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ORIGINAL PAPER

Social differentiation and well-being in the Italian Iron Age: exploring the relationship between sex, age, biological stress, and burial complexity among the Picenes of Novilara (8th–7th c. BC)

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Abstract
The possible association between "biological" and "social" status in the past is a central topic in bioarchaeological studies. For the Italian Iron Age, previous research comparing skeletal and funerary variables depicts a multifaceted scenario consistent with nuanced biocultural patterns. This calls for additional studies on a broader series of archaeological contexts and skeletal assemblages. Here, we contribute new data about the biological correlates of social differentiation during the Italian Iron Age by comparing paleopathological and funerary variables in the Picene necropolis of Novilara (Marche region, 8th–7th c. BC). Novilara is one of the largest Picene necropolises in the Italian Peninsula and one of the most important funerary sites of the Italian Iron Age. The skeletal sample includes 147 individuals (females: 70; males: 35; 10 unsexed adults; 32 non-adults). We use linear enamel hypoplasia, cribra orbitalia, porotic hyperostosis, non-specific periosteal lesions, and stature to approximate non-specific stressors and compare them with archaeological variables summarizing funerary variability by means of logistic models, Mann–Whitney and Spearman tests. Results are heterogeneous and vary according to the considered variables. On average, they however show that (a) adults featuring a more complex funerary treatment have a lower probability of showing stress-related skeletal changes, and (b) even though funerary features suggests a strong gender differentiation, frequencies of paleopathological variables do not differ between sexes. Our analyses point to a complex link between biological and social status in this population and call for a critical reflection about the theoretical and methodological issues affecting similar studies.

Keywords Non-specific stress markers · Funerary treatment · Stature · Iron Age · Picene culture

Introduction

The potential association between status, wealth, and health patterns (Marmot and Bell 2016; Nguyen and Peschard 2003; Pechenkina and Delgado 2006; Rathbun and Steckel 2003) informs a long tradition of bioarchaeological studies focused on the exploration of links between "social and biological status" (sensu Robb et al. 2001). Bioarchaeological proxies of social status may include various types of funerary features (e.g., type and amount of grave goods). Dental, skeletal, and stable isotope data are usually used as proxies of biological status: exposure to environmental and biomechanical stress and relative access to food resources (e.g., Laffranchi et al. 2019; Minozzi et al. 2020; Reitsema and Vercellotti 2012; Robb et al. 2001; Sparacello et al. 2015, 2017; Vercellotti et al. 2011; Weiss et al. 2019).

Bioarchaeological comparisons of social and biological status are often complicated by a number of theoretical

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and methodological issues. Especially when lacking written sources, classifications of burials into "elite" or "non-elite" risk to be affected by subjective bias (Härke 2000; Pechenkina and Delgado 2006; Robb et al. 2001). Furthermore, social status is rarely a fixed variable and not necessarily just a representation of personal wealth. Another issue relates to the social and biological representation of the analyzed skeletal sample. A necropolis may reflect the self-representation of a community rather than its objective mirror image (Cuozzo 1996, 2000; D'Agostino 1985; Parker Pearson 1982, 1993). This may concretize in selective burial practices and/or the allocation of burial areas to specific members/segments of a society. This, in turn, would result in a bias of the social and demographic composition of the analyzed population (e.g., apparent absence of rich burials, underrepresentation of infants) leading to fundamental interpretive challenges.

From a biological point of view, the main issues include the type of information provided by skeletal and dental data and the challenges posed by the "osteological paradox" (Wood et al. 1992). Skeletal and dental data can provide only a fragmentary perspective on past "health" (Temple and Goodman 2014). The latter, in its medical meaning, incorporates indeed a number of archaeologically invisible variables (see WHO 1948). In addition, the anthropological variables typically used as proxy of biological status (e.g., cribra orbitalia, enamel hypoplasia) have a complex etiology, which limits their applicability beyond the exploration of general stress patterns. Heterogeneity in disease risk, selective mortality, and demographic non-stationarity adds to these issues (Wood et al. 1992). Different publications have addressed these problems, leading to new or revised theoretical and methodological approaches (e.g., Laffranchi et al. 2019; McFadden and Oxenham 2020; Pechenkina and Delgado 2006; Sparacello et al. 2015). The recognition of the multifaceted nature of social status and health, in particular, has suggested the suitability of a nuanced approach to these studies (Robb 1997) and the suitability of multivariate methods for testing biocultural hypotheses (Laffranchi et al. 2019; Pechenkina and Delgado 2006; Sorrentino et al. 2018). In any case, considering all the above issues, the heterogeneous conclusions reached by previous comparisons of social and biological status are hardly surprising. For the Italian Peninsula (focus of this contribution), this is highlighted by a number of studies which have shown a variable correlation between archaeological and anthropological data (Laffranchi et al. 2019; Minozzi et al. 2020; Sorrentino et al. 2018; Sparacello et al. 2017; Vercellotti et al. 2011; Weiss et al. 2019).

The Italian Iron Age and the Picenes: archaeological and biocultural context

During the Early Iron Age (10th–8th c. BC) the Italian peninsula was characterized by a mosaic of populations featuring specific cultural traits and geographical distributions. In the central regions (focus of this contribution), these groups included, among others, Etruscans, Latins, Sabines, Volsci and Hernici (Latium region), Etruscans and Umbrians (Umbria), and Picenes (Marche). Similarities in material culture and other archaeological features suggest the presence of substantial networks between these communities and their cultural openness to exogenous influences (Bietti Sestieri 1992).

The Picene culture developed from the ninth century BC to the beginning of the third century BC, until its incorporation in the Roman cultural sphere. The "Picenes" were distributed along the Adriatic coast, in the area limited to the west by the Apennine range and to the north and south by the rivers Foglia and Tronto, respectively. This area, ecologically diverse (from mountains to hills and plains), provides rich agricultural plains, forestry resources, and pastures. The term "Picenes" derives from Greek and Roman authors who referred to the inhabitants of this region in later periods. It is therefore prone to the same cultural and ethnic over-simplifications characterizing other similar terminologies (e.g., "Celts"). Nonetheless, independently from the specific terminology used, the Picenes have left archaeological traces (material culture and funerary customs) pointing to a strong cultural homogeneity, albeit with some degree of local cultural heterogeneity. The latter was probably favored by (a) the diverse ecology of the Marche region, (b) the presence of different networks with other cultural groups, and (c) the lack of well-defined urban centers. Most information about the Picenes comes from excavations of funerary contexts (Naso 2000; Silvestrini and Sabbatini 2008; Various authors 1992). Based on data from necropolises, the Picene culture is chronologically subdivided into six phases, from *Piceno I* (900–800 BC) to *Piceno VI* (385–268 BC) (Lollini 1976). The period between the second and third of these phases (ca. 8th–7th c. BC) is of particular interest due to an increase in the density of burials in the necropolises and the presence of selected burials with numerous and rich funerary items, which in some cases included exotic elements. This pattern hints at the rise of a social elite starting from ca. the 8^{th} c BC with a probably inherited status as suggested by infant burials with rich grave goods.

Few anthropological data are available for the Picenes, and no information is available about the possible link between social differentiation, health, and living

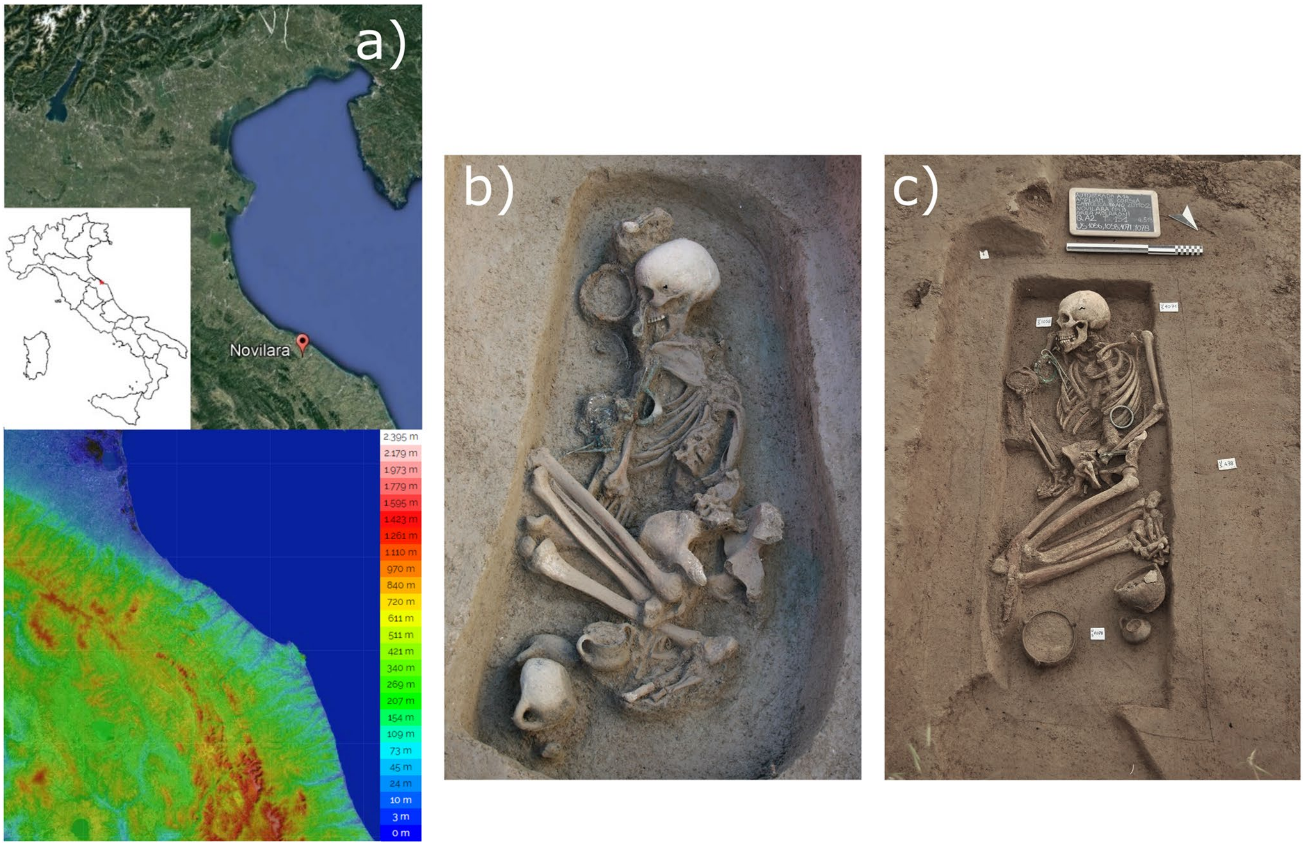


Fig. 1 Geographical position of Novilara and examples of adult burials: (**a**) map of Italy with localization of Novilara (above) and terrain map of the surrounding areas (below); (**b**–**c**) burials 171 (middle adult female) and 151 (young adult male). Burial images courtesy of SABAP – Soprintendenza Archeologia Belle Arti e Paesaggio delle Marche

conditions in this population. The present study focuses on one of the largest and best-documented Picene funerary contexts (the necropolis of Novilara) and explores the possible links between social and biological status in a Picene population. We compare demographic and funerary patterns with a suite of skeletal and dental variables (linear enamel hypoplasia, cribra orbitalia, porotic hyperostosis, non-specific periosteal lesions, and stature) potentially informative about individual exposure to physiological stress.

The necropolis of Novilara

The necropolis of Novilara (province of Pesaro and Urbino, 43° 51′ 46.75″ N, 12° 55′ 51.771″ E[1]), placed near the Adriatic coast in the Marche region (Fig. 1a), is one of the largest and best documented Picene funerary contexts (Baldelli 1982; Brizio 1895). First excavations during the nineteenth century led to the discovery of at least 263 burials, overall dating to ca. the 8th–seventh centuries BC (Beinhauer 1985; Brizio 1895) and distributed along two funerary areas, the *Servici* and *Molaroni* areas. The latter has been the focus of more recent investigations between 2012 and 2013. Hereby, an additional 150 burials were discovered, and 36 previously detected interments were re-excavated. All these findings also date to the 8th–seventh centuries BC.

With the exception of three incinerations, burials at Novilara conform to the funerary rituals of other Picene contexts, and include primary inhumations in simple pits, with the skeleton lying flexed or hyperflexed on their side (Delpino et al. 2016) (Fig. 1b and c). A limited number of burials at Novilara are spatially close to each other while relatively separated from the rest of the necropolis. Although the possible meaning of this “funerary cluster” is still unclear, a possible association to social differences based on status and/or kinship affiliation has been postulated (Delpino 2018; Delpino et al. 2016).

Burials includes a variable amount and type of items including vessels, weapons, pins, necklaces, and amber earrings, as well as tools related to weaving and spinning (e.g., spools, spindle whorls, spindles). Specific funerary features

[1] Geographic coordinates of the site.

(e.g., layers of sea pebbles on the bottom and top of the pit, exotic grave goods) hint at the presence of distinct social groups in this community and to a social differentiation possibly based on status and/or geographic origin (Delpino 2018). In some cases, elaborate grave goods characterize closely spaced burials of non-adults and adults, a possible expression of social status based on kinship relationships. The level of elaboration of sporadically found garments (represented by decorations of amber, colored glass paste, and bone beads) hints at their possible ceremonial use and is of special interest.

Previous anthropological analyses of skeletal material from Novilara recovered during the nineteenth century include analyses of cranial morphology (Sergi 1907), skeletal traumas (Brasili et al. 2004), and non-masticatory dental lesions (Consiglio 2008). More recently, a series of studies have analyzed the burials exposed during the 2012–2013 campaign. Delpino (2018) provides a discussion of funerary and demographic patterns among the non-adult population. A paleogenetic study (Serventi et al. 2018) explores patterns of kinship and genetic affinity. Beck de Lotto et al. (2018) analyze patterns of trauma and interpersonal violence.

Skeletal and dental markers of physiological stress

Due to their partial correlation with environmental factors, a number of dental and skeletal features have traditionally been the focus of studies aimed at reconstructing patterns of developmental stress, health, and general living conditions among past societies. Among these variables, linear enamel hypoplasia, cribra orbitalia, porotic hyperostosis, periostitis, and stature are classically analyzed (e.g. Goodman and Rose 1990, 1991; Laffranchi et al. 2019; Larsen 2015; Rathbun and Steckel 2003; Robb 2019; Robb et al. 2001; Smith-Guzman 2015; Smith et al. 2016; Sparacello et al. 2017; Steckel et al. 2002; Vercellotti et al. 2011).

Linear enamel hypoplasia are band-like defects on the tooth crown caused by temporary disruptions of ameloblastic activity (Goodman and Rose 1990, 1991) following non-specific stress episodes during early life (Goodman and Rose 1991; Pindborg 1970, 1982; Sarnat and Schour 1941; Suckling and Thurley 1984).

Cribra orbitalia and porotic hyperostosis are porous lesions, respectively, on the roof of the orbit and on the cranial vault. They result from marrow hyperplasia, thickening of the orbital roof and diploe, and thinning of the outer cranial table during childhood. Much debate surrounds the relationship between these conditions and their link to specific etiological factors. Possible causes include various forms of anemia, parasitic infections, and chronic illness (Brickley 2018; Hengen 1971; O'Donnell et al. 2020; Stuart-Macadam and Kent 1992; Walker et al. 2009).

Periostitis is a non-specific inflammation of the periosteal surface of the bone, variously associated with infective processes (e.g., leprosy, tuberculosis, treponemal disease, fluorosis), traumas, nutritional deficiencies, and non-specific stress-related inflammatory processes (Ortner 2003). Macroscopically it can appear as accentuated longitudinal striations, osseous plaques with demarcated margins, or as irregular elevations of bone surfaces (Larsen 2015; Steckel et al. 2006). The term *periostitis* has recently been criticized due to its link to inflammatory states of infective origin (see Klaus 2017; Roberts 2019). Following Roberts (2019), we opted for the more generic term "nonspecific periosteal lesions".

Adult stature is determined by both genetic and environmental factors (e.g., diet and overall health) (King and Ulijaszek 1999; Maat 2005; Shin et al. 2012; Silventoinen et al. 2012; Vercellotti et al. 2011). Intrapopulation variability in stature can therefore provide useful information about differential exposure to developmental stressors possibly associated to socioeconomic changes and/or social differentiation (Cohen and Armelagos 1984; Cohen and Crane-Kramer 2007; Larsen 2006; Mieklejohn and Babb 2011; Mummert et al. 2011; Robb et al. 2001).

This study tries to address three main research questions:

a) Are there any age and/or sex patterns in funerary variability at Novilara, and what do they tell about possible social differentiation according to gender and life course stages?
b) Are there any demographic patterns in non-specific stress markers (LEH, CO, PH, NPL, stature) in this population, and what do they reveal about sex- and age-related differences in health, with special reference to exposure to stressors during growth?
c) Is there any association in individuals who survived into adulthood between their funerary treatment and their relative exposure to health insults during growth, and what does it say about possible links between social and biological status?

Material and methods

The skeletal sample

The most recently excavated skeletal remains from Novilara amount to a minimum number of 207 individuals, corresponding to 186 burials. After excluding 60 individuals due to their extreme fragmentation, our final dataset includes 147 individuals. We determined sex only in adults (> 20 years old) based on the dimorphic features of the Os pubis (Phenice 1969) and of the greater sciatic notch on the ileum (Acsádi and Nemeskéri 1970; Walker

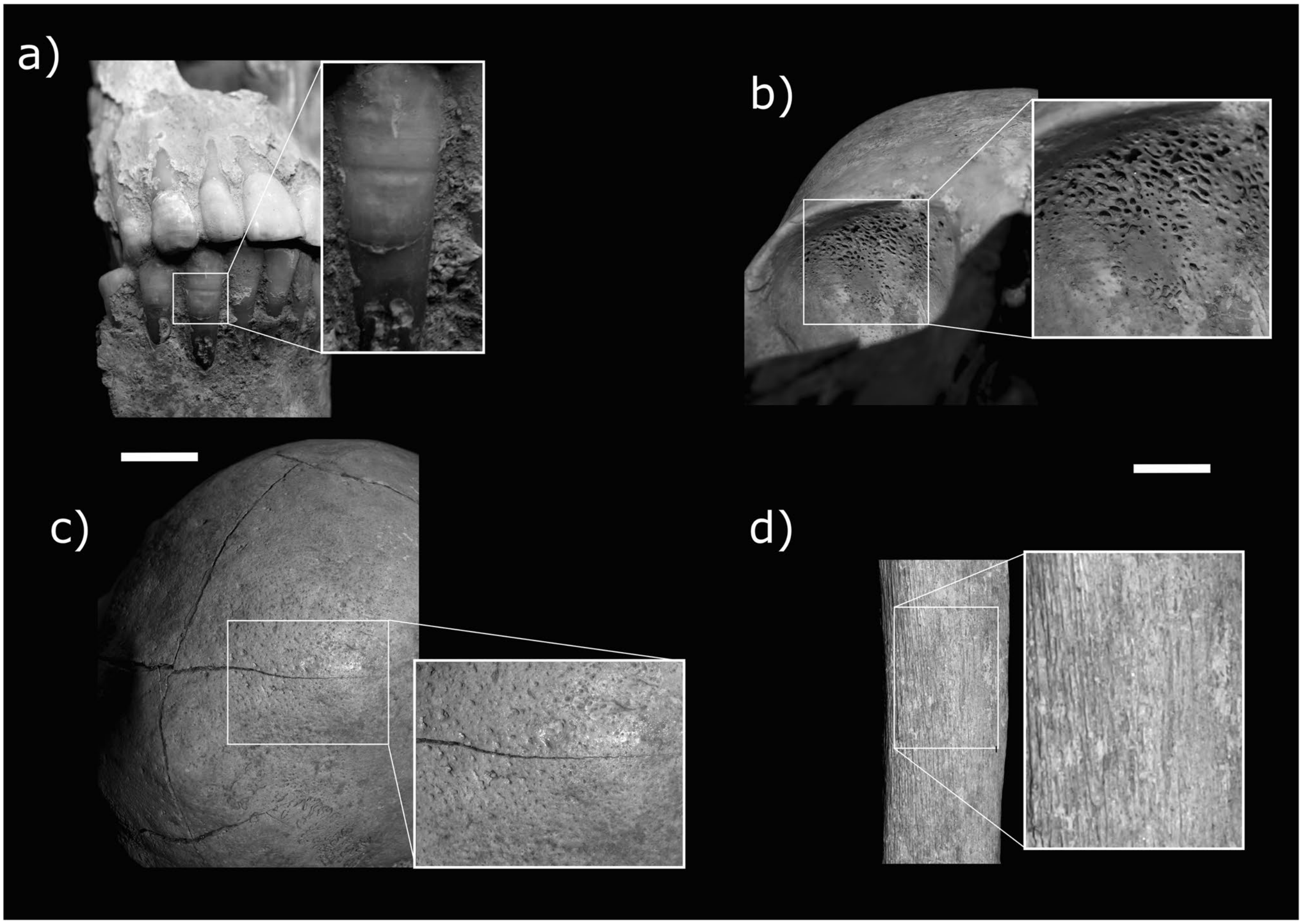


Fig. 2 Examples of the paleopathological variables in different individuals from Novilara: (**a**) linear enamel hypoplasia; (**b**) cribra orbitalia; (**c**) porotic hyperostosis; (**d**) non-specific periosteal reaction. Bars = 2 cm

2005). In a minority of cases where these elements were missing, we assessed the sexually dimorphic features of the cranium and mandible (Acsádi and Nemeskéri 1970; Ferembach et al. 1980).

We estimated adult age-at-death based on morphological changes of the pubic symphysis (Brooks and Suchey 1990; Todd 1921), the auricular surface of the ilium (Lovejoy et al. 1985), and the sternal end of the 4th rib (Işcan et al. 1984, 1985). For the estimation of non-adults' age-at-death, we used the development and eruption of the deciduous and permanent dentition (Ubelaker 1989), diaphyseal measurements, and degrees of epiphyseal fusion (Schaefer et al. 2009; Scheuer and Black 2000; Ubelaker 1989).

We then grouped individuals in six age classes following Buikstra and Ubelaker (1994): infants (I: birth to 3 years old); children (C: > 3 years to 12 years old); adolescents (Ao: > 12 years to 20 years old); young adults (YA: > 20 years to 35 years old); middle adults (MA: > 35 years to 50 years old); and old adults (OA: > 50 years old).

Paleopathological variables and stature

For each individual, we evaluated the presence of cribra orbitalia (CO, Fig. 2a), porotic hyperostosis (PH, Fig. 2c), linear enamel hypoplasia (LEH, Fig. 2b), and non-specific periosteal lesions (NPL, Fig. 2d). We then calculated, when possible, their stature.

We scored LEH on the permanent upper and lower incisors and canines with the aid of a magnifying glass following the criteria of Steckel et al. (2006). We included only teeth preserving ca. 70% of the crown and lacking extensive calculus deposits or occlusal wear (i.e., maximum wear stage of 6 according to Smith 1984). We counted LEH on an individual level, including only cases where it was possible to score at least 3 anterior teeth of different dental typologies (I1, I2, C independently of side and location) (see also Manzi et al. 1999; Minozzi et al. 2020). We then classified individuals as having LEH if they presented linear enamel defects on at least one tooth. We complemented the LEH dataset by recording the age at onset of hypoplastic defects. For this purpose, we first measured the distance between the first hypoplastic band and the cemento-enamel junction the nearest 0.01 mm with a digital caliper. With these measurements, we calculated the age at onset of LEH using the regression formula of Goodman and Rose (1990) and then grouped the estimates into 1-year classes.

We scored CO and PH macroscopically following the protocol of Steckel et al. (2006). Both variables were scored as dichotomous (presence/absence), with presence corresponding to the scores 2 and 3 of Steckel (2006). We considered only individuals with at least one preserved orbital roof (for CO) and at least one parietal bone (for PH).

We scored non-specific periosteal lesions (NPL) on the tibiae following Steckel et al. (2006). NPL was recorded as a dichotomous variable, with the presence of the condition corresponding to the scores 2 and 3 on at least one tibia. The dataset of NPL includes only individuals with at least 50% of one tibia preserved and without traumatic lesions on these bones (Slaus 2008).

We estimated stature applying the equations of Pearson (1899) to the length of the femur, or, if the latter was not available, of the tibia, humerus, or radius. The choice to use these formula was suggested by the results of analyses on another Iron Age population from Southern Italy (Sparacello et al. 2017) which indicated a good agreement among estimates based on different bones.

Funerary classification

In trying to summarize the funerary variability at Novilara, we opted for five dichotomous variables, describing the presence or absence of (1) grave goods, (2) weapons among grave goods, (3) textile production items among grave good, (4) elaborate garment, and (5) location of burial in a funerary cluster.

We then counted the number of grave good items in each burial and subdivided the latter into four classes: 1 (0 items), 2 (1–3 items), 3 (4–11 items), and 4 (≥ 12 items). It is important to stress that such classification does not imply any a priori qualitative differences between numerosity classes. We are aware that the number of objects in a grave may well be linked to other factors besides status. However, since differences between numbers of items in burials do exist, we thought worthwhile to at least explore the possible association between this aspect of funerary variability and age, sex, and expression of the chosen biological features and to then discuss the possible meaning of the observed associations based on the results of the analyses. The number of classes and range of items in each class derive from the need to adequately describe the variability in grave good numerosity obtaining at the same time classes with an adequate sample size.

Data analysis

The analysis of the data included the following steps:

1) A first screening for associations between demographic, funerary, and paleopathological variables. This was performed by means of a multiple correspondence analysis (MCA). We excluded the variables *number of items* and *age at onset of LEH* from the analysis in order to maximize the clarity of the results (note that the presence/absence of LEH and grave goods is in any case included). We also did not consider stature since MCA accepts only categorical variables.

   This step aimed at having a broad stroke picture of the relationship between the considered variables. This, in turn, was then used to inform the following, more detailed, analyses.
2) The test for demographic patterns among paleopathological variables, stature, and funerary variables. We applied logistic models to test the association between sex and age (independent variables) and the binary paleopathological and funerary variables (for the variable *number of items* we used ordered logistic models). We then used a Mann–Whitney test to check for difference in stature between males and females (i.e., only adults). We applied a Spearman test to explore the correlation between age class and age at onset of LEH.
3) The test for association between paleopathological variables, stature, and funerary variables. First, we used logistic models with LEH, CO, PH, and NPL as predictors, and each funerary variable as outcome. We then tested the association between stature and funerary variables for each sex separately using Mann–Whitney tests, and when considering number of items, we applied Spearman tests.

We performed the MCA with the package FactomineR (Lê et al. 2008) for R (v. 4.0.4) (R Core Team 2021). For all the other analyses, we used JMP 15.2.0 (SAS Institute 2019), setting alpha = 0.05.

Results

Table 1 summarizes the distribution of the analyzed skeletal sample by age class and sex. Adults and non-adult individuals represent 71.4% (*n*: 105) and 28.6% (*n*: 42) of the sample, respectively. Among sexed adults, females are twice as numerous as males (*n* females: 70, 66.7%; *n* males: 35, 33.3%). Non-adults age classes present similar frequencies. Females and males show the highest frequencies for the middle adult and young adult classes, respectively.

Table 1 Age and sex distribution of the skeletal sample. *I* infant; *C* child; *Ao* adolescent; *YA* young adult; *MA* middle old adult; *OA* old adult; *A* adult; *F* female; *M* male; *NA* not assessable

Age class (year range)	F		M		NA		
	n	%	*n*	%	n	%	Total (%)
I (0–3 y)	0	0.0	0	0.0	10	23.8	10 (6.8)
C (> 3–12 y)	0	0.0	0	0.0	11	26.2	11 (7.5)
Ao (> 12–20 y)	0	0.0	0	0.0	11	26.2	11 (7.5)
YA (> 20–35 y)	26	37.1	20	57.1	5	11.9	51 (34.7)
MA (> 35–50 y)	31	44.3	13	37.1	3	7.1	47 (32.0)
OA (> 50 y)	13	18.6	2	5.7	1	2.4	16 (10.9)
A (> 20y)	0	0.0	0	0.0	1	2.4	1 (0.7)
Total	70		35		42		147

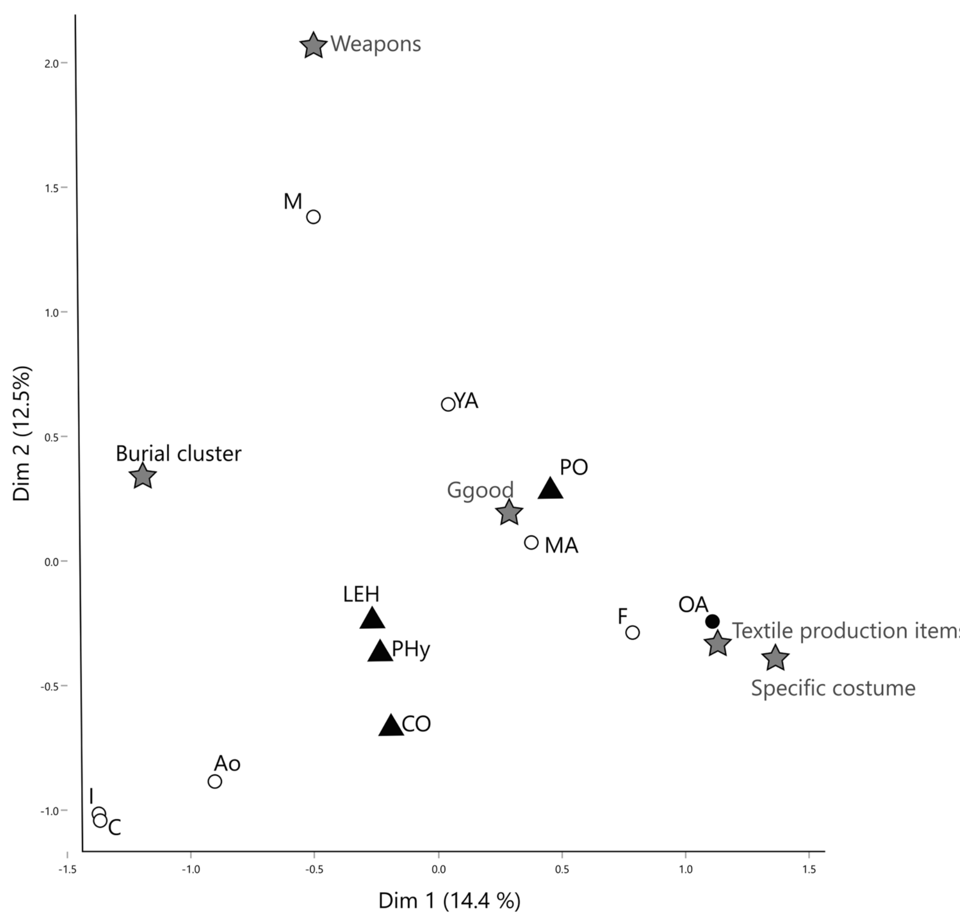


Fig. 3 Distribution of demographic, biological, and funerary variables along the first two dimensions from the MCA analysis. Circles, triangles, and stars indicate demographic, paleopathological, and funerary variables respectively. Absence of features is not shown to make the plot easier to read. M: sex corresponding to male; F: sex corresponding to female; I: infants; C: children; Ao: adolescents; YA: young adults; MA: middle adults; OA: old adults; Cgood: presence of grave goods.; LEH: presence of linear enamel hypoplasia; CO: presence of cribra orbitalia; PH: presence of porotic hyperostosis; NPL: presence of non-specific periosteal lesions; Ggood: presence of grave goods

MCA: association between demographic, funerary, and paleopathological variables

Figure 3 plots the first two dimensions obtained from the MCA. In order to make the plots less confusing, we show only the presence of each funerary and paleopathological variable (but the analysis included the entire dataset).

This plot provides some preliminary insights about the association between variables. Non-adult age classes are not associated with the presence of grave goods, while specific funerary features differ in their association with sex. Textile production items and elaborate garments are associated with females (especially old adult individuals), whereas weapons are associated with males.

The position of paleopathological features in each plot suggests two trends: first, the presence of LEH, PH, and CO is closely positioned, suggesting an association between these variables. Second, they are close to non-adult age classes, and apparently associated with the absence, in general, of grave good items and of specific grave good features.

Table 2 Results of logistic models with age and sex as independent variables and paleopathological (a) and funerary variables (b) as outcomes

a)	LEH			LEH OC*			PH			NPL			CO					
	DF	Cs	*p*	DF	Cs	*p*	DF	Cs	*p*	DF	Cs	*p*	DF	Cs	*p*			
Age[a]	5	6.3	0.28	5.0	8.7	0.12	5	8.2	**0.15**	**5**	**32.1**	**< 0.0001**	5	10.5	0.06			
Age[b]	2	0.9	0.65	2.0	0.3	0.87	2	2.2	0.33	2	4.9	0.09	2	0.1	0.95			
Sex[c]	1	0.1	0.71	1.0	0.6	0.46	1	1.1	0.29	1	0.8	0.36	1	2.1	0.15			
Age	2	4.7	0.10	**2.0**	**6.8**	**0.03**	**2**	**6.1**	**0.05**	2	5.8	0.06	2	0.3	0.87			
b)	Nr Items*			Grave good			Garments			TP items			Weapons					
	DF	Cs	*p*	DF	Cs	*p*	DF	Cs	*p*	DF	Cs	*p*	DF	Cs	*p*	DF		p
Age[a]	**5**	**14.8**	**0.01**	**5**	**18.6**	**0.00**	5	9.1	0.11	**5**	**22.2**	**0.00**	**5**	**15.3**	**0.01**	5		0.27
Age[b]	2	1.1	0.57	2	1.5	0.47	2	0.0	1.00	2	4.4	0.11	2	0.0	1.00	2	0.6	0.73
Sex[c]	**1**	**5.1**	**0.02**	1	1.1	0.29	**1**	**15.9**	**< .0001**	**1**	**26.8**	**< .0001**	**1**	**40.7**	**< .0001**	**1**	**4.2**	**0.04**
Age	2	0.4	0.8	2	2.0	0.37	2	0.2	0.92	2	1.6	0.46	2	0.9	0.65	2	0.4	0.82

Statistically significant results are highlighted in bold. *LEH* linear enamel hypoplasia; *LEH OC* LEH age-at-onset class; *PH* porotic hyperostosis; *NPL* non-specific periosteal lesions; *Nr items* grave goods numerosity; *Grave good* presence of grave goods; *Garment* presence of elaborate garments; *TP items* presence of items related to textile production; *Weapons* presence of weapons; *Burial cluster* position of burial in funerary cluster; *DF* degrees of freedom; *Cs* residual deviance

a: all sample; b: non-adults; c: adults; * Calculated with ordered logistic model

Age and sex vs. paleopathological variables

Table 2 shows the summary of the logistic models performed for the paleopathological (a) and funerary (b) variables. Analyses are repeated on all individuals and separately on non-adults and adults.

The analysis of all individuals highlights a statistically significant effect of age on the presence of NPL, a marginally non-significant effect on CO, and no effect on PH, LEH, and stature.

When adults and non-adults are analyzed separately, no statistically significant association links age and paleopathological features in non-adults. Conversely, age shows in adults a significant association with PH, LEH onset class, and a marginally non-significant effect on NPL.

Sex in adults is associated with stature, as demonstrated by the Mann–Whitney test, which highlights that males are significantly taller than females (Table 3).

The details of the logistic models (Table S1) and age-class-specific frequencies (Table S2a) provide information about the directions of these patterns. Incidence of CO shows a drop in frequencies following adolescence. LEH presents a marked increase in adolescents when compared with all the other age classes. Frequency of NPL sharply increases starting from young adults and reaches the highest frequency among old adults.

Table S3a shows the frequency of LEH age-at-onset classes for each sex and age class. As highlighted by the logistic models (Table 2), age at onset of LEH does not differ between sexes, but shows some interesting association with age-at-death. In the complete sample and in females, age at onset of LEH is concentrated around 3–4 years, whereas in males, the most represented age-at-onset classes are those between 2 and 3 and between 4 and 5 years. Spearman tests highlight a significant positive correlation between age-at-onset and age-at-death (i.e., individuals with later age at onset of LEH tend to have survived longer) in the full sample (rho: 0.3; *p*: 0.04), and, especially, in females (rho: 0.7, *p*: 0.003) (Table S3b; Fig. 4). This pattern is not confirmed in adult males although this is likely to be attributed to sampling biases (the old adult male class includes only one individual).

Age and sex vs. funerary treatment

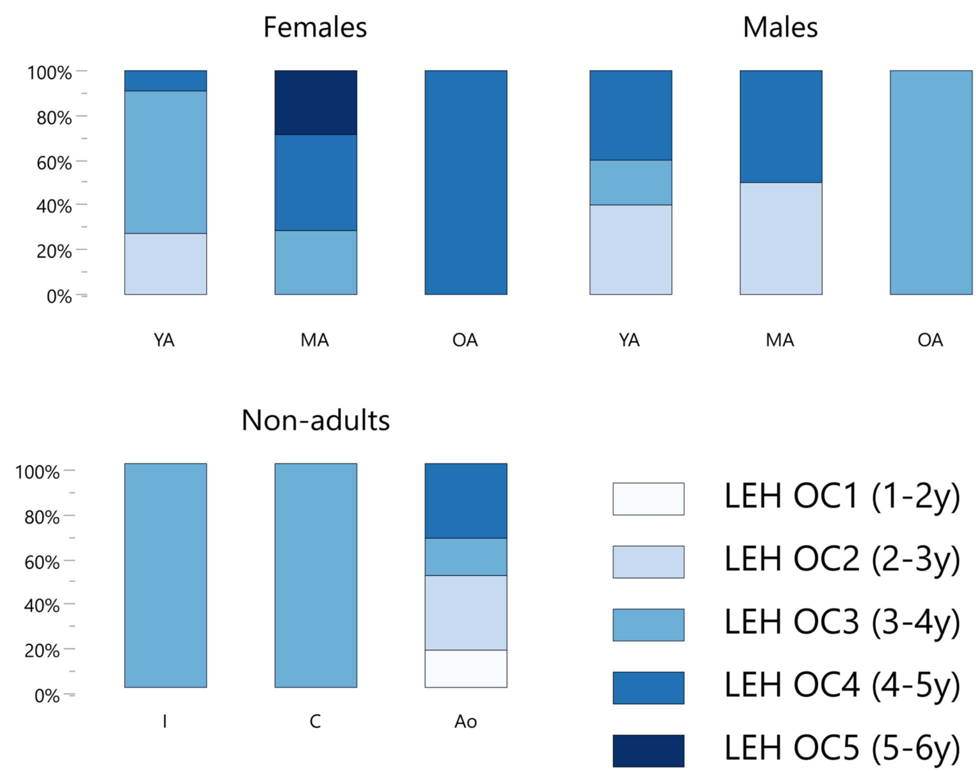
Age shows a marked influence on funerary treatment. Non-adults are in general characterized by lower frequencies of each funerary variable (Tables 2, S1, and S2b), and this is especially evident for the most "genderized" (see below) variables (e.g., elaborate garments, weapons, textile production items), which start to appear only after adolescence (Table S1). In both adults and non-adults separately, age is not associated with the presence of funerary variables.

Table 3 Differences in stature between sexes (a) and funerary categories (b)

a)	Females			Males										
	n	median	SE	*n*	median	SE	M-Whitney *p*							
	59	**154.1**	**0.5**	**28**	**166.5**	**0.7**	**< 0.0001**							
b)	Females							Males						
	Present			Absent				Present			Absent			
	n	Median	SE	*n*	Median	SE	M-Whitney *p*	*n*	Median	SE	*n*	Median	SE	M-Whitney p
Grave goods	50	154.0	0.6	7	155.4	0.9	0.0779	**22**	**167.3**	**0.8**	**6**	**164.2**	**1.3**	**0.0438**
Garments	12	153.5	1.1	44	154.4	0.6	0.5034	0			28	166.5	0.7	
TP items	31	154.5	0.6	26	153.8	0.9	0.7124	0			28	166.5	0.7	
Weapons	0			57	154.1	0.5		12	168.6	1.1	16	166.1	0.9	0.0947
Burial cluster	0			57	154.1	0.5		2	168.7	2.2	26	166.4	0.8	0.3724
	n	Median	SE					*n*	Median	SE				
Nr items class 1	5	155.4	0.9			rho	*p*	6	164.2	1.3			rho	p
Nr items class 2	11	153.0	1.3			0.0072	0.9581	10	166.5	1.1			**0.3744**	**0.0497**
Nr items class 3	33	154.0	0.7					11	168.1	1.2				
Nr items class 4	7	156.1	1.3					1	165.1					

Statistically significant results are highlighted in bold. *Nr items Class* grave goods numerosity class; *SE* standard error

Fig. 4 Frequencies of LEH age-at-onset (LEH OC) classes by age category. In females, older age classes are characterized by later age-at-onset of LEH



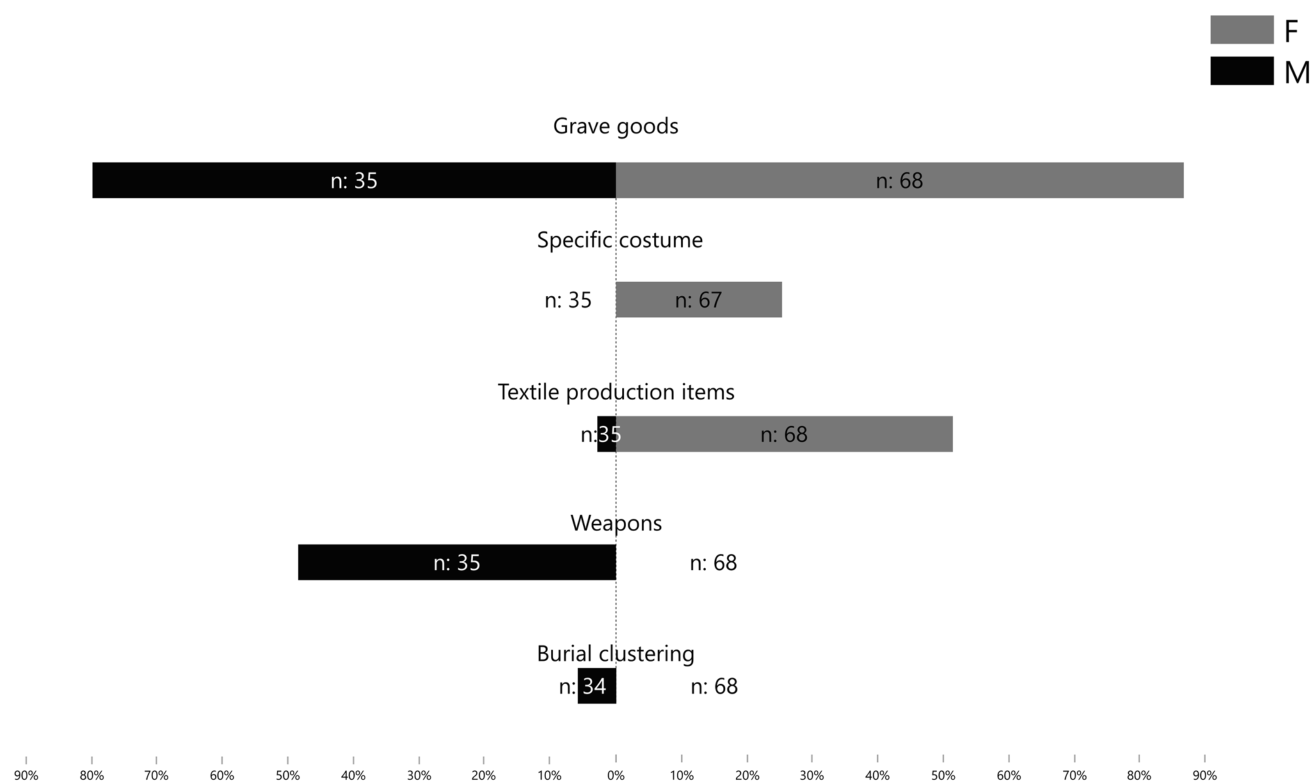


Fig. 5 Frequencies of funerary variables in the two sexes (number of funerary items not shown)

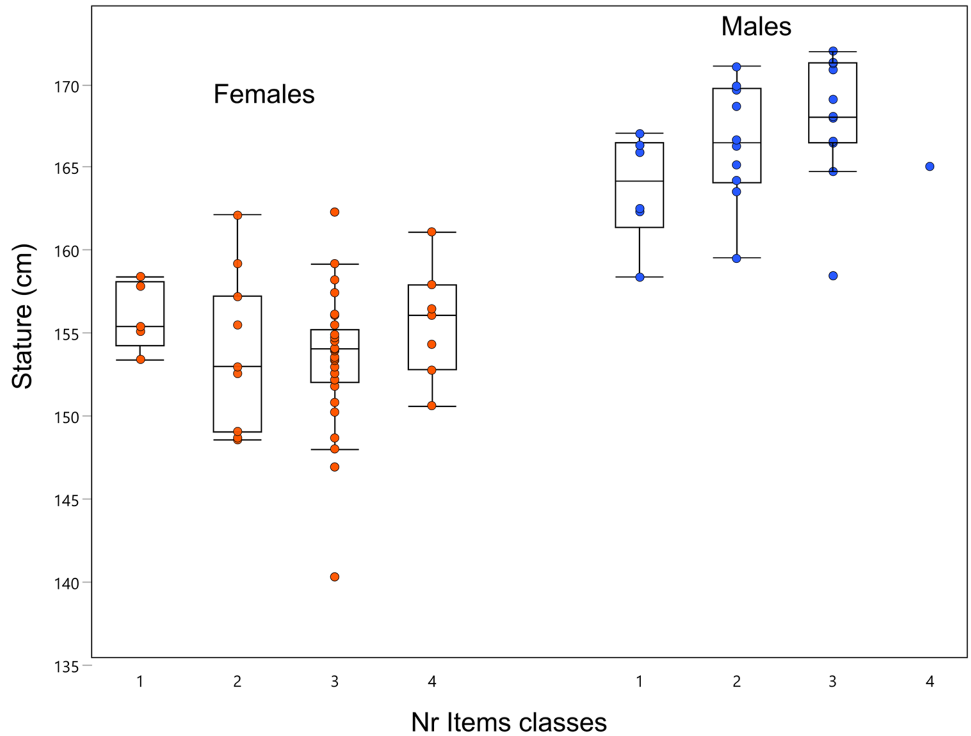


Fig. 6 Stature by number of funerary items class. In males, stature tends to increase in parallel with the increase in funerary items

Conversely, sex influences all variables with the exception of the presence of grave goods (Fig. 5). Elaborate garments, textile production items, and number of grave good items are significantly associated to females. Weapons and deposition in a cluster are more frequent among males (Tables S1 and S2b). Males and females also differ in the number of funerary items (females in general having more numerous grave goods). The item numerosity classes 1 and 2 are more frequent in males, while classes 3 and 4 are more frequent in females (Table S2b).

Paleopathological variables and stature vs. funerary treatment

The previous analyses highlighted a heterogeneous distribution of biological and funerary variables across age classes, especially a sharp contrast between non-adults and adults. Non-adults show both a higher frequency of stress markers and a lower presence of grave goods. This result, likely due to the combination of different mortality risk following early life stressors and differential funerary treatment of non-adults (see also discussion), requires attention. Including non-adults in a combined analysis of biological and funerary variables would indeed raise the chance of observing (spurious) association between the presence of LEH, PH, and CO and the absence of funerary features. For this reason, we decided to exclude non-adults from this part of the study, which is therefore focused on the association between stress indicators and funerary differences among individuals who survived into adulthood.

LEH and CO are inversely associated with the presence of textile production items and elaborate garments, respectively (Table 4) (Tables S4b, S5, and S6).

Moreover, in adult males provided with grave goods are taller than those without (p: 0.04), and male stature increases together with the number of grave good items (rho: 0.4; p: 0.05) (Table 3; Fig. 6). Males with weapons are also taller than those without, but in this case, the difference does not reach statistical significance.

Discussion

Limitations of the study

Before discussing our results, it is important to consider a set of limitations affecting this study. These principally relate to (a) the actual information provided by the skeletal and dental variables used in our analyses, (b) the error associated with social reconstructions based on funerary data; (c) the complex link between social and biological status; and (d) the potential selective use of the analyzed necropolis.

First, we need to take into account the possible bias played on our results by the "osteological paradox" (Wood et al. 1992). In synthesis, it would be simplistic to assume a univocal relationship between the frequency of paleopathological variables and the actual health condition experienced

Table 4 Results of logistic models with age and paleopathological variables as independent variables and funerary variables as outcomes

Adults	Nr items			Grave goods			Garments			TP items			Weapons			Burial cluster		
	DF	Cs	*p*	DF	Cs	*p*	DF	Cs	*p*	DF	Cs	*p*	DF	Cs	*p*	DF	Cs	*p*
Sex	1	3.4	0.066	1	0.1	0.758	**1**	**6.6**	**0.010**	**1**	**20.5**	**< .0001**	**1**	**17.5**	**< .0001**	1	2.6	0.105
Age	2	1.2	0.561	2	0.4	0.804	2	0.6	0.743	2	0.3	0.840	2	0.1	0.931	2	0.1	0.950
LEH	1	0.2	0.651	1	0.0	0.846	1	0.5	0.477	**1**	**4.3**	**0.039**	1	0.4	0.532	1	0.6	0.431
NPL	1	2.6	0.105	1	0.0	0.864	1	1.5	0.226	1	1.0	0.306	1	0.0	0.910	1	0.0	0.997
CO	1	1.3	0.257	1	3.4	0.067	**1**	**4.7**	**0.030**	1	0.0	0.909	1	0.0	0.998	1	0.0	1.000
PH	1	1.3	0.259	1	1.0	0.315	1	0.6	0.457	1	0.0	0.917	1	1.7	0.189	1	0.5	0.477

Statistically significant results are highlighted in bold. *DF* degrees of freedom; *Cs* residual deviance

by the population of Novilara. Heterogeneity in frailty, selective mortality, and genetic variability are likely to have shaped the observed mortality trend.

Moreover, LEH, CO, PH, and NPL can be influenced by different factors, or by the same factors (interplay between genetic, epigenetic, environmental etc.) but in different ways and with different timing (Cole and Waldron 2019; Mittler et al. 1992; Obertová and Thurzo 2008; Rivera and Mirazon Lahr 2017). This increase the "background noise" in our data, hampering the detection of more complex tendencies. Being limited to a discussion of unspecific stressors is especially a limit in a study like this. The relationship of these features to different etiological factors (e.g., nutritional, parasitic, infective, traumatic) would largely influence our definition of biological status and of its relationship with social status.

The resulting imprecision needs to be considered when testing the association between biological and social status. In our case, these problems are accentuated by the methods used in our study. We scored LEH, CO, PH, and NPL as binary variables and grouped age at onset of LEH in rough 1-year classes. Moreover, we did not differentiate between single and multiple hypoplastic defects. This decision, while justified by our need to minimize possible errors or imprecise measurements, eliminates the possibility to distinguish between the single vs. repeated stressful episodes and to analyze enamel defects in teeth with different growth/eruption timing. The equations we used to estimate age at onset of LEH have been recently criticized due to the underlying assumption of a linear enamel growth rate during tooth formation. More recent alternatives include the decile method proposed by Reid and Dean (2000, 2006) and the exponential regression published by Cares Henriquez and Oxenham (2019). Note, however, that significant differences in age at onset between the Goodman and Rose's and Reid and Dean methods are in the range of 1 to 4 months (Martin et al. 2007; Ritzman et al. 2008). Since the aim of this study is not an in-depth analysis of diachronic patterns in developmental stress, we think that our estimates, even if possibly rough, are still adequate for our purposes.

Second, reconstructions of social status based on funerary data are complicated by specific features of each funerary context, and especially challenging for prehistoric settings like Novilara, where social differentiation, although likely present, may not be so obvious. In such situations, it may be tempting to apply subjective criteria in organizing the data for analysis, resulting in biased funerary variabilities. In our study, we tried to minimize this risk, but subjective biases are however still likely to have influenced our analysis. Moreover, social status is probably expressed not only along a vertical axis, but also horizontally. This, combined with the (admittedly rough) binary coding of funerary variables, is likely to mask the actual social variability and complexity in the analyzed context (see also Laffranchi et al. 2019). A similar issue affects the number of grave goods, which would be unwise to blindly identify as marker of status. Different objects have different economic and symbolic values, not necessarily related to hierarchical differences, and a single precious item may be more informative about status than several common objects (Cuozzo 1996; D'Agostino 1985; Parker Pearson 1982). In this study, we included this variable just to express a side of the funerary variability of Novilara, postponing any interpretation on its potential social meaning based on the analysis of the associated biological patterns.

Third, even in an ideal situation where both social and biological status can be archaeologically determined, the association between the two is likely to be influenced by additional variables (e.g., gender, age, geographic origin, chronological differences) (Robb et al. 2001). In addition, with the exception of NPL, the biological variables analyzed in our study provide information about exposure to stressors before adulthood. Conversely, if funerary treatment was actually related to social status, and the latter was acquired rather than inherited, funerary variability may be more informative about later phases of an individual life course.

Fourth, our analyses revealed a marked imbalance in the sex ratio (ca. 2:1 in favor of females). This result, by itself interesting, may suggest selective burial practices. When discussing our data, we need to be aware of this potential bias.

Finally, we need to acknowledge the relatively small size of our sample, a limitation which becomes especially obvious when subdividing individuals between age classes and sexes. Although this is a common issue of osteoarchaeological samples, it calls for additional caution when trying to infer general biocultural patterns in our population.

The above considerations call for caution when discussing our results and highlight the unsuitability of straightforward interpretations and the need for a nuanced discussion. Nevertheless, our analyses do depict a number of interesting patterns and provide various, albeit preliminary, answers to our research questions. At the same time, the non-intuitive association between biological and social status needs to be kept at the center of the discussion.

Paleopathological variables and stature vs. age-at-death and sex

As mentioned, although the specific etiology of CO, LEH, and PH is unclear, they can provide information about exposure to early life stressors. Based on of previous studies, we would expect a decrease in the frequency of these features with advancing age (Steckel et al. 2002; Walker et al. 2009). Results generally agree with these expectations.

For CO, the steady decrease in frequency with advancing age and the drop in the presence from adolescents to young adults find support in earlier studies which identified similar trends (Facchini et al. 2004; Steckel et al. 2002) and attributed them to the higher exposure of the youngest individuals to environmental stressors. Interestingly, age trajectories of PH do not align with those of CO. This result supports earlier claims about different etiologies of these conditions, which justifies our choice to analyze them separately (Brickley 2018; Rivera and Mirazon Lahr 2017; Walker et al. 2009).

While age-related patterns of CO and PH do not deviate from expectations based on previous studies, results on LEH are particularly interesting due to their complexity.

Life history traits (e.g., weaning period), environmental (relative exposure to pathogens), and cultural (socioeconomic systems) factors can influence the incidence and timing of enamel hypoplasia (Goodman and Rose 1991; Larsen 2015). Previous discussions of LEH in archaeological samples have invoked the weaning phase and post-weaning stress as the main factors responsible for the emergence of hypoplastic defects (e.g., Corruccini et al. 1985; Goodman et al. 1987), a conclusion mitigated by other researchers who signaled the more likely contribution of additional factors (Ham et al. 2020; Kyle et al. 2020; Towle and Irish 2020).

The peak in frequency of LEH in adolescents combined with the positive correlation between age-at-onset and age-at-death point to a link between early life stressors and mortality risk. It is also interesting that the frequency of LEH decreases in adults from YA to OA. Although this may be related to the long-term effect of early life stressors resulting in a shorter life expectancy (Boldsen 2007), additional causes cannot be excluded (e.g., cumulative adversity – Amoroso et al. 2014). In the future, more focused analyses will allow to better explore this aspect of the Novilara population.

The etiology of NPL includes nutritional, environmental, physiological, and biomechanical factors (Klaus and Tam, 2009; Larsen 1997). Previous studies highlighted a variable association between this feature and age (e.g., Larsen et al. 2015; Šlaus 2008; Zoëga and Murphy 2016), a likely result of the various types of inflammatory processes responsible for this feature. In our case, the increase of NPL with age points to biomechanical processes as the main factor responsible for the observed patterns (accumulation of localized microtraumatic events throughout life) rather than to infectious processes. A probable explanation is that individuals sustaining infectious processes simply died before they had time to develop observable periosteal reactions. Naturally, we cannot exclude that NPL in adults may be at least in part related to earlier infections which the individual survived.

If the culture of Novilara envisioned a different parental investment on male vs. female offspring, we would expect an association between sex and paleopathological variables in our data. Results show however no such association, suggesting similar exposures to environmental stressors for males and females. Similar patterns were observed among other Iron Age populations such as the Etruscan-Samnites from Pontecagnano (Salerno, 7th–5th c. BC) especially for porotic hyperostosis and periostitis (Sonego and Scarsini 1994) and the Etruscans from Spina (Ferrara, 6th–3rd c. BC) for cribra orbitalia, porotic hyperostosis, and periostitis (Manzon and Gualdi-Russo 2016). Based on our data, we cannot exclude dietary differences between the men and women of Novilara, nor subtle differences in their living conditions. It is also important to note that we did not attempt to determine sex of non-adults. This means that our data likely describe only part of the actual variation of paleopathological variables according to sex. It is important to keep in mind that in the anthropological examination of skeletal remains we are facing with sex differences, which are conceptually distinct from gender patterns, the latter referring to culturally constructed social identities (Agarwal and Wesp 2017; Zuckerman and Crandall 2019). Gender roles in the society at Novilara are clearly represented in funerary rituals (see below), and a gender subdivision of labor has been preliminarily suggested based on sex-specific frequencies of non-masticatory dental wear in individuals excavated during the nineteenth century (Consiglio 2008: 419). Based on our results, it seems however that this did not translate into sharp differences in health status between sexes. This type of inference needs to be considered with caution though due to the uncertain overlap between biological sex and gender (see Zuckerman and Crandall 2019; Walker and Cook 1998).

Age-at-death, sex, and funerary treatment

In general, our analyses point to the importance of age and especially sex as driving factors behind funerary variability at Novilara. Moreover, our results provide additional insights into possible life course and sex-related patterns of social identity in the analyzed population. As already mentioned, simplistic interpretations of funerary features are in most cases inadvisable (Härke 2000; Laffranchi et al. 2021; Robb et al. 2001). Similarly, biological sex is not necessarily synonymous with gender identity (Walker and Cook 1998), and this is an often-mentioned limitation of archaeological discussions of gender differences based on sex-related differences of archaeological and skeletal variables (Zuckerman and Crandall 2019). While these caveats also need to be considered in the present study, the marked demographic variability characterizing funerary features strongly suggests an intersection between sex, age, and social identity in this community. This is especially indicated by the sudden change in the amount of grave goods and the appearance of "genderized" items (e.g., elaborate garments, weapons) after adolescence.

The sharp separation of these funerary variables between sexes and the larger number of grave goods in female burials are common patterns in other Picene necropoles (Delpino et al. 2016) which indicates a strong gender differentiation and the idealized association of specific objects and activities to women and men.

Similar funerary patterns are also highlighted in a bioarchaeological study of a subsample from Pontecagnano (Southern Italy, 5th–3rd c. BC) (Robb 2019). Previous hypotheses postulated a link between the spatial organization of Novilara (funerary clusters) and some type of inherited status (e.g., familiar or other forms of kinship – Beinhauer 1985; Delpino 2018). This is particularly evident from the beginning of the seventh century BC, with the change of the status of some children through the formalization of hereditary wealth and social status (Delpino 2018). Sample preservation hampered tests of kinship patterns across closely spaced burials or "Groups" (see Fig. S1 and supplemental information in Serventi et al. 2018). Our analyses do not help to clarify the meaning of this funerary organization. The larger proportion of males in clusters may indeed be biased by the small number of male individuals in the analyzed skeletal sample and the lack of information about the sex of the non-adults.

Grave good variability at Novilara is clearly related to the age of the individual, at least until adolescence. Non-adults are provided with grave goods (e.g., ceramic vessels, personal ornaments) only starting from ca. 1–2 years of age, a possible sign of a culturally sanctioned age threshold toward their inclusion in the social group. A second age threshold is signaled by the appearance of gender-specific items in the burials of young adults. Another potentially interesting pattern is the apparent increase of the presence of textile production items with advancing age in females, which is however not statistically significant.

Paleopathological variables, stature, and funerary treatment

The third part of this study aimed to test if exposure to stressors during growth was linked to social status (at the moment of death). If for example some individuals were less exposed to early life health insults due to their social status, we would expect to find an association between paleopathological, stature and funerary variables.

Our results partially agree with this expectation. The inverse association in adults between LEH and textile production items, CO and elaborate garments, and the larger stature of male individuals with grave goods and with more numerous funerary items may indeed suggest an association between biological and social status at Novilara, as expected based on a theoretical lower risk for chronic or infectious diseases (Cohen 1999) and malnutrition episodes (Van de Poel et al. 2008) in individuals of a "higher economic and social status" (Peck 2013) and, potentially, of their better diet. Note, however, that the lower frequency of paleopathological features in a specific group is not necessarily a sign of their better health. Rather, it may well be that these individuals simply died before the stressors had the time to leave their traces on the skeletal system (Wood et al. 1992). It is in any case interesting that at Novilara male individuals with weapons are also on average taller than those without (although the difference does not reach statistical significance). This result may be related to a privileged social status of these men presented in death as warriors. The importance of warfare in the society of Novilara has been also cited by Brasili et al. (2004), when discussing the frequency and type of cranial lesions in the skeletons excavated during the nineteenth century, and recently by Beck De Lotto and colleagues (2018), in their analysis of inflicted traumas in the skeletal remains from the 2012 to 2013 investigations.

Data from another Iron Age context of Italy (Pontecagnano – 7th–3rd c. BC) highlighted no association between funerary treatment and skeletal features (e.g., stature, enamel hypoplasia, and cribra orbitalia) (Robb et al. 2001). Similar results were also obtained in a study of a Middle Iron Age population (400–100 BC) from Northern England (Peck 2013). In this case, skeletal markers did not differ between "elite" and "non-elite" individuals. Conversely, Sparacello et al. (2017) found a significant positive correlation between stature and socioeconomic status expressed by funerary features only among males and only for a specific period (800–500 BC) when analyzing several Iron Age necropolises from Abruzzo (Central Italy). For Novilara, it is important to consider that various biological variables (e.g., stature in females, paleopathological variables in males) do not show any clear patterning according to funerary treatment. This, in conjunction with the heterogeneous results obtained from the cited studies, can firstly be linked to theoretical limitations (see above). Secondly, the diversified results of our study demonstrate that the association between social and biological status at Novilara was rather complex and multifaceted. Social differentiation and living conditions in this Iron Age population were not straightforwardly associated, but rather differently intertwined across sexes and age.

Conclusion

Our results highlight some important patterns related to the association between social and biological status in the population of Novilara. In general terms, it appears that the increasing complexity of funerary treatment was negatively associated to the experience of stressful living conditions. Our data suggest the presence of a complex influence of social differentiation on the living condition of this population and that such influence strongly varied based on sex, age, type, and quantity of experienced stressors. This study demonstrates the challenges involved in the reconstruction of social and biological status, and of their possible links, among past populations. The results of our analyses suggest the presence of a complex influence of social differentiation upon the lives of the people buried at Novilara and that such influence strongly varied based on sex, age, and the type and quantity of experienced stressors. The dental and skeletal variables used in this study provide only non-specific information about environmental stressors experienced by this population. Similarly, our funerary variables can only (and cautiously) be linked to rough patterns of social differentiation. These considerations suggest the need for additional analyses in order to better quantify the biological and social variability characterizing this population.

Planned analyses include an extensive isotopic study (carbon, nitrogen, sulfur, oxygen, and strontium) aimed at reconstructing diet and mobility, and their possible link to social differentiation, as well as additional aDNA analyses. The latter will provide further insights into kinship patterns as well as biological affinities with other protohistoric and historic populations from the Italian Peninsula and the Mediterranean area.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12520-021-01449-3.

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Chiara Delpino: Conceptualization, supervision, resources, data collection and curation, and writing-review and editing.

Sandra Lösch: Supervision, and writing-review and editing.

Marco Milella: Conceptualization, methodology, validation, formal analysis, supervision, writing-original draft, and writing-review and editing.

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Data availability The data that support the findings of this study are available from the corresponding author upon request.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare no competing interests.

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