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RESEARCH

Emphasising the community: demographic composition of an exceptional tomb—the Chalcolithic burial site of Camino del Molino, Caravaca de la Cruz, Murcia

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Abstract
Reconstructing the biological profile of a skeletal sample is essential for defining a particular demographic group or classifying isolated remains. These results allow us to complete the population pyramid of a settlement, analyse mortality trends and relate individuals of a particular sex or age-at-death category to possible funerary rituals, lifestyles and/or states of health and disease. In this work, we carry out a paleodemographic analysis of a singular tomb: the chalcolithic burial site of Camino del Molino, Murcia, SE Spain. The tomb hosted 1348 individuals (30.7% non-adults and 69.3% adults) over two contiguous funerary phases, spanning a large part of the third millennium BC, which makes it a reference site for knowledge of the Recent Prehistoric populations. For this purpose, we estimated different paleodemographic parameters (life tables, mortality rates and sex ratios) and compared them to model life tables of preindustrial populations and data from other contemporary peninsular series to evaluate possible demographic anomalies. The results suggest that Camino del Molino was home to individuals of all ages and sex. However, there is a clear under-representation of newborns and nursing/breastfeeding infants and an over-representation of 5–15-year-old individuals. These findings could indicate potential issues related to diet/weaning, disease and early inclusion in the economic activities of the group.

Keywords Bioarchaeology · Paleodemography · Copper age · Iberian Peninsula · Collective burial

Introduction

Paleodemography is a subdiscipline that attempts to identify the demographic parameters of populations that precede archaeological contexts from a data set of skeletal remains and historical documentary sources (Hoppa 2002: 9). The first studies on archaeological collections were developed in the late 1940s, although they were at their peak during the 1970s and 1980s (e.g., Angel 1947, 1969; Acsádi and Nemeskéri 1970; Masset 1973; Armelagos and Medina 1977; Bocquet-Appel 1977, 1986; Bocquet-Appel and Masset 1977; Gage 1985). At the same time, a profound scientific debate emerged about the validity of these analyses in archaeological populations due to possible biases related to the nature of the reference samples used in the model life tables and age-at-death estimation methods (Bocquet-Appel and Masset 1982, 1985, 1996; Van Gerven and Armelagos 1983; Buikstra and Konigsberg 1985). This discussion led to a methodological review of the discipline, with skeletal collections of which sex and age at death were already known, testing their validity on a larger number of archaeological samples. Subsequently, life tables were improved through the development of mathematical adjustments that offset the known biases (e.g., Gage 1988; 1990; Konigsberg and Frankenberg 2002; Paine and Boldsen 2002; Séguy and Buchet 2013).

Studies that attempt to reconstruct the population composition of prehistoric burials are becoming increasingly common. The Neolithic demographic transition has been one of the main topics in Recent Prehistoric population research (e.g., Piontek et al. 1996; Meiklejohn et al. 1997; Bocquet-Appel 2002, 2008, 2009, 2011; Bocquet-Appel and Dubouloz 2003; Séguy and Buchet 2013; Dubouloz et al. 2017;

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Eshed and Gopher 2018). In contrast, recent studies from the Iberian Peninsula have mainly focused on skeletal collections from megalithic ossuaries (e.g., Silva 2003, 2012; Costa Caramé et al. 2010; Rivera 2011; Tomé and Silva 2013; Boaventura et al. 2014; Cunha et al. 2015; Silva and Ferreira 2007; Fernández-Crespo and de la Rúa 2015, 2016; Díaz-Navarro 2021), enriching the debate on selection trends by documenting the demographic anomalies of the individuals deposited there, with particular focus on age and sex.

It is important to take into account the limitations of the peninsular osteoarchaeological record of Recent Prehistory. Firstly, the fact that the skeletal remains are generally found in collective burials with disjointed remains hinders an accurate record and recovery. Furthermore, the poor bone preservation typical in this type of context and high fragmentation render it impossible to produce accurate estimates of sex and age. On the other hand, anthropologists often analyse past excavated collections, with little documentation and which are often poorly preserved as a result of old and obsolete storage protocols. Furthermore, until recently, human bones were rarely directly radiocarbon dated. The small size of prehistoric skeletal assemblages, coupled with their limited representation of the population as a whole, poses another challenge that further restricts our understanding of the communities that inhabited a specific time and place. This is directly linked to possible selection biases arising from mortuary practices. Finally, the temporal average of the skeletal groups that the prehistoric cemeteries comprise is another limitation.

On this basis, this research aims to contribute to the knowledge of the populations of the third millennium BC through the paleodemographic and chronometric analysis of a skeletal sample that is unique due to its volume, varied population composition, the excellent preservation of the skeletal remains and its recent excavation, with exhaustive documentation and recording methods. This is the collective burial of Camino del Molino (CMOL), Murcia, SE Spain, which contains the largest prehistoric funerary record known to date (Fig. 1a).

Material and methods

Material

This study analyses the full skull collection from the CMOL site, which was discovered by chance in December 2007 and excavated during 2008 (Lomba et al. 2009a, 2009b).

The burial site was defined by a circular structure excavated from travertine with a diameter of c.6–7 m. The lower 2 m of this structure, where the archaeological deposit was located, was preserved intact (Haber et al. 2012; Lomba et al. 2009a, 2009b) (Fig. 1b). Geomorphological analysis indicates that the structure was part of a cave, although a clear anthropic alteration can be noted both in the walls—which were regularised, adopting a bell-shaped form—and in the floor (Lomba et al. 2009b). This leads us to believe that it was originally an artificial cave or hypogeum with an entrance at the top and a perishable structure as a support, of which only the postholes are preserved (Díaz-Navarro et al. 2023).

The crania count carried out during the fieldwork indicated a minimum of 1300 individuals (Lomba et al. 2009a, 2009b)—a figure that has now increased after the study of the remains—making CMOL the largest cemetery in European Prehistory. The funerary sequence is characterised by the repeated introduction of corpses, in many cases simultaneously, which were grouped around the walls of the structure as the space filled up (Haber et al. 2012). This has led to the recovery of 167 complete and articulated individuals, mainly from the perimeter (Díaz-Navarro et al. 2023).

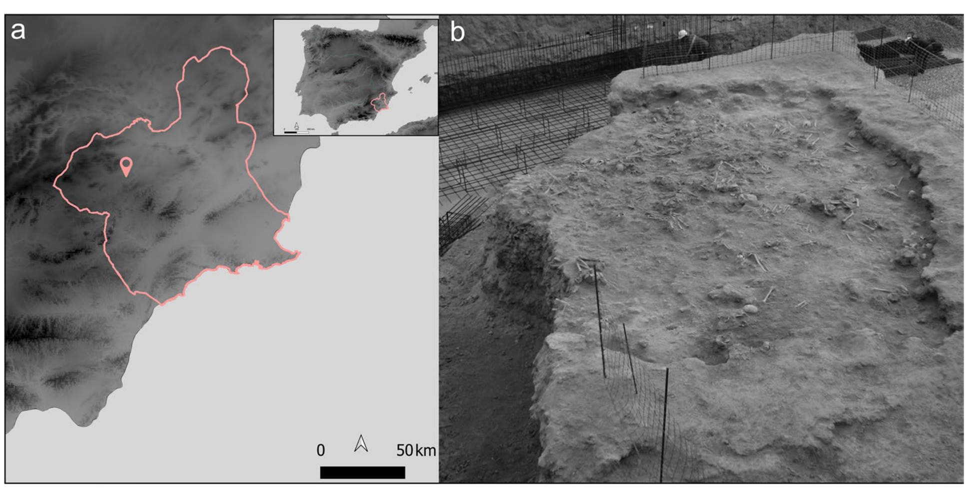

Fig. 1 **a** Map showing the location of the burial site of Camino del Molino, Caravaca de la Cruz, Murcia (QGIS, 3.16 Hannover). **b** Aerial photograph after surface cleaning prior to archaeological excavation

Methods

Radiocarbon dating and Bayesian analysis

A total of 28 14C dates from different articulated individuals (Table 1) are included. The main objective in selecting the samples was to have a well-balanced representation of the different stratigraphic units (SUU) and tomb areas (Fig. 2).

The chronometric analyses and the calibration and modelling graphs were performed with OxCal v4.4.4 software (Bronk Ramsey 1995, 2001), available online http://c14.arch.ox.ac.uk/, using the IntCal20 atmorpheric calibration curve (Reimer et al. 2020).

Bayesian inference was the analytical tool implemented to precisely define the phases of use and estimate their time boundaries with a high percentage of probability. The phase model, the overlapping phase model and the contiguous phase model were carried out, with an agreement of over 60%, for both the general models and for each of the data analysed (*Supplementary Information* S1).

Osteological analysis

Determination of the minimum number of individuals

Due to the large volume of skeletal remains, we conducted a quantitative analysis focusing on the most commonly found anatomical element in the sample, which was the skull. Only complete crania or fragmentary crania with preserved parietal, occipital, *pars petrosa* and frontal bones were taken into account.

Sex and age-at-death estimation

In non-adult individuals, the degree of dental eruption was analysed according to Ubelaker's (1989) chart method as

Table 1 Table of 14C dates of 28 articulated individuals from CMOL burial site with corresponding archaeological information (SUU, stratigraphic units) and isotopic measurement. Radiocarbon analyses have been carried out at Tandem Laboratory (Uppsala (Ua), Sweden) and Beta Analytics (USA)

No. of ind	SUU	Sample type	Lab Reference	13C/12C ‰	15N/14N ‰	C/N	BP	CAL BC 1σ (68.2%)	CAL BC 2σ (95.4%)
79	1108	Human bone	Beta-261524	– 18.9	9.1	3.2	3830 ± 40	2396–2202	2456–2146
4	1100	Human bone	Ua-74394	– 19.6	9.9	3.2	3870 ± 32	2453–2291	2462–2209
96	1109	Human bone	Ua-74398	– 19.2	8.4	3.3	3871 ± 32	2454–2292	2463–2209
61	1108	Human bone	Ua-74397	– 19.5	10.2	3.2	3871 ± 32	2454–2292	2463–2209
7	1106	Human bone	Beta-261518	– 18.6	8.2	3.2	3890 ± 40	2458–2307	2470–2209
32	1107	Human bone	Beta-261521	– 8.8	11.2	3.2	3890 ± 40	2458–2307	2470–2209
25	1107	Human bone	Ua-74395	– 19.6	9	3.2	3900 ± 32	2461–2345	2471–2287
27	1107	Human bone	Ua-74396	– 19.3	8.3	3.3	3903 ± 32	2462–2345	2471–2287
6	1106	Human bone	Beta-261517	– 19.7	10.7	3.2	3910 ± 40	2466–2343	2559–2214
21	1106	Human bone	Beta-261520	– 19.4	10.2	3.2	3920 ± 40	2469–2344	2566–2239
36	1107	Human bone	Beta-261522	– 19	9.5	3.2	3930 ± 40	2474–2344	2567–2292
73	1108	Human bone	Beta-261523	– 19.2	9.3	3.2	3940 ± 40	2556–2347	2570–2297
169	WP	Human bone	Ua-74400	– 19.1	8.9	3.2	3956 ± 32	2566–2355	2571–2344
168	SWP	Human bone	Ua-74403	– 20.1	7.7	3.3	3967 ± 32	2567–2460	2574–2348
12	1106	Human bone	Beta-261519	– 18.9	10.3	3.2	3970 ± 40	2571–2456	2579–2342
98	1109	Human bone	Beta-261525	– 19.1	8.2	3.2	4030 ± 40	2579–2475	2837–2464
163	1109	Human bone	Ua-74401	– 19.6	8.7	3.2	4089 ± 32	2842–2574	2862–2495
161	1109	Human bone	Beta-261532	– 19.1	8	3.2	4100 ± 40	2848–2577	2870–2498
151	1109	Human bone	Ua-74399	– 19.3	8	3.4	4117 ± 32	2851–2586	2868–2576
106	1109	Human bone	Ua-74402	– 19.5	7.9	3.3	4122 ± 32	2857–2623	2869–2578
105	1109	Human bone	Beta-261527	– 18.6	11.1	3.2	4130 ± 40	2862–2626	2874–2578
181	1109	Human bone	Beta-261534	– 18.8	8.7	3.2	4140 ± 40	2866–2631	2876–2582
100	1109	Human bone	Beta-261526	– 19.2	8.5	3.2	4140 ± 40	2866–2631	2876–2582
175	1109	Human bone	Beta-261533	– 18.7	9.9	3.2	4160 ± 40	2874–2671	2884–2588
131	1109	Human bone	Beta-261530	– 19.6	8.1	3.2	4160 ± 40	2874–2671	2884–2588
108	1109	Human bone	Beta-261528	– 18.7	9.7	3.2	4160 ± 40	2874–2671	2884–2588
123	1109	Human bone	Beta-261529	– 18.6	10.5	3.2	4210 ± 40	2893–2702	2905–2636
133	1109	Human bone	Beta-261531	– 19.7	9.9	3.2	4260 ± 40	2916–2782	3010–2696

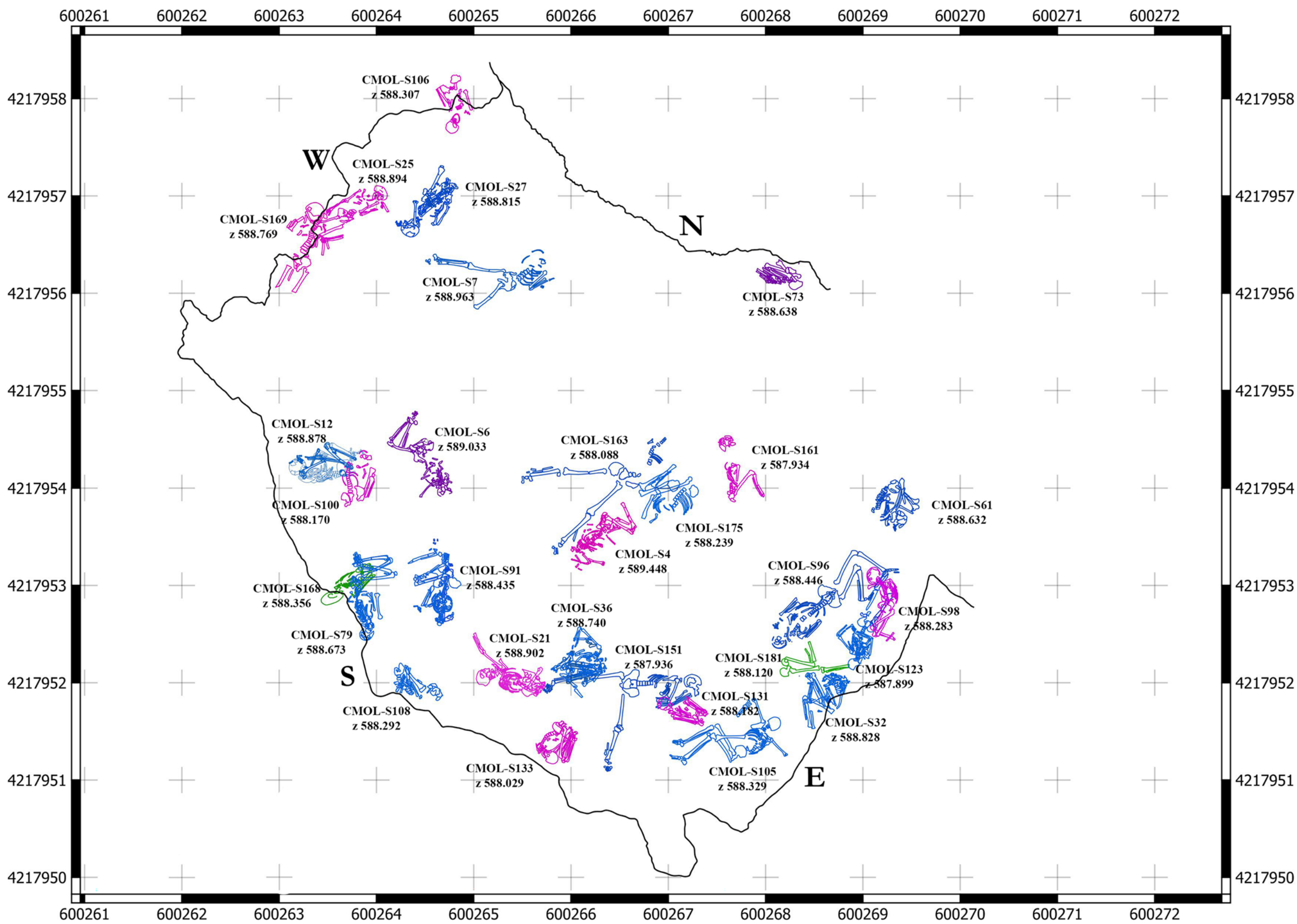

Fig. 2 Digital planimetry with the CMOL-dated individuals indicating their depth (*z*). Males are shown in blue, females in pink, probably females in purple, and non-adults in green (QGIS, 3.16 Hannover)

the main criteria. Where teeth were not preserved, morphometric variables of different cranial regions such as the *pars basilaris*, *pars squama* and *pars lateralis* (Fazekas and Kosa 1978) were analysed, as well as the degree of ossification of temporal or sphenoid bones (Scheuer and Black 2000). Sex estimation in non-adults has been categorized as indeterminable, except for some individuals older than 16 years, where clear skull sex indicators were observed.

The conservation of 82 articulated individuals with skull and pelvis of both sexes and all age categories has allowed us to establish the morphological and morphometric skull traits that best discriminate between sexes (Herrmann et al. 1990; Buikstra and Ubelaker 1994). For this purpose, 12 cranial and mandibular features were analysed, assigning each of them a sex estimation category (not preserved, female, male, indeterminate). The results were then compared with the most reliable estimates obtained from the pelvis, which were further validated through DNA analysis on 20 articulated skeletons. As a result, the most reliable indicators for sex estimation from isolated skulls were determined, as well as those that should be used with caution due to their wide margins of error (*Supplementary Information* S2).

Likewise, the data on the degree of dental wear according to the method of Zoubov (1968) in 93 articulated skeletons whose age at death has been determined by other more reliable methods analysed in the pelvic (Meindl et al. 1985; Lovejoy et al. 1985) and costal (Işcan et al. 1985a, 1985b) region were cross-checked. This has made it possible to establish a series of wear patterns that facilitate the ascription of the isolated skulls to an age-at-death category (*Supplementary Information* S2). The method designed by Zoubov (1968) offers a scale comprising five degrees of occlusal wear for incisors and canines and six for premolars and molars.

Paleodemography

There are a few limitations to be considered before commencing a paleodemographic analysis on an archaeological sample. These include (1) the size of the sample and how it represents the original population of the buried and the living (Bocquet-Appel and Masset 1977; Waldron 1994), (2) the stationary nature of the population (Sellier 1994) and (3) the existence of an archaic mortality pattern (Ledermann 1969).

In the CMOL case, although we accept the Waldron scheme (1994) and we are aware of the lack of information regarding the destruction of the north-east zone of the burial site by machinery (Lomba et al. 2009a, 2009b; Díaz-Navarro 2023), we believe that we are dealing with a reliable and representative sample of the original living population, taking into account (1) the large volume of individuals, (2) the prolonged funerary use of the grave, (3) the complete excavation of the site with modern methods, (4) the population trends according to dates and the results of mobility analyses (Merner 2017) and (5) the presence of individuals of both sexes and all age categories, suggesting that there was apparently no selection process to access the grave.

From the estimates of the sex and age at-death of the crania, mortality tables have been produced based on stationary populations (Acsádi and Nemeskéri 1970) to determine the demographic composition of CMOL throughout the time of use of the grave. In addition, life expectancy (e_0) at birth was calculated for the overall sample, by sex and funerary use.

For this purpose, the age at death has been classified in 5-year intervals (Acsádi and Nemeskéri 1970) considering men and women both as a whole and separately. For the adult individuals, who were generally classified as young (20–39 years) or middle-aged adults (40–59 years), 5-year intervals have been established by cubic interpolation (Burden and Faires 1985) from the cumulative d_x, while the relative d_x was calculated from the representation of the interpolated cumulative d_x (Valverde and Bush 1992). This is based on the premise that the distribution of a sample of archaeological adult individuals over short age intervals is currently impossible (Bocquentin 2003).

For individuals with a large standard error in age-at-death estimation, located between two or more intervals, the distribution was made according to Sellier's (1994) principle of minimisation of demographic anomalies.

To detect demographic anomalies, several mortality coefficients have been calculated, which are useful to address problems arising from bias in adult age-at-death estimates and the frequent under-representation of non-adults in archaeological populations (Bocquet-Appel and Masset 1977; Bocquet-Appel 1979).

Finally, the sex ratio has been calculated to record irregularities related to the sex of the buried individuals (Ledermann 1969).

The demographic data has been compared to other contemporary archaeological series of the site under study, as well as to the Ledermann (1969) model life tables for preindustrial populations with a 30-year life expectancy, which closely resembles the estimated life expectancy of the CMOL population.

Results

Chronometric analysis

The calibrated date graph suggests that the time span of this tomb covers almost the entirety of the third millennium BC (Table 1; *Supplementary Information* S1). However, the uncertainty intervals of each of the radiocarbon dates and the inaccuracy of the calibration curve in these chronological ranges make the temporal sequences appear much longer than they were.

Bayesian modelling shows that the contiguous phase model (Bayliss and Bronk Ramsey 2004) is the most robust as it has the highest agreement index (Amodel: 99.3) and more acceptable individual agreement indices (> 60%) (*Supplementary Information* S1).

The results of this analysis suggest that the first funerary phase of use started at the beginning of the third millennium (2971–2711 years cal BC, 2σ) and spanned a maximum of three centuries (0–259/82–377 years cal BC, 2σ). The second funerary phase was shorter (0–220/20–282 years cal BC, 2σ), and the end of the sequence is marked between 2451 and 2251 cal BC 2σ). The transition period between the two phases was 80 years at most (Fig. 3).

Osteological analysis

The number of isolated crania from CMOL amounts to 1348 individuals (30.7% non-adults and 69.3% adults), of which 469 belong to the first funerary phase (SUU 1109 and 1110) and 879 to the second (SUU 1101, 1104, 1106–1108).

The age-at-death estimation allows us to conclude that 13.5% belong to the Infant I category (*N* 182) (0–6 years old), 11.3% to the Infant II category (*N* 152) (7–12 years old), 5.9% are juvenile (*N* 80) (13–19 years old), 30.9% are young adults (*N* 417) (20–39 years old), 34.7% are middle adults (*N* 468) (40–59 years old) and 3.7% are old adults (*N* 50) (more than 60 years).

With regard to sex, we can advance that the CMOL population was constituted by 377 females (27.9%), 400 males (29.7%), 62 probable females (4.6%), 62 probable males (4.6%) and 447 individuals of undetermined sex (33.2%) (Fig. 4).

Paleodemography

In order to define the CMOL population, a mortality table has been prepared by dividing the total population into

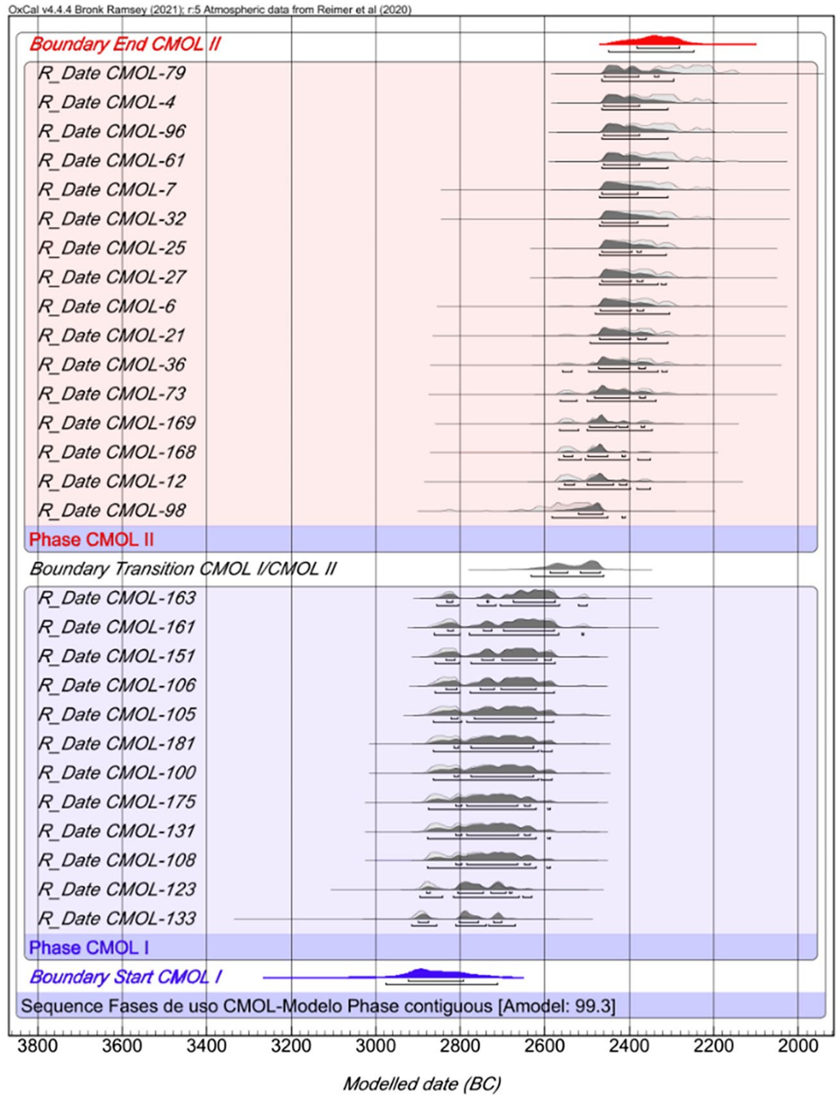

Fig. 3 Contiguous phase model, with the estimated start and end boundaries of each funerary phase (CMOL I: blue; CMOL II: red) (OxCal v4.4.4)

5-year age groups, without taking into account the different levels of funerary use.

A total of 10 perinatal, 122 individuals aged 1–4 years, 167 aged 5–9 years, 63 aged 10–14 years, 51 aged 15–19 years, 417 young adults, 468 middle adults and 50 old adults were deposited in CMOL (Table 2). We can also state that life expectancy at birth was 31.3 years, a value that decreases to 30.4 years if the perinatal individuals

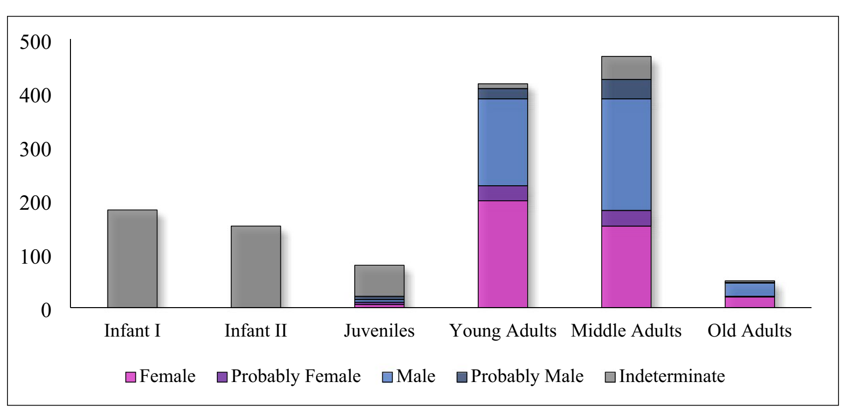

Fig. 4 Bar graph showing the population composition (*N*) of CMOL site by sex and age categories (Microsoft Excel)

Table 2 Life table for the CMOL population, which provides information on life expectancy at birth (e_x) ${}_nD_x$ absolute frequency of individuals in the age range; ${}_nd_x$ absolute frequency of individuals in the age interval among the total population per 100; ${}_nd_{xi}$ relative frequency of individuals in the age interval after proportional distribution of indeterminates by cubic interpolation per 100 divided by the total population (${}_nd_x \cdot 100/\Sigma D_x$); l_n surviving population at an age interval. It is calculated by subtracting the sum of the percentages of the preceding age intervals from the total population (l_n-1–${}_nd_x$-1); ${}_nq_x$ probability of death for each age group obtained by dividing the percentage of deaths in an interval (d_x) by the number of survivors (l_n); ${}_nL_x$ total years lived by the survivors of the age interval ($n\cdot$ (l_n+l_n+1)/2); ${}_nT_x$ total years left to live in an age range (${}_nL_x$+${}_nL_x$+1+${}_nL_x$+2+…+${}_nL_x$+n); e_x life expectancy for each age interval (${}_nT_x$/${}_nL_x$)

Age ranges	${}_nD_x$	${}_nd_x$	${}_nd_{xi}$	l_n	${}_nq_x$	${}_nL_x$	${}_nT_x$	e_x
< 1	10	0.7418	0.742	100.000	0.007	99.63	3135.497	31.35
1–4	122	9.0504	9.050	99.258	0.091	378.93	3035.87	30.59
5–9	167	12.3887	12.389	90.208	0.137	420.07	2656.94	29.45
10–14	63	4.6736	4.674	77.819	0.060	377.41	2236.87	28.74
15–19	51	3.7834	3.783	73.145	0.052	356.27	1859.46	25.42
20–24	417	30.9347	5.2769	69.362	0.076	333.62	1503.19	21.67
25–29			7.2250	64.085	0.113	302.36	1169.57	18.25
30–34			8.7077	56.860	0.153	262.53	867.21	15.25
35–39			9.7251	48.152	0.202	216.45	604.68	12.56
40–44	468	34.7181	10.1983	38.427	0.265	166.64	388.23	10.10
45–49			9.8117	28.229	0.348	116.62	221.59	7.85
50–54			8.4862	18.417	0.461	70.87	104.97	5.70
55–59			6.2219	9.931	0.627	34.10	34.10	3.43
60–	50	3.7092	3.7092	3.709	1.000	0.00	0.00	0.00
Total	1348	100.000	100.000			3135.497		

are added to those aged 1–4 years, creating a 5-year age group of 0–4 years.

A clear under-representation of children under 5 is observed compared to the typical profile established for preindustrial populations (${}_1q_0$=7.41‰ vs 288‰; ${}_4q_1$=90.5‰ vs 306.5‰ and ${}_5q_0$=97.92‰ vs 521‰ calculated by Ledermann (1969)) (Fig. 5a).

In contrast, mortality increases considerably among individuals aged 5–15 years in CMOL (Fig. 5a), tripling the Ledermann (1969) calculated values (${}_5q_{10}$=123.88‰ vs. 39.5‰ and ${}_5q_{15}$=170.62‰ vs. 56‰).

However, if we consider the mortality coefficient of the non-adult bulk (${}_{20}q_0$), the CMOL figures are lower than those calculated for preindustrial populations (306.38‰ versus 557.5‰) (Fig. 5a).

Adults are the most numerous, accounting for 65% of the total population, and both subcategories (young and mature) have a similar number of individuals, with a slightly higher number of deaths in the mature age group (35% vs 31%). Old adults are the age category with the lowest mortality (3.7%) (Table 2).

The sex ratio offers a value of 1.05:1, close to parity (1:1). Within the male sample, the highest number of deaths occurs in middle-aged adults (37%), surpassing the percentage of deaths among young adults (27%). In contrast, the higher percentage of women deaths occurs in youth (36% young adults compared to 29% of middle-aged adult females).

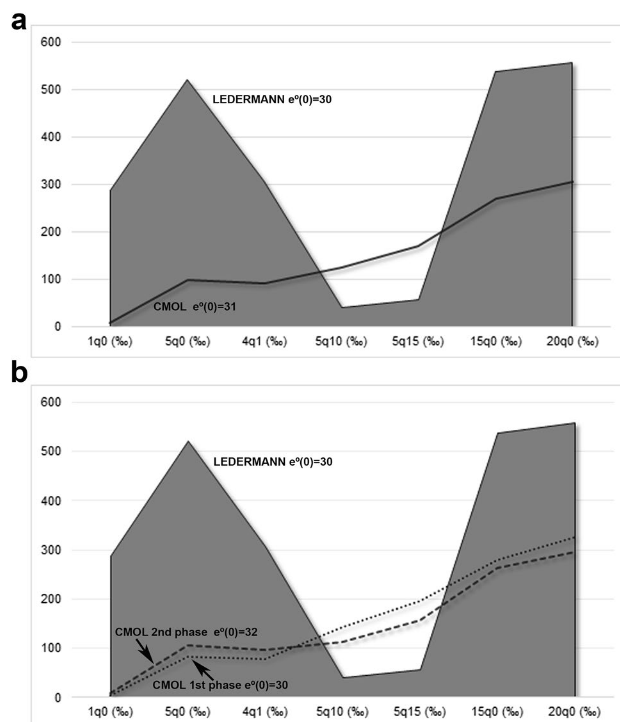

Fig. 5 **a** Graph showing mortality coefficients for the non-adult CMOL population (black line) and comparison with those calculated by Ledermann (1969) (grey area). **b** Graph with the mortality coefficients of the non-adult population of the first (dotted line) and second (dashed line) funerary phases and comparison with those calculated by Ledermann (1969) (grey area) (Microsoft Excel)

Table 3 Life table of the individuals deposited at the first funerary phase that allows us to know the life expectancy at birth

Age ranges	$_nD_x$	$_nd_x$	$_nd_{xi}$	l_n	$_nq_x$	$_nL_x$	$_nT_x$	e_x
< 1	2	0.4264	0.426	100.000	0.004	99.79	3009.763	30.10
1–4	37	7.8891	7.889	99.574	0.079	382.52	2909.98	29.22
5–9	67	14.2857	14.286	91.684	0.156	422.71	2527.46	27.57
10–14	25	5.3305	5.330	77.399	0.069	373.67	2104.75	27.19
15–19	22	4.6908	4.691	72.068	0.065	348.61	1731.08	24.02
20–24	156	33.2623	6.4848	67.377	0.096	320.67	1382.47	20.52
25–29			8.1029	60.893	0.133	284.21	1061.80	17.44
30–34			9.1246	52.790	0.173	241.14	777.59	14.73
35–39			9.5500	43.665	0.219	194.45	536.45	12.29
40–44	144	30.7036	9.3819	34.115	0.275	147.12	342.00	10.02
45–49			8.6311	24.733	0.349	102.09	194.88	7.88
50–54			7.3005	16.102	0.453	62.26	92.79	5.76
55–59			5.3901	8.802	0.612	30.53	30.53	3.47
60–	16	3.4115	3.4115	3.412	1.000	0.00	0.00	0.00
Total	469	100.000	100.000			3009.763		

Furthermore, the sample has been divided by funerary phases (according to the archaeological results, the radiocarbon and Bayesian analysis) to determine possible differences in the demographic patterns of both phases of funerary use. The division of the sample allows us to observe a significant difference in the number of subjects deposited in both levels, documenting twice as many individuals in the second phase (Tables 3 and 4).

Looking at the life tables, we identify an increase in life expectancy of 2 years between the first and second level of use (Tables 3 and 4). Focusing on the 5-year age intervals, a similar distribution is documented in both phases, starting with a mortality peak among 5–9-year-olds that is more remarkable in the first phase (14.3%) than in the second (11.4%). From this category onwards, the figures decrease in both funerary levels until the young adult stage, with a mortality rate of 33.2% in the first phase and 29.7% in the second. The middle-aged adult's rate is 30.7% for the first level and 36.9% for the second. In the old adult's category, we did not observe any differences between the two phases (3.4% and 3.9%, respectively).

Mortality coefficients for both types of funerary use do not differ from those observed in the full sample (Fig. 5b and Table 5). It should be noted that there is under-representation of perinatal and under-five individuals at both levels ($_1q_0 = 4.26‰$ and 9.1‰ vs. 288‰ of preindustrial populations (Ledermann 1969); $_5q_0 = 83.1‰$ and 105.8‰ vs. 521‰; $_4q_1 = 78.9‰$ and 96.7‰ vs. 306.5‰). However, mortality in this age range is higher in the second level of funerary use.

Table 4 Life table of the subjects deposited at the second funerary phase that allows us to know the life expectancy at birth

Age ranges	$_nD_x$	$_nd_x$	$_nd_{xi}$	l_n	$_nq_x$	$_nL_x$	$_nT_x$	e_x
< 1	8	0.9101	0.910	100.000	0.009	99.54	3208.366	32.08
1–4	85	9.6701	9.670	99.090	0.098	377.02	3108.82	31.37
5–9	100	11.3766	11.377	89.420	0.127	418.66	2731.80	30.55
10–14	38	4.3231	4.323	78.043	0.055	379.41	2313.14	29.64
15–19	29	3.2992	3.299	73.720	0.045	360.35	1933.74	26.23
20–24	261	29.6928	4.5693	70.421	0.065	340.68	1573.38	22.34
25–29			6.6489	65.852	0.101	312.64	1232.70	18.72
30–34			8.3860	59.203	0.142	275.05	920.07	15.54
35–39			9.7807	50.817	0.192	229.63	645.02	12.69
40–44	324	36.8601	10.6927	41.036	0.261	178.45	415.39	10.12
45–49			10.5609	30.343	0.348	125.31	236.94	7.81
50–54			9.2450	19.782	0.467	75.80	111.62	5.64
55–59			6.7451	10.537	0.640	35.82	35.82	3.40
60–	34	3.8680	3.8724	3.792	1.021	0.00	0.00	0.00
Total	879	100.000	100.000			3208.366		

Table 5 Mortality ratios of the CMOL non-adult population by burial phases and comparison with Ledermann (1969) data for preindustrial populations

Sample	$_1q_0$ (‰)	$_5q_0$ (‰)	$_4q_1$ (‰)	$_5q_{10}$ (‰)	$_5q_{15}$ (‰)	$_{15}q_0$ (‰)	$_{20}q_0$ (‰)
CMOL first phase $e°$ (0) = 30	4.26	83.15	78.89	142.85	196.16	279.31	326.23
CMOL second phase $e°$ (0) = 32	9.1	105.8	96.7	113.7	157	262.8	295.8
Ledermann $e°$ (0) = 30	288	521	306.5	39.5	56	537	557.5

Again, in both phases, the numbers increase considerably as the non-adults grow older. This is perceived in the $_5q_{10}$ coefficient, documenting 142.85‰ in the first funerary level and 113.7‰ in the second, and likewise in the $_5q_{15}$ coefficient, which yields values of 196.16‰ in the first funerary phase and 157‰ in the second, figures that are far from the parameters calculated by Ledermann (1969) (Table 5). In this case, mortality is more pronounced in the first phase (Fig. 5b and Table 5).

If we consider the mortality of individuals under 15 years of age at death and of all non-adults, the figures for both CMOL levels are lower than those established by Ledermann (1969) (Table 5). A difference of 30‰ is observed between the two phases, with the first phase expressing a higher non-adult mortality rate (Fig. 5b).

In terms of sex distribution, there are no significant differences by funerary phases and, as in the general sample, parity is documented (sex ratio of the first level is 1.1:1 and that of the second is 1.03:1). However, a higher proportion of women dying in youth than in middle-aged is documented in both phases (64 mature women compared to 78 young women in the first phase and 117 mature women compared to 149 young women in the second phase, Fig. 6a, b). This contrasts with the pattern observed in male deaths, especially in the second funerary phase, with higher mortality after the age of 40 (75 young adults and 79 middle adult males in the first phase and 106 young adults vs 165 middle adult males in the second phase, Fig. 6a, b).

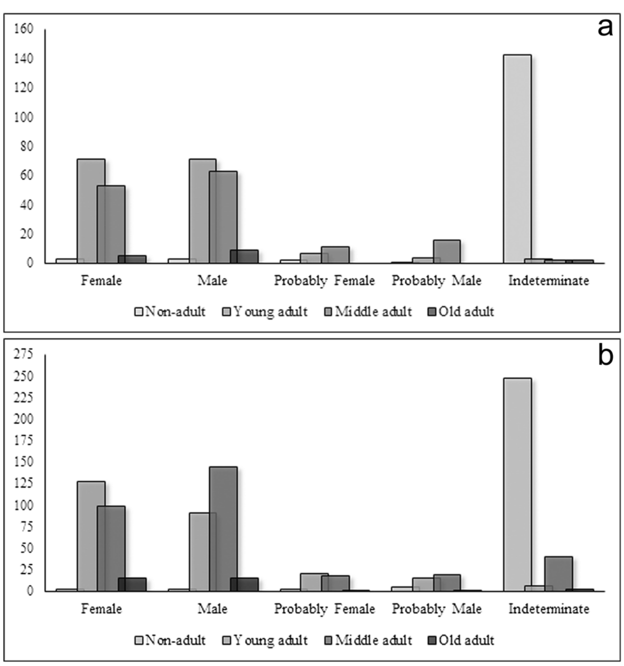

Fig. 6 **a** Bar graph showing the population composition (*N*) of the first burial phase of CMOL by sex and age at death. **b** Bar graph showing the population composition (*N*) of the second funerary phase of CMOL by sex and age at death (Microsoft Excel)

Discussion and conclusions

The CMOL collective burial housed the largest prehistoric ossuary known to date, with a minimum of 1348 individuals, deposited in two contiguous phases that span a large part of the third millennium (2971–2711 to 2451–2251 years cal. BC). The first burial phase housed the remains of 469 individuals, while during the somewhat shorter second phase, almost twice as many people (*N* 879) were buried in this grave. This seems to suggest a considerable demographic increase, supported by evidence of a decrease in infant mortality and a slight increase in life expectancy. Additionally, the results of the $^{87}Sr/^{86}Sr$ mobility analysis carried out on 93 individuals (Merner 2017) point to the presence of 12 non-local individuals at CMOL, 10 of them (83.3%) from the most recent burial phase.

To understand the magnitude of this tomb, it is necessary to investigate the funerary record of other contemporary sites. In Europe, although there are collective burials with a large number of individuals, such as the hypogeum of Crottes in Roaix with 136 individuals (Chambon 2003), or the hypogeum of Boileau in Vaucluse (Mahieu 1987) with 350, none come close to the size of CMOL. Other tombs with a large volume of human remains have also been identified in the Iberian Peninsula, such as the rock shelter of San Juan Ante Portam Latinam in Alava—MNI 388—(Etxeberría and Herrasti 2007), the *tholos* of Paimogo I in Lourinhã—MNI 413—(Silva 2012), the artificial cave of São Paulo II in Almada—MNI 255—(Silva 2012), the *tholos* of La Pijotilla in Badajoz—MNI 308—(Díaz-Zorita et al. 2017a), or the hypogeum of Can Martorell—MNI 194—(Mercadal et al. 2005) and La Sagrera—MNI 207—(Balaguer et al. 2015) in Barcelona.

The exceptional nature of the site lies not only in the size of the skeletal series, but also in the excellent conservation of the skeletal remains and the preservation of a large sample of articulated individuals. This is unusual for third millennium collective tombs, which generally have reduced or displaced primary deposits—in which the remains undergo continuous removal once they have been skeletonised—or secondary deposits. These aspects make CMOL a site of reference for studying the paleodemographic composition of the community deposited there.

A series of demographic patterns can be traced in this work. A homogeneous population composed of individuals of both sexes and different ages was deposited at CMOL. However, anomalies have been identified in the frequencies of non-adults regarding the mortality pattern established for preindustrial populations. This is characterised by high infant mortality, most pronounced in the first 5 years of life, which decreases with increasing age (Masset 1973: 96–97).

Only 10 perinatal subjects were found at the study site, accounting for 0.7% of the total population. Therefore, their presence could be described as anecdotal. Likewise, there is an under-representation of subjects aged 1 to 4 years, three times below the parameters established in Ledermann's (1969) model life tables for preindustrial populations. This is especially significant at the first moment of use. Similar demographic patterns have been documented in other third millennium peninsular tombs (Botella 1973; Mercadal et al. 2005; Díaz-Zorita 2013; Fernández-Crespo and de la Rúa 2015; Díaz-Zorita et al. 2016, 2017a, 2017b; Evangelista 2018; Herrero Corral 2019).

This demographic anomaly could be due to several factors. Firstly, we must consider a possible methodological bias in the fieldwork, related to an incorrect identification of the infant cranial remains. However, an anthropological specialist was present during the entire excavation, so methodological bias is unlikely. Another option to be considered is the differential preservation of the immature remains due to their more cartilaginous composition (Sellier 1994; Lewis 2006). The fact that a considerable number of skulls of this age category were preserved allows us to reject this possibility. We also ruled out a possible bias in age-of-death estimation methods, as this does not pose difficulties or large margins of error in non-adults when teeth are used.

The absence of infants in prehistoric burials has already been mentioned by other authors and has been related to cultural practices (e.g., Dedet et al. 1991, 2022; Gusi et al. 2008; Lancy 2014; Matney 2018), such as the possible exclusion of newborns and infants, whose social recognition would come later, or to the existence of a specific funerary ritual for this population group (Scott 1999; Delibes 2010; Fernández-Crespo and de la Rúa 2015; Burgos 2016; Blanco 2020). Traditionally, if a child died at an early age, they did not receive the same funeral treatment as other members of their community, renouncing an emotional bond with infants until they passed through critical developmental periods (Gennep 1981; Scott 1999). Lancy (2014) suggests that the infants' differential funerary practices must be related to the delay in the status recognition of these individuals and their acceptance as persons, so that they would not be integrated into the group until they reached a certain age. Similar patterns have been documented in other Iberian IV-III millennium graves, including the megalithic tombs of the Rioja Alavesa region (Fernández-Crespo y de la Rúa 2015), the necropolis of Humanejos (Madrid) (Herrero Corral 2019), the tholos I of Perdigões (Evora) (Evangelista 2018), the hypogeum of Costa de Can Martorell (Barcelona) (Mercadal et al. 2005) as well as southern sites such as La Pijotilla (Badajoz), Valencina-Castilleja (Seville), Panoría (Granada) and Los Millares and El Barranquete (Almeria) (Botella 1973; Peña 2011; Díaz-Zorita 2013; Díaz-Zorita et al. 2016, 2017b).

On the other hand, there is a significant mortality peak in individuals of 5–15 years, with a higher incidence at the first funerary phase. This data, again, contrasts that estimated by Ledermann (1969) for preindustrial populations. This mortality peak is especially representative at 5–9 years, which is significant considering that mortality should decrease from the age of 5, when individuals are no longer as vulnerable (Masset 1973; Sellier 1994). This anomaly is not only found in CMOL but can also be traced in other collective burials in the Iberian Peninsula (Silva 2003; Mercadal et al. 2005; Cunha et al. 2015; Fernández-Crespo and de la Rúa 2015; Evangelista 2018; Herrero Corral 2019; Díaz-Navarro 2021).

The methodological approach applied renders it impossible for the over-representation of individuals aged 5–15 years to be the result of a compensation derived from a lack of such individuals in preceding groups, also ruling out a methodological bias in the age estimates for reasons previously explained for the preceding age group.

Therefore, this over-representation seems to allude, once again, to cultural practices. The analysis of the dentition of the skulls has allowed us to observe a large number of deaths between 3 and 6 years of age (36% of non-adults), which could be related to weaning. This could explain the higher mortality documented in individuals aged 5–6 years, which decreases considerably in the following age range (7–8 years, 4.1%) (Díaz-Navarro 2023). In most archaic societies, weaning occurs at 2–4 years of age (Nájera et al. 2010; Pearson et al. 2010; Fulminante 2015), and it has been shown to be a critical factor in an individual's life, with high mortality rates identified in the years immediately following (Schurr 1998; Pearson et al. 2010). This is because after breastfeeding, immunological benefits decrease and subjects are exposed to environmental pathogens and are therefore more likely to contract diseases (Katzenberg and Saunders 2008). Furthermore, a recent study on the Moro de Alins cave identified intermittent post-weaning stress episodes in individuals aged 4 to 7 years, suggesting that this period was as stressful or more stressful than weaning itself (Fernández-Crespo et al. 2022). Therefore, this dietary change could explain the over-representation of individuals in the 5–9-year category in both funerary phases. The paleopathological data also points to a special prevalence of metabolic indicators of non-specific origin in this age range, which seems to corroborate this hypothesis (Díaz-Navarro 2023).

The mortality of older non-adults does not seem to be associated with the same factor as, although some authors have proposed that children may have had a different and/or poorer diet than adults (Waterman 2012), analyses at certain sites show no significant differences in diet between age groups (Fernández-Crespo and Schulting 2017; Díaz del Río et al. 2017). In the absence of specific CMOL analyses, it is worth considering whether this demographic anomaly could be related to the community's rites of passage, i.e., the development of certain activities at an early age that endangered the lives of individuals, as well as their inclusion in the daily work of the community.

After weaning, non-adults would go from being protected in the family nucleus and directly linked to their mothers to acquiring freedom and exposure to the dangers of the outside world and the harsh conditions of physical labour (De Miguel 2010; Herrero Corral 2019). Different authors have suggested that children and adolescents would have been an important source of labour in multiple tasks such as sibling care, handicrafts (Lancy 2018), mining (Villalba et al. 1986), or livestock care, which could have led to increased exposure to animal pathogens (Waterman and Thomas 2011). In this regard, a high frequency of infectious diseases is documented in individuals of this age from CMOL, which could suggest close contact with livestock (Díaz-Navarro 2023).

These same patterns can be traced in present-day societies. For example, Lapp children receive their first leather belt and knife at the age of eight, when they are able to drive a reindeer to pasture, while Nigerian children take care of goats and camels (Lancy 2018: 90). Thus, the early development of physical labour or certain dangerous activities in children with still under-developed bodies could explain the higher mortality of 10–15-year-old individuals. We must also consider the impact of pubertal skeletal development. This process requires a greater demand for energy (body formation, growth spurts, hormonal processes and sexual development) which in CMOL was possibly not compensated for by a proper diet, leading to a growth retardation (Díaz-Navarro 2023) and, ultimately, a shortage of defences that exposed children, possibly already active, to a greater risk of contracting diseases (Cusick and Kuck 2012; Rogol et al. 2000).

The last 5-year category of non-adult individuals (15–19 years) exhibits the lowest mortality rates after individuals in their first year of life. These figures are similar to those observed in certain archaeological populations (González-Martín 2007; Livi-Bacci 2009; Fernández-Crespo and de la Rúa 2015; Díaz-Navarro 2021). Researchers suggest that individuals in this age range are at their optimal developmental stage and acquire maximum skills for the development of activities that in previous years could be lethal. However, these values differ from those observed by Ledermann (1969) in pre-Jennerian populations, which points to an increase in mortality from the 10–14-year age category to the subsequent group. This should be related to possible problems related to pregnancy and childbirth, as well as to the involvement of individuals in violent conflicts or risky activities that could lead to accidents. The contemporary samples to CMOL that report high juvenile mortality rates generally show numerous signs of violent deaths (Mercadal et al. 2005; Etxeberría and Herasti 2007; Rivera 2011). Even though the first possibility is plausible, we must also consider a potential methodological bias in the age-at-death estimation of skulls within 15–20-year range, which could explain the absence of this population age group. Determining an accurate age for individuals within this age becomes challenging once the process of tooth eruption and dental development is completed, especially if the measurement of open apices cannot be analysed, or if agenesis of the third molar is documented (AlQahtani et al. 2010).

The overall count of immature subjects calculated from the ${}_{20}q_0$ coefficient is lower than that estimated for preindustrial populations, given the low proportion of individuals aged 0–4 years. Despite this, the total number of non-adults is 30%, which is within the limit of normal parameters for ancient populations (Bocquet-Appel and Masset 1977). This rate is higher in the first level of funerary use, suggesting a slight decrease in infant mortality in the community over the time of the grave's use, which could point to an improvement in living conditions.

The widespread presence of non-adults over 5 years of age in the grave shows that they were considered a member of the community, and therefore, it can be implied that, while the death of an infant affected only the most direct family sphere, the death of a child active in communal work had an impact on the whole community (Waterman and Thomas 2011).

The paleodemographic study also revealed that life expectancy at birth in CMOL was approximately 30 years. This age is at the limit of the values established for pre-Jennerian populations, which is estimated at 20–30 years (Ledermann 1969; Masset 1973). This is higher than that of earlier, contemporary, and later skeletal series, which we relate to the under-representation of non-adults in relation to the sample size, which clearly exceeds that estimated at other sites. In the megalithic ossuaries of the Duero Valley, the calculated life expectancy is 26 years (Díaz-Navarro

2021), while in sites from the fourth to third millennium BC transition, such as San Juan Ante Portam Latinam or Longar in Navarra, it is lower (20.3 years and 23.8 years, respectively) (Etxeberría and Herasti 2007; Rivera 2011), in accordance with the higher proportion of immature individuals compared to adults, which may be related to the violent acts previously mentioned. In Chalcolithic and Bronze Age tombs, this indicator varies from 20 to 27 years (Kunter 1990; Nájera et al. 2010; Pérez Villa 2013; Herrero Corral 2019).

The sex ratio allows us to rule out demographic anomalies related to the sex of the individuals, as it offers a value close to the parity found in natural populations (Ledermann 1969). When the sample is divided into funerary phases, a similar distribution of individuals of both sexes is observed, so there is no change in the conditions of access to the grave influenced by the sex of the individuals.

However, we documented differences in the age at death of males and females. When we cross-checked the sex and age-at-death estimations in both funerary phases, we observe that most males died in middle age, while females generally died in their youth. The higher mortality of females while young is related to obstetric risk, as childbirth is considered to be one of the most significant causes of mortality in preindustrial populations, especially the first birth (Pfeiffer et al. 2014). Complications in childbirth are generally related to anomalies between pelvic dimensions and baby size or infant positioning (Pfeiffer et al. 2014). The association of short maternal height with greater difficulties in childbirth is relevant (Guzmán et al. 2001; Toh-Adam et al. 2012; Stulp et al. 2011), given that CMOL women are significantly short (148 cm) (Díaz-Navarro 2023). Furthermore, some authors argue that plasticity in maternal skeletal growth may lead to a reduction in pelvic size in response to poor health and nutrition during this period (Wells 2012), which is also noticeable among CMOL women, as they show a much higher morbidity status than men in the community (Díaz-Navarro 2023).

There is an imbalance between the sexes in favour of males in the tombs dated to the transition from the fourth to the third millennium in the north of the Iberian Peninsula (Etxeberría and Herasti 2007; Fernández-Crespo and de la Rúa 2015). In contrast, the sex ratio values are inverted in caves from the same geographical area such as Las Yurdinas II, Peña Larga and Peña de Marañón, which leads researchers to suggest the existence of burial practices differentiated by sex (Fernández-Crespo and de la Rúa 2016). There is also a slight male superiority in Chalcolithic tombs from the south of the peninsula (Jiménez-Brobeil 1988; Nielsen et al. 2010; Díaz-Zorita 2013; Díaz-Zorita et al. 2016), while in other sites in the south and west, the values are reversed (Silva 2012; Pecero 2016; Beck 2016).

The sexual composition of the contemporary peninsular tombs presents a heterogeneous panorama, although there are no patterns of selective access related to the sex of the individuals that are visible in previous periods (Fernández-Crespo and de la Rúa 2015, 2016; Díaz-Navarro 2021). The socioeconomic and political transformation observed in the transition from the fourth to the third millennium appears to be linked to a change in the rules of access to collective tombs, which is reflected in homogeneous population compositions in Chalcolithic tombs. This is especially visible in CMOL, where individuals of both sexes and all age categories are included, with the exception of clearly underrepresented children under 5 years of age, a pattern well documented in prehistoric and protohistoric societies.

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Declarations

Competing interests The authors declare no competing interests.

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