



Diachronic shifts in biological parameters from prehistory to modernity in Barcelona

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Abstract

The present study analyzes the biological parameters of life expectancy at birth (LE), stature (ST), body mass (BM), and body mass index (BMI) in the population of Barcelona from Prehistory through to the Modern period. The objective is to assess whether these biological parameters exhibit measurable diachronic shifts corresponding to sociocultural and environmental change. Skeletal remains were analyzed using standard anthropological methods. Sex-related differences were evaluated using Student's t-tests or Mann–Whitney U tests, depending on data distribution, while temporal trends were assessed through one-way ANOVA. The sample comprises 1,090 individuals: 297 non-adults and 793 adults (258 males, 244 females, and 291 of undetermined sex). Results indicate that LE remained relatively almost stable across most periods, ranging from 21 to 27 years, with a marked increase during the Modern period. ST showed no significant diachronic variation, with male averages ranging between 164 and 166 cm and female averages between 151 and 154 cm. Notably, underweight and obese classifications emerged in more recent periods, suggesting that biological outcomes were influenced by socio-environmental and historical contexts. By integrating multiple biological indicators, this study offers a comprehensive assessment of human adaptation in Barcelona over almost seven millennia. Despite potential sampling limitations, it provides a valuable reference framework for future diachronic bioarchaeological research in the Iberian Peninsula and contributes to a broader discussion on the relationship between human biology, environment, and history. This study represents the largest sample and the broadest chronological range analyzed in the Iberian Peninsula to date.

Keywords Diachronic study · Life expectancy · Stature · Body mass · Paleodemography · Biological anthropology

Introduction

Barcelona is a city on the northeastern coast of the Iberian Peninsula, situated in the province of the same name and in the autonomous community of Catalonia, Spain (Fig. 1A and B). Currently, it is the second-most populous municipality in Spain and the fifth in the European Union, characterized by its rich cultural and historical heritage. The city's development has been shaped by almost over seven millennia of human settlement, cultural transitions, and societal

evolution. The earliest evidence of human habitation in the city of Barcelona dates back approximately to 5500 BCE, during the Neolithic period (Pericot 1960). Archaeological findings in this period, including human and animal remains, pottery fragments, stone tools, and traces of rudimentary farming, have been uncovered at various sites across the city (Riu 2016).

In Catalonia, bioanthropological research has traditionally relied on localized datasets derived from individual archaeological assemblages or site-specific anthropological reports (e.g., Jordana and Malgosa 2007; Pujol et al. 2011). Although these studies provide valuable insights into discrete populations, their limited spatial and temporal scope constrains broader interpretations of demographic dynamics, particularly within major urban centers such as Barcelona (Cevallos et al. 2026). This fragmentation highlights the need for comprehensive bioanthropological approaches that integrate multiple assemblages within a shared geographic context and span extended chronological frameworks. Such

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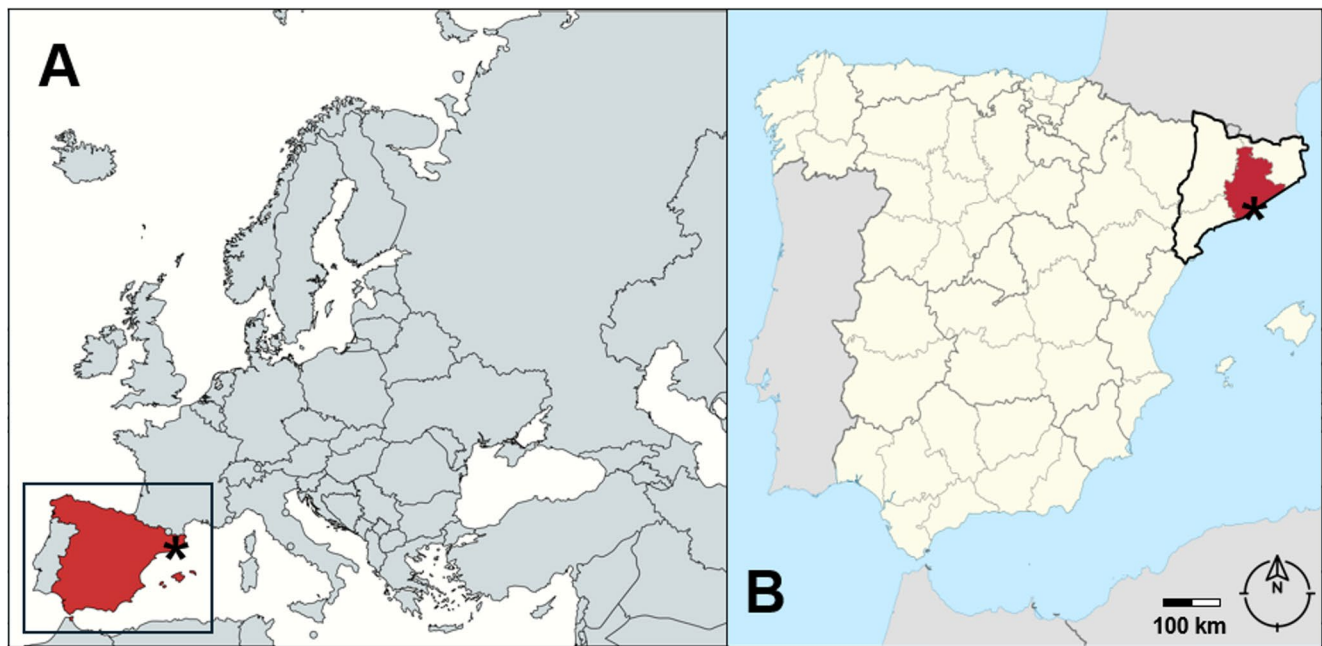


Fig. 1 (A) Map of Europe indicating the location of Spain in red. (B) Enlarged view of the Iberian Peninsula depicting Spain (white), the autonomous community of Catalonia (thick black outline), the province of Barcelona (red), and the city of Barcelona (*)

integration allows for the establishment of baseline biological and demographic patterns, facilitating robust diachronic comparisons and reducing geographical and social biases. It is noteworthy that this framework facilitates the identification of long-term trends, encompassing mortality crises, disease prevalence, and other significant demographic transformations (Weiss 1975; McFadden 2021).

Biological parameters such as life expectancy at birth (LE), stature (ST), body mass (BM), and body mass index (BMI) are particularly informative for reconstructing broad patterns in past populations. LE offers insight into survivorship and overall mortality regimes, while ST reflects long-term growth conditions shaped by nutritional status, disease burden, and environmental stress during critical developmental periods. BM and BMI, although necessarily estimated, provide complementary information on body composition and energetic status, helping to contextualize dietary practices and lifestyle strategies. When considered together, these four variables, support a cautious yet integrative interpretation of population-level biological and demographic trends through time.

A person's phenotype reflects the interaction between genetic and environmental factors (McClearn 2004). LE, ST, BM, and BMI are particularly sensitive to external influences that affect growth, such as nutrition and health, including socioeconomic conditions, life disruptions such as migration or famine, physiological stress, environmental change, social status, urbanization, demographic cycles, and

the spread of infectious diseases (Steckel 2004; Elliott et al. 2014; Vilcins et al. 2018; Sørensen et al. 2020). Although these traits are partially determined by genetic factors, they are strongly modulated by environmental influences (Formicola and Giannecchini 1999; Kemkes-Grotenthaler 2005; Marciniak et al. 2022). This complex interplay has made the ST particularly, a widely used indicator of stress in biological anthropology, reflecting responses to climate variability, nutritional constraints, health status, and broader socio-environmental conditions (Vercellotti et al. 2014; Perkins et al. 2016; Temple and Edes 2022). Environmental pressures may reduce growth velocity and prevent individuals from reaching their genetic growth potential, rendering these biological traits especially sensitive proxies for reconstructing living conditions and microevolutionary trends (Uliaszek 2010; Jelenkovic et al. 2016).

Diachronic bioanthropological research across Europe has highlighted the value of integrating biological parameters to contextualize population changes and adaptive responses within specific geographic settings (e.g., Koukli et al. 2023; Parkinson et al. 2023; Mongillo et al. 2025). Building on this approach, the present study undertakes a diachronic analysis of the population of the city of Barcelona from Prehistory through the Modern period, examining LE, ST, BM and BMI alongside documentary evidence. The aim of this study is to evaluate whether these biological parameters exhibit measurable diachronic shifts corresponding to

sociocultural and environmental transformations. On the other hand, Barcelona city allows the observation of these four parameters in a major European city throughout history and reduces geographical and social biases.

Prehistorical and historical context

There is limited paleodemographic and bioanthropological data from the Prehistory in Barcelona city due to fragmentary burial records and poor preservation conditions, hindering analyses of population health and preventing the collection of genetic data from archaeological assemblages to date (Malgosa 2016). During the Neolithic and Bronze periods in the city of Barcelona was sparsely populated, with small settlements of huts. The recovered grave goods reveal the technology used in their work and the first trade exchanges (Gómez et al. 2015). Studies reveal an increase in agricultural activity, including grain production, while ovicaprids provided essential resources in the early Bronze Age (Gómez and Molist 2016). In these periods, burials were conducted collectively within hypogea, exhibiting no discernible social differentiation, as documented at the Plaça de la Gardunya (Gardunya Square) by Velasco et al. (2017).

Furthermore, a study of the diet of Early Bronze Age populations from the city of Barcelona suggests a mixed diet, with a high consumption of meat, secondary animal products, and fish (Gluitz et al. 2023). It is important to say that during this period, the Mediterranean area experienced more humid climatic conditions, known as the Holocene climatic optimum. This was an important factor for Neolithic settlement in the city of Barcelona, especially given its proximity to the sea. It is important to note that sea levels were significantly affected by the melting of polar ice caps during this period (Wanner et al. 2008; Riera et al. 2016).

One of the most defining transitions in Barcelona city's history came with Roman colonization (1st century – 4th century CE). During this period, Barcelona, known as *Barcino*, was founded by Emperor Augustus in 14 BCE. The city was strategically situated on a hill (Mont Taber) and followed the typical Roman colony layout, with two main streets, *Decumanus Maximus* and *Cardo Maximus*, intersecting at right angles (Hernández 2001). *Barcino* flourished as an agricultural and commercial hub, producing significant quantities of cereals, wine, and iron, and was well connected via trade routes along the Llobregat River (Álvarez and Estrada 2009). Seafaring and fishing, particularly oyster production, also played a crucial role in the city's economy and fish consumption (Rissech et al. 2016). As usual in the Roman cities, *Barcino* necropolises were located outside the city walls but along the main roads (Prida 2009). These burial areas were organized by social status, with higher-status individuals buried closer to the city gates. Two major

burial areas have been found so far in Barcelona city. One is situated in the northeast of *Barcino* and is related to the *Porta Principal Sinistra*, and the other lies to the southwest of *Barcino* and is related to the *Sea Gate* (Prida 2009; Beltrán de Heredia 2010).

The period of late Antiquity in *Barcino*, spanning from the 5th to the 7th century CE, marked a significant transition from Roman rule to Visigothic dominance on the Iberian Peninsula. This period was characterized by political, social, economic, and cultural changes, including the fall of the Western Roman Empire and the rise of Christianity (Puig 1999; Beltrán de Heredia 2010). By the 5th century, these shifts had laid the socio-economic, political, and cultural foundations of the city's future, with the *Ciutat Vella* (Old City) district, the former Roman nucleus of Barcelona, undergoing major transformations driven by population growth and diversification (Puig 1999; Beltrán de Heredia 2010).

During the Medieval period, Barcelona transformed from a small settlement into a significant medieval city. The city began to expand beyond its Roman defenses, though the medieval walls had not yet been constructed (Merino and Rissech 2025). These will be built in the 13th century. Life in medieval Barcelona was characterized by a blend of artisanal work, commerce, and a rigid social hierarchy (Bensch 1995). However, the 9th and 11th centuries were difficult, as the city experienced recurring periods of famine, violence, and sieges (Benito 2022). In 985, Barcelona city was sacked by the army of Almanzor (Kagay 1994). The sack was so traumatic that most of Barcelona's population was either killed or enslaved (Collins 2012). During the Early Middle Ages, across Europe access to fruit was primarily reserved for the wealthy, with the poorer classes struggling to acquire it (Glick et al. 2005). Historians agree that peasants lived on the outskirts of the city, while merchants and artisans gathered within the medieval walls, particularly in what is now the Gothic neighborhood in the Old City district of current Barcelona city (González and Miró 2020). Urban life was organized around guilds, churches, and markets, and the city grew to become a key hub for commercial exchange in the Mediterranean (Bernaus 2010). While most homes were modest, wealthier individuals and the nobility resided in larger, more ostentatious houses and palaces, as those on *Moncada Street* (Aguelo et al. 2005). Between the 15th and 18th centuries, during the modern period, Barcelona's inhabitants underwent significant social changes. In the 15th century, most people were engaged in trade, crafts, and agriculture, with the wealthy merchants and noble classes controlling economic and political life (Simon 2014). Industrialization led to the rise of the working class, and the city's population grew rapidly.

Materials and methods

The material analyzed in this study comes from 46 archaeological assemblages at 36 different locations in the present-day city of Barcelona (Supplemental material Table 1). Given the fact that the city of Barcelona is constituted by 10 different districts, the material of this compound is specifically within the geographic districts of the Ciutat Vella, Eixample, Sant Martí, Sant Andreu, and Horta-Guinardó, which together encompass the majority of the present-day city of Barcelona (Fig. 2). The archaeological interventions were conducted between 1984 and 2019. The sample consists of 1,090 skeletal individuals recovered from archaeological assemblages and currently stored in the collections center of the Barcelona History Museum (MUHBA).

The chronology of the material spans several distinct periods: Prehistory (5500–1500 BCE, 45 individuals), including the Neolithic (5500 to 4000 BCE) and the Bronze Age (2100 to 1500 BCE); the Roman period (186 individuals, 1st to 4th centuries CE); Late Antiquity (478 individuals, 5th to 7th centuries CE); the Medieval period (131 individuals, 8th to 14th centuries CE); and the Modern period (588 individuals, 15th to 18th centuries CE). In Barcelona city, there is a lack of available assemblages dating to the period between the Neolithic and Bronze periods to be studied. Despite this chronological gap, which limits the diachronic scope of the study and restricts the ability to assess potential biological

or demographic changes during this transitional period, this dataset nevertheless offers a valuable opportunity to present evidence from the Prehistory of the city of Barcelona. Even though it is a small cohort, it contributes important insights and helps to broaden the overall past population of Barcelona city framework.

Late Antiquity as a period was included in this study because it is pivotal for understanding the transition from Roman Hispania to the early Medieval kingdoms in Spain, culminating with the Umayyad conquest in 711 CE. In Spain during Late Antiquity, the decline of Roman structures, the spread of Christianity, and the rise of the Visigothic Kingdom, alongside economic transformations, created a cultural and social foundation bridging classical heritage and the Medieval period (Heredero et al. 2014; Pazdernik 2015; Cameron 2023). For detailed information on the archaeological assemblages, please refer to the Supplemental Material, Supplementary Data Table 1.

Regarding the socioeconomic status of the individuals analyzed, for the Prehistoric period, this aspect cannot be assessed. The remains of this period derive from a collective burial in a single hypogeal chamber, with no observable differentiation among individuals in terms of grave goods, spatial organization, or burial treatment. This lack of distinction suggests an absence of evident social stratification within the population, at least as reflected in the funerary context (Gómez and Molist 2016).

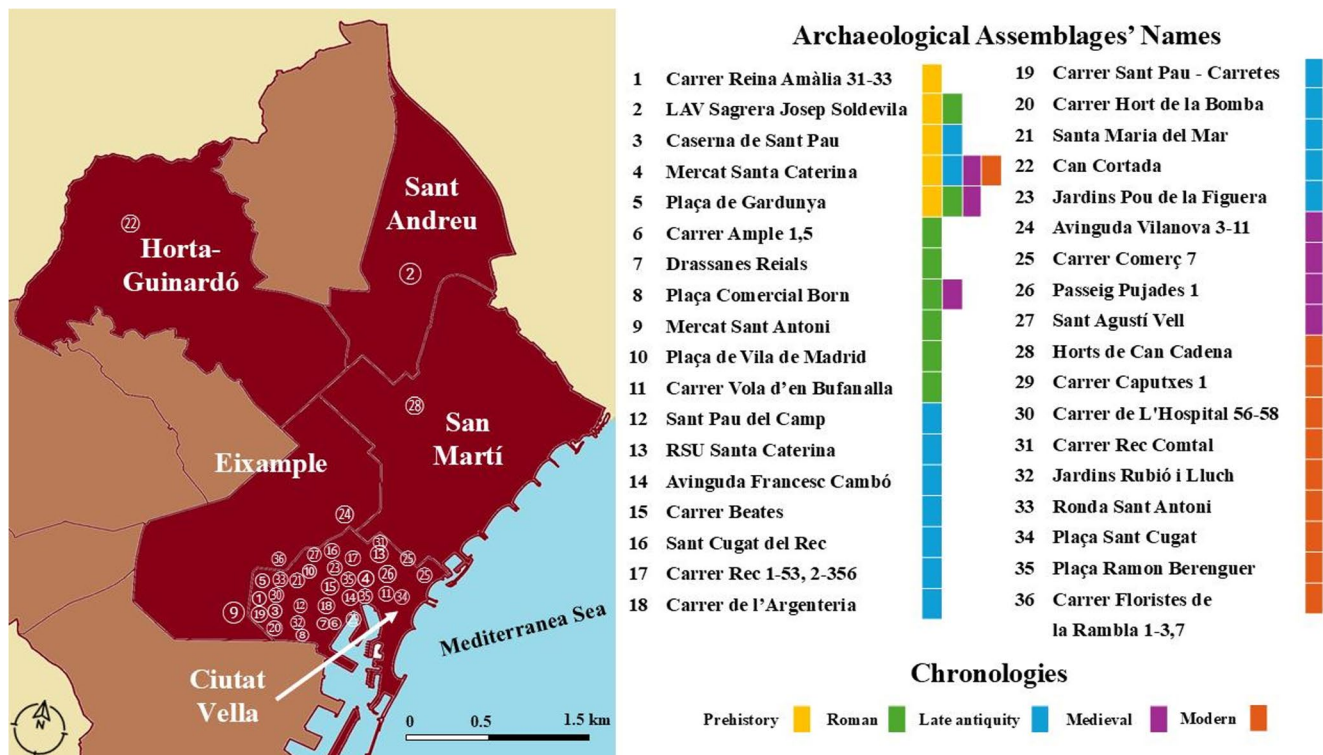


Fig. 2 Magnification of the map of Barcelona city highlighting the location within the city of the 36 archaeological assemblages from which the material for this study was sourced

The remaining individuals analyzed in this study, which belong to historical periods, derive from churchyards, extra-mural burials, and intra-church interments (Supplemental Material Table 1, and Fig. 2). Archaeological and anthropological evidence suggests that these individuals primarily represent lower socio-economic groups (Supplemental Material Table 1 and references therein). Osteological physical activity markers and contextual evidence indicate engagement in manual occupations, ranging from skilled trades (e.g., carpentry, metalworking, and weaving) to unskilled general labor (see Supplementary Material Tables 1 and references therein). Individuals from these groups were interred in simple earth-cut graves or simple burials, in contrast to the more costly burials within the chapels of a church or well-constructed tombs (Aguelo et al. 2005; Prida 2009; Beltrán de Heredia 2010) (Supplementary Material, Table 1), such as those at the Santa Caterina and Vila de Madrid. Notably, individuals buried in the latter contexts did not exhibit comparable physical activity markers (Rissech et al. 2016, 2023a; Cevallos et al. 2023; Trujillo et al. 2023; Merino and Rissech 2025).

Biological profile analysis

The bioanthropological study was conducted between the Collection Center of the Barcelona History Museum (MUHBA) in Barcelona and the Unit of Human Anatomy and Embryology in the University Rovira i Virgili in Reus.

The skeleton's biological sex was estimated using the morphology of the innominate bones, cranium, and mandible (Ferembach et al. 1980; Brothwell 1981; Rissech and Malgosa 1991, 1997; Mitchell and Brickley 2017). These estimations were performed only for individuals over the age of 15, as skeletal sexual dimorphism is based on secondary sexual characteristics, and these develop after puberty.

For adults, age-at-death was estimated using various criteria, including pubic symphysis (Brooks and Suchey 1990; Todd 1920, 1921), auricular surface (Lovejoy et al. 1985), acetabulum (Rissech et al. 2006, 2019), ectocranial suture obliteration (Meindl and Lovejoy 1985), the morphology of the sternal ends of the fourth ribs (İşcan et al. 1984, 1985), the sternal end of the clavicle (Falys and Prangle 2015), and patterns of dental wear (Brothwell 1981). For non-adults, age at death was primarily estimated using the degree of ossification center formation and epiphyseal fusion (Scheuer and Black 2000), diaphyseal lengths of long bones (Fazekas and Kósa 1978; Rissech and Black 2007; Rissech et al. 2013a, b), and tooth eruption and formation (Crétot 1978; Ubelaker 1989).

The sample was divided into ten age categories: fetal and perinatal (<1 year), infant (1–6 years), children (7–12 years), juvenile (13–20 years), young adult (21–30 years),

middle adult (31–39 years), mature adult (40–59 years), and old adult (≥ 60 years), following the age classification recommendations of Mansilla (2000). An additional “undetermined adult” category was included for cases in which the approximate age could not be established. Although these categories are not the most commonly used in bioarchaeological studies, we selected Mansilla's system because it provides a more detailed subdivision of adult age groups, enabling finer resolution in the analysis of age-related bioanthropological studies. Furthermore, Mansilla's classification has been widely applied in studies of Spanish and Catalanian populations similar to ours (e.g., Pujol et al. 2011; Carrascal 2021; Trujillo et al. 2023), allowing for meaningful comparisons within the regional and temporal context of the sample. This approach ensures both precision and relevance in interpreting age-related patterns.

LE was estimated using a stationary population life table for attritional cemeteries, based on Halley's model as outlined by Chamberlain (2006). This approach was chosen because the burial assemblage reflects a non-catastrophic mortality profile and provides the level of age-at-death resolution typical of many archaeological samples. Although more recent demographic methods, such as model life tables incorporating modern mortality schedules or hazard model analyses, have been proposed, these approaches require larger sample sizes and more precise adult age estimates than are available for the present population. Moreover, Halley-based life tables allow for direct comparison with a substantial body of published paleodemographic research from the Iberian (e.g., Jordana et al. 2010; Carrascal 2021) and Italian Peninsulæ (e.g., De Lucca et al. 2023). While alternative approaches can provide valuable contextual insights into regional mortality patterns, they do not offer a standardized quantitative framework for estimating LE. Therefore, Halley's life table was considered the most appropriate and conservative method for the available data.

ST was estimated using the regression equations proposed by Pearson (1899), based on the physiological length of the left femur and tibia, using these bones when they were well preserved. If the left side was unavailable or fragmented, the right side was used instead. The femur and tibia were selected because the lengths of these long bones are considered the most reliable indicators of ST, as the association between ST and long lower-limb bones is stronger than that with upper-limb bones, particularly for the femur and tibia (Duyar and Pelin 2003; Albanese et al. 2016). Pearson's formulae were applied, taking into account the Mediterranean origin of both the studied remains and the reference sample of the method. Despite the fact that there are several methods for estimating the ST in European populations (e.g., Ruff et al. 2012; Albanese et al. 2016), the Pearson (1899) method was chosen to estimate ST in

the archaeological population from Barcelona because it provides the most biological and geographically closest reference. The formulae proposed by Pearson at the end of 19th century, based on a French sample, perform better than other methods when applied to Spanish and Italian populations because of the intertwined biological population history of French, Spanish, and Italian populations (Formicola 1993; Formicola and Franceschi 1996; Lalueza-Fox 1998) and because they are all populations of medium ST (Formicola 1993; Formicola and Franceschi 1996).

For BM estimation in adults, we applied the BM based on the femoral head diameter (FHD) equations from Ruff et al. (1991, 2012), as FHD is a well-established proxy for BM due to its strong correlation with weight-bearing capacity and overall body size. BMI was calculated as the ratio of BM to the square of ST (kg/m^2). Individuals were classified into four body weight status categories based on BMI: underweight (<18.49), normal weight ($18.5\text{--}24.9$), overweight (≥ 25), and obese (≥ 30) (Keys et al. 2014). ST, BM, and BMI estimations were only performed for adult individuals whose biological sex could be estimated. Adult individuals were identified as those who had completed fusion of all long bone epiphyses. For analyses of ST, BM, and BMI, individuals exhibiting severe skeletal pathologies that markedly affect skeletal proportions, such as rickets, were excluded from the samples. However, individuals with less severe conditions, including osteoarthritis, were retained and were not excluded.

Statistics

Differences between sexes in ST and BM were examined using parametric or non-parametric tests depending on the data distribution. Normality of each variable was assessed using the Shapiro-Wilk test, and homogeneity of variances was evaluated with Levene's test. For normally distributed variables with equal variances, Student's t-test was applied. For variables that did not meet these assumptions, the Mann-Whitney U test was used.

Differences in ST and BM across periods within each sex were assessed using one-way ANOVA. This test was deemed appropriate because the data met the assumptions of independence, normality, and homogeneity of variances (the latter assessed using Levene's test). When ANOVA revealed significant differences, Tukey's post-hoc test was conducted to identify which periods differed.

All statistical analyses were conducted using SPSS version 29.0 (SPSS Inc., Chicago, IL, USA), and the significance level was set at $p < 0.05$ for all tests.

Results

The results from a total of 1,090 individuals include 297 (27.25%) non-adults and 793 (72.75%) adults. Among all individuals, 258 were males (23.67%), 244 were females (22.39%), and 588 (53.94%) were of undetermined sex (of which 271 were non-adults and 317 were adults). Of the 297 non-adults 46 were fetal and perinatal (4.22%), 104 were infants (9.54%), 82 were children (7.52%), and 65 were juveniles (5.96%) (Table 1). Among the 793 adults, 155 were young adults (19.54%), 169 were middle adults (21.31%), 125 were mature adults (15.76%), 22 were old adults (2.77%), and 322 were adults of undetermined age (40.60%) (Table 1).

The Prehistoric sample was the smallest assemblage (Table 1) of all periods. It was made up of 45 individuals, primarily composed of 27 non-adults, including 3 fetal and perinatal remains, 15 infants, 4 children, and 5 juveniles, while adult representation was limited (18), comprising 8 young adults, 2 middle adults, 1 mature adult, and 7 adults of undetermined age. In contrast, the Roman period (Table 1) included 189 individuals (63 non-adults and 126 adults), with 41 males, 44 females, and 104 of undetermined sex. Of the 63 non-adults 23 were fetal and perinatal, 23 were infants, 10 were children, and 7 were juveniles. Of the 126 adults 34 were young adults, 29 were middle adults, 18 were mature adults, 1 were old adult, and 44 were adults of undetermined age. Following this, Late Antiquity presented the largest sample (Table 1) of this study, with 478 individuals (125 non-adults and 353 adults), including 122 males, 108 females, and 248 undetermined. Of the 125 non-adults 15 were fetal and perinatal, 37 were infants, 47 were children, and 26 were juveniles. Of the 353 adults 65 were young adults, 73 were middle adults, 66 were mature adults, 18 were old adults, and 131 were adults of undetermined age. The Medieval sample, on the other hand, consisted of 37 non-adults and 94 adults, including 36 males, 28 females, and 67 undetermined. The 37 non-adults comprised 3 fetal and perinatal, 19 infants, 8 children, and 7 juveniles and while the 94 adults comprised 18 young adults, 23 middle adults, 18 mature adults, 2 old adults, and 33 adults of undetermined age. Similarly, the Modern period (Table 1) consisted of 247 individuals (45 non-adults and 202 adults), including 52 males, 58 females, and 137 undetermined. The 45 non-adults comprised 2 fetal and perinatal, 10 infants, 13 children, and 20 juveniles and while the 202 adults comprise 30 young adults, 42 middle adults, 22 mature adults, 1 old adult, and 107 adults of undetermined age. This last period represented the second largest sample in the present

Table 1 Distribution of individuals recovered from archaeological assemblages in Barcelona, categorized by period, age, and sex. M: Male, F: Female, U: Undetermined, and T: Total

Period	Sex	Non- adult		Adult				Undetermined	Total	Total Sample		
		Fetal and perinatal	Infant (1–6)	Children (7–12)	Juvenile (13–20)	Total	Young (21–30)				Middle (31–39)	Mature (40–59)
Prehistory	M	-	-	-	-	-	5	2	-	-	7	7
	F	-	-	-	2	2	3	-	1	-	4	6
	U	3	15	4	3	25	-	-	-	-	7	32
Roman	T	3	15	4	5	27	8	2	1	-	18	45
	M	-	-	-	1	1	14	14	11	1	40	41
	F	-	-	-	2	2	20	15	7	-	42	44
Late Antiquity	U	23	23	10	4	60	-	-	-	-	44	104
	T	23	23	10	7	63	34	29	18	1	126	189
	M	-	-	-	7	7	28	42	38	6	115	122
Medieval	F	-	-	-	-	-	37	31	28	12	108	108
	U	15	37	47	19	118	-	-	-	-	130	248
	T	15	37	47	26	125	65	73	66	18	353	478
Modern	M	-	-	-	-	-	6	16	13	-	36	36
	F	-	-	-	2	2	12	7	5	2	26	28
	U	3	19	8	5	35	-	-	-	-	32	67
Combined	T	3	19	8	7	37	18	23	18	2	94	131
	M	-	-	-	4	4	10	22	12	-	48	52
	F	-	-	-	8	8	20	20	10	-	50	58
	U	2	10	13	8	33	-	-	-	-	104	137
	T	2	10	13	20	45	30	42	22	1	202	247
	M	-	-	-	12	12 (4.04%)	63	96	74	7	246 (31.00%)	258 (23.67%)
	F	-	-	-	14	14 (4.71%)	92	73	51	14	230 (29.00%)	244 (22.39%)
	U	46	104	82	39	271 (91.25%)	-	-	-	1	316 (40.00%)	588 (53.94%)
	T	46 (4.22%)	104 (9.54%)	82 (7.52%)	65 (5.96%)	297 (27.25%)	155 (19.54%)	169 (21.31%)	125 (15.76%)	22 (2.77%)	793 (72.75%)	1090

study and, as the previously described periods, featured a substantial number of undetermined adults as well as a notable presence of non-adults. Notably, a high proportion of non-adult individuals was observed across all periods, particularly in the Prehistoric sample, whereas older adults were consistently underrepresented throughout each chronological period.

Life expectancy at birth and stature

The analysis of LE across the five periods in Barcelona city, including Prehistory, Roman, Late Antiquity, Medieval, and Modern, indicated an upward trend between the Prehistory and Late Antiquity periods (Fig. 3); later, in the following periods, a zigzag line is observed, with the Medieval period having the lowest LE between the Late Antiquity, Medieval and Modern periods (Fig. 3). In this study, in Prehistory, the value of the LE should be observed with caution because of the small sample size in this period. Calculations for each period in the present study are presented in the supplemental material (Supplementary Data Table 2). Table 2 shows a

comparison of LE considering the five analyzed periods in this study in Barcelona city and in Catalonia.

Regarding ST (Table 3), as expected, males were significantly taller than females across all periods analyzed in this study. However, no significant differences in ST between periods were observed within each biological sex (Table 3). Notably, despite the small sample size for the analyzed Prehistoric period (Table 3), the average ST of males (166.25 cm) and females (151.75 cm) in this study is consistent with that reported for later periods in Barcelona city and across Catalonia (Table 2).

Body mass and body mass index

Table 4; Fig. 4 show BM and BMI, respectively, for males and females of each analyzed period, indicating significant sex differences in the Roman, Late Antiquity, and Modern periods (Table 4), with male BM higher than that of females, as expected. BMI was also generally higher, in this case in females than in males, except during Late Antiquity, when the values were equal for both sexes (Fig. 4). In general, in

Fig. 3 Life expectancy values across different historical periods in present-day city of Barcelona

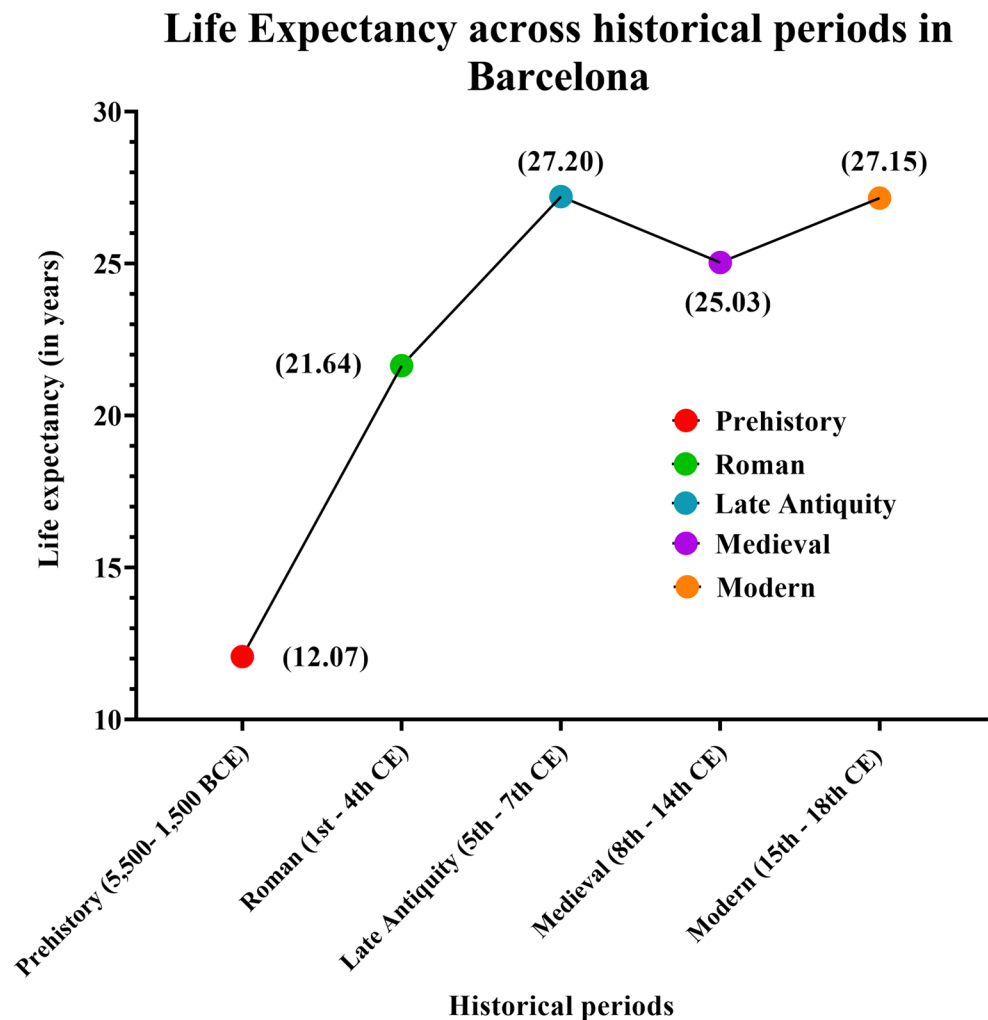


Table 2 Comparison of LE, average male and female ST (in cm), and difference between sexes in ST across different periods in Catalonia. The standard deviation (SD) and the number of individuals analyzed for ST in the present study can be found in Table 3

Sample/City	Location (Province)	Historical period	Centuries	LE	Mean Stature ST Male	Mean ST Female	Differ- ence between sexes	Reference
Barcelona	Barcelona	Prehistory (Neolithic to Bronze)	5,500-1,500 BCE	12.07	166.25	151.75	14.54	Present study
Barcelona	Barcelona	Roman	1st-4th CE	21.64	165.04	153.25	11.79	Present study
Tarragona	Tarragona	Roman	3rd- 5th CE	-	163.18	151.82	11.36	Pons 1949
Cathedral of Egara (Terrassa)	Barcelona	Late Antiquity	4th – 8th CE	25.63	-	-	-	Jordana et al. 2010
Barcelona	Barcelona	Late Antiquity	5th – 7th CE	27.20	164.90	152.47	12.43	Present study
Accés Est Casserres (Berguedà)	Barcelona	Late antiquity and Medieval CE	5th – 9th CE	19.33	166.41	153.70	12.70	Carrascal 2021
Antics Jutjats de Barcelona	Barcelona	Medieval	9th – 10th CE	27.46	166.60	153.60	13.00	Merino and Rissech 2025
Jews Montjuïc (Barcelona)	Barcelona	Medieval	11th – 14th CE	-	161.95	149.10	12.90	Prevosti and Pre- vosti 1951
Barcelona	Barcelona	Medieval	8th – 14th CE	25.03	164.99	152.40	12.59	Present study
Laypeople Santa Caterina friary, Barcelona	Barcelona	Medieval	13th – 14th CE	-	169.02	154.53	14.49	Cevallos et al. 2023
Parish Churches of Terrassa, Barcelona	Barcelona	Medieval	9th – 13th CE	26.94	-	-	-	Jordana et al. 2010
Laypeople Santa Caterina friary, Barcelona	Barcelona	Modern	15th – 16th CE	-	163.02	156.75	6.27	Cevallos et al. 2023
Plaça Vella (Terrassa)	Barcelona	Modern	16th – 17th CE	20.53	164.62	152.46	12.16	Jordana and Mal- gosa 2002
Barcelona	Barcelona	Modern	15th – 18th CE	27.15	164.79	154.29	10.50	Present study

both males and females, a BM increase is observed across periods with statistical significance (Table 4), except in the Medieval period. It is noticeable the decrease in male BM in Medieval (59.01 kg), which is the lowest in males among all periods (Table 4). In this period, female BM remained relatively stable, with an average of 54.73 kg (Table 4). Perhaps that decrease can explain the lack of sexual differences in this period. It is also noticeable that, the peak in BM observed in the Modern period, reached the highest percentages of overweight males and females (Table 4; Fig. 4).

Figure 4 shows the BMI for each period divided by sex. The analysis of BMI categories across the five analyzed periods revealed clear trends over time. In Prehistory, all females and 85.71% of males fell within the normal weight range, with a small proportion of males (14.29%) classified as overweight (Fig. 4A). In this period, no individuals were identified as underweight or obese. During the Roman period, the proportion of normal-weight individuals remained high (around 60% in males and 70% in females), but overweight cases increased to 30.30% in males and 28.57% in females (Fig. 4B). A negligible percentage of males (9.99%) were underweight, and no obesity was detected (Fig. 4B). In the Late Antiquity period, normal weight continued to predominate (71.43% in males and 70.45% in females), while overweight individuals accounted for approximately 24% and

27% in males and females, respectively (Fig. 4C). This last period marked the first appearance of obesity, observed in 1.14% of females, and a small proportion of underweight individuals in both sexes (Fig. 4C). During the Medieval period, normal weight remained most common, though slightly lower among males (68.18%) compared to females (75%) (Fig. 4D). Overweight individuals were present in 11.54% of males and 18.75% of females, with underweight (19.23%) and obesity (3.85%) appearing modestly in males (Fig. 4D). In the Modern period, a notable shift occurred with a significant increase in overweight prevalence (46.67%) of males and (40%) of females, while normal-weight individuals constituted (50%) of males and (60%) of females (Fig. 4E). A small fraction of males (3.33%) was underweight, but no obesity cases were recorded (Fig. 4E).

Discussion

The present study evaluated 1,090 individuals from Barcelona city, spanning from Prehistory to the Modern period. It provides a comprehensive overview of LE, ST, BM, and BMI in past populations from this geographical area. Despite the small sample size in the Prehistoric period, which warrants caution, the results of this study indicate

Table 3 Comparison table of ST in males and females across the five historical periods analyzed in this study, taking into account biological sex. It includes the sample size (n), mean, minimum, maximum, and standard deviation (SD) for each sex in each period. Statistical tests (t=t-test or U=Mann-Whitney U test), one-way ANOVA, p-values, and asterisks (*) indicating significant differences ($p < 0.05$)

Period	Male (n = 177)					Female (n = 152)					Statistical test	p-value
	n	Mean	Minimum	Maximum	SD	n	Mean	Minimum	Maximum	SD		
Prehistory	7	166.25	153.87	171.55	6.06	3	151.75	151.03	152.59	0.79	U=0.000	0.017*
Roman	33	165.04	155.70	172.67	3.35	36	153.25	142.80	169.67	4.85	t=25.121	0.001*
Late Antiquity	81	164.90	151.33	173.43	4.92	72	152.47	142.86	164.01	4.27	t=11.647	0.001*
Medieval	26	164.99	147.37	173.61	5.70	16	152.40	145.78	156.87	3.75	U=14.000	0.001*
Modern	30	164.79	150.60	173.80	4.61	25	154.29	148.70	166.40	3.85	U=43.500	0.001*
	ANOVA $p=0.966$					ANOVA $p=0.406$						

Table 4 Comparison table of BM in males and females across the five historical periods analyzed in this study. It includes the sample size (n), mean, minimum, maximum, and standard deviation (SD) for each sex. Statistical tests (t=t-test or U=Mann-Whitney U test), one-way ANOVA, p-values, and asterisks (*) indicating significant differences ($p < 0.05$)

Period	Male (n = 180)					Female (n = 163)					Statistical test	p-value
	n	Mean	Minimum	Maximum	SD	n	Mean	Minimum	Maximum	SD		
Prehistory	7	64.02	49.54	71.06	7.47	4	53.57	49.86	56.19	2.66	U=4.000	0.059
Roman	33	64.69	43.06	80.86	8.52	35	57.18	47.68	67.42	5.95	t=4.235	0.001*
Late Antiquity	81	63.27	41.60	79.74	8.43	80	54.74	43.76	71.66	6.75	t=7.074	0.001*
Medieval	27	59.01	42.50	79.74	10.85	16	54.73	46.14	67.52	6.44	U=171.000	0.258
Modern	32	67.57	44.46	84.78	8.35	28	59.54	48.56	81.69	6.99	t=4.004	0.001*
	ANOVA $p=0.007^*$					ANOVA $p=0.012^*$						
	Tukey= Medieval vs. Modern					Tukey= Late antiquity vs. Modern						

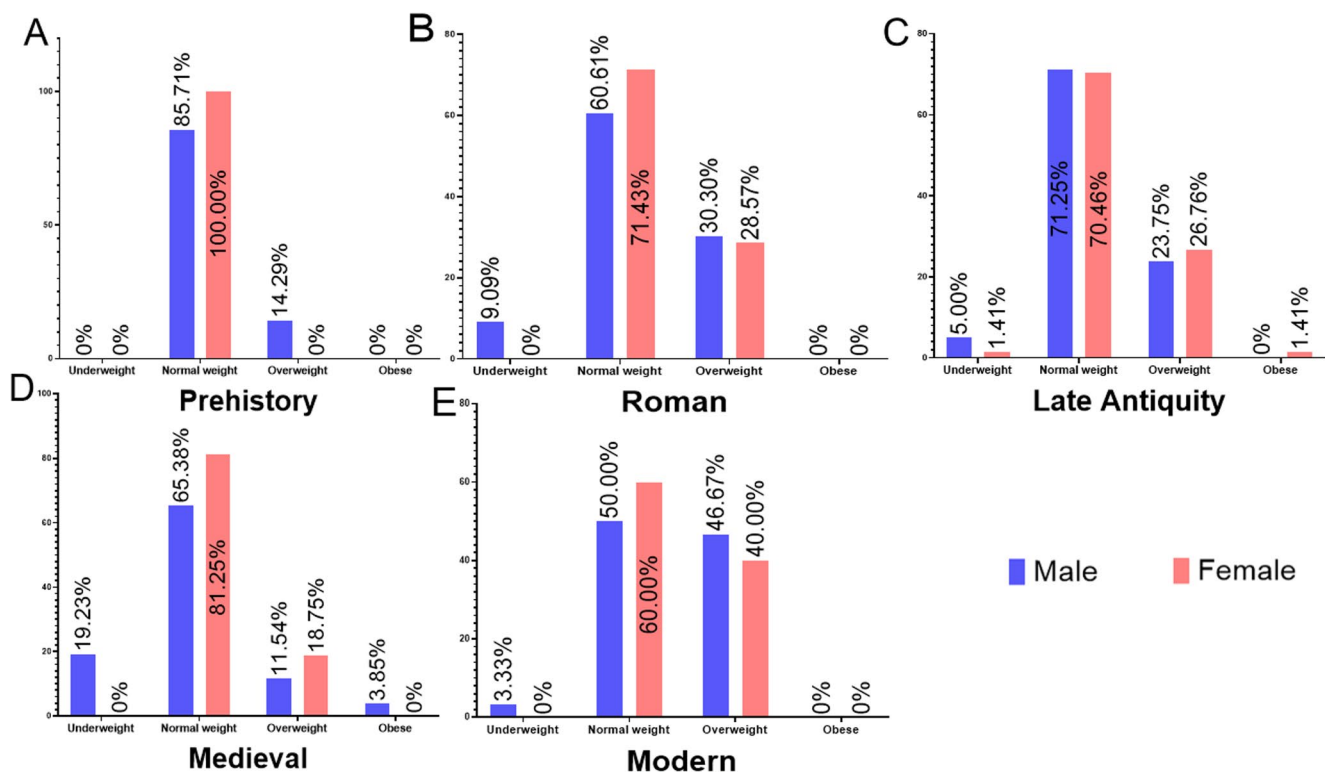


Fig. 4 BMI values of past populations of Barcelona across the five analyzed periods: Prehistory (A), Roman (B), Late Antiquity (C), Medieval (D), and Modern (E). Each of them was distributed into male and female with the subgroups of underweight, normal weight, overweight, and obese

that the analyzed four biological parameters increased from Prehistory to Late Antiquity, declined during the Medieval, and then rose again in the Modern period. Notably, no significant differences in ST between periods were observed for both sexes.

The analysis of these data from the past population of present-day Barcelona city, combined with previous documental and archaeological literature (Collins and Goodman 2002; Cruz-Berrocal et al. 2013), indicates the existence of two major cultural transitions associated with broad social transformations: the transition from Prehistory to the Roman period and the transition from the Medieval to the Modern period. In the Northeast of the Iberian Peninsula, the transition from the Prehistory to the Roman period led to the emergence of the Iberian period (Iron Age II). The Iberian period represents the ending of the prehistory in this coastal region (Sanmartí 2004). It was the result of a socio-cultural change from native Bronze Age local groups of the Mediterranean coast (from Andalusia to south of France in the Languedoc region) to stratified societies and regional political entities (Sanmartí 2004). This socio-cultural change was due to (i) the increase in population density, (ii) the incorporation of iron technology, and, very importantly, (iii) the commercial interaction with Phoenician Punic, and Hellenic colonial centers in this coastal region (Sanmartí 2004). However, the small sample size of the Prehistoric assemblage in

the present study does not allow us to observe confidently this transition on the analyzed biological parameters of this period. One of the major sources of bias in the reconstruction of mortality and LE in the Prehistoric population of the northeast of the Iberian Peninsula is funerary practices. From the Late Bronze Age up to the Roman period adult individuals are underrepresented because of its cremation (Rissech et al. 2023b). Such differentiated funerary treatment significantly reduces the archaeological visibility of adults in the Late Bronze Age and Iron Age.

The transition between the Medieval and Modern periods, which involved notable changes in European dietary practices and medical knowledge: Fracastoro (1478–1553) proposed that diseases might have been caused by pathogens outside the body; Paracelsus (1493–1541) began using chemical and mineral remedies to treat certain ailments; and the discovery of the Americas led to the interchange of a wide variety of crops and livestock, contributing to increased European population and food production (Nunn and Qian 2010). In the present study, the importance of the transition from Medieval to Modern period is indicated by a marked increase in LE, BM and overweight individuals. To facilitate comprehension, the text will be divided into two subsections: (1) Life expectancy at birth and stature and (2) Body mass and body mass index.

Life expectancy at birth and stature

Starting with the Prehistory, the LE in the present study is 12.07 years, which is exceptionally low (Fig. 3), reflecting extremely high early-age mortality and a dynamic population reliant on elevated birth rates to maintain demographic stability. When compared to other past Spanish populations of comparable periods, this value is strikingly low: for example, S'Illot des Porros, an Iron Age population from Majorca, had a LE of 23 years (Alesan et al. 1999), and the Chalcolithic population of Camino del Molino (Murcia) reached 31.35 years (Díaz-Navarro et al. 2023). Near Eastern populations also exhibit higher LE, with Neolithic and pre-Neolithic groups averaging 25.4 and 24.6 years, respectively (Eshed et al. 2004; Hershkovitz and Gopher 2008). Although, the low LE observed in the Prehistoric Barcelona city cohort likely reflects the small sample size rather than biological or cultural conditions of this city. However, this framework is useful for having some information on Prehistoric Barcelona. LE trends within a population are important for understanding the possible local environmental and cultural factors that influence it. For example, Eshed et al. (2004) and Hershkovitz and Gopher (2008) associated LE with shifts in subsistence strategies.

As noted previously, the data from the Prehistoric Barcelona assemblage should be interpreted with considerable caution. The observed patterns on LE obtained in this period may primarily reflect the small sample size rather than underlying biological, cultural, or socioeconomic conditions specific to Prehistoric populations in the Barcelona region. As it has been said, one of the major sources of bias in the reconstruction of mortality and LE in this assemblage of the northeast of the Iberian Peninsula is funerary practices. In this region, Prehistoric funerary practices evolved from individual cave or pit burials in the Neolithic to collective and megalithic tombs, reflecting complex social beliefs during the Chalcolithic, as shown by the "Pit Grave Culture" (Estebanranz et al. 2008; Gibaja et al. 2012). Later, during the Late Bronze Age (c. 1300–800/700 BCE), Catalonia experienced major cultural changes with the arrival of the Urnfield culture, Mediterranean contacts such as Phoenicians, advanced metallurgy, and developments that led toward the Iron Age and Iberian period (López-Cachero and Pons-i-Burn 2008). In these four temporal periods, while adults were commonly buried in collective graves, caves, pits, or cists or cremated, infants and very young children were often treated differently. The infants are frequently underrepresented in formal Prehistoric funerary contexts and were commonly buried within settlements, in pits, silos, or beneath house floors (Estebanranz et al. 2008; Gibaja et al. 2012). However, from the Late Bronze Age up to the Roman period are the adults who are underrepresented because of

its cremation (Rissech et al. 2023b). Such differentiated funerary treatment significantly reduces the archaeological visibility of infants in the Neolithic and Chalcolithic and adults in Late Bronze Age and Iron Age, producing biases in the reconstruction of mortality and LE in the Catalan Prehistoric populations.

The Roman period from Barcelona of this study yielded a LE of 21.64 years, a value consistent with studies across the ancient Mediterranean (Table 2), which during the Roman period typically ranged from 22 to 25 years (Saller 1997; Scheidel 2007; Boatwright 2021). The known social and economic conditions of the Roman Empire indicate LE toward the usual lower bound of pre-modern populations (Frier 1982; de Vries and Zwalve 2003). Roman LE bears comparison to available data for India and rural China in the early 20th century, where LE was also in the 20s (Bagnall and Frier 1994; Scheidel 2007). High infant and child mortality rates played a major role in depressing these averages; nearly half of all children may have died before age five, as was usual in pre-antibiotic populations (Bagnall and Frier 1994). The consistency of our results with broader Roman period data supports its plausibility, though it should again be contextualized within a small sample size and potential osteological biases. Although LE in the Roman period increased in relation to that of prehistory (Fig. 3), average ST remained almost similar (Table 2).

The Late Antiquity (5th–8th centuries CE) in the city of Barcelona city: the present study indicates that the LE peaked at 27.20 years (Table 2), marking one of the highest values among the five periods analyzed in this study. This improvement may suggest enhanced living conditions in urban Barcelona during this period, possibly linked to more stable food supplies, increased social organization, or improved public health practices.

During the Medieval period, in the present study, Barcelona city (8th–14th centuries) showed a LE of 25.03 years. These values place it in the mid-range compared to other medieval Catalan populations (Table 2). The Antics Jutjats assemblage (9th–10th CE) from Barcelona city showed the higher LE (27.46 years), likely reflecting improved health conditions during its growth (Merino and Rissech 2025). Barcelona city, in Medieval period, particularly Early Medieval period, was characterized by both urban growth and socio-political instability. Barcelona transitioned from a fortified Roman settlement to a growing Medieval city, expanding beyond the Roman walls, which were constructed in the 13th century. Although the city was prosperous at that time, the conflict between Islamic forces in the south and Christian forces in the north, together with the establishment of the Spanish March (Banks 1980; Tischler 2019), ushered in a very long period of frequent hardship, including famines, violence, sieges, and the devastating sack of

Barcelona in 985 by the forces of Almanzor (Kagay 1994; Collins 2012). In addition, during the 14th century, the city of Barcelona was severely affected by outbreaks of the Black Death, which decimated the population, profoundly affected social and economic life, and left a legacy of fear and decline, although there were later recurrences (such as in 1651) (Kagay 1994; Collins 2012; Merino and Rissech 2025). Epidemic diseases had a profound impact on mortality regimes in this period, as shown in paleodemographic studies across Europe (e.g., Green 2015; Barbiera and Dalla 2024). Dietary data for this period in Barcelona are limited, but studies from other regions, such as Gandía and Pedro I's court, highlight dietary stratification, with elites consuming more meat and fish (Alexander et al. 2015; Jiménez et al. 2016). Health stress markers such as enamel hypoplasia and cribra orbitalia suggest widespread stresses due to malnutrition, nutritional deficiencies, socioeconomic adversity, epidemic events, and among other factors (e.g., Trujillo et al. 2023; Merino and Rissech 2025). Food scarcity, social stratification, and limited access to medical care (especially among the lower classes) most likely contributed to the decline in LE relative to Late Antiquity (Glick et al. 2005). These data underscore the vulnerability of urban populations to short-term crises, even amid broader structural growth. These results underscore how structural inequality, conflict, and disease outbreaks left measurable marks on the biological record.

In the Modern period (15th to 18th centuries CE), and according to the results of this study, Barcelona LE increased to 27.15 years. Regarding the ST, the present study indicated no significant differences in adult ST between periods for either sex in the city of Barcelona. This finding is consistent with the results of the diachronic analysis of adult ST in the population of Milan (Biehler-Gomez et al. 2023). It also does not contradict the study of Rosenstock et al. (2019), which reported that on a broader European scale, human stature between 10,000 and 1,000 BCE changed unevenly, influenced by genetic background and living conditions, producing a northwest-to-southeast gradient around 3000 BCE). However, it contrasts with the conclusions reported in earlier studies, which observed a U-shaped trend in adult ST, with tall individuals in Roman and Early Medieval periods and a negative secular trend in the Late Medieval periods and/or Early Modern periods, and then a ST substantial recovery in the twentieth century (e.g., Koepke and Baten 2008; Maat 2005; Giannecchini and Moggi-Cecchi 2008; Cardoso and Gomes 2009). Some studies also suggest there was an overall decline in ST from the Paleolithic to Neolithic, with gradual recovery toward modern times, potentially due to reduced protein intake from the Neolithic onwards (Hermanussen 2003; Marciniak et al. 2022). We may ask what similarities exist between the Milan study

and the present research and how both differ from earlier studies. The explanation is that both studies (Milan and Barcelona), although they include individuals from various archaeological assemblages, focus on necropolises within a single urban area—namely, the cities of Milan and Barcelona—whereas earlier studies examined populations from different geographical urban and rural regions. Focusing the studies on a restricted geographical area seems to help to minimize bias. In particular, it avoids distortions that may arise when combining individuals from rural and urban contexts or from multiple regions characterized by differing topographies, microclimates, agricultural systems, population densities, and economic activities, factors that reflect substantially different living conditions. In both studies (Milan and Barcelona), the context is entirely restricted to an urban area, in our case, in the city of Barcelona.

Body mass and body mass index

When comparing BM and BMI data from Barcelona's past populations in this study, there is a clear increase in overweight and obesity over time (Table 4; Fig. 4). Results from this study reveal that in the Prehistory, nearly all individuals had a normal weight, with only 14% of men categorized as overweight (Fig. 4A). During the Roman period, a slight increase in overweight individuals is observed, with obesity first appearing in Late Antiquity. By the Medieval period (Fig. 4D), obesity was rare, but underweight conditions became more common, especially among men. However, in the Modern period, overweight rates have risen sharply, with 47% of males and 40% of females now classified as overweight, reflecting dietary changes and increasingly sedentary lifestyles.

In the present study, sex differences in BM are notable (Table 4), with female rates increasing more over time than those of males (Fig. 4). Although both sexes in the Modern period exhibit similar rates of overweight, female obesity rates remain slightly lower. It is important to note that no signs of obesity are observed in Prehistoric samples (Fig. 4); this BMI category first appears in the Late Antiquity period and continues through the Medieval and Modern periods, clearly revealing the widespread prevalence of obesity today.

Overall, the data demonstrates a clear trajectory of increasing overweight and obesity, probably driven by dietary changes, urbanization, and lifestyle shifts from ancient times to the present. The evolution of BM and BMI in Europe may reflect broader shifts in diet, lifestyle, and socioeconomic conditions (Claassen et al. 2019; Bogin 2020). Historically, higher BM in pre-industrial societies was often associated with wealth and social status, as those with access to resources had the means to consume

richer diets (Pickett et al. 2005; Vartanian and Porter 2016). In contrast, contemporary trends indicate that higher BMI is increasingly prevalent among lower-income groups, largely driven by the widespread availability of inexpensive, unhealthy food options and reduced physical activity due to modern lifestyles (Claassen et al. 2019). It is noteworthy that these two biological parameters (BM and BMI) decreased during the Medieval period compared to their values in Late Antiquity. This decline may also be related to the reduction in LE observed during the same period.

Despite their importance, estimates of BM and BMI are seldom reported in biological anthropological studies in Europe, and especially in Spain. This lack of data makes it difficult to draw direct comparisons between past populations and contemporary reference values. The gap is particularly evident in biological anthropology research, where the absence of BM and BMI information limits our understanding of historical health, nutrition, and population biology in the region. A notable exception is a recent study on populations from the Dutch cities of Arnhem and Zwolle that dates back to the 17th–19th centuries (Niu and Schrader 2024). This study estimated the average male BM in Arnhem (67.33 kg) and Zwolle (65.41 kg), with figures comparable to the modern male sample in our study, which averages 67.57 kg. Similarly, the average female BM in Arnhem (57.07 kg) and Zwolle (57.88 kg) closely aligns with our modern female sample (59.54 kg). Given that both the Dutch cemeteries and our sample represent urban populations, future research could benefit from comparing BM trends between urban and rural communities. This would help to provide further insights into cross-population differences in BM and the influence of varying socioeconomic and environmental conditions across time.

Industrialization has led to higher obesity rates in urban areas, where access to high-calorie foods and sedentary lifestyles are more common. Studies across Europe and North America show that urban populations are more likely to be overweight compared to rural ones, who maintain more active lifestyles and traditional diets (Marques et al. 2018). Research into Barcelona's trends could further explore the impact of urbanization on obesity. The 2020 European Health Survey in Spain (EHEC), conducted by the National Institute of Statistics (INE), reported the average BM of Spanish adults as 83.6 kg for males and 68.3 kg for females, with average BMI values of 27.5 for males and 25.8 for females (INE 2020). These data suggest that a significant portion of the adult population is classified as overweight, highlighting public health concerns tied to nutrition and sedentary behaviors that have become more prevalent in contemporary Spain. According to the results of this study, obesity was rare in past populations in Barcelona. The rise in modern obesity highlights the need for more

paleopathological research in Spain and Europe to better understand how lifestyle and diet changes have contributed to current obesity patterns.

A longitudinal analysis of biological trends in Barcelona: Insights across time

The present bioanthropological study adopts a diachronic perspective, spanning from Prehistory to the Modern period, and focuses on the urban area of the city of Barcelona. This analytical framework enhances comparability between assemblages by minimizing confounding variables related to divergent living conditions, such as differences in topography, microclimate, agricultural practices, population density, and economic activity. Archaeological evidence further indicates that the skeletal remains from the necropolises included in this study predominantly represent individuals from lower socioeconomic strata, whereas individuals from the middle classes appear to have been relatively rare. Additionally, estimations of LE, ST, BM, and BMI were conducted using consistent methodological approaches, ensuring reliable comparisons across samples and facilitating the analysis of diachronic trends. Taken together, these characteristics strengthen the internal consistency of the study and enhance the robustness of the diachronic analysis, allowing for more reliable interpretations of long-term biological patterns within urban Barcelona city's past populations.

The first notable finding of the present study is the absence of significant temporal variation in ST. This pattern aligns with the results reported by Biehler-Gomez et al. (2023) in their diachronic investigation of ST in Milan, which likewise concentrated exclusively on an urban population. As these authors suggested in their study, we could say that the observed ST homogeneity across periods in Barcelona city may be attributable to the relatively favorable living conditions of this city compared to other urban centers. However, in the present study, despite the absence of temporal differences in ST, the other three analyzed biological parameters (LE, BM, and BMI) exhibit significant differences across periods. Although the Prehistory data of this study must be viewed with caution, these three biological parameters display an overall increasing trend from the Prehistory to Modern periods. This upward trend was interrupted during the transition from Late Antiquity to the Medieval period, when all three biological parameters declined, showing the lowest BM and augmenting the frequency of underweight individuals (Fig. 4; Table 4). However, a strong recovery of the upward trend occurred from the Medieval to the Modern periods, particularly for BM and BMI.

As indicated by documental information (Banks 1980; Kagay 1994; Collins 2012; Tischler 2019; Suñé-Arce 2019)

and some anthropological studies (Merino and Rissech 2025), in Barcelona the Medieval period was involved in a very long (at least three centuries, from the 9th to 11th centuries) bloody war between Islamic and Christian forces for the establishment of their territorial limits, the known Spanish March (Banks 1980; Tischler 2019). This conflict led to violence, famines, sieges, and devastating sacks of Barcelona, in which males were killed and females and children were kidnapped and enslaved (Kagay 1994; Collins 2012; Suñé-Arce 2019). In addition, during the 14th century, the city of Barcelona was severely affected by several outbreaks of Black Death, which decimated the population by 40%, profoundly affected social and economic life, and left a legacy of fear and decline (Kagay 1994; Collins 2012). A common response to this incomprehensible outbreak was to turn on others, especially on marginal members of society. The Jews were attacked and killed. The violence committed against Jews in the city led to the end of the Jewish neighborhood (El Call). All these had a profound impact on mortality regimes in the Medieval period in Barcelona. It took about 200 years to recover its pre-1348 population levels (Günzberg-Moll 1989).

In the present study, in addition to this Medieval shift, the results for LE, BM, and BMI suggest two additional shifts. The first, which must be interpreted with great caution because of the small sample size of the Prehistory assemblage, occurs between this period and the Roman period. The second occurs between the Medieval and Modern periods. In the Prehistoric period results indicated the lowest values for LE, BM, and BMI, with no signs of underweight and obesity. As indicated previously, archaeological literature indicates the importance of this transition, which transformed the Prehistoric population of the northeast of the Iberian Peninsula and led the emergence of the Iberian period (Iron Age II). The Iberian period represents the ending of the prehistory in this coastal region (Sanmartí 2004). It was the result of a socio-cultural change from native Bronze Age local groups of the Mediterranean coast (from Andalusia to south of France in the Languedoc region) to stratified societies and regional political entities (Sanmartí 2004). This transformation was due to the contact between this Prehistoric populations and Romans, Phoenicians, and Greeks (Sanmartí 2004).

In the Modern period, bioanthropological evidence suggests a general potential improvement in living conditions for the people of Barcelona during the transition to modernization (Cevallos et al. 2023, 2024; Trujillo et al. 2023). A high increment in LE, BM, and BMI were observed, particularly in the last two biological parameters, which are related to corporal mass. In this period, the highest values of BM were observed in both sexes and overweight rates raised sharply, with 47% of males and 40% of females. All

this probably reflects dietary changes and increasingly sedentary lifestyles. Proto-industrialization and textile manufacturing spurred economic recovery by the 18th century (Vilar 1977). Dietary change during this time was gradual but profound: traditional staples like cereals and legumes persisted, but American crops such as maize and potatoes became increasingly common, especially among the poor (McNeill 2010). For instance, Spain had a drop in mortality during the eighteenth century as a result of advancements in nutrition (the introduction of new foods), health, hygiene, and disease treatment (Santonja 1999), as well as growing economic and technological development (Floristán 2011).

Across Barcelona's history, nutrition and physiological condition reflected shifting social, economic, and environmental circumstances. Average LE in prehistoric and early historic populations was often around 20 years or even lower, largely driven by extremely high infant and child mortality, recurrent infectious diseases, famine, and precarious living conditions. Archaeological and demographic evidence from Barcelona, as well as from Europe more broadly, indicates that frequent epidemics, malnutrition, warfare, and deficiencies in essential nutrients critical for physiological development and immune function significantly constrained survival in early societies (e.g., Knapp 1998; Glick et al. 2005; Collins 2012). LE remained low until substantial improvements in food supply, sanitation, public health, and disease control occurred much later in history.

An average LE of around 20 years reflects severe demographic instability, with mortality concentrated in early life and a limited proportion of individuals reaching older adulthood. Such conditions required high fertility to sustain population size and likely affected social continuity, labor organization, and economic stability, particularly during periods of famine and epidemic disease. These low values therefore indicate the cumulative impact of environmental and social stressors rather than biological limits to human longevity.

All these results seem to suggest that these three biological parameters (LE, BM, and BMI) are more sensitive indicators of diachronic shifts associated with sociocultural and environmental change than the ST.

Limitations and further research

By analyzing data from Prehistory to the Modern period, this study provides a comprehensive overview of past populations in Barcelona based on LE, ST, BM, and BMI. A notable strength of the study is the relatively large number of individuals represented in the Roman, Late Antiquity, Medieval, and Modern period assemblages. Because these samples originate from archaeological contexts, their

size adds considerable reliability to the findings for these periods. The data contribute significantly to constructing a biological profile of past populations in Barcelona, laying a foundation for future comparative studies with populations from other regions and chronological periods.

However, several limitations should be acknowledged. Unlike contemporary demographic research, which relies on comprehensive census data, paleodemographic reconstructions are based on incomplete and often biased samples, typically derived from skeletal remains (Konigsberg and Frankenberg 2002). These remains usually represent only a fraction of the population from specific times and places, potentially introducing bias into demographic estimates (DeWitte and Stojanowski 2015). The “known unknowns” that contribute to the persistent interpretive uncertainties in studies of population health from archaeological skeletal series are the many hidden factors influencing observable patterns in bioarchaeological data; bioarcheologists refer to this phenomenon as the “osteological paradox” (Anderson and DeWitte 2026). Additionally, paleodemographic estimates often depend on hypotheses that are difficult to verify, which can result in inaccuracies or misrepresentations (Hoppa and Vaupel 2002). Researchers must therefore critically assess the theoretical assumptions underlying these studies to avoid overgeneralization (De Luca et al. 2023). Future research could apply more robust approaches to mortality analysis, such as survivorship and hazard models, which can provide deeper insight into the reconstruction of past mortality patterns while also taking into consideration biases related to immigration that could affect the sample.

This study is further limited by the lack of BM and BMI data for historical Spanish populations, which complicates cross-regional and temporal comparisons. The scarcity of anthropological and paleopathological research on these metrics also restricts the scope of comparative analyses. Small sample sizes from the prehistoric period, along with temporal gaps between certain periods (e.g., Prehistoric and Roman), reduce the generalizability of findings and prevent reliable inference about continuity or transitions between these periods. Consequently, the study focuses on comparisons between distinct chronological periods rather than interpreting biological “transitions” across centuries.

Conclusions

To our knowledge, this is the first bioarchaeological study to provide a diachronic perspective on the past population of present-day Barcelona city, using the largest skeletal sample and the broadest chronological span analyzed to date in the Iberian Peninsula. By examining 1,090 individuals from Prehistory to the Modern period, the study offers a

long-term view of biological and demographic trends, while acknowledging that sample limitations and potential biases constrain broad generalizations.

LE at birth relatively increased across most periods, ranging from 21 to 27 years, with a marked increase during the Modern period. This increase is likely to reflect improvements in living conditions and healthcare access, coinciding with the transition from the pre-industrial to the industrial era. ST showed no statistically significant inter-period differences, with male averages of 164–166 cm and female averages of 151–154 cm. In contrast, BM and BMI exhibited statistically significant inter-period differences in males and females, with higher averages observed during the Modern period.

These four biological parameters, particularly LE, BM, and BMI, appear to be sensitive to sociocultural and environmental changes, displaying measurable diachronic shifts associated with these transformations. In this study, three main shifts were identified: the transition from the Prehistoric to the Roman period, a shift during the Medieval period, and the transition from the Medieval to the Modern period. Overall, these findings underscore that observed biological trends reflect population-level patterns shaped by local living conditions, environmental factors, and historical events. Despite limitations, this study provides a valuable long-term reference for understanding human adaptation and health in past populations, offering a framework for future diachronic bioarchaeological research in the Iberian Peninsula.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s12520-026-02504-7>.

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Author contributions A.C. designed the study, performed data acquisition and curation, and created the figures and tables. A.C. and C.R. wrote the main manuscript text. C.R. refined the analysis methodology, contributed to the study design, and supervised its development. Both authors contributed to the interpretation of the results, revised the manuscript, and approved the final version.

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Data availability The data supporting the findings of this study are

available from the first author upon reasonable request. The data are not publicly available due to privacy or ethical restrictions.

Declarations

Ethical approval Not applicable. As we used archaeological human remains from the Neolithic to the 18th century, this research did not require approval from an Ethics Committee.

Competing interests The authors declare no competing interests.

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