Bianca Casa[1*], Giulia Riccomi[1,2*], Maurizio Marinato[3], Alessandra Mazzucchi[3], Federico Cantini[4], Alexandra Chavarría Arnau[3], Valentina Giuffra[1]

research

Physiological stress, growth disruptions, and chronic respiratory disease during climatic downturn: The Late Antique Little Ice Age in Central and Northern Italy

1. Introduction

The late 5th century of the common era (CE) and the onset of the post-classical period were marked by profound socioeconomic and political upheavals in Italy. The collapse of the Western Roman Empire in 476 CE led to the establishment of the Ostrogothic Kingdom, which ruled Italy and neighbouring regions from 493 CE onwards. In 553 CE, Emperor Justinian I launched a campaign to reconquer Italy, triggering three decades of devastating wars. These conflicts unfolded alongside a period of climatic change known as the Late Antique Little Ice Age (LALIA) in which weather became more variable, with intermittent colder and drier conditions in some regions and probably a significant period of cooling in Northern Europe (Büntgen *et al.* 2016; Eisenberg *et al.* 2019; Erdkamp 2021; Labuhn *et al.* 2019). LALIA has been linked to the outbreak of the Justinianic Plague, which struck Italy around 543 CE and recurred in waves over the following two centuries (Harper 2017; Luterbacher *et al.* 2020). During the last decades the combined effects of warfare, climatic change and disease have been extensively discussed, as well as their consequences ranging from severe population decline, abandonment of rural settlements, and widespread economic collapse (Harper 2017; Little 2007) to more nuanced transformations underlining geographical variability (Haldon *et al.* 2018; Labuhn *et al.* 2019; Luterbacher *et al.* 2020; Peregrine 2020). After the Ostrogoths' defeat in 554 CE, the Eastern

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

[2] Max Planck Institute of Geoanthropology, Jena, Germany.

[3] Department of Cultural Heritage, University of Padova.

[4] Department of Civilisations and Forms of Knowledge, University of Pisa.

* Corresponding authors: *bianca.casa@med.unipi.it, giulia.riccomi@unipi.it.*

Roman Empire briefly reasserted control over the peninsula, but this dominance was short-lived. In 568 CE, the Lombards invaded Northern and Central Italy, consolidating their power throughout the 7th century CE.

1.1. The Late Antique Little Ice Age (LALIA)

The year 536 CE was documented by historical sources as the "year without summer" when a mysterious cloud dimmed the light of the sun for 18 months (Gunn 2000; Stothers 1984, p. 344; Stothers, Rampino 1983, p. 6537). A climatic shift was initiated in the Northern Hemisphere by a series of sequential volcanic eruptions in 536, 540, and 547 CE, which injected vast quantities of aerosols into the stratosphere (Büntgen *et al.* 2016, p. 3; Newfield 2018; Sigl *et al.* 2015, p. 5). The diminished solar radiation caused substantial and prolonged cooling and may have been associated with precipitation shifts. Moreover, the event in 536 CE was only one of many unfavourable climate developments, as shown by the advance of the Alpine glaciers (McCormick 2013; McCormick *et al.* 2012). Compared to other cold phases, the LALIA was exacerbated by a stronger inclination angle of the Earth's axis, and summer temperatures dropped by up to 2°C (Büntgen *et al.* 2016, pp. 2-3). The worsening of the climate is described by contemporary writers such as Cassiodorus, Bishop Zacharias of Mytilene, and Procopius of Caesarea, who mention how colder weather had provoked serious food shortages for people and animals. Cassiodorus in particular describes the winter of 536-37 CE as '*drier and harsher than usual*' with '*the air thickened into snow for the excessive cold*' that '*could not be melted by the warmth of the sun*, *persisting in that condition*' (*Variae*, XII, XXV). The duration of the LALIA cold phase in the Northern Hemisphere ranged from 536 to ~660 CE (Büntgen *et al.* 2016, p. 1).

The LALIA is hypothesised to have had an indirect impact on major societal changes of the 6th century CE, which was marred by pestilence, crop failures, and famine (Büntgen *et al.* 2022, p. 2337; Toohey *et al.* 2016, p. 410). The volcanic-induced cooling of the LALIA disrupted weather patterns (diminished sunlight, lower temperatures, altered precipitation patterns) and led to shorter growing seasons, crop failures, and agricultural decline across the Northern Hemisphere, particularly impacting Scandinavia and Northern Europe. Historical accounts from 536-537 CE describe the sun shining for only four hours a day in the spring and summer, and that the fruits did not ripen (Stothers 1984, p. 344). Coinciding with the apparent food shortages of the LALIA was the outbreak of the great Justinianic plague across Europe from 541 CE until the mid-8th century CE, which led to mass mortality (Harbeck *et al.* 2013, p. 1; McCormick *et al.* 2012, pp. 198-199). The same climate event may have also caused the migration of some populations, such as the Pannonian Avars and the Slavs, westward in

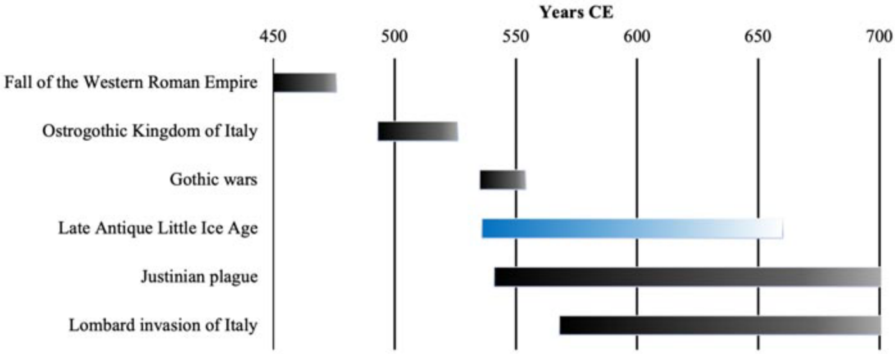

Fig. 1. Major events in Italy during the 5^{th} to 7^{th} centuries CE, which coincided with the LALIA.

search of new opportunities after the collapse of the Roman administrative structure. Such migrations would have had consequences for Italy also. In particular, the arrival of the Avars to Pannonia (present-day Hungary) in 550 CE pushed the Lombards towards Italy, which they invaded in 568 CE (Pohl 1988) (fig. 1). Even in Northern Europe, in the Baltic area north of the Oder (the border between Germany and Poland), multidisciplinary studies point to climate change as the motivator for the sudden migrations that produced numerous abandonments and the gradual depopulation of that area between the 5^{th} and 12^{th} centuries CE (Volkmann 2015).

Historically, climatic downturns have acted as stress multipliers that intensified sociocultural, political, and economic vulnerabilities, leading to famine, plague, mass migrations, and political transformations (Büntgen *et al.* 2016, p. 5, 2020, p. 8; McCormick *et al.* 2012; Toohey *et al.* 2016, p. 408). If economic and population growth favour climatic stability, then the opposite should be found in periods of environmental instability (Büntgen *et al.* 2020, p. 9). The extent to which the LALIA indirectly influenced the social, cultural, political, and economic transformation of Italy cannot be definitively ascertained. An apparent relationship between climatic shifts and acute episodes of health crises has been posited as the climate-infectious disease nexus (Zonneveld *et al.* 2024, p. 5). Marine-core data from southern Italy indicate that the abrupt onset of the LALIA resulted in a temperature drop of -3°C compared to the highest decadal averages of the Roman Climate Optimum (Zonneveld *et al.* 2024, pp. 3, 5), and the average temperature drop caused by the LALIA in the Northern Hemisphere was -1.54°C (Büntgen *et al.* 2022, p. 2337). Oxygen isotopes from stalagmites in the Ranella Cave in Lucca (Tuscany, Central Italy) returned a prominent century of lower $\delta^{18}O$ values between 500 and 600 CE, indicating elevated autumn and winter precipitation, which was influenced by an increase in moisture transported from the North Atlantic that incited a secondary cyclogenesis the Gulf of Genoa (Isola *et al.* 2019; Zanchetta *et al.* 2021). This period of increased rainfall coincides with evidence of recurrent palaeoflood activity (Bini *et al.* 2020). These climatic and environmental changes caused by the downturn of the LALIA would have led to both human social changes and food shortages, which in turn, impacted human mortality and morbidity. A relationship between short-term health impacts (i.e., plague, epidemics) and the LALIA has been postulated in the literature based on textual sources (Büntgen *et al.* 2016; McCormick *et al.* 2012; Zonneveld *et al.* 2024). Despite this, limited investigation into the long term implications of the LALIA on the relative health of Italy's populations has been conducted using bioarchaeological evidence.

The present study aims to evaluate whether the climatic shift of the LALIA caused physiological disruptions in individuals from Central and Northern Italy during the 6th and 7th centuries CE, or if people exhibited resilience to these extrinsic influences. The approach used to fulfil this aim is to evaluate the frequency of physiological stress markers, growth disruptions, and chronic respiratory disease in spatiotemporally relevant osteoarchaeological assemblages.

2. Materials and methods

2.1. Archaeological sites

Six archaeological skeletal assemblages with contexts dating to the post-Classical period formed the study base, including one site from Central Italy (*vicus Wallari*/borgo San Genesio) and five sites from Northern Italy (Bariano, Covo, Verona, Arcole, and Povegliano) (fig. 2). These six sites were included based on the presence of skeletal remains dating to the 6th and 7th centuries CE, and that substantial excavations have been completed at these sites.

Vicus Wallari-borgo di San Genesio, hereafter called San Genesio, is a rural site located in northern Tuscany, approximately three kilometres from San Miniato (Pisa), and positioned along the *via Francigena* (fig. 2) (Cantini 2010, p. 81). In the Roman Period, the site hosts a *mansio* along the *Via Quinctia*, the road that joined Pisa to Florence. In the first half of the 6th century CE, a barrier was created on the road, using wooden posts and earth. The structure was meant to control the road system during the Greco-Gothic war (Cantini *et al.* 2017, pp. 251-252; Cantini, Citter 2021, pp. 210-211). The area accommodated a large necropolis which was in use from the mid-6th to the mid-13th centuries CE (Cantini 2010, p. 90). Between the end of the 6th to the 7th centuries CE, the site became a central node of religious, economic, and military activity, and was

Fig. 2. Map of Italy showing the location of sites included in the study (base map taken from Ministero dell'Ambiente e della Tutela del Territorio e del Mare – Geoportale Nazionale, CC BY 3.0).

first mentioned in 715 CE with the place name *Vicus Wallari*, likely reflecting the name of the Lombard aristocrat who controlled the settlement (*Wallar*) (Cantini 2010, pp. 83, 93-94). From over 400 inhumations which have been excavated at the site (Viva *et al.* 2022, p. 39), a total of 59 individuals from the necropolis of San Genesio dating to the 6th and 7th centuries CE were included in the present study (tab. 1). During this period, the necropolis likely hosted the burial of both local inhabitants and those passing through the area at the end of the Greco-Gothic War and the Lombard conquest (Cantini *et al.* 2017, p. 252; Viva *et al.* 2022).

The former Convent of the Neveri at Bariano, located in the Bergamo region of Lombardy, forms part of a rural settlement that was possibly founded in the Roman period and occupied until the Middle Ages (fig. 2) (Fortunati *et al.* 2024, p. 201; Brogiolo 2014). During the late Roman period, a mausoleum was built, and it attracted a privileged cemetery. A total of 98 inhumations have been excavated, some containing grave-goods (e.g., a gold cross); the earliest burials date to the 5th and 6th centuries CE, of which eight individuals were included in the present study (tab. 1) (Fortunati *et al.* 2024, pp. 202, 205).

Site	**Region**	**Chronology of the sites**	**No. of individuals from the 6th-7th c.**
San Genesio	Tuscany	Mid-6th-7th centuries CE	59
Bariano	Lombardy	5th-6th centuries CE	8
Covo *Cascina Bellinzana*	Lombardy	5th-7th centuries CE	21
Verona	Veneto	4th-10th centuries CE	28
Arcole	Veneto	6th-7th centuries CE	6
Povegliano	Veneto	6th-7th centuries CE	14

Tab. 1. Archaeological sites, chronology, and the number of individuals per site included in the study.

Covo *Cascina Bellinzana* is a rural site located in the region of Bergamo in Lombardy that dates to the 5th to 7th centuries CE (fig. 2). The site comprises mainly a rural cemetery with a total of 24 inhumations, of which 21 individuals were included in the current study (tab. 1) (Marinato 2019, p. 52).

Verona underwent several transformations after the fall of the Western Roman Empire (fig. 2). In the early 6th century CE, the city was under the control of the Ostrogoths and was a key location during the Gothic wars (535-553 CE). After its conquest by the Lombards in 568 CE, Verona's urban centre became a regional centre of governance and military activity (Pohl 1997). The urban centre of Verona has produced late Roman funerary contexts ranging from the 4th to the 10th centuries CE. The contexts included in this research include: the suburban cemeteries of via Cantore, Corso Cavour, via Leoncino, and via Oberdan; the urban cemeteries of via Pigna and via Duomo 8; and the Arena of Verona. The site dates to the 1st century CE, and was in continuous use until the 14th-17th centuries CE (Bolla 2012; Bruno 2016; Laffranchi *et al.* 2020), including funerary reuse. A total of 28 individuals from Verona were included in this study, dating between the 6th to 7th centuries CE (tab. 1) (Bruno 2016; Laffranchi *et al.* 2020).

The site of Arcole (Verona) (fig. 2) originated as a Roman rural settlement (Arzone *et al.* 2012, pp. 49-51). In the absence of defined archaeological evidence, it has been hypothesised that the site was likely reused for agricultural activities from the Lombard period until the 10th century CE, and funerary reuse was practiced at the site (Arzone *et al.* 2012, pp. 108-109). Six individuals from Arcole were included in the present study (tab. 1).

Povegliano is located approximately 15 km from the city of Verona and hosts a renowned Lombard necropolis (fig. 2). The area of Povegliano has been in use since at least the Bronze Age, and was continually occupied from the Iron Age through the Roman period and until the Early Middle Ages (Bruno, Giostra 2012, p. 216). Fourteen individuals derived from Povegliano were used in the current study (tab. 1). Archaeological evidence attests to the site being inhabited by Lombards during the 6th and 7th centuries CE, and their mortuary accoutrements suggest individuals of moderate to high status (Bruno, Giostra 2012, pp. 218-219).

The chronology of site occupation and use often exceeds the scope of the present study; therefore, only the contexts dating to the 6th and 7th centuries CE were included in the study. Articulated and semi-articulated individuals were included in the study, and only crania from commingled contexts were included in the study.

2.2. Limitations

Some contexts have not undergone absolute dating methods and, therefore, their chronology may expand past the scope of the study. The archaeological context is not published for all sites included in the present study, which may limit more nuanced interpretations of the data on a site-specific basis.

2.3. Biological profile

For this study, age at death refers to physiological age, which is estimated from biological changes to the body, and does not reflect social age (Halcrow, Tayles 2008). Individuals were classified as adults upon the complete eruption of the third molar at approximately 20 years of age (Hillson 2014, pp. 29, 229). Adult age at death was assessed according to morphological changes to the pubic symphysis (Brooks, Suchey 1990) and auricular surface of the ilium (Buckberry, Chamberlain 2002; Lovejoy *et al.* 1985). Adults were classified into three categories: young adults (20-34 years), middle adults (35-49 years), and older adults (50+ years) (Buikstra, Ubelaker 1994). Preadult age at death (< 20 years) was estimated based on dental development and eruption (AlQahtani 2010), timing of epiphyseal union, and long bone diaphyseal measurements (Cunningham *et al.* 2016). To aid analyses, preadult age at death was classified into five categories modified from Cunningham *et al.* (2016): foetal (nine weeks in utero to birth); infant (birth to one year); early childhood (two to six years); late childhood (seven to 12 years); and adolescence (13-19 years).

Sex was estimated using the dimorphic features of the pelvis and cranium (Acsádi, Nemeskéri 1970; Ferembach *et al.* 1980; Klales *et al.* 2012; Walker 2008), and adult individuals were categorised as male, probable male, indeterminate sex, probable female, female, and unknown sex. Adolescents with observable dimorphic features were assigned to probable male or probable female categories.

2.4. Physiological stress markers

As health cannot be quantified, disruptions to the homeostasis of individuals are assessed through non-specific physiological stress markers, interruptions to growth and development, and disease (Pilloud, Schwitalla 2020, p. 2). During periods of stress, such as malnutrition, disease, or chronic strain, the body develops a physiological response to adapt to the disturbance. These physiological markers are expected to occur more frequently with increased periods of stress (Pilloud, Schwitalla 2020, p. 2). As the exact aetiology of physiological stress markers is heavily debated, they are often referred to as nonspecific and include *cribra orbitalia*, *cribra cranii*, subperiosteal new bone formation (SPNBF), and enamel hypoplasia (Pilloud, Schwitalla 2020, p. 2).

Cribra orbitalia presents as porosity on the orbital roof, and *cribra cranii* occurs on the cranial vault, most frequently on the parietal bones (Walker *et al.* 2009, p. 109). Traditionally, *cribra orbitalia* and *cranii* have been linked to iron deficiency anaemia and typically occur during childhood and infancy (Brickley 2024), but recent research has suggested that their aetiology is multifactorial and could result from genetic haemolytic anaemias (thalassemia or sickle cell disease), megaloblastic anaemia (vitamin B12 or folate deficiencies), inflammatory disease, or chronic parasitic infections (Walker *et al.* 2009, pp. 110-116). *Cribra orbitalia* could be assessed if at least one (right or left) orbital roof was preserved, and *cribra cranii* could be observed if at least one parietal bone was present. *Cribra orbitalia* and *cranii* were evaluated according to the 5-scale scoring system defined by Stuart-Macadam (1991, p. 109). Only severe cases of *cribra orbitalia* and *cranii*, corresponding to stages three to five on the Stuart-Macadam (1991, p. 109) scale, were considered for statistical analyses.

SPNBF on long bones is linked to trauma, nonspecific inflammation, although their aetiology may reflect their own or another pathological condition (Pilloud, Schwitalla 2020, p. 2). In preadults, it can be difficult to discern new bone formation resulting from normal growth versus inflammation caused by pathological processes (Lewis 2007, pp. 134-138). SPNBF in preadults typically presents as an isolated area of new bone raised above the cortex and unilateral (Lewis 2007, pp. 135-136). Active lesions of SPNBF have been suggested to reflect individuals who succumbed to disease or stressors compared to individuals with healed lesions, and thus reflect frailty (DeWitte 2014, p. 39). SPNBF on the long bones was assessed on the femora, tibiae, and fibulae, and an individual was considered observable if a minimum of one tibia was present. Long bones with evidence of trauma or other pathological changes were excluded from assessment of the presence and absence of SPNBF. Bone changes were classified as active, healed, or mixed, and localised or diffused based on the criteria of Stothers and Metress (1975).

Enamel hypoplasia refers to pits or linear grooves on tooth crowns caused by disruptions of amelogenesis during childhood when enamel is forming due to episodes of malnutrition, systemic metabolic disturbances, and disease (Hillson 2014, pp. 184-197). Enamel hypoplasia could be assessed if a minimum of two anterior teeth, incisors or canines, were present and observable from the maxillary or mandibular dentition. Enamel hypoplasia was considered present if it occurred in two or more teeth. The types of enamel hypoplasia were recorded following Buikstra and Ubelaker (1994, p. 56) and the severity as per Corruccini *et al.* (1985).

2.5. Short stature and stunted growth

Prolonged nutritional deficiencies, recurrent infections, disease, and systemic inflammation during development can disrupt growth (Welsh, Brickley 2024, p. 2). Intrinsic and extrinsic environmental factors can constrain the growth rate of bones, and long periods of stress can alter limb proportions and cause stunting and receded adult stature (Humphrey 1998, pp. 70-72; Spake *et al.* 2022, p. 100; Welsh, Brickley 2024, p. 2).

Adult stature was calculated based on the maximum length of long bones, with a preferential use of lower limb bones and the left side, using the regression formulae for Afroamerican males and females by Trotter and Gleser (1958, 1952, 1977) because it is considered the most reliable for archaeological skeletal assemblages from Italy (Giannecchini, Moggi-Cecchi 2008). Short stature was evaluated in adult males and females by comparing the modified Z-scores to the median for each sex group, as recommended for small sample sizes by Pezo-Lanfranco *et al.* (2020). Short stature in adults was classified as final achieved stature below the median.

Preadults could be included for assessment of stunting if they had at least one long bone intact and if their age at death could be estimated from dental development and eruption. Stunted growth in preadults was evaluated in individuals up to 12 years of age at death to avoid the influence of the pubertal growth spurt (Newman, Gowland 2015, pp. 156-158). Stature equations for preadults followed Ruff (2007), and stunting was evaluated using the World Health Organisation's length- and height-for-age formula for Z-scores: $Z=[(x-m)/SD]$. Estimated stature is x, the median of the reference population per age group is m, and the standard deviation of each age range is SD (WHO Multicentre Growth Reference Study Group 2006). The *SD* of Z-scores were compared to the World Health Organisation length and height-for-age charts (WHO Multicentre Growth Reference Study Group 2006), and the European height-for-age charts (Bonthuis *et al.* 2012). Moderate stunting was classified as ≤-2 SD, and severe stunting was classified as ≤-3 SD.

2.6. Chronic respiratory disease

Chronic respiratory disease has a variety of risk factors, including health deficiencies in childhood, as well as environmental influences such as air pollution and high concentrations of fine particulate matter due to both natural (volcanic eruptions, fires, vegetation, dust, pollen) and anthropogenic (industrial and agricultural activities, smoke) influences (Kim *et al.* 2015, p. 137; Lakey *et al.* 2016, p. 1). In archaeological human skeletal remains, chronic respiratory disease can be identified through bone changes to the maxillary sinuses (chronic maxillary sinusitis) and the auditory ossicles (chronic *otitis media*) (Davies-Barrett *et al.* 2021, p. 63; Krenz-Niedbała, Łukasik 2017).

Chronic maxillary sinusitis could be observed in adult individuals with either a right or left maxillary sinus present that was a minimum of 50% preserved, including the floor and either the medial or lateral wall (Riccomi *et al.* 2021, p. 42), and that were taphonomically broken so the internal surfaces could be observed macroscopically. Maxillary sinuses with osseous changes consistent with chronic maxillary sinusitis were included in the study, irrespective of their preservation. Diagnostic features of chronic maxillary sinusitis, including spicules, remodelled spicules, and pitting, followed the definitions of Boocock *et al.* (1995, p. 486). Thickening of the sinus walls was considered as per Casa *et al.* (2025, p. 7), and lobules after Merrett and Pfeiffer (2000, p. 309).

Adult and preadult individuals with at least one auditory ossicle, being either an incus or malleus, could be assessed for osseous changes consistent with chronic *otitis media* because the stapes is the least frequently preserved. Auditory ossicles were examined using stereomicroscopy, and bone changes, including pitting, erosion, bone resorption, and new bone formation, were recorded following Gentile *et al.* (2025) and Krenz-Niedbała and Łukasik (2017). Pitting was differentiated from the vascularisation of the ossicles through the location, quantity and margin of osseous changes (Gentile *et al.* 2025, p. 60). The severity of pathological changes to the ossicles was scored in accordance with Gentile *et al.* (2025).

3. Results

3.1. Demography

A total of 136 individuals were observable for all sites, including 59 individuals from Central Italy and 77 individuals from Northern Italy (tab. 2). Overall, 96 individuals (70.58%) were adults and 40 (29.41%) were preadults, and 49 individuals were estimated males and 32 individuals were estimated females (tab.

Site	**Adult**	**Preadult**	**Male**	**Female**	**Total**
San Genesio	38	21	20	11	59
Verona	18	10	9	5	28
Bariano	8	0	6	2	8
Covo	18	3	6	10	21
Arcole	4	2	2	2	6
Povegliano	10	4	6	2	14
Total	96	40	49	32	136

Tab. 2. Number of individuals by age at death and sex per site.

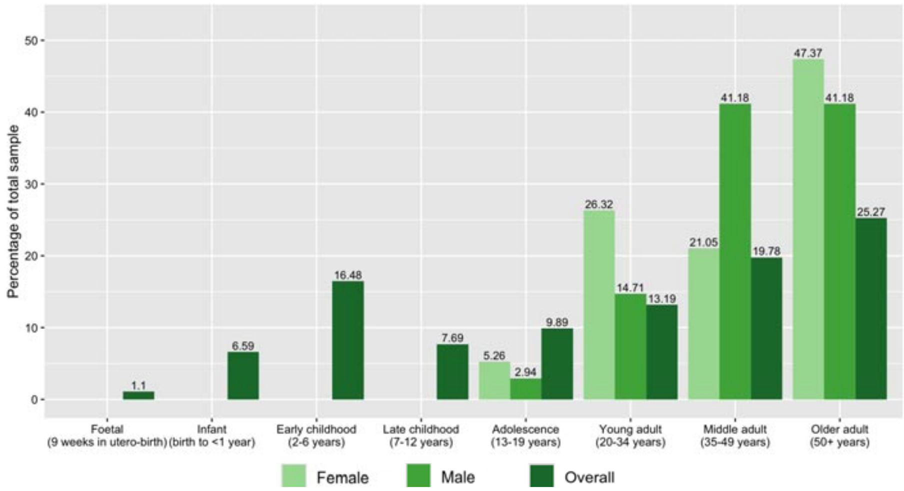

Fig. 3. Proportion of individuals per age at death category for the overall sample, males, and females.

2). Regarding adult age at death, the highest proportion of individuals were older adults (50+ years) at 25.27%, followed by middle (19.78%) and young (13.19%) adults (fig. 3). Preadult mortality was highest in early childhood (two to six years) at 16.48%, followed by adolescence (13-19 years) comprising 9.89% of individuals (fig. 3), late childhood (seven to 12 years) at 7.69% and infants (birth to one year) at 6.59%. Foetuses were underrepresented, accounting for 1.10% of individuals (fig. 3). The most frequent age at death category for females was older adults, followed by young and middle adults, respectively (fig. 3). In contrast, males were equally represented in both middle and older adult categories and least represented by young adults (fig. 3).

3.2. Physiological stress markers

Healed *cribra orbitalia* (score 1) was present in 25.39% (16/63) of individuals, comprising 33.33% (15/45) adults and 5.55% (1/18) preadults. Severe cases of *cribra orbitalia* (score 3-5) occurred in 17.46% of individuals, including 10.64% of adults and 35.29% of preadults (tab. 3). Notably, males were more affected by *cribra orbitalia* than females (tab. 3).

Four individuals (5.63%, 4/71) exhibited healed *cribra cranii* (score 1) on the parietal bones. Active *cribra cranii* presented in 7.04% (5/71) of individuals, being 6.12% (3/49) of adults and 9.09% (2/22) of preadults, and more frequently in females (10.53%, 2/19) than males (3.33%, 1/30) (tab. 3). One infant (~1.5 years of age at death) from San Genesio (SK238) presented porotic changes to the cranial bones consistent with scurvy on the endocranial surface, the orbital

Sample	*Cribra orbitalia*		*Cribra cranii*		SPNBF		Enamel hypoplasia	
	n/N	%	n/N	%	n/N	%	n/N	%
Adults	5/47	10.64%	3/49	6.12%	10/70	14.29%	17/37	45.95%
Preadults	6/17	35.29%	2/22	9.09%	0/23	0	2/9	22.22%
Males	5/28	17.86%	1/30	3.33%	5/35	14.29%	10/24	41.66%
Females	0/17	0	2/19	10.53%	4/28	14.29%	7/12	58.33%
Overall	11/63	17.46%	5/71	7.04%	10/93	10.75%	19/46	41.30%

Tab. 3. Crude frequency of physiological stress markers (severe and active lesions only) (n=affected, N=observable).

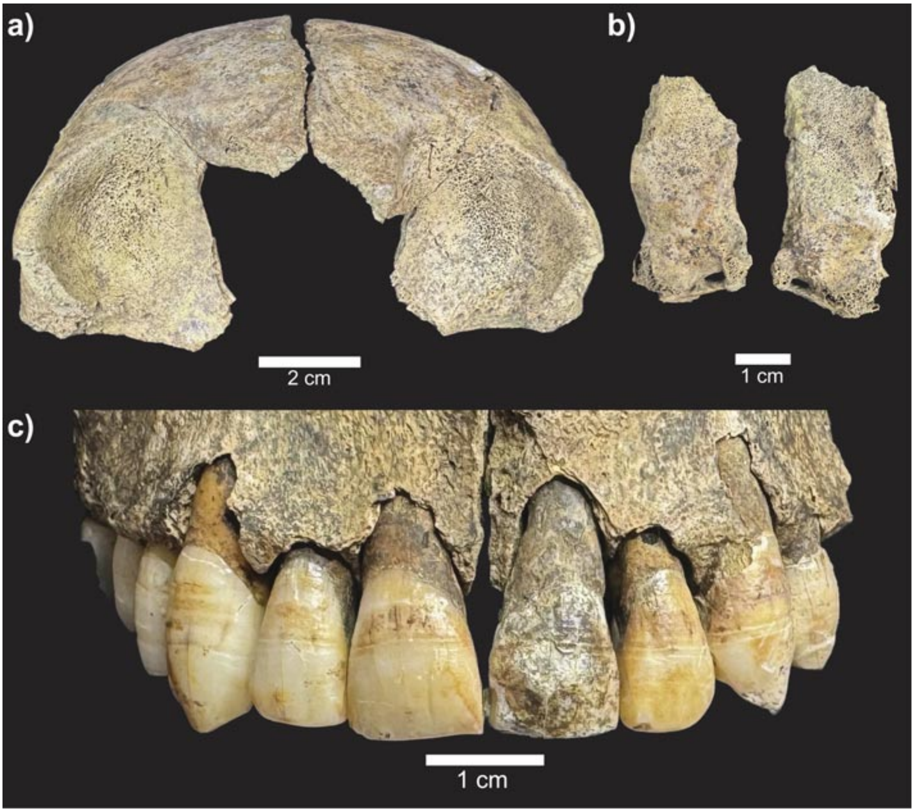

Fig. 4. San Genesio SK238 exhibiting bone changes diagnostic of infantile scurvy: (a) bilateral and symmetrical *cribra orbitalia* of trabecular type in active stage and (b) bilateral and symmetrical porosity <1 mm and new bone formation on the greater wings of the sphenoid; (c) Linear enamel hypoplasia on the anterior maxillary dentition of San Genesio US26122 SK303.

roofs and on the left zygomatic bone (fig. 4a), as well as diagnostic changes to the right and left greater wings of the sphenoid (fig. 4b) (Brickley, Ives 2006).

Lesions of SPNBF occurred in 10.75% (10/93) of individuals, exclusively in adults (14.29%, 10/70), and to a similar extent in both males (14.29%) and females (14.29%) (tab. 3). Enamel hypoplasia was found in 41.30% of individuals, and more than twice as frequent in adults (45.95%) than preadults (22.22%) (tab. 3) (fig. 4c). Females presented enamel hypoplasia more frequently (58.33%) than males (41.66%) (tab. 3).

Enamel hypoplasia was the most common stress marker, followed by *cribra orbitalia*, SPNBF, and, least frequently, *cribra cranii* (tab. 3).

3.3. Short stature and stunted growth

Stature could be calculated for 28 adult males, of which the minimum stature calculation was 161.58 cm and the maximum was 194.32 cm. The mean stature of males was 180.59 cm, and the median was 182.50 cm. Adult female stature could be calculated in 19 individuals and ranged from 140.93 cm to 170.57 cm, with a mean of 154.58 cm and a median of 153.07cm. Stature below the median occurred in 48.39% (14 /28) of estimated males and 47.62% (9/19) of estimated female individuals.

Preadult stature could be estimated for 10 individuals, of which six exhibited stunted growth. When compared to the European height-for-age charts (Bonthuis *et al.* 2012), two preadults exhibited moderate stunting and four preadults had severe stunting (fig. 5). Eight preadults could be compared to the World Health Organisation's length-for-age and height-for-age charts (WHO Multicen-

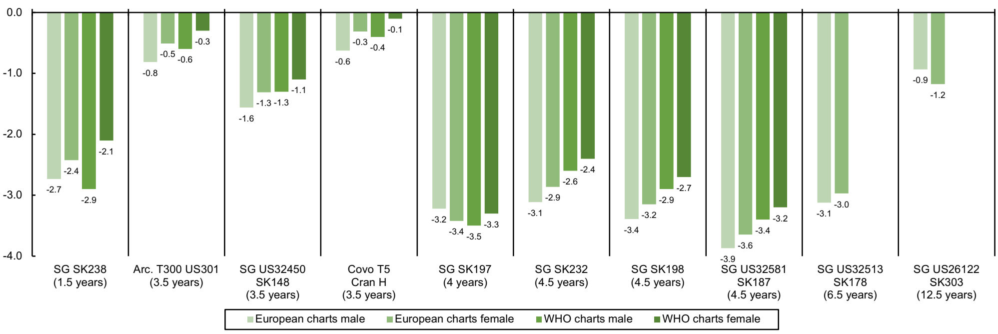

Fig. 5. Standard deviation of preadult stature z-scores compared to the European height-for-age charts and the World Health Organisation (WHO) length and height-for-age charts for males and females (SG=San Genesio, Arc.=Arcole).

tre Growth Reference Study Group 2006), of which three individuals presented moderate stunting at negative two standard deviations, and two individuals had severe stunting at negative three standard deviations, indicating that six of eight preadults had stunted growth (fig. 5).

3.4. Chronic respiratory disease

A total of 35 adult individuals, including 22 males and six females, had at least one preserved and observable maxillary sinus (tab. 4). Overall, 51.52% of individuals presented pathological changes consistent with chronic maxillary sinusitis (tab. 4, figs. 6a-b). A similar frequency of chronic maxillary sinusitis was found in females (60.00%) and males (50.00%) (tab. 4). A total of 29 individuals had at least one incus or malleus present and observable (tab. 4). Chronic *otitis media* occurred in 58.62% of assessable individuals, with a similar frequency in preadults (55.55%) and adults (60%) (tab. 4; figs. 6c-e).

4. Discussion

This study analysed archaeological human skeletal remains from Central and Northern Italy dating to the 6th and 7th centuries CE to determine whether the climatic downturn of the LALIA contributed to the burden of physiological stress, impaired growth, and chronic respiratory disease. Out of the 136 individuals analysed, the majority of individuals lived into adulthood, and specifically into older adulthood, while under one-third (29.41%) of individuals succumbed as preadults, particularly during early childhood (two to six years). In general, females lived into older adulthood more frequently than males, who most often succumbed in middle adulthood. Active cases of *cribra orbitalia* and *cranii*, and SPNBF occurred in a small portion of individuals, whereas enamel hypoplasia occurred in almost half of the observable individuals. Physiological stress mark-

Sample	Chronic maxillary sinusitis		Chronic *otitis media*	
	n/N	%	n/N	%
Adult	17/33	51.52%	12/20	60.00%
Preadult	N/A	N/A	5/9	55.55%
Male	11/22	50.00%	7/9	77.78%
Female	6/10	60.00%	5/10	50.00%
Total	17/33	51.52%	17/29	58.62%

Tab. 4. Crude frequency of chronic maxillary sinusitis and chronic *otitis media* (n=affected, N=observable).

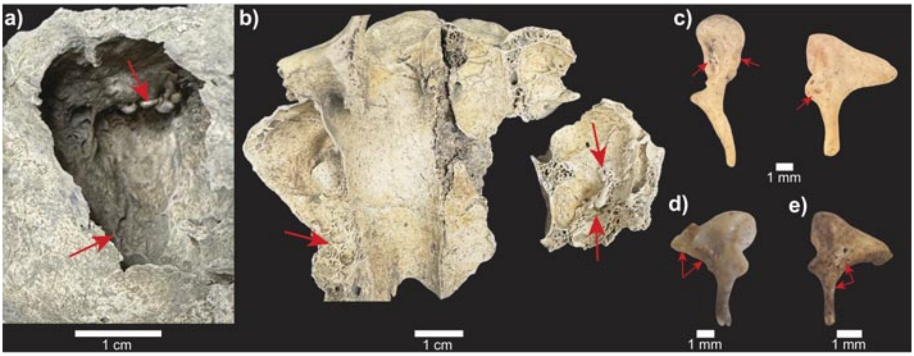

Fig. 6. Osseous changes consistent with chronic maxillary sinusitis in (a) San Genesio US 32521 SK180 right maxillary sinus with remodelled spicules and spicules, and (b) San Genesio US 13022 left (spicules) and right (remodelled spicules and spicules) maxillary sinuses; Bone changes of chronic *otitis media*, (c) San Genesio US 32730 SK230 pitting and erosion of left malleus and pitting of left incus of grade one, (d) San Genesio US 32078 SK89 left incus with periosteal new bone formation, and (e) San Genesio US 32524 SK174 left incus with pitting of grade one.

ers generally occurred in females more than in males, and were relatively similar in adults and preadults. Growth disruptions were evidenced through short stature below the median in roughly half of adult males and females, and more than half of assessable preadults exhibited stunted growth. Chronic respiratory disease was apparent in half of the observable individuals, evidenced by both chronic maxillary sinusitis and chronic *otitis media*.

The stasis between frailty and resilience, morbidity and mortality, is a way in which bioarchaeologists can quantify the intrinsic and extrinsic, as well as anthropogenic and environmental factors, that impact survivorship in the human past. Frailty refers to an individual's ability to survive exposure to stressors (e.g., malnutrition) and disease. Individuals who survive multiple stress events throughout their lives tend to live longer and exhibit greater resilience; however, in turn, these individuals have increased frailty (Marklein *et al.* 2016, p. 209). This leads to the osteological paradox, whereby individuals with increased frailty likely succumbed to disease or stressors before it affected the skeleton, whereas individuals with skeletal lesions likely reflect resilience (McFadden, Oxenham 2020, p. 206; Wood *et al.* 1992). Furthermore, individuals with healed lesions exhibit resilience, whereas individuals with active lesions near the time of death were frailer (McFadden, Oxenham 2020, p. 206; Wood *et al.* 1992).

Considering the climatic disruptions caused by the LALIA in Italy, in combination with the sociopolitical and economic transformation, warfare, pestilence, and famine reported during the 6th and 7th centuries CE, a high level of frailty could be anticipated in the populations of Central and Northern Italy. Despite this, the results of the present study seem to indicate that the majority of individuals lived into older adulthood, and that preadults show a slight increase in mortality during early childhood, but then remain stable into adulthood and increase with age. This mortality pattern corresponds with that of other Lombard period sites, such as Università Cattolica of Milan (Moro *et al.* 2025, p. 5) and La Selvicciola (Salvadei *et al.* 2001, pp. 711-712). However, in these studies, the highest proportion of adults died during middle adulthood.

To assess if there is a shift in the frequency of physiological stress markers coinciding with the 6th and 7th centuries CE in Italy and the LALIA, their prevalence was compared to other published post-Classical sites from Italy preceding and following the temporal scope of the present study. No temporal or geographically relevant comparative studies are available for chronic maxillary sinusitis and chronic *otitis media*. There is a slight shift in mortality patterns from Roman-period sites of the common era compared to the Lombard period. For example, 5th-century CE *Portus Romae* exhibited high childhood mortality, particularly before the age of 10 (De Angelis *et al.* 2025, p. 3), and 1st to 3rd centuries CE *Lucus Feroniae* had higher preadult mortality from birth to three years of age at death (Salvadei *et al.* 2001, p. 712), in addition to a higher proportion of young adults from Isola Sacra and young-middle adults in *Lucus Feroniae* (Manzi *et al.* 1999, p. 330). This pattern of decreasing childhood and young mortality from the Roman to the Medieval period has previously been identified by Baldoni *et al.* (2021, pp. 7-8), and suggests there was a relatively high level of resilience in individuals from Central and Northern Italy during the 6th and 7th centuries CE, which raises questions about the adaptation strategies to the climatic shift of the LALIA.

As the frequencies of *cribra orbitalia* and *cranii*, and SPNBF were less than 17%, they are, in general, substantially lower than those of preceding centuries (tab. 5), suggesting that only a small portion of the sample succumbed to physiological stress. An important consideration is that only active cases were included in frequency counts of the present study, meaning individuals who succumbed while the pathological process was still ongoing. These results support the interpretation that the study sample exhibited resilience in the face of the challenges caused by climatic and anthropogenic changes of the 6th and 7th centuries CE. Comparisons are limited, however, by the differential recording protocol; many studies have not defined whether they included both healed and active cases in their prevalence counts, and some studies only included adults

Tab. 5. Comparative crude frequencies of physiological stress markers from Italian archaeological sites dating to the Common Era.
**Cribra orbitalia* and *cranii* grouped together

Site	**Region**	**Chronological period**	***Cribra orbitalia***	***Cribra cranii***	**SPNBF**	**Enamel hypoplasia**	**Bibliographic reference**
Isola Sacra	Lazio (Central Italy)	1^{st}-2^{nd} centuries				81%	Manzi *et al.* 1999
Urbino (San Donato necropolis and Bivio CH necropolis)	Marche (Central Italy)	1^{st}-3^{rd} centuries CE	41% (15/37)*		31% (13/42 adults)	100% (35/35 adults)	Paine *et al.* 2009
Lucus Feroniae	Lazio (Central Italy)	1^{st}-3^{rd} centuries CE	32.3%	10.7%		82%	Manzi *et al.* 1999; Salvadei *et al.* 2001
Contrada Nevola	Marche (Central Italy)	1^{st}-3^{rd} centuries CE	37.5% (3/7)	37.5% (3/7)	10% (6/60)	30.9% (13/42)	Moro *et al.* 2025
Quadrella, Isernia	Molise (Southern Italy)	1^{st}-4^{th} centuries CE	22.8% (No active cases)		63.4% (tibial)	95.2%	Belcastro *et al.* 2007
Ravenna	Emilia Romagna (Central Italy)	1^{st}-4^{th} centuries CE	60%	44.8%		84%	Facchini *et al.* 2004
Università Cattolica of Milan	Lombardy (Northern Italy)	1^{st}-5^{th} century CE	38.8% (7/18)		24% (12/50)	36% (18/50)	Moro *et al.* 2025
Necroplis of Vallerano	Lazio (Central Italy)	2^{nd}-3^{rd} centuries	69.23% (18/26)				Cucina *et al.* 2006
Rimini	Emilia Romagna (Central Italy)	2^{nd}-4^{th} centuries CE	52.6%	37.8%		57.1%	Facchini *et al.* 2004
Portus Romae	Lazio (Central Italy)	5^{th} century CE	50%	46.15% (6 inds.)	7.14% (1 ind.)		De Angelis *et al.* 2025
Poggio Gramignano	Umbria (Central Italy)	5^{th} century CE	22.64% (12/53, preadults only)	34.48% (20/58, preadults only)	85.11% (40/47, preadults only)	3.12% (1/32, preadults only)	Malis *et al.* 2024
Present study	Lombardy, Veneto, Tuscany (Central and Northern Italy)	6^{th}-7^{th} centuries CE	17.46%	7.04%	10.75%	41.30%	
Vicenne-Campochiro, Campobasso	Molise (Southern Italy)	6^{th}-8^{th} centuries CE	18.7% (No active cases)		52.1% (tibial)	100%	Belcastro *et al.* 2007
Caravaggio (Masano)	Lombardy (Northern Italy)	Early Medieval			14.2% (1/7)		Marinato 2019
Fara Olivana	Lombardy (Northern Italy)	End of 6^{th}-7^{th} centuries CE	44.82% (13/29)	1 ind.	24% (12/50)	10.16% (6/59)	Marinato 2019
La Selvicciola	Lazio (Central Italy)	7^{th} century CE	41.5%	15.5%		75%	Manzi *et al.* 1999; Salvadei *et al.* 2001
Bolgare necropolis	Lombardy (Northern Italy)	7^{th}-9^{th} centuries CE	4 inds.	10 inds.		48 inds.	Sguazza *et al.* 2015
Castel Tirolo	South Tyrol (Northern Italy)	7^{th}-11^{th} centuries CE	8/9 preadults				Paladin *et al.* 2018

or preadults, respectively (tab. 5). Comparative studies (tab. 5) have ascribed *cribra orbitalia* and *cranii* to undernutrition, parasites poor sanitation, weaning practices, cultural traditions, and anaemia potentially relating to lead poisoning (Belcastro *et al.* 2007; Facchini *et al.* 2004; Malis *et al.* 2024). SPNBF has been interpreted as indicative of nonspecific inflammation, nutritional deficiencies, trauma, and localised or systemic infection (Malis *et al.* 2024), which could also account for the occurrence of SPNBF in this study. Similarly, enamel hypoplasia has been attributed to alimentary deficiencies acquired during childhood, parasitic and worm infections, and unsanitary conditions (Belcastro *et al.* 2007; Manzi *et al.* 1999; Facchini *et al.* 2004). Concerning the current study, the LALIA may have contributed to the burden of *cribra orbitalia* and *cranii* through consequent environmental changes impacting both food supply and diversity, leading to nutritional deficiencies, which is also evidenced through the moderate prevalence of enamel hypoplasia in <42% of assessable individuals, the most common physiological stress marker observed. Finally, while the aetiology of cribrotic lesions has been heavily debated (Oxenham, Cavill 2010; Walker *et al.* 2009), they have been linked to iron deficiency anaemia, megaloblastic anaemia (B12/folate deficiency) (Ferrando-Bernal 2023; Rivera, Mirazón Lahr 2017; Wang *et al.* 2023), malaria (Gowland, Western 2012; Smith-Guzmán 2015), and thalassemia (Lewis 2012). The climatic shift of the LALIA in Italy caused increased rainfall and humidity as well as the formation of swamp-like areas (Kaniewski *et al.* 2022, p. 8), which likely served as an ideal breeding ground for mosquitoes and the consequent spread of malaria, which was endemic to Italy until the 20th century. Swamp and marsh areas are known to have existed in the vicinity of the sites of Covo (Marinato 2019, p. 151) and Povegliano (Bruno, Giostra 2012, p. 218), as well as wetlands near Arcole and Bariano (Arzone *et al.* 2021; Fortunati *et al.* 2024). Although malaria could have afflicted individuals from these sites, no evidence of porotic hyperostosis of the cranial vault was found in the current study.

Limited evidence of metabolic disease was found in the current study, with only one child from San Genesio, Tuscany, exhibiting infantile scurvy. Despite this, several other contemporaneous studies from Italy have found evidence of vitamin C deficiency. Another case of infantile scurvy was found in a two-month-old male infant, dating to the 3rd to 5th centuries CE from Piano della Civita di Artena in Central Italy (Cecconi *et al.* 2025). The 7th and 8th centuries CE Lombard necropolis of Selvicciola, Central Italy, presented 22 preadults with pathological features diagnostic of scurvy (Panella *et al.* 2019). In the 7th to 11th centuries CE Castel Tirolo, in South Tyrol, Northern Italy, exhibited two cases of scurvy (Paladin *et al.* 2018, pp. 716, 723). Some of the primary sources of vitamin C include fruits, vegetables, as well as marine fish, and scurvy can develop more rapidly in children due to the nutritional requirements of growth (Brickley, Ives 2006, p. 163). Infantile scurvy can manifest after approximately four to five months of vitamin C deficiency, which impairs collagen synthesis and causes fragile blood vessels, which can cause haemorrhages, as well as defective osteoid formation, leading to bone thinning and widened trabeculae (Brickley, Ives 2006, p. 163; Tamura *et al.* 2000). The underreporting of cases of scurvy in archaeological assemblages from Italy has led to the assumption that such metabolic disorders were not common in Italy (Paladin *et al.* 2018, p. 723); however, vitamin C deficiency is likely underrepresented in the literature due to the poor preservation of archaeological human infantile skeletal remains and a lack of systematic studies on its occurrence. During the post-Classical period, isotopic data from adults suggest an increasing reliance on cereals in Italy (Riccomi *et al.* 2020, pp. 2, 12). Ongoing isotopic studies of children will investigate whether this shift, together with inappropriate weaning practices and variations in the composition of children's diets compared to adults (Mays 2014, p. 60), contributed to the development of metabolic diseases, such as vitamin C deficiency, during the LALIA.

Prolonged periods of malnutrition and disease during childhood cause an energy trade-off between phenotypic adaptation to extrinsic and intrinsic stressors and the prioritisation of biological functions needed for survival (McFadden, Oxenham 2020, p. 206; McPherson 2021; Quade, Gowland 2020). This adaptive resilience causes disruptions to growth, as well as reduced life expectancy and increased frailty (McFadden, Oxenham 2020, p. 206). Concerning the present study, almost half of the adults exhibited evidence of growth disruptions in the form of stature below the median, indicating a high level of adaptive resilience to stressors during childhood. The median calculation of adult stature may, however, be influenced by the different genetic admixture of individuals present at the sites included in the study. For example, at San Genesio, Goths and Lombards of Germanic origin were present at the site, who are known to have a substantially higher stature than those local to Italy for the period (Cantini *et al.* 2017, p. 252; Viva *et al.* 2022). Other sites from Northern Italy (e.g., Verona (Pohl 1997)) are known to have had Lombard occupation, which may have also contributed to deviations in the median stature of adults. Stunted growth in most of the assessable preadults is not wholly surprising when considering the osteological paradox and that the preadults that could be observed were the frailer members of society, and consequently, they succumbed to stressors when they surpassed their bandwidth of adaptive resilience (McFadden, Oxenham 2020; Wood *et al.* 1992).

The onset of volcanic winter in the LALIA created the ideal environment for the spread of respiratory diseases, which could have contributed to the presence of chronic maxillary sinusitis and chronic *otitis media* in more than 50%

of assessable individuals from Central and Northern Italy. The temperature drop of ~2°C caused by the LALIA and resultant colder winters probably caused people to spend more time indoors; in turn, the close proximity indoors to other people and potentially animals would have exacerbated the spread of viral and bacterial diseases and consequently increased the susceptibility of individuals to chronic maxillary sinusitis and chronic *otitis media* (Büntgen *et al.* 2016, pp. 2-3; Gentile *et al.* 2025, p. 64; Panhuysen *et al.* 1997). In addition, the increased time spent indoors likely also heightened exposure to smoke from hearth fires, exacerbated by poor ventilation, a known risk factor for chronic maxillary sinusitis (Panhuysen *et al.* 1997; Riccomi *et al.* 2021, p. 45; Roberts 2007). Agricultural activities are known to be associated with chronic maxillary sinusitis; crop harvesting, ploughing of fields, and the use of animals for labour during cultivation exposed people to dust, animal dander, as well as zoonotic diseases, which could account for part of the burden of chronic maxillary sinusitis in the present study (Åhman *et al.* 2001; Sundaresan *et al.* 2015). The palaeoclimatic changes induced by the LALIA in Italy increased humidity and swamp environments, which in turn would have increased exposure to mould and fungi, which could have both contributed to the burden of chronic maxillary sinusitis (Cacciari *et al.* 2024, p. 1235; Kaniewski *et al.* 2022, p. 8; Slavin *et al.* 2005, p. S16).

After the collapse of the Western Roman Empire in Northern Italy, there was a greater reliance on local resources for subsistence that had been previously underutilised (Rottoli 2014, p. 5). For example, in the Po Valley in northeastern Italy, the LALIA caused cooler and wetter winters, increased humidity, the expansion of wetlands, and stimulated river avulsions (Cacciari *et al.* 2024, p. 1235). In consequence, there was an expansion of lowland cultivation, dominated by oats (*Avena-Triticum*) and barley (*Hordeum*), and a notable introduction of millet (*Panicum miliaceum* (L.), which is characteristic of impoverished environments (Cacciari *et al.* 2024, p. 1235). Archaeobotanical evidence from Northern Italy also supports this model of localised adaptation, with increased cultivation of rye, millet, and sorghum; the spread of edible chestnuts from the 5^{th} to 6^{th} centuries CE; and a combination of cultivated and wild/semi-wild plant species being utilised as part of a self-sufficient system (see Marinato 2019; Rottoli 2014, pp. 5-6). An increasing incorporation of minor crops into the diet during the post-Classical period was apparent at San Genesio, with evidence of both C_3 and C_4 plants consumed by individuals at the site from mid-6^{th} to 7^{th} centuries CE onwards (Riccomi *et al.* 2020, pp. 12-14). These localised adaptive strategies to the climatic fluctuations of the LALIA may account for the low levels of physiological stress observed in the skeletal assemblages from Central and Northern Italy.

5. Conclusion

This study reveals that communities in Central and Northern Italy during the 6th and 7th centuries CE endured a period of profound climatic instability and shifting subsistence strategies with a remarkable degree of resilience. This is supported by mortality patterns indicating the majority of individuals lived into late adulthood, low frequencies of active physiological stress markers, limited evidence of metabolic disease, and a high proportion of individuals encountered growth disruptions and chronic respiratory disease. Archaeobotanical and zooarchaeological data support the interpretation that communities modified their subsistence practices by diversifying crops, exploiting local resources, and shifting their dietary patterns to buffer against climatic fluctuations. Although the bioarchaeological evidence does indicate a relative health impact on individuals during the period (e.g., short stature from growth disruptions), particularly during childhood, the behavioural adjustments likely mitigated the potential impacts of environmental stressors on the nutritional requirements of populations long-term. Future research should systematically assess the frequency of physiological stress markers, growth disruptions, and chronic respiratory disease in archaeological skeletal assemblages from Italy dating from the post-classical period to the end of the Early Middle Ages to determine if there are indeed fluctuations coinciding with the LALIA and other periods of climatic disruption. This study underscores that the human experience of climatic downturns is neither uniformly catastrophic nor uniformly benign; rather, it reflects the interplay between vulnerability, adaptation, and endurance, highlighting how past communities navigated ecological crises – insights that remain strikingly relevant in understanding human responses to climate change today.

Acknowledgements

This research was funded by the project 'Bioarchaeology of climatic change: an investigation on the Late Antique Little Ice Age' (BIOLALIA). 559901_PRIN 2022_GIUFFRA_2022BTT2Y2 CUP: I53D23000060006 Missione 4 "Istruzione e Ricerca" del PNRR, componente C2 – investimento 1.1, Fondo per il Programma Nazionale di Ricerca e Progetti di Rilevante Interesse Nazionale (PRIN).

Prior research on the archaeological remains from Bariano, Covo, Arcole, Verona and Povegliano were conducted by Maurizio Marinato and Alessandra Mazzucchi under the project 'Palaeopathology and molecular analysis in times of transition: understanding diet and health in the early Middle Ages (UDHEMA)' funded through a STARS (Supporting TAlent in ReSearch) Fellowship at the University of Padova, 2020-2022.

The preliminary results of this study were partially presented as a podium presentation at the 52nd Annual Paleopathology Association meeting in Baltimore, Maryland, on the 10th-12th March 2025, and as a poster at the 94th annual meeting of the American Association of Biological Anthropologists from the 12th-15th March 2025, Baltimore, Maryland.

The authors are grateful to the Soprintendenza Archeologia, Belle Arti e Paesaggio for the provinces of Pisa and Livorno; Verona, Rovigo and Vicenza; Padova, Treviso and Belluno; and Bergamo and Brescia, for providing permission to access and analyse the archaeological human skeletal remains from San Genesio, Bariano, Covo *Cascina Bellinzana*, Verona, Arcole, and Povegliano, and for supporting this research.

Abstract
The Late Antique Little Ice Age (LALIA) introduced cooler, wetter conditions to 6th and 7th centuries CE Italy, coinciding with sociopolitical and economic transformation. This study evaluated whether this climatic shift caused physiological disruptions in individuals from Central and Northern Italy during this period. Bioarchaeological analysis of 136 individuals from six sites revealed low frequencies of active physiological stress markers, frequent growth disruptions, and chronic respiratory disease. Despite environmental challenges, most individuals lived into adulthood, exhibiting adaptive resilience. Bioarchaeological evidence suggests local adjustments to subsistence mitigated environmental stress and highlights complex human-environment interactions during the LALIA.
Keywords: LALIA, climate change, volcanic winter, adaptive resilience, frailty.

La piccola era glaciale tardoantica (abbreviata dall'inglese con l'acronimo LALIA) ha portato condizioni climatiche più fredde e umide nell'Italia del VI e VII secolo d.C., in coincidenza con una trasformazione socio-politica ed economica. Questo studio ha valutato se tale cambiamento climatico abbia causato disturbi fisiologici negli individui dell'Italia centrale e settentrionale durante questo periodo. L'analisi bioarcheologica di 136 individui provenienti da sei siti ha rivelato una bassa frequenza di marcatori di stress fisiologici in stadio attivo, frequenti ritardi della crescita e malattie respiratorie croniche. Nonostante le difficoltà ambientali, la maggior parte degli individui è vissuta fino all'età adulta, dimostrando capacità di adattamento. Le prove bioarcheologiche suggeriscono che gli adattamenti locali alla sussistenza hanno mitigato lo stress ambientale e mettono in evidenza le complesse interazioni tra uomo e ambiente durante la piccola era glaciale tardoantica.
Parole chiave*: LALIA, cambiamento climatico, inverno vulcanico, capacità di adattamento, fragilità.*

References

HISTORICAL SOURCES

Cassiodorus, Variae, in A. J. Fridh, J. W. Halporn (eds), CCL, 95, Lund 1973.

STUDIES

G.Y. ACSÁDI, J. NEMESKÉRI 1970, *History of Human Life Span and Mortality*, Budapest.

M. ÅHMAN, M. HOLMSTRÖM, B. KOLMODIN-HEDMAN, A. THELIN 2001, *Nasal symptoms and pathophysiology in farmers*, "International Archives of Occupational and Environmental Health", 74(4), pp. 279-284. DOI: 10.1007/PL00007944.

S.J. ALQAHTANI 2010, *Atlas of Tooth Development and Eruption*, London.

A. ARZONE, B. BRUNO, A. CANCI, G. FALEZZA, A. GABUCCI, M. MARINATO, B. PORTULANO 2012, *Vicende di un insediamento nella pianura veronese nel corso di un millennio: lo scavo archeologico in località Alzana di Arcole (Verona)*, "Archeologia Veneta", XXXIV - 2011, pp. 49-119.

M. BALDONI, A. NARDI, F. DE ANGELIS, O. RICKARDS, C. MARTÍNEZ-LABARGA 2021, *How does diet influence our lives? Evaluating the relationship between isotopic signatures and mortality patterns in Italian Roman Imperial and Medieval periods*, "Molecules", 26(13), 3895. DOI: 10.3390/molecules26133895.

G. BELCASTRO, E. RASTELLI, V. MARIOTTI, C. CONSIGLIO, F. FACCHINI, B. BONFIGLIOLI 2007, *Continuity or discontinuity of the life-style in central Italy during the Roman Imperial Age-Early Middle Ages transition: Diet, health, and behavior*, "American Journal of Physical Anthropology", 132(3), pp. 381-394. DOI:10.1002/ajpa.20530.

M. BINI, G. ZANCHETTA, E. REGATTIERI, I. ISOLA, R. N. DRYSDALE, F. FABIANI, S. GENOVESI, J. C. HELLSTROM 2020, *Hydrological changes during the Roman climatic optimum in northern Tuscany (Central Italy) as evidenced by speleothem records and archaeological data*, "Journal of Quaternary Science", 35(6), pp. 791-802. DOI: 10.1002/jqs.3224.

M. BOLLA 2012, *L'Arena di Verona*, Verona.

M. BONTHUIS, K.J. VAN STRALEN, E. VERRINA, A. EDEFONTI, E.A. MOLCHANOVA, A.C.S. HOKKEN-KOELEGA, F. SCHAEFER, K. J. JAGER 2012, *Use of national and international growth charts for studying height in European children: Development of up-to-date European height-for-age charts*, "PLoS ONE", 7(8), pp. e42506. DOI: 10.1371/journal.pone.0042506.

P. BOOCOCK, C. A. ROBERTS, K. MANCHESTER 1995, *Maxillary sinusitis in Medieval Chichester, England*, "American Journal of Physical Anthropology", 98(4), pp. 483-495. DOI: 10.1002/ajpa.1330980408.

M.B. BRICKLEY 2024, *Perspectives on anemia: Factors confounding understanding of past occurrence*, "International Journal of Paleopathology", 44, pp. 90-104. DOI: 10.1016/j.ijpp.2023.12.001.

M. BRICKLEY, R. IVES 2006, *Skeletal manifestations of infantile scurvy*, "American Journal of Physical Anthropology", 129(2), pp. 163-172. DOI: 10.1002/ajpa.20265.

S. BROOKS, J.M. SUCHEY 1990, *Skeletal age determination based on the os pubis*, "Human Evolution", 5(3), pp. 227-238.

B. BRUNO 2016, *Archeologia nell'Arena di Verona: dati preliminari sugli interventi di scavo 2013-2014*, in S. LUSARDI SIENA, C. PERASSI, F. SACCHI, M. SANNAZARO (eds), *Archeologia classica e post-classica tra Italia e Mediterraneo. Scritti in ricordo di Maria Pia Rossignani*, Milan, pp. 275-284.

B. BRUNO, C. GIOSTRA 2012, *Il territorio di Povegliano Veronese fra Tardantichita e Altomedioevo: nuovi dati e prime riflessioni*, in F. REDI, A. FORGIONE (eds), *VI Congresso Nazionale di Archeologia Medievale* (L'Aquila, 12-15 settembre 2012), Florence, pp. 216-222.

J.L. BUCKBERRY, A.T. CHAMBERLAIN 2002, *Age estimation from the auricular surface of the ilium: A revised method*, "American Journal of Physical Anthropology", 119(3), pp. 231-239. DOI: 10.1002/ajpa.10130.

J.E. Buikstra, D.H. Ubelaker 1994, *Standards for Data Collection from Human Skeletal Remains*, Fayetteville.

U. Büntgen, D. Arseneault, E. Boucher, O.V. Churakova (Sidorova), F. Gennaretti, A. Crivellaro, M.K. Hughes, A.V. Kirdyanov, L. Klippel, P.J. Krusic, H.W. Linderholm, F.C. Ljungqvist, J. Ludescher, M. McCormick, V.S. Myglan, K. Nicolussi, A. Piermattei, C. Oppenheimer, F. Reinig, M. Sigl, E.A. Vaganov, J. Esper 2020, *Prominent role of volcanism in Common Era climate variability and human history*, "Dendrochronologia", 64. DOI:10.1016/j.dendro.2020.125757.

U. Büntgen, A. Crivellaro, D. Arseneault, M. Baillie, D. Barclay, M. Bernabei, J. Bontadi, G. Boswijk, D. Brown, D.A. Christie, O.V. Churakova, E.R. Cook, R. D'Arrigo, N. Davi, J. Esper, P. Fonti, C. Greaves, R.M. Hantemirov, M.K. Hughes, A.V. Kirdyanov, P.J. Krusic, C. Le Quesne, F.C. Ljungqvist, M. McCormick, V.S. Myglan, K. Nicolussi, C. Oppenheimer, J. Palmer, C. Qin, F. Reinig, M. Salzer, M. Stoffel, M. Torbenson, M. Trnka, R. Villalba, N. Wiesenberg, G. Wiles, B. Yang, A. Piermattei 2022, *Global wood anatomical perspective on the onset of the Late Antique Little Ice Age (LALIA) in the mid-6th century CE*, "Science Bulletin", 67(22), pp. 2336-2344. DOI: 10.1016/j.scib.2022.10.019.

U. Büntgen, V.S. Myglan, F.C. Ljungqvist, M. McCormick, N. Di Cosmo, M. Sigl, J. Jungclaus, S. Wagner, P.J. Krusic, J. Esper, J.O. Kaplan, M.A.C. de Vaan, J. Luterbacher, L. Wacker, Q. Tegel, A.V. Kirdyanov 2016, *Cooling and societal change during the Late Antique Little Ice Age from 536 to around 660 AD*, "Nature Geoscience", 9(3), pp. 231-236. DOI: 10.1038/ngeo2652.

M. Cacciari, A. Amorosi, M. Marchesini, S. Marvelli, V. Rossi 2024, *From the Roman Empire to the present: Two millennia of pollen-based environmental changes and climate-human interactions in the Po Delta area (NE Italy)*, "Holocene", 34(9), pp. 1225-1241. DOI: 10.1177/09596836241254487.

F. Cantini 2010, Vicus Wallari-*borgo San Genesio. Il contributo dell'archeologia alla ricostruzione della storia di un* central place *della valle dell'Arno*, in F. Cantini, F. Salvestrini (eds), Vico Wallari-*San Genesio. Ricerca storica e indagini archeologiche su una comunità del Medio Valdarno*, Florence, pp. 81-123.

F. Cantini, C. Citter 2021, *Sistemi di difesa tra guerra Greco-Gotica e invasione Longobarda in area Toscana*, in F. Marazzi, C. Raimondo, G. Hyeraci (eds), *La difesa militare bizantina in Italia (secoli VI-XI)*, Atti del Convegno Internazionale (15-18 aprile 2021), Cerro del Volturno (IS), pp. 201-218.

F. Cantini, S. Viva, F. Marani 2017, *La necropoli di seconda metà VI secolo di San Genesio (San Miniato-Pisa): elementi endogeni ed esogeni*, in C. Ebanista, M. Rottili (eds), *Dalle steppe al mediterraneo popoli, culture, integrazione,* Atti del Convegno Internazionale di Studi (Cimitile-Santa Maria Capua Vetere, 18-19 giugno 2015), Napoli, pp. 251-268.

B. Casa, V. Giuffra, G. Riccomi 2025, *Environment, occupation, and chronic maxillary sinusitis in pre-Roman Italy*, "American Journal of Biological Anthropology", 187(1). DOI: 10.1002/ajpa.70059.

V. Cecconi, A. Nava, F. Lugli, A. Mittnik, S. Sawyer, J. Gadeyne, C. Brouillard, R. Pinhasi, D. Reich, A. Sperduti 2025, *A short and sickly life. Multi-indicator analysis of an infant from a late antique Italian burial site (Piano della Civita, Artena, 3rd-5th cent CE)*, "International Journal of Paleopathology", 49, pp. 93-103. DOI: 10.1016/j.ijpp.2025.03.004.

R.S. Corruccini, J.S. Handler, K.P. Jacobi 1985, *Chronological Distribution of Enamel Hypoplasias and Weaning in a Caribbean Slave Population*, "Biology", 57. https://www.jstor.org/stable/41464779?seq=1&cid=pdf-.

A. Cucina, R. Vargiu, D. Mancinelli, R. Ricci, E. Santandrea, P. Catalano, A. Coppa 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, pp. 104-117. DOI: 10.1002/oa.808.

C. Cunningham, L. Scheuer, S.M. Black 2016, *Developmental Juvenile Osteology*, 2nd ed., London.

A.M. Davies-Barrett, D. Antoine, C.A. Roberts 2021, *Respiratory Disease in the Middle Nile Valley. The impact of environment and aridification*, in G. Robbins Schug (ed), *The Routledge Handbook of the Bioarchaeology of Climate and Environmental Change*, London, pp. 182-206.

F. De Angelis, S. Vaccaro, M. Romboni, M.R. Di Cicco, N. Mantile, S. Altieri, A. Mezzogiorno, M. Lo Blundo, O. Rickards, C. Lubritto, P.F. Rossi 2025, *Echoes from the past: Bioarchaeological insights into the burial grounds of Portus Romae*, "Journal of Archaeological Science: Reports", 61. DOI: 10.1016/j.jasrep.2024.104931.

S.N. DeWitte 2014, *Differential survival among individuals with active and healed periosteal new bone formation*, "International Journal of Paleopathology", 7, pp. 38-44. DOI: 10.1016/j.ijpp.2014.06.001.

F. Facchini, E. Rastelli, P. Brasili 2004, Cribra orbitalia *and* cribra cranii *in Roman skeletal remains from the Ravenna area and Rimini (I-IV century AD)*, "International Journal of Osteoarchaeology", 14(2), pp. 126-136. DOI: 10.1002/oa.717.

D. Ferembach, I. Schwidetzky, M. Stloukal 1980, *Recommendation for age and sex diagnoses of skeletons*, "Journal of Human Evolution", 9, pp. 517-549.

M. Ferrando-Bernal 2023, *Ancient DNA suggests anaemia and low bone mineral density as the cause for porotic hyperostosis in ancient individuals*, "Scientific Reports", 13(1), 6968. DOI: 10.1038/s41598-023-33405-7.

M. Fortunati, M. Marinato, A. Mazzucchi 2024, *Primi dati sull'ex Convento dei Neveri di Bariano (BG)*, in M. Braconi, M. David, V. Fiocchi Nicolai, D. Nuzzo, L. Spera, F.R. Stasolla (eds), *Archeologica Cristiana in Italia. Ricerche, metodi e prospettive (1993-2022)*, Atti del XII Congresso Nazionale di Archeologia Cristiana (Roma, 20-23 settembre 2022), Quingentole (MN), pp. 201-211.

E. Gentile, V. Giuffra, S. Campana, G. Riccomi 2025, *Ossicular chain changes revealed middle ear inflammation in medieval rural central Italy (Tuscany 10th-12th century)*, "International Journal of Paleopathology", 49, pp. 58-68. DOI: 10.1016/j.ijpp.2025.02.008.

M. Giannecchini, J. Moggi-Cecchi 2008, *Stature in archeological samples from central Italy: Methodological issues and diachronic changes*, "American Journal of Physical Anthropology", 135(3), pp. 284-292. DOI: 10.1002/ajpa.20742.

R.L. Gowland, A. G. Western 2012, *Morbidity in the marshes: Using spatial epidemiology to investigate skeletal evidence for malaria in Anglo-Saxon England (AD 410–1050)*, "American Journal of Physical Anthropology", 147(2), pp. 301-311. DOI: 10.1002/ajpa.21648.

J.L. Gunn 2000 *The Years without Summer. Tracing A.D. 536 and its Aftermath*, Oxford.

S.E. Halcrow, N. Tayles 2008, *The bioarchaeological investigation of childhood and social age: Problems and prospects*, "Journal of Archaeological Method and Theory", 15(2), pp. 190-215. DOI: 10.1007/s10816-008-9052-x.

M. Harbeck, L. Seifert, S. Hänsch, D.M. Wagner, D. Birdsell, K.L. Parise, I. Wiechmann, G. Grupe, A. Thomas, P. Keim, L. Zöller, B. Bramanti, J.M. Riehm, H.C. Scholz 2013, *Yersinia pestis DNA from Skeletal Remains from the 6th Century AD Reveals Insights into Justinianic Plague*, "PLoS Pathogens", 9(5). DOI: 10.1371/journal.ppat.1003349.

J. Haldon, H. Elton, S.R. Huebner, A. Izdebski, L. Mordechai, T.P. Newfield 2018, *Plagues, climate change, and the end of an empire: A response to Kyle Harper's The Fate of Rome* (1, 2 &3), "History Compass", 16(12), e12506. DOI: 10.1111/hic3.12506.

K. Harper 2017, *The Fate of Rome: Climate, Disease, and the End of an Empire*, Princeton.

S. Hillson 2014, *Tooth Development in Human Evolution and Bioarchaeology*, Cambridge.

L.T. Humphrey 1998, *Growth Patterns in the Modern Human Skeleton*, "American Journal of Physical Anthropology", 105, pp. 57-72.

I. Isola, G. Zanchetta, R.N. Drysdale, E. Regattieri, M. Bini, P. Bajo, J.C. Hellstrom, I. Baneschi, P. Lionello, J. Woodhead, A. Greig 2019, *The 4.2ka event in the central Mediterranean: new data from a Corchia speleothem (Apuan Alps, central Italy)*, "Climate of the Past", 15(1), pp. 135-151. DOI: 10.5194/cp-15-135-2019.

D. Kaniewski, N. Marriner, G. Sarti, D. Bertoni, M. Marchesini, V. Rossi, A. Lena, A. Bivolaru, M. Pourkerman, M. Vacchi, R. Cheddadi, T. Otto, F. Luce, D. Cottica, C. Morhange 2022, *Northern Adriatic environmental changes since 500 AD reconstructed at Aquileia (Italy)*, "Quaternary Science Reviews", 287, 107565. DOI: 10. 1016/j.quascirev.2022.107565.

K.H. Kim, E. Kabir, S. Kabir 2015, *A review on the human health impact of airborne particulate matter*, "Environment International", 74, pp. 136-143.

A.R. Klales, S.D. Ousley, J.M. Vollner 2012, *A revised method of sexing the human innominate using Phenice's nonmetric traits and statistical methods*, "American Journal of Physical Anthropology", 149(1), pp. 104-114.

M. Krenz-Niedbała, S. Łukasik 2017, *Skeletal evidence for otitis media in medieval and post-medieval children from Poland, Central Europe*, "International Journal of Osteoarchaeology", 27(3), pp. 375-386.

Z. Laffranchi, A. Mazzucchi, S. Thompson, A. Delgado-Huertas, A. Granados-Torres, M. Milella 2020, *Funerary reuse of a Roman amphitheatre: Palaeodietary and osteological study of Early Middle Ages burials (8th and 9th centuries AD) discovered in the Arena of Verona (Northeastern Italy)*, "International Journal of Osteoarchaeology", 30(4), pp. 435-448. DOI: 10.1002/oa.2872.

P.S.J. Lakey, T. Berkemeier, H. Tong, A.M. Arangio, K. Lucas, U. Pöschl, M. Shiraiwa 2016, *Chemical exposure-response relationship between air pollutants and reactive oxygen species in the human respiratory tract*, "Scientific Reports", 6, 32916. DOI: 10.1038/srep32916.

M.E. Lewis 2007, *The Bioarchaeology of Children: Perspectives from Biological and Forensic Anthropology*, Cambridge.

M.E. Lewis 2012, *Thalassaemia: Its diagnosis and interpretation in past skeletal populations*, "International Journal of Osteoarchaeology", 22(6), pp. 685-693.

L.K. Little 2007, *Life and afterlife of the first plague pandemic*, in L.K. Little (ed), *Plague and the End of Antiquity. The Pandemic of 541-750*, Cambridge, pp. 3-32.

C.O. Lovejoy, R.S. Meindl, T.R. Pryzbeck, R.P. Mensforth 1985, *Chronological metamorphosis of the auricular surface of the ilium: A new method for the determination of adult skeletal age at death*, "American Journal of Physical Anthropology", 68(1), pp. 15-28.

I. Labuhn, M. Finné, A. Izdebski, N. Roberts, J. Woodbridge 2019, *Climatic changes and their impacts in the Mediterranean during the first millennium AD*, in A. Izdebski, M. Mulryan (ed), *Environment and Society in the Long Late Antiquity,* Leiden-Boston, pp. 65-88.

J. Luterbacher, T.P. Newfield, E. Xoplaki, E. Nowatzki, N. Luther, M. Zhang, N. Khelifi 2020, *Past pandemics and climate variability across the Mediterranean*, "Euro-Mediterranean Journal for Environmental Integration", 5, 46. DOI: 10.1007/s41207-020-00197-5.

S.W. Malis, J.A. Wilson, M.K. Zuckerman, A.J. Osterholtz, J. Paige, S. Miller, L. Paraman, D. Soren 2024, *Compromised health: Examining growth and health in a late antique Roman infant and child cemetery*, "American Journal of Biological Anthropology", 184(2), e24925. DOI: 10.1002/ajpa.24925.

G. Manzi, L. Salvadei, A. Vienna, P. Passarello 1999, *Discontinuity of life conditions at the transition from the Roman imperial age to the early middle ages: Example from central Italy evaluated by pathological dento-alveolar lesions*, "American Journal of Human Biology", 11(3), pp. 327-341.

M. Marinato 2019, *Alimentazione, salute e mobilità della popolazione in Italia settentrionale tra IV e VIII secolo. Approcci bioarcheologici*, Mantova.

K.E. Marklein, R.E. Leahy, D.E. Crews 2016, *In sickness and in death: Assessing frailty in human skeletal remains*, "American Journal of Physical Anthropology", 161(2), pp. 208-225.

S. Mays 2014, *The palaeopathology of scurvy in Europe*, "International Journal of Paleopathology", 5, pp. 55-62.

M. McCormick 2013, *What climate science, Ausonius, Nile floods, rye and thatch tell us about the environmental history of the Roman Empire*, in W.V. Harris (ed), *The Ancient Mediterranean Environment between Science and History*, New York, pp. 61-88.

M. McCormick, U. Büntgen, M.A. Cane, E.R. Cook, K. Harper, P. Huybers, T. Litt, S.W. Manning, P.A. Mayewski, A.F.M. More, K. Nicolussi, W. Tegel 2012, *Climate change during and after the Roman Empire: Reconstructing the past from scientific and historical evidence*, "Journal of Interdisciplinary History", 43(2), pp. 169-220.

C. McFadden, M.F. Oxenham 2020, *A paleoepidemiological approach to the osteological paradox: Investigating stress, frailty and resilience through* cribra orbitalia, "American Journal of Physical Anthropology", 173(2), pp. 205-217. DOI: 10.1002/ajpa.24091.

D.C. Merrett, S. Pfeiffer 2000, *Maxillary sinusitis as an indicator of respiratory health in past populations*, "American Journal of Physical Anthropology", 111(3), pp. 301-318.

C. Moro, L. Biehler-Gomez, F. Boschi, C. Cattaneo 2025, *Urban vs rural lifestyle in Roman Italy: a bioarchaeological and paleopathological investigation*, "Journal of Archaeological Science: Reports", 62, 105007. DOI: 10.1016/j.jasrep.2025.105007.

T.N. Newfield 2018, *Mysterious and mortiferous clouds: The climate cooling and disease burden of Late Antiquity*, "Late Antique Archaeology", 12, pp. 89-115.

S.L. Newman, R.L. Gowland 2015, *The use of non-adult vertebral dimensions as indicators of growth disruption and non-specific health stress in skeletal populations*, "American Journal of Physical Anthropology", 158(1), pp. 155-164.

M.F. Oxenham, I. Cavill 2010, *Porotic hyperostosis and cribra orbitalia: the erythropoietic response to iron-deficiency anaemia*, "Anthropological Science", 118(3), pp. 199-200.

R.R. Paine, R. Vargiu, C. Signoretti, A. Coppa 2009, *A health assessment for Imperial Roman burials recovered from the necropolis of San Donato and Bivio CH, Urbino, Italy*, "Journal of Anthropological Sciences", 87, pp. 193-210.

A. Paladin, J. Wahl, A. Zink 2018, *Evidence of probable subadult scurvy in the Early Medieval cemetery of Castel Tirolo, South Tyrol, Italy*, "International Journal of Osteoarchaeology", 28(6), pp. 714-726.

S. Panella, I. Micarelli, R.R. Paine, M.A. Tafuri, G. Manzi 2019, *Scurvy among 22 juvenile burials from an early Italian medieval anthropological series that may have also been affected by tuberculosis*, Conference Paper presented at: V Meeting Nazionale GiPaleo - Gruppo Italiano di Paleopatologia.

R.G.A.M. Panhuysen, V. Coenen, T. D. Bruintjes 1997, *Chronic Maxillary Sinusitis in Medieval Maastricht, the Netherlands*, "International Journal of Osteoarchaeology", 7(6), pp. 610-614.

P.N. Peregrine 2020, *Climate and social change at the start of the Late Antique Little Ice Age*, "The Holocene", 30(11), pp. 1643-1648.

L. Pezo-Lanfranco, J. Filippini, M. Di Giusto, C. Petronilho, V. Wesolowski, P. DeBlasis, S. Eggers 2020, *Child development, physiological stress and survival expectancy in prehistoric fisher-hunter-gatherers from the Jabuticabeira II shell mound, South Coast of Brazil*, "PLOS ONE", 15(3), pp. e0229684. DOI: 10. 1371/journal.pone.0229684.

M.A. Pilloud, A.W. Schwitalla 2020, *Re-evaluating traditional markers of stress in an archaeological sample from central California*, "Journal of Archaeological Science", 116, 105102. DOI: 10.1016/j.jas. 2020.105102.

W. Pohl 1988, *The Avars. A Steppe Empire in Central Europe*, Ithaca NY.

W. Pohl 1997, *The Empire and the Lombards: treaties and negotiations in the sixth century*, in W. Pohl (ed), *Kingdoms of the Empire. The Integration of Barbarians in Late Antiquity*, Leiden, pp. 75-134.

G. Riccomi, J. Casaccia, S. Minozzi, C. Felici, S. Campana, V. Giuffra 2021, *Maxillary sinusitis as a respiratory health indicator: a bioarchaeological investigation into medieval central Italy*, "International Journal of Paleopathology", 35, pp. 40-48. DOI: 10.1016/j.ijpp.2021.09.001.

G. Riccomi, S. Minozzi, J. Zech, F. Cantini, V. Giuffra, P. Roberts 2020, *Stable isotopic reconstruction of dietary changes across Late Antiquity and the Middle Ages in Tuscany*, "Journal of Archaeological Science: Reports", 33, 102546. DOI: 10. 1016/j.jasrep.2020.102546.

F. Rivera, M. Mirazón Lahr 2017, *New evidence suggesting a dissociated etiology for cribra orbitalia and porotic hyperostosis*, "American Journal of Physical Anthropology", 164(1), pp. 76-96.

C.A. Roberts 2007, *A bioarcheological study of maxillary sinusitis*, "American Journal of Physical Anthropology", 133(2), pp. 792-807.

M. Rottoli 2014, *Reflections on Early Medieval resources in northern Italy: The archaeobotanical and archaeozoological data*, "Quaternary International", 346, pp. 20-27.

C. Ruff 2007, *Body size prediction from juvenile skeletal remains*, "American Journal of Physical Anthropology", 133(1), pp. 698-716.

L. Salvadei, F. Ricci, G. Manzi 2001, *Porotic hyperostosis as a marker of health and nutritional conditions during childhood: Studies at the transition between imperial Rome and the early Middle Ages*, "American Journal of Human Biology", 13(6), pp. 709-717.

E. Sguazza, A. Mazzucchi, M. Fortunati, C. Cattaneo 2015, *The necropolis of Bolgare (Lombardy, Italy): Anthropological and paleopathological features of a Lombard population*, "Homo", 66(2), pp. 139-148.

M. Sigl, M. Winstrup, J.R. McConnell, K.C. Welten, G. Plunkett, F. Ludlow, U. Büntgen, M. Caffee, N. Chellman, D. Dahl-Jensen, H. Fischer, S. Kipfstuhl, C. Kostick, O.J. Maselli, F. Mekhaldi, R. Mulvaney, R. Muscheler, D.R. Pasteris, J.R. Pilcher, M. Salzer, S. Schüpbach, J.P. Steffensen, B.M. Vinther, T.E. Woodruff 2015, *Timing and climate forcing of volcanic eruptions for the past 2,500 years*, "Nature", 523(7562), pp. 543-549.

R.G. Slavin, S.L. Spector, I.L. Bernstein, R.G. Slavin, M.A. Kaliner, D.W. Kennedy, F.S. Virant, E.R. Wald, D.A. Khan, J. Blessing-Moore, D.M. Lang, R.A. Nicklas, J.J. Oppenheimer, J.M. Portnoy, D.E. Schuller, S.A. Tilles, L. Borish, R.A. Nathan, B.A. Smart, M.L. Vandewalker 2005, *The diagnosis and management of sinusitis: A practice parameter update*, "Journal of Allergy and Clinical Immunology", 116(6), pp. S13-S47. DOI: 10.1016/ j.jaci.2005.09.048.

N.E. Smith-Guzmán 2015, Cribra orbitalia *in the ancient Nile Valley and its connection to malaria*, "International Journal of Paleopathology", 10, pp. 1-12. DOI: 10.1016/ j.ijpp.2015.03.001.

L. Spake, R.D. Hoppa, S. Blau, H.F.V. Cardoso 2022, *Biological mortality bias in diaphyseal growth of contemporary children: Implications for paleoauxology*, "American Journal of Biological Anthropology", 178(1), pp. 89-107. DOI: 10.1002/ajpa. 24486.

D.M. Stothers, J.F. Metress 1975, *A system for the description and analysis of pathological changes in prehistoric skeletons*, "Ossa", pp. 3-9.

R.B. Stothers 1984, *Mystery cloud of AD 536*, "Nature", 307, pp. 344-345.

R.B. Stothers, M.R. Rampino 1983, *Volcanic eruptions in the Mediterranean before A.D. 630 from written and archaeological sources*, "Journal of Geophysical Research", 88(B8), pp. 6357-6371.

P. Stuart-Macadam 1991, *Anaemia in Roman Britain*, in H. Bush, M. Zvelebil (eds), *Health in Past Societies. Biocultural interpretations of human remains in archaeological contexts*, Oxford, pp. 101-113.

A.S. Sundaresan, A.G. Hirsch, M. Storm, B.K. Tan, T.L. Kennedy, J.S. Greene, Jr.C. Kern, B.S. Schwartz 2015, *Occupational and environmental risk factors for chronic rhinosinusitis: a systematic review*, "International Forum of Allergy & Rhinology", 5(11), pp. 996-1003.

Y. Tamura, D.C. Welch, J.A. Zic, W.O. Cooper, S.M. Stein, D.S. Hummell 2000, *Scurvy presenting as painful gait with bruising in a young boy*, "Archives of Pediatrics & Adolescent Medicine", 154(7), 732. DOI: 10.1001/archpedi.154.7.732.

M. Toohey, K. Krüger, M. Sigl, F. Stordal, H. Svensen 2016, *Climatic and societal impacts of a volcanic double event at the dawn of the Middle Ages*, "Climatic Change", 136(3-4), pp. 401-412.

M. Trotter, G. Gleser 1952, *Estimation of stature from long bones of American Whites and Negroes*, "American Journal of Physical Anthropology", 10(4), pp. 463-514.

M. Trotter, G. Gleser 1958, *A re-evaluation of estimation of stature based on measurements of stature taken during life and of long bones after death*, "American Journal of Physical Anthropology", 16(1), pp. 79-123.

M. Trotter, G. Gleser 1977, *Corrigenda to "estimation of stature from long limb bones of American Whites and Negroes," American Journal Physical Anthropology (1952)*, "American Journal of Physical Anthropology", 47(2), pp. 355-356.

S. Viva, C. Lubritto, F. Cantini, P.F. Fabbri 2022, *Evidence of Barbarian migrations and interpersonal violence during the Gothic War in sixth-century Tuscany: the case of the Goth horseman from San Genesio (Pisa)*, "Archaeological and Anthropological Sciences", 14(3), 39. DOI: 10.1007/s12520-022-01515-4.

A. Volkmann 2015, *Climate change, environment and migration: a GIS-based study of the Roman Iron Age to the Early Middle Ages in the river Oder region*, "European Journal of Post-Classical Archaeologies", 5, pp. 69-94.

P.L. Walker 2008, *Sexing skulls using discriminant function analysis of visually assessed traits*, "American Journal of Physical Anthropology", 136(1), pp. 39-50.

P.L. Walker, R.R. Bathurst, R. Richman, T. Gjerdrum, V.A. Andrushko 2009, *The causes of porotic hyperostosis and* cribra orbitalia*: A reappraisal of the iron-deficiency-anemia hypothesis*, "American Journal of Physical Anthropology", 139(2), pp. 109-125.

T. Wang, C. McFadden, H. Buckley, K. Domett, A. Willis, H.H. Trinh, H. Matsumura, M. Vlok, M.F. Oxenham 2023, *Paleoepidemiology of cribra orbitalia: Insights from early seventh millennium BP Con Co Ngua, Vietnam*, "American Journal of Biological Anthropology", 181(2), pp. 250-261. DOI: 10.1002/ajpa.24738.

H. Welsh, M.B. Brickley 2024, *Investigating femoral growth disruption in subadults from the 10th-13th century St. Étienne cemetery of Toulouse, France*, "American Journal of Biological Anthropology", 185(1), 24984. DOI:10.1002/ajpa.24984.

WHO Multicentre Growth Reference Study Group 2006, *WHO Child Growth Standards: Methods and development: Length/height-for-age, weight-for-length, weight-for-height and body mass index-for-age: Methods and development*, Geneva.

J.W. Wood, G.R. Milner, H.C. Harpending, K.M. Weiss 1992, *The osteological paradox*, "Current Anthropology", 33(4), pp. 343-370.

G. Zanchetta, M. Bini, K. Bloomfield, A. Izdebski, N. Vivoli, E. Regattieri, I. Isola, R.N. Drysdale, P. Bajo, J.C. Hellstrom, R. Wiśniewski, A.E. Fallick, S. Natali, M. Luppichini 2021, *Beyond one-way determinism: San Frediano's miracle and climate change in Central and Northern Italy in late antiquity*, "Climatic Change", 165(1-2), 25. DOI: 10.1007/s10584-021-03043-x.

K.A. Zonneveld, K. Harper, A. Klügel, L. Chen, G. De Lange, G.J.M. Versteegh 2024, *Climate change, society, and pandemic disease in Roman Italy between 200 BCE and 600 CE*, "Science Advances", 10(4). DOI: 10.1126/sciadv.adk1033.