Received: 5 March 2019 | Revised: 11 October 2019 | Accepted: 12 October 2019
DOI: 10.1002/oa.2830

Check for updates

RESEARCH ARTICLE

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

Simona Minozzi[1] | Carla Caldarini[2] | Walter Pantano[2] | Stefania di Giannantonio[2] | Paola Catalano[2] | 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

**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

**Funding information**
2015 PRIN Ministerial Project "Diseases, Health and Lifestyles in Rome: from the Empire to the Early Middle Age", Grant/Award Numbers: 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 (Armelagos, 1969; Cucina, 2002; Goodman & Rose, 1990; Griffin & Donlon, 2007; Rose, Armelagos, & 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 (Miszkiewicz, 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).

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, 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, 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, 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

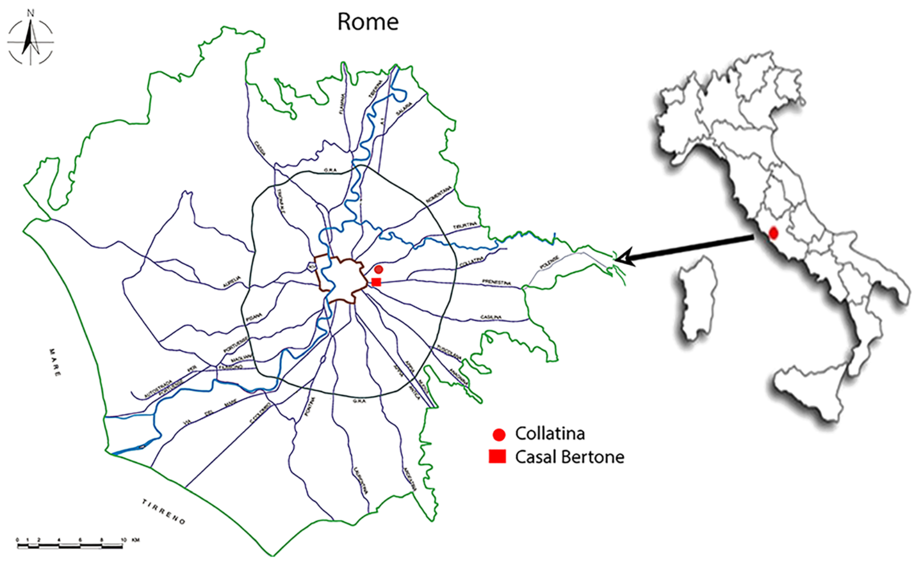


**FIGURE 1** Location of the Casal Bertone and Collatina necropolises in Rome (Italy)

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.

## 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).

**TABLE 1a** Biological profiles of the selected individuals from the two necropolises

| | Number of individuals | | | | Number of teeth | | | |
|---|---|---|---|---|---|---|---|---|
| Collatina | Females | Males | Subadults | Total | Females | Males | Subadults | Total |
| 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

| | Lower class | | | | Upper class | | | |
|---|---|---|---|---|---|---|---|---|
| Age | 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 |

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 cementoenamel 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 3 and 4 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 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.

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

**TABLE 2a** Distribution of LEH in age ranges and in each dental category in the upper class

| | | Maxilla | | | | | | | | | Mandible | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Upper class** | | **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 2b** Distribution of LEH in age ranges and in each dental category in the lower class

| | | Maxilla | | | | | | | | | Mandible | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lower class** | | **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** 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 |

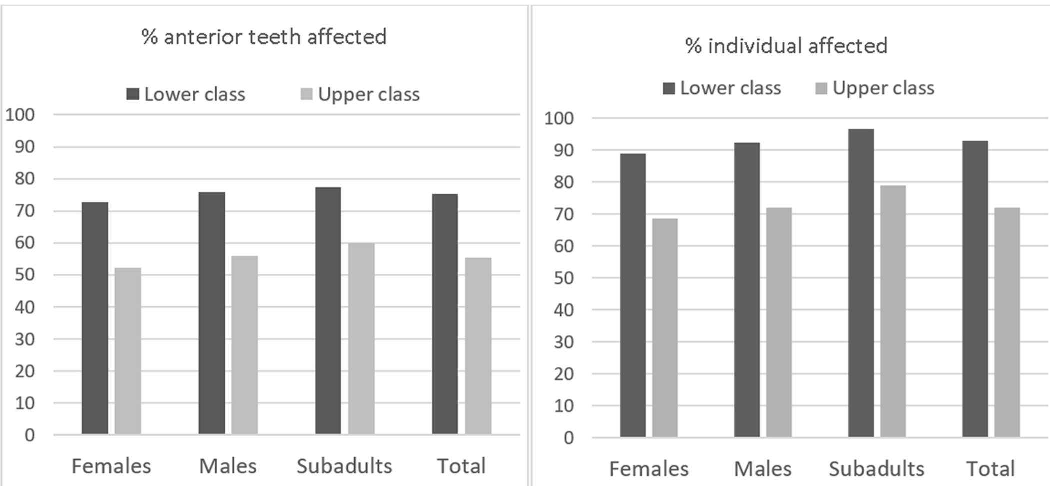


**FIGURE 2** Frequency of enamel hypoplasia by sex and age in anterior dentition and in individuals

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

| | Lower class | | | | Upper class | | | |
|---|---|---|---|---|---|---|---|---|
| Age range | 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 |

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.

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

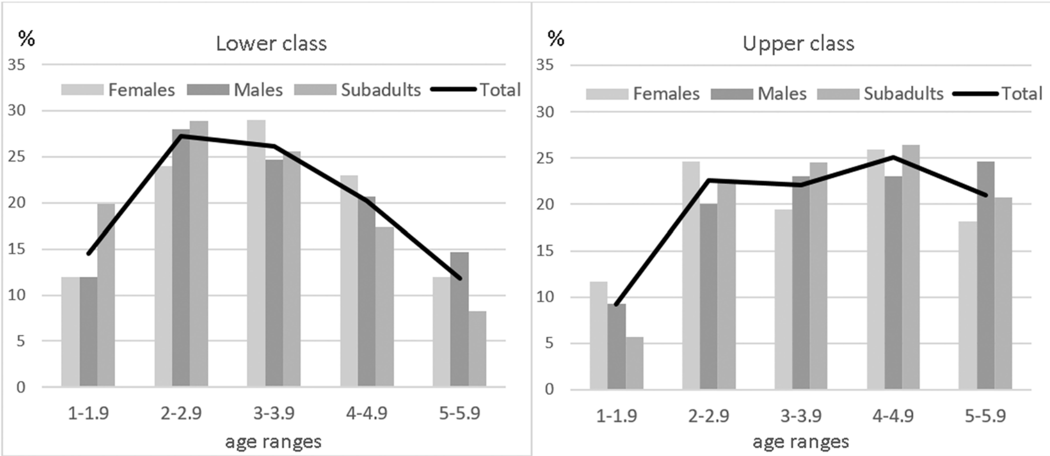


**FIGURE 3** Chronological distribution in percentage of LEH in a 1-year-age ranges (% number of events for age range divided by total events) in the lower and upper social classes. Data are reported in Table 4

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 (Bocaege & 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 3; 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 3, 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 (Bocaege & 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 3 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).

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 (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, 2006), located in the Roman *suburbium*, LEH affects 63.5% of teeth. Despite the slight variability of frequencies observed in the

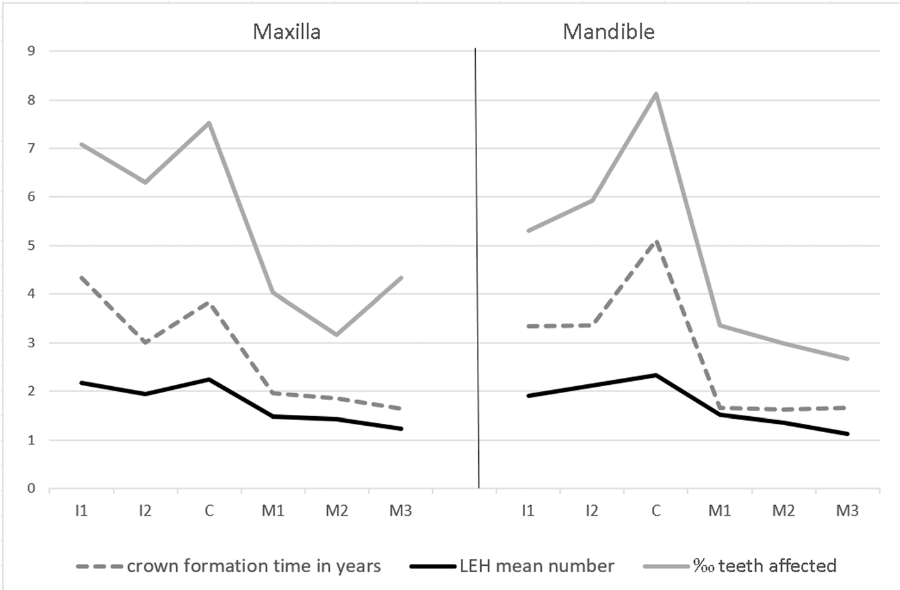


**FIGURE 4** Enamel formation time on the basis of data reported by Reid and Dean for Northern European populations (2006), compared with the frequency (‰) of teeth affected and to the mean number of lines in each tooth of the Roman sample

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, 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, 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, 2003), whereas Manzi, Salvadei, Vienna, and Passarello (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 & Song, 1999; King, Humphrey, & Hillson, 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 Ephesos (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 (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, 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 (Armelagos, Goodman, Harper, & Blakey, 2009; Boldsen, 2007; King, Humphrey, & Hillson, 2005; Palubeckaitė, Jankauskas, & Boldsen, 2002). Cucina (2011) also found significantly more defects in subadults than in adults (see also Duray, 1996; Goodman & Armelagos, 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.

## ORCID

*Simona Minozzi* https://orcid.org/0000-0003-3303-0014
*Valentina Giuffra* https://orcid.org/0000-0001-9108-039X

## REFERENCES

Acsádi, G., & Nemeskéri, J. (1970). *History of human life, span and mortality*. Akadémiai Kiadó: Budapest.

Alqahtani, S. J., Hector, M. P., & Liversidge, H. M. (2010). Brief communication: The London atlas of human tooth development and eruption. *American Journal of Physical Anthropology*, *142*, 481–490.

Armelagos, G. J. (1969). Disease in ancient Nubia. *Science*, *163*, 255–259.

Armelagos, G. J., Goodman, A. H., Harper, K. N., & Blakey, M. L. (2009). Enamel hypoplasia and early mortality: Bioarchaeological support for the Barker hypothesis. *Evolutionary Anthropology: Issues, News, and Reviews*, *18*, 261–271. https://doi.org/10.1002/evan.20239

Bagley, A. M. (2016). Roman children in the early empire: A distinct epidemiological and therapeutic category? Doctoral dissertation. School of Applied Health Research, College of Medical and Dental Sciences, University of Birmingham.

Bocaege, E., & Hillson, S. (2016). Disturbances and noise: Defining furrow-form enamel hypoplasia. *American Journal of Physical Anthropology*, *161*, 744–751.

Boldsen, J. L. (2007). Early childhood stress and adult age mortality: A study of dental enamel hypoplasia in the Medieval Danish village of Tirup. *American Journal of Physical Anthropology*, *132*, 59–66. https://doi.org/10.1002/ajpa.20467

Bonfiglioli, B., Brasili, P., & Belcastro, M. G. (2003). Dento-alveolar lesions and nutritional habits of a Roman Imperial age population (1st–4th c. AD): Quadrella (Molise, Italy). *Homo*, *54*(1), 36–56.

Bradley, K. R. (1991). *Discovering the Roman Family: Studies in Roman Social History*. New York: Oxford University Press.

Buccellato, A., Catalano, P., & Musco, S. (2008). Alcuni aspetti rituali evidenziati nel corso dello scavo della necropoli Collatina (Roma). In *Pour une archéologie du rite. Nuvelle perspectives de l'archéologie funéraire.*, Scheid J (ed.). *Collection de l'Ecole Francaise de Rome*, *407*, 59–88.

Buikstra, J. E., & Ubelaker, D. H. (1994). *Standards for data collection from human skeletal remains*. Arkansas Archeological Survey Research Series: Fayetteville.

Cares Henriquez, A., & Oxenham, M. F. (2019). New distance-based exponential regression method and equations for estimating the chronology of linear enamel hypoplasia (LEH) defects on the anterior dentition. *American Journal of Physical Anthropology*, *168*, 510–520.

Catalano, P. (2015). Gli scheletri degli antichi romani raccontano indagini antropologiche su 11 sepolcreti di età imperiale del suburbio romano. *Journal of History of Medicine - Medicina Nei Secoli Arte e Scienza*, *27*(3), 773–786.

Corruccini, R. S., Handler, J. S., & Jacobi, K. F. (1985). Chronological distribution of enamel hypoplasia and weaning in a Caribbean slave population. *Human Biology*, *57*, 699–711.

Cucina, A. (2002). Brief communication: Diachronic investigation of linear enamel hypoplasia in prehistoric skeletal samples from Trentino, Italy. *American Journal of Physical Anthropology*, *119*, 283–287.

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. https://doi.org/10.1179/cip.2011.4.1.105

Cucina, A., Vargiu, R., Mancinelli, D., Ricci, R., Santandrea, E., Catalano, P., & Coppa, A. (2006). The necropolis of Vallerano (Rome, 2nd–3rd Century AD): An anthropological perspective on the Ancient Romans in the suburbium. *International Journal of Osteoarchaeology*, *16*, 104–117.

Duray, S. M. (1996). Dental indicators of stress and reduced age-at-death in prehistoric native Americans. *American Journal of Physical Anthropology*, *99*, 275–286.

Ferembach, D., Schwidetzky, J., & Stloukal, M. (1980). Recommendations for age and sex diagnosis of skeletons. *Journal of Human Evolution*, *9*, 517–549.

Goodman, A. H., & Armelagos, G. J. (1985). Factors affecting the distribution of enamel hypoplasias within the human permanent dentition. *American Journal of Physical Anthropology*, *68*, 479–493.

Goodman, A. H., & Armelagos, G. J. (1988). Childhood stress and decreased longevity in a prehistoric population. *American Anthropologist*, *90*, 936–944.

Goodman, A. H., & Rose, J. C. (1990). Assessment of systemic physiological perturbations from dental enamel hypoplasias and associated hisological structures. *Yearbook of Physical Anthropology*, *33*, 59–110.

Goodman, A. H., & Rose, J. C. (1991). Dental enamel hypoplasias as indicators of nutritional status. In M. A. Kelley, & C. S. Larsen (Eds.), *Advances in Dental Anthropology* (pp. 279–293). New York: Wiley Liss.

Goodman, A. H., & Song, R. (1999). Sources of variation in estimated ages at formation of linear enamel hypoplasias. In R. D. Hoppa, & C. Fitzgerald (Eds.), *Human growth in the past: studies from bones and teeth* (pp. 210–240). Cambridge: Cambridge University Press.

Griffin, R. C., & Donlon, D. (2007). Dental enamel hypoplasias and health changes in the Middle Bronze Age-Early Iron Age transition at Pella in Jordan. *Homo*, *58*, 211–220.

Guatelli-Steinberg, D., Ferrell, R. J., & Spence, J. (2012). Linear enamel hypoplasia as an indicator of physiological stress in great apes: Reviewing the evidence in light of enamel growth variation. *American Journal of Physical Anthropology*, *148*, 191–204.

Guatelli-Steinberg, D., & Lukacs, J. R. (1999). Interpreting sex differences in enamel hypoplasia in human and non-human primates: Developmental, environmental, and cultural considerations. *Yearbook of Physical Anthropology*, *42*, 73–126.

Hassett, B. R. (2012). Evaluating sources of variation in the identification of linear hypoplastic defects of enamel: A new quantified method. *Journal of Archaeological Science*, *39*, 560–565.

Hassett, B. R. (2014). Missing defects? A comparison of microscopic and macroscopic approaches to identifying linear enamel hypoplasia. *American Journal of Physical Anthropology*, *153*, 463–472.

Hillson, S., & Bond, S. (1997). Relationship of enamel hypoplasia to the pattern of tooth crown growth: A discussion. *American Journal of Physical Anthropology*, *104*, 89–103.

Hillson, S. W. (1996). *Dental Anthropology*. Cambridge: Cambridge University Press.

Jelliffe, D. B., & Jelliffe, E. F. P. (1971). Linear hypoplasia of deciduous teeth in malnourished children. *American Journal of Clinical Nutrition*, *24*, 893. https://doi.org/10.1093/ajcn/24.8.893

King, T., Humphrey, L. T., & Hillson, S. (2005). Linear enamel hypoplasias as indicators of systemic physiological stress: Evidence from two known age-at-death and sex populations from postmedieval London. *American Journal of Physical Anthropology*, *128*, 547–559.

Lanphear, K. M. (1990). Frequency and distribution of enamel hypoplasias in a historic skeletal sample. *American Journal of Physical Anthropology*, *81*, 35–43.

Larsen, C. S. (1997). *Bioarchaeology*. Cambridge: Cambridge University Press.

Lovejoy, C. O. (1985). Dental wear in Libben population: Its functional pattern and role in the determination of adult skeletal age at the death. *American Journal of Physical Anthropology*, *68*, 47–56.

Manzi, G., Salvadei, L., Vienna, A., & Passarello, P. (1999). Discontinuity of life conditions at the transition from the Roman imperial age to the early Middle Ages: Examples from central Italy evaluated by pathological dento-alveolar lesions. *American Journal of Human Biology*, *11*, 327–341.

Martin, S. A., Guatelli-Steinberg, D., Sciulli, P. W., & Walker, P. L. (2008). Brief communication: Comparison of methods for estimating chronological age at linear enamel formation on anterior dentition. *American Journal of Physical Anthropology*, *135*, 362–365.

May, R. L., Goodman, A. H., & Meindl, R. S. (1993). Response of bone and enamel formation to nutritional supplementation and morbidity among malnourished Guatemalan children. *American Journal of Physical Anthropology*, *92*, 37–51.

Meindl, R. S., & Lovejoy, C. O. (1985). Ectocranial suture closure: A revised method for the determination of age at death based on the lateral-anterior sutures. *American Journal of Physical Anthropology*, *68*, 57–66.

Miszkiewicz, J. J. (2012). Linear enamel hypoplasia and age-at-death at medieval (11th–16th Centuries) St. Gregory's Priory and Cemetery, Canterbury, UK. *International Journal of Osteoarchaeology*, *25*, 79–87. https://doi.org/10.1002/oa.2265

Mosticone, R., Pescucci, L., & Porreca, F. (2015). Le condizioni di vita: Indicatori di stress aspecifici e affezioni dento-alveolari. *Journal of History of Medicine - Medicina Nei Secoli Arte e Scienza*, *27*(3), 969–1042.

Musco, S., Catalano, P., Caspio, A., Pantano, B. W., & Killgrove, K. (2008). Le complexe archéologique de Casal Bertone. *Dossiers d'Archéologie*, *330*, 32–39.

Nakayama, N. (2016). The relationship between linear enamel hypoplasia and social status in 18th to 19th century Edo, Japan. *International Journal of Osteoarchaeology*, *26*, 1034–1044.

Palubeckaitė, Z., Jankauskas, R., & Boldsen, J. (2002). Enamel hypoplasia in Danish and Lithuanian late Medieval/early modern samples: A possible reflection of child morbidity and mortality patterns. *International Journal of Osteoarchaeology*, *12*, 189–201. https://doi.org/10.1002/oa.607

Prowse, T. L., Saunders, S. R., Schwarcz, H. P., Garnsey, P., Macchiarelli, R., & Bondioli, L. (2008). Isotopic and dental evidence for infant and young child feeding practices in an imperial Roman skeletal sample. *American Journal of Physical Anthropology*, *137*, 294–308.

Rawson, B. (2003). *Children and Childhood in Roman Italy*. Oxford: Oxford University Press.

Reid, D. J., & Dean, M. C. (2000). Brief communication: The timing of linear hypoplasias on human anterior teeth. *American Journal of Physical Anthropology*, *113*, 135–139.

Reid, D. J., & Dean, M. C. (2006). Variation in modern human enamel formation times. *Journal of Human Evolution*, *50*, 329–346.

Ritzman, T. B., Baker, B. J., & Schwartz, G. T. (2008). A fine line: A comparison of methods for estimating ages of linear enamel hypoplasia formation. *American Journal of Physical Anthropology*, *135*, 348–361.

Rose, J. C., Armelagos, G. J., & Lallo, J. W. (1978). Histological enamel indicator of childhood stress in prehistoric skeletal samples. *American Journal of Physical Anthropology*, *49*, 511–516.

Rose, J. C., Condon, K. W., & Goodman, A. H. (1985). Diet and dentition: Developmental disturbances. In R. I. Gilbert, Jr., & J. H. Mielke (Eds.), *The analysis of prehistoric diets* (pp. 281–305). Orlando: Academic Press.

Rudney, J. D. (1983). Dental indicators of growth disturbance in a series of ancient Lower Nubian populations: Changes over time. *American Journal of Physical Anthropology*, *60*, 463–470.

Saunders, S. R., & Keenleyside, A. (1999). Enamel hypoplasia in a Canadian historic sample. *American Journal of Human Biology*, *11*, 513–524.

Schaefer, M., Black, S., & Scheuer, L. (2008). *Juvenile Osteology: A Laboratory and Field Manual*. London: Academic Press.

Scheuer, L., & Black, S. (2000). *Developmental Juvenile Osteology*. London: Academic Press.

Schwartz, G. T., & Dean, C. (2001). Ontogeny of canine dimorphism in extant hominoids. *American Journal of Physical Anthropology*, *115*, 269–283.

Swärdstedt, T. (1966). *Odontological aspects of a Medieval population from the province of Jamtland/Mid-Sweden*. Tiden-Barnangen: Stockholm.

Sweeney, E. A., Cabrera, J., Urrtia, J., & Mata, L. (1969). Factors associated with linear hypoplasia of human deciduous incisors. *Journal of Dental Research*, *48*(2), 1275–1279.

Ubelaker, D. H. (1989). *Human Skeletal Remains*. Washington: Taraxacum.

Wood, J. W., Milner, J. R., Harpending, H. C., & Weiss, K. M. (1992). The osteological paradox. *Current Anthropology*, *3*, 343–370.

Wood, L. (1996). Frequency and chronological distribution of linear enamel hypoplasia in a North American colonial skeletal sample. *American Journal of Physical Anthropology*, *100*, 247–259.

**How to cite this article:** 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*. 2020;30:53–64. https://doi.org/10.1002/oa.2830