	33.8	57.2
	LEH number	202	170	256	127	82	106	80	38	1061	139	189	299	146	100	93	71	30	1067
	LEH mean number*	2.2	2.0	2.3	1.7	1.5	1.5	1.5	1.3	1.9	2.0	2.3	2.5	1.6	1.5	1.6	1.4	1.2	1.9

* LEH mean number: ratio between the number of LEH and teeth affected in each tooth category.

Table 3 reports the distribution of LEH for teeth and individuals in females, males, and subadults. As concerns the LEH frequencies for teeth, the anterior is much more affected than the posterior dentition in both social classes. The differences in anterior dentition between the two social classes have been checked by the chi-squared test with one degree of freedom, and they result to be highly statistically significant in all sexes and age categories. p values coming from the comparison between classes are as follows: lower versus upper females $p = 0.0001$ (chi-squared value: 19.322), lower versus upper males $p = 0.0004$ (chi-squared value: 16.61), and lower versus upper subadults $p = 0.0005$ (chi-squared value: 11.982). In both social classes, the frequency of the anterior teeth affected seems to increase in males with respect to females and in subadults with respect to adults (Figure 2), but the differences between sex and age category are not statistically significant within the same social class.

Table 3 Distribution of enamel hypoplasia in teeth and in individuals of the lower and upper classes

	Lower class				Upper class			
	Females	Males	Subadults	Total	Females	Males	Subadults	Total
Teeth observed	606	727	576	1909	554	362	280	1196
Teeth affected	372	424	353	1149	163	131	103	397
% Teeth affected	61.4	58.3	61.3	60.2	29.4	36.2	36.8	33.2
Anterior teeth observed	241	262	247	750	197	134	117	448
Anterior teeth affected	175	199	191	565	103	75	70	248
% Anterior teeth affected	72.6	76.0	77.3	75.3	52.3	56.0	59.8	55.4
Individuals observed	27	40	31	98	35	25	19	79
Individuals affected	24	37	30	91	24	18	15	57
% Individuals affected	88.9	92.5	96.8	92.9	68.6	72.0	78.9	72.2

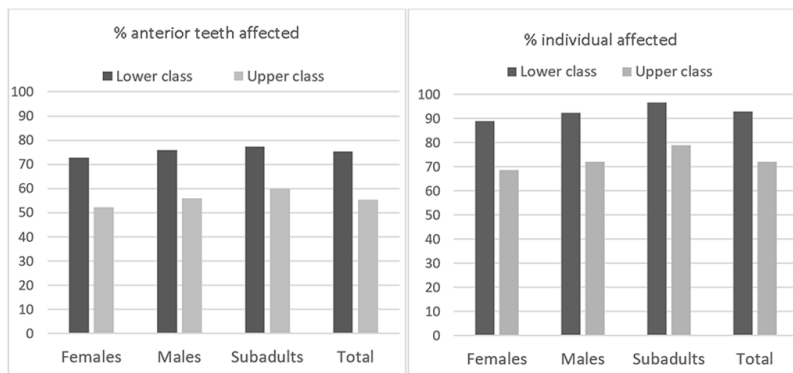


Figure 2 Frequency of enamel hypoplasia by sex and age in anterior dentition and in individuals

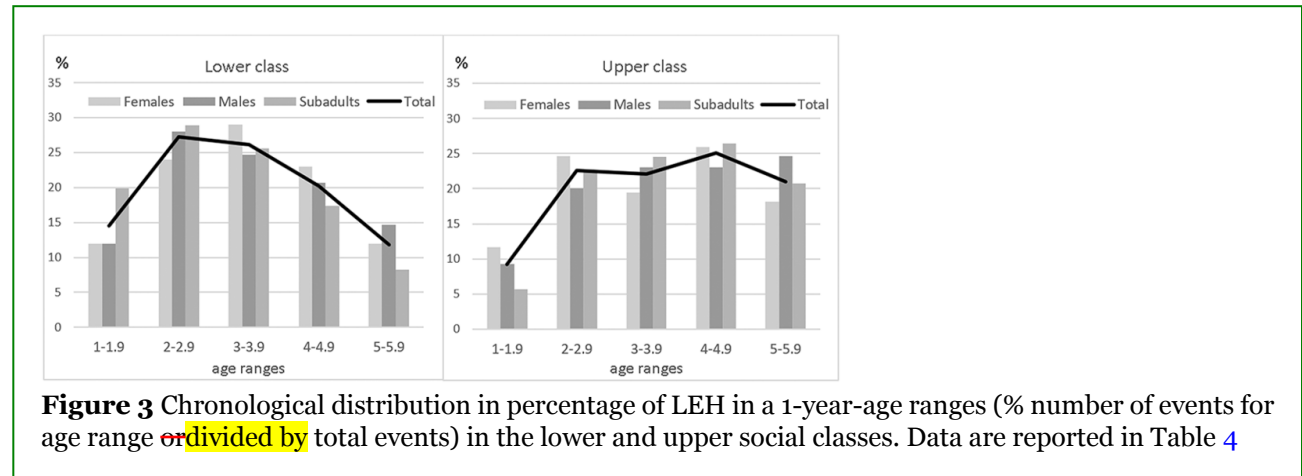
Considering the LEH frequencies for individuals, the general prevalence is high: 72.2% of individuals in the upper class and 92.9% in the lower class are affected by LEH. The differences between the two social classes are statistically significant in all sex and age categories with the following p values (with one degree of freedom): lower versus upper males $p = 0.025$ (chi-squared value: 4.966), lower versus upper females $p = 0.057$ (almost significant, chi-squared value: 3.599), and lower versus upper subadults $p = 0.041$ (chi-squared value: 4.159). Similarly to what has been observed for the frequencies of affected teeth, also the frequency of affected individuals seems to increase from females, to males, to subadults, but the differences within the same social class and between adults and subadults are not statistically significant.

Table 4 shows the number of stressful events in each age range of the females, males, and subadults in the two social classes. The lower class presents a higher number of episodes per individual than the upper class, as revealed by the mean number of events per individual (ratio between total number of events and individual affected). The differences between sex and age do not seem relevant within the same social class, although the number of stressful events per individual is slightly higher in the females (4.2) than in the males (4.1) in the lower class and vice versa (females 3.2 and males 3.6) in the upper class.

Table 4 Number of stressful events in a 1-year-age ranges in females, males, and subadults for the two social classes

Age range	Lower class				Upper class			
	Females	Males	Subadults	Total	Females	Males	Subadults	Total
1-1.9 years	12	18	24	54	9	6	3	18
2-2.9 years	24	42	35	101	19	13	12	44
3-3.9 years	29	37	31	97	15	15	13	43
4-4.9 years	23	31	21	75	20	15	14	49
5-5.9 years	12	22	10	44	14	16	11	41
Total events	100	150	121	371	77	65	53	195
Individuals affected	24	37	30	91	24	18	15	57
Mean number of events per individual	4.2	4.1	4.0	4.1	3.2	3.6	3.5	3.4

Figure 3 shows the chronological distribution percentage of LEH. Hypoplasia occurs from the first year of life and has a higher frequency in the lower (14.6%) than in the upper class (9.2%). In the lower class, LEH peaks at 2–2.9 years and frequency then decreases at increasing age. In the upper class, LEH also peaks at 2–2.9 years, but the frequency does not decrease as much as in the lower class in the successive years (Figure 3). The differences between the two social classes are statistically significant ($p = 0.01$, chi-squared value: 13.356, with four degrees of freedom).



4 DISCUSSION

Microscopic studies revealed that LEH are more difficult to identify in certain enamel regions, owing to the variation in perikymata spacing across the teeth, so LEH are not equally observable to the naked eyes in all the regions compared (Bocaage & Hillson, 2016; Hassett, 2012, 2014; Hillson & Bond, 1997). The aim of this study is to compare macroscopically the defects that are most evident to the naked eyes, assuming that if LEH are not equally observable in all the regions compared, this is also true for all the teeth observed. A total of 3,105 teeth were observed, and the frequency of LEH and the mean number of defects in each tooth type are reported in Table 2; therefore, if some defects in some regions were missed, the high number of observations could partially cover this error. For these reasons, LEH prevalence might be underestimated, but this occurs proportionally in all the samples, and we think this does not influence the comparison between the two subsamples.

LEH examination in the two Roman necropolises indicates differences between the upper and lower social classes in terms of frequency of affected teeth and individuals, mean number of stressful episodes per teeth and individual, and chronological distribution of defects.

As reported in Table 2, differences are also found among the dental categories: The anterior teeth are more affected than the posterior, and maxillary central incisors and maxillary and mandibular canines are more sensitive in terms of registration of hypoplasia. Differences in frequencies of enamel defects among different teeth has been reported in previous studies; for example, Goodman and Armelagos (1985) suggested that this may be the result of higher susceptibility to stress of incisors and canines. Recently, some researchers have found that differences in tooth crown geometry and in appositional enamel layers during crown formation, as well as variation in perikymata spacing across the teeth, result in variation when recording enamel defects (Bocaage & Hillson, 2016; Hassett, 2012, 2014; Hillson & Bond, 1997). Probably, a combination of many factors, including the variation in the timing and duration of tooth crown formation, contributes to these differences (King, Humphrey, & Hillson, 2005).

In our samples, the distribution of LEH in each dental category seems to reflect the time of crown development, as shown in Figure 4, where the percentage of the affected teeth and the mean number of lines in each tooth are compared with the crown formation time. This has been calculated as the difference between

crown and cusp completion on the basis of data reported in Tables 4 and 5 published by Reid and Dean for Northern European populations (2006). The correlation coefficient R calculated between the crown formation time and the percentage of affected teeth is highly significant ($R = 0.948$, $p < 0.001$), the same occurring with the mean number of lines in each tooth ($R = 0.946$, $p < 0.001$). This suggests that a longer time of crown formation may have a greater opportunity to record defects, as hypothesized by Schwartz and Dean (2001) for great apes, but not definitely confirmed by other researchers (Guatelli-Steinberg, Ferrell, & Spence, 2012).

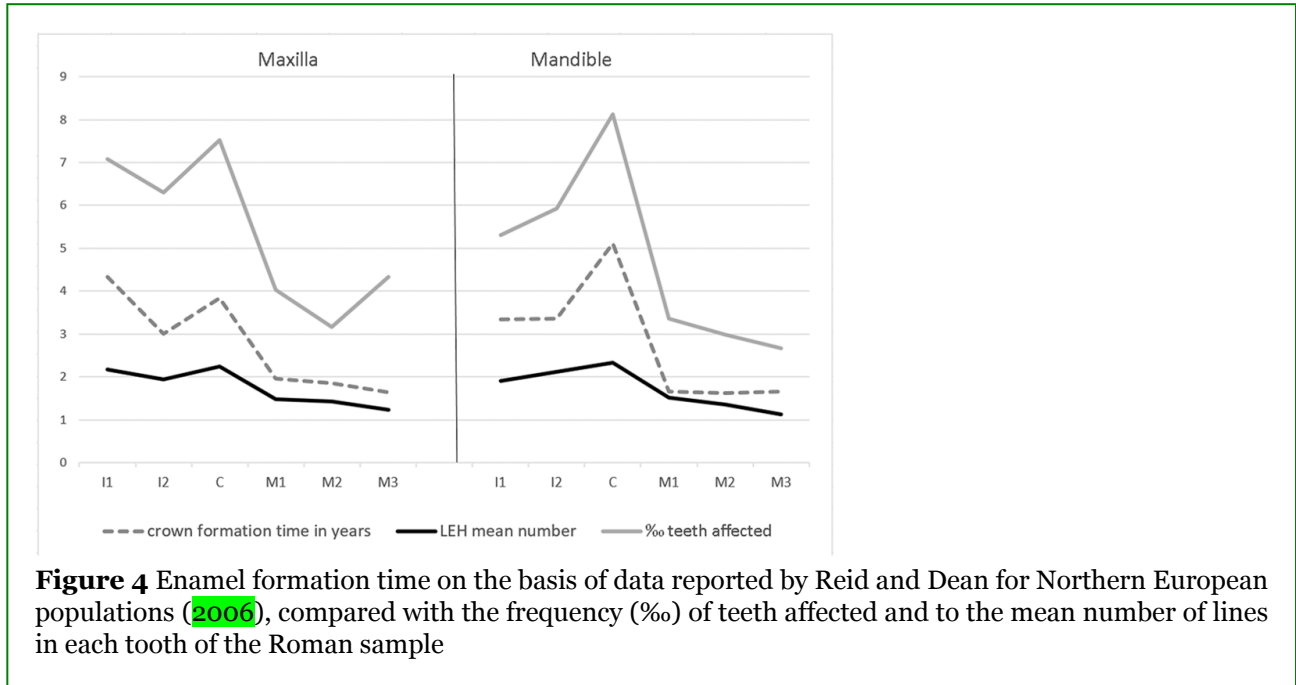


Figure 4 Enamel formation time on the basis of data reported by Reid and Dean for Northern European populations (2006), compared with the frequency (%) of teeth affected and to the mean number of lines in each tooth of the Roman sample

As regards the whole dentition, the frequency of affected teeth is relatively high (49.8%), although most defects indicate slightly stressful events. The frequency in the lower class (60.2%) is twice the frequency in the upper class (33.2%). Comparisons with other Italian Imperial Age samples have been performed, and the data available mainly concern the rural and lower class sites. In the rural necropolis of Locus Feroniae, near Rome, Manzi, Salvadei, Vienna, & Passarello *et al.* (1999) observe LEH in 46% of the teeth, whereas in the necropolis of Quadrella in Molise (Bonfiglioli, Brasili, & Belcastro, 2003), composed by poor social status people, LEH affects 58.9% of the teeth. In the rural necropolis of Vallerano (Cucina, Vargiu, Mancinelli, Ricci, Santandrea, Catalano, & Coppa *et al.*, 2006), located in the Roman *suburbium*, LEH affects 63.5% of teeth. Despite the slight variability of frequencies observed in the comparison of the lower class samples, the values are close to those of the lower class of this study (60.2%). In the necropolis of Isola Sacra (Rome), constituted by people of the middle class, LEH affects 35.5% of the teeth (Manzi, Salvadei, Vienna, and Passarello *et al.*, 1999), and the frequency is very close to that of the upper class of this research (32.8%). The comparison evidences that the distribution of LEH reflects the social status of the samples, mostly affecting the teeth of the individuals from rural sites or belonging to poor social classes. As regards the coeval comparison samples, only a few authors report the frequencies of LEH in the anterior dentition: in the Quadrella sample, LEH affects 86.9% of the anterior teeth (Bonfiglioli, Brasili, & Belcastro *et al.*, 2003), a frequency that is close to that of the lower class of our sample (75.3%).

If we consider the frequency of LEH per individual, in our sample, the lower class individuals are significantly more affected (92.9%) than those of the upper class (72.2%) ($p = 0.0002$, chi-squared value: 13.688). Comparison with other Roman coeval necropolises shows very high frequencies in all sites. In the Quadrella necropolis, linear enamel hypoplasia affects 95.2% of the individuals (Bonfiglioli, Brasili, & Belcastro *et al.*, 2003), whereas Manzi, Salvadei, Vienna, and Passarello *et al.* (1999) report 81% and 82% individual frequencies, respectively, for Isola Sacra and Locus Feroniae. Mosticone, Pescucci, and Porreca

(2015) report 98.4% and 96%, respectively, for the Roman Imperial Age necropolises of Castel Malnome and Padre Semeria, both represented by lower class individuals.

In our sample, as in all the other samples used by comparison (with the exception of the Quadrella necropolis), males exhibit a higher LEH incidence than females. Although the differences are not statistically significant, this trend agrees with other studies suggesting that a higher male vulnerability in childhood and in the cultural practices of sex-biased parental investment after birth may have effects on sex differences in enamel defects (see review in Guatelli-Steinberg & Lukacs, 1999).

In the ancient Roman society, women occupied a minor role, but discrimination against females in parental care is not evident in historical sources (Rawson, 2003). On the other hand, we can assume differences between the lives of the wealthy and poor children. Male children represented an important family support in rural works, and they may have been advantaged over females, so that sex-related disparities in parental care may have been possible among poor people. It is difficult to support this condition with our data, because the frequency of LEH is higher in the female teeth of the lower class (Table 3) only in terms of whole dentition.

Differences between the lower and upper classes are also evident in the chronological distribution of defects per individual (Figure 3): The stressful events start to occur from the first year of life, in higher frequency in the lower class (14.6%) than in the upper class (9.2%). This might have been due to the more accurate parental care in the upper class during the first years of life (with better or prolonged breastfeeding and postponed weaning age). In Roman families, the babies were often nursed and cared for by wet nurses, and this occurred more frequently in wealthy families (Bradley, 1991). The lack of LEH prior to 1 year of age might be related to a limitation of the Goodman and Rose (1990) regression equations, which include the cuspal enamel formation time and underestimate the chronology of early LEH formation (Goodman and Song, 1999; King, Humphrey, & Hillson et al., 2005). However, problems related to the inaccuracy of the Goodman and Rose method (1990) should not affect the internal comparison among the social classes of our samples (see Figure 4).

In both social classes, LEH peaks at 2–2.9 years of age, but in the lower class, the frequencies decrease with increasing age, whereas the frequencies in the upper class remain constant (Figure 4). Historical medical treatises provided guidance for breastfeeding and weaning in ancient Rome. Soranus of Ephesus (98–117 AD) and Galen of Pergamum (130–200 AD) suggested that weaning should take place around 6–7 months and should be completed between the ages of 2 and 3 (Bagley, 2016). The same ages were identified through stable isotope analysis in the Isola Sacra sample by Prowse, Saunders, Schwarcz, Garnsey, Macchiarelli, and Bondioli et al. (2008), who indicated that transitional feeding began at the end of the first year and weaning at 2–2.5 years of age.

LEH peak frequency around 2.5 years corresponds to the findings of other studies regarding LEH chronological distribution; and this is explained as a combined effect of weaning/postweaning stress, or nutritional deficiencies, or major susceptibility to disease in children who had not yet developed immune resistance (Corruccini, Handler, & Jacobi, 1985; Goodman & Armelagos, 1985; Wood, 1996 et al., 1992). However, differences in the methodological approach make it difficult to compare the LEH chronological distribution with that of other skeletal samples.

The trends of chronological LEH distribution follow a platykurtic tendency in the upper class and a leptokurtic curve in the lower class that might be related to the different conditions involved in LEH occurrence. For example, children from the lower class able to overcome the critical weaning age seem to have more resistance and better health conditions in the successive years. On the other hand, perhaps, they were the strongest who survived, whereas the others died at an infantile age. Instead, the upper class children continued to have health problems after weaning, but they probably survived because of better parental care and living or nutritional conditions. However, although suggestive, these are only theoretical speculative argumentations difficult to prove without more extensive studies.

In both social classes, subadults are more affected than adults in terms of LEH frequencies (Figure 2) for teeth and for individuals, but the differences are not statistically significant. Previous studies investigated on the prevalence of enamel hypoplasia in different age categories, evidencing a positive connection between stressful events suffered during childhood (higher LEH frequencies) and early age at death (Armелagos, Goodman, Harper, & Blakey, 2009; Boldsen, 2007; King, Humphrey, & Hillson ~~et al.~~, 2005; Palubeckaitė, Jankauskas, & Boldsen ~~et al.~~, 2002). Cucina <<Query: AUTHOR: "Cucina (2011)" is cited in text but not provided in the reference list. Please provide details in the list or delete the citation from the text. Ans: Please, add the reference to the list:

Cucina A. 2011. Maya sub adult mortality and individual physiological frailty: an analysis of infant stress by means of linear enamel hypoplasia. *Childhood in the Past* 4(1): 105-116, DOI: 10.1179/cip.2011.4.1.105 >> (2011) also found significantly more defects in subadults than in adults (see also Duray, 1996; Goodman & Armелagos, 1988); however, he observed no differences among the subadult age groups.

The results in our research may suggest a more severe stress impact on the individuals who died at a juvenile age, but we should consider the possibility that dental wear may reduce the defect recording in older-aged individuals. On the other hand, differences in dental wear between the two subsamples—due to a different age-class distribution—should not affect the prevalence of LEH between the two social classes, because the differences in age range are not statistically significant.

In conclusion, this research investigates the relation between LEH and social status in Imperial Rome, and all comparisons between the two social class samples and other Imperial Age samples indicate that the LEH frequencies and chronological distribution of LEH were different according to social status. These findings indicate that the socially advantaged group enjoyed better health in this past population, suggesting that the differences reflect the childhood stress episodes related to nutritional, health, and living conditions.

ACKNOWLEDGEMENT

This research was supported by the 2015 PRIN Ministerial Project "Diseases, Health and Lifestyles in Rome: from the Empire to the Early Middle Age" (prot. 2015PJ7H3K). We wish to thank the anonymous reviewers for their useful suggestions that have helped us improve the manuscript.

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