

The demography of two early European medieval communities: combining genetic data with “classical” demographic analysis

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Long abstract

The aim of this paper is to combine the demographic information obtained through DNA analysis with that derived from "classic" anthropological analyses of sex and age. Using DNA data, we can obtain demographic information much greater than that usually deducible from the remains of cemeteries. The combined use of these two types of analysis allows us, first of all, to estimate the size of the population that used the cemetery, even if no information is available on the settlement that used the cemetery. Furthermore, the mortality pattern and other information on the demographic dynamics can be reconstructed more reliably.

The full paper will analyse data from both cemeteries, Leobersdorf and Mödling excavated in Lower Austria, and dated between the 7th and 8th centuries. In this long abstract, we briefly present some results for the Leobersdorf (Leo) cemetery. Table 1 shows the distribution by age and sex of the skeletons. For 84% of the skeletons, the sex was estimated (by DNA and/or anthropological analysis), while for all the skeletons the age was estimated (by anthropological analysis), although for 20 skeletons (11% of the total) it was only possible to say that they were adults (aged 20+). The DNA analysis allows to identify other individuals (the *inferred individuals*), for which it is possible to establish the existence, the sex and the kinship relationship with the buried skeletons, but whose remains were not found. For the 74 *inferred individuals (IF)*, identified by DNA analysis of the skeletons, it was also only possible to determine sex and to say that they were adults.

Table 1. Original data of the Leobersdorf cemetery

	Skeletons by age												
Sex	0-4	5-9	10-14	15-19	20-29	30-39	40-49	50-59	60+	20+	Tot	IF (20+)	Tot
M	8	6	11	4	7	6	12	19	7	0	80	34	114
F	7	4	3	10	13	14	7	10	4	0	72	40	112
Unk	6	2	0	0	0	0	0	1	0	20	29	0	29
Tot	21	12	14	14	20	20	19	30	11	20	181	74	255

Estimation of size of the population that used the Leobersdorf cemetery

We consider the formula:

$$[1] \quad \mathbf{d} = \mathbf{D}/\mathbf{tP} \rightarrow \mathbf{P} = \mathbf{D}/\mathbf{td}$$

where **d** is the annual mean general death rate, **D** is the total number of burials in the cemetery, **t** is the number of years the cemetery has been in use, and **P** is the mean population during the period **t**.

It is possible to estimate that the general death rate **d** for Leo ranged between 40 and 50 per thousand. To estimate the value of **D**, let's first assume that the deaths of people over five years old, including *inferred individuals*, in Table 1 represent the total number of individuals over 5 buried in the cemetery. This amounts to 255-21=234 individuals, where 21 is the number of skeletons under 5 (Table 1). Clearly, the number of deaths under 5 is strongly underestimated, as is often the case for remains in ancient cemeteries. The standard Coale & Demeny tables suggest that, in the case of a stationary population, the proportion of deaths under 5 is 45% if **d**=40‰, and 53% if **d**=50‰.

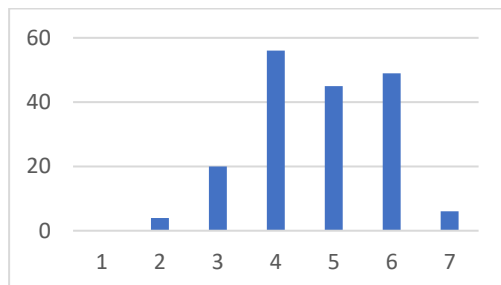
As we will see shortly, the stationary population hypothesis seems acceptable during the 90 years of intensive use of the cemetery. Therefore, to estimate the total number of deaths among the population buried in the Leo cemetery, to the 234 individuals over 5 who were buried or traced through genetic analysis, it is necessary to add 191 or 264 deaths of children who died before their fifth birthday, depending on the level of the generic mortality rate d (40 or 50‰, respectively). Consequently, the total number D of deaths is 425 (if $d=40‰$) or 498 (if $d=50‰$), see **Table 2**.

Table 2. The procedure for estimating the population that used the Leobersdorf cemetery

Deaths aged 5+ D_{5+} (including <i>IF</i>)	Gross death rate d	% Deaths <5	Total deaths D	Formula [1] $Pt = D/d$	P (if $t=90$)
234	40‰	45‰	425	10,625	118
234	50‰	53‰	498	9,960	111

Starting from these estimates of the number of deaths, thanks to the formula [1] it is possible to estimate Pt , that is the product of the average population that used the Leo cemetery and the number of years in which this cemetery was used. To estimate t , we consider the distribution by generation of the 180 skeletons and *inferred individuals* for which it was possible, by DNA analysis, to attribute the generation to which they belonged (**Figure 1**). The great majority of individuals are concentrated in three generations. Since the distance between one generation and the next was (and is) approximately thirty years, we can define the period of continuous use of the cemetery as about 90 years. Furthermore, since the number of individuals for each generation is almost constant, we can affirm that during a century of intensive use of the cemetery the population did not change in number (i.e. the main characteristic of a stationary population). Our estimation of the average annual population P using the Leo cemetery is between 110 and 120 individuals (see the last column of **Table 2**).

Figure 1. Distribution by generation of the 180 deaths of the Leobersdorf cemetery (skeletons and *IF*) inserted in a kinship by DNA analysis (*)



Estimate the mortality function and the demographic dynamic of Leobersdorf community

We estimate the mortality function by sex and age for the Leo cemetery using data of the 181 skeletons excavated and the 74 *inferred individuals*, whose presence was deduced through DNA analysis of the skeletons. We apply a procedure similar to the one we did in our estimates of 75 European cemeteries from the pre-Black Death period (A.D. 0-1349).¹ The skeletons of unknown sex and age were redistributed according to those of known sex and age. It is likely that – as observed in other cemeteries – deaths over 60 are significantly underestimated. To support this assertion, we note that in the Coale & Demeny West level 1 female standard life-table (${}_FC&D_{w1}$, $Fe_0=20$), among the 50+ age deceased, 36% are aged 50-59, while 64% are aged 60+, whereas in the Leo cemetery, 73% of the skeletons aged 50+ have been assigned to the age group 50-59. The underestimation of deaths over 60 could be due to the disappearance of their skeletons and/or a systematic underestimation of ages of over 50. To avoid underestimating deaths over 60 and overestimating younger adults, we arbitrary assign 2/3 of the 78 deaths aged 50+ to the 50-59 age group, and 1/3 to the 60+ age group. This choice

¹ I. BARBIERA, M. CASTIGLIONI E G, DALLA ZUANNA, *Standard Life Tables for Western and Southern Europe from Antiquity to the Black Death*, “Popolazione e Storia”. 22, 2, 73-97, 2021.

does not influence the estimate of the probability of dying under 50. Finally, we distribute the 34 *IF* men and the 40 *IF* women according to the known distribution of skeletons aged 20+. (**Table 3A**).

The pedigrees suggest the plausibility of the stationarity hypothesis. This does not mean that Leo was not touched by migration, as also shown by the presence of a good number of skeletons for which it was not possible to identify any relatives through DNA (7 males, 23 females and 1 of undefined sex, suggesting the prevalence of a patrilocal residence system). Since the number of skeletons for three successive generations is similar, it is presumable that net migration was close to zero, with a number of people, especially women, leaving the community similar to the number of people, especially women, entering it. The stationarity hypothesis is credible if a cemetery is used for a significant number of years (90 years could be enough), because the fluctuations due to epidemics or famines compensate each other.²

If the stationarity hypothesis holds, the growth population rate r is around zero, the mortality and fertility function and the population distribution by age is constant over time, and the distribution of population by age corresponds to the distribution of L_x (the number of years lived at age x) in the associated life-table. Consequently, the deaths at age x are proportional to the d_x of the life-table, and it is possible to calculate each death probability by age q_x :

$$[2] \quad q_x = D_x / \sum D_i \quad (i=x\dots z) \quad \text{where } D_x \text{ are the number of deaths at age } x.$$

For the calculation of the q_x of the Leo population not distinguished by sex, see **Tables 3B** and **3C**.

Table 3. Rearranging original data of the Leobersdorf cemetery (table 1) by sex and age and estimation of probability of death under the hypothesis of stationary population

(A) Final distribution by sex and age of the 181 skeletons and 74 <i>IF</i>											
Males	11	7	11	4	13	11	22	19	31	0	129
Females	10	5	3	10	26	28	14	10	19	0	125
Total (Num)	21	12	14	14	39	40	37	29	50	0	255
(B) Denominators											
Total (Den)	255	234	222	208	194	154	115	78	50		
(C) Probability of dying (Num/Den)											
Num/Den	0.082	0.051	0.063	0.067	0.203	0.256	0.318	0.367	1.000		

Note. Some sums differ by one due to rounding

Comparing Leo and Europe on mortality function

Table 4 and **Figure 2** show first of all that Leo shares with other European cemeteries – both those studied by us and those studied by Steckel – the low number of deaths under the age of five (and likely also for the 5-9 class). This fact prevents using these data to arrive at credible estimates of mortality in ages 0-4. Moreover, the estimates of Leo's death probabilities for the age groups between 10 and 60 are close to the European median of the period 0-1349 AD. The mortality in Leo at age 10-60, like that of all pre-plague cases, is instead much higher than that recorded in European countries on the threshold of modernity (see in **Table 4** the cases of Italy and Russia at the end of the 19th century). Recent genetic studies suggest that 300 years of plague outbreaks (1349-1650) selected genotypes better able to resist the attack of other diseases as well.³

Building life-table by sex for the Leobersdorf cemetery

Starting from the data in **Table 3**, we calculate life-tables for males and females buried in Leo, accepting the hypothesis of a stationary population (**Table 5**). To limit the fluctuations related to small numbers, we consider broader age classes. Furthermore, given the evident underestimation of mortality in the 0-4 age group provided by the cemetery data, we consider three hypotheses for child mortality (age 0-4), using the standard life-tables of Coale & Demeny: HIGH (level 1, $r_{e0}=20$), MEDIUM (level 3, $r_{e0}=25$), LOW (level 5, $r_{e0}=30$). The same

² G.Y. Acsádi, J. Nemeskéri, *History of Human Life Span and Mortality*, Akadémiai, Budapest, 1970.

³ J. KLUNK ET AL., *Evolution of immune genes is associated with the Black Death*, "Nature", 19 October 2022.

three standard life-tables are used to complete the table for the age group 60+, imputing e_{60} . Here, we show only results for HIGH.

Life expectancy at birth is around 19 years. Up to age 20, life expectancy is increasingly lower for women, due to a probability of death more than double for women compared to men at the age group 20-39 (0.561 vs. 0.252). This difference is confirmed – at least partially – also by the analysis of the pedigrees, which report the presence of ten second and third marriages of men, and only three of women. Furthermore, for the eight couples with children for which both skeletons are available, only in one case is the woman's age at death higher than that of the man. We have no information on the causes of death, but it is clear that in that age group the differences in mortality between men and women could be linked to high maternal mortality. Between the ages of 40 and 59, however, mortality is very similar for men and women.

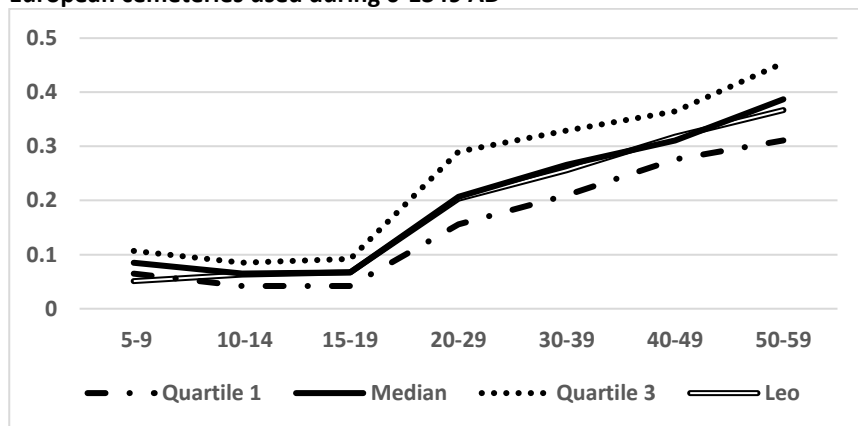
Finally, at age 5+ the number of deaths (skeletons plus *IF*) of men (118) and women (115) is almost identical. Since the sex ratio at birth is almost the same in all human populations, also the number of deaths under 5 must have been practically the same for males and females: we can deduce that mortality at age 0-4 was the same for males and females. Consequently, in the community that buried its dead in Leo there was no gender discrimination in the care of female children, as in the most of medieval cemeteries in Central-Northern Europe, unlike what happened in medieval Italy.⁴

Table 4. Comparing the mortality pattern of the Leobersdorf cemetery with other mortality functions: the Median of 75 European sites of 0-1349 AD; the Median of 47 sites of 6th-9th centuries; the median of cemeteries considered by Steckel; the standard life-table of Coale & Demeny (Model West 1, $e_0=19$); the standard life-table of Woods ($e_0=20$); Italy in 1872 ($e_0=29.8$); Russia in 1996-97 ($e_0=29.4$)

	Age group							
	0-4	5-9	10-14	15-19	20-29	30-39	40-49	50-59
	Probability of dying q_x							
Median	0.112	0.085	0.065	0.067	0.207	0.266	0.311	0.387
(*)	0.125	0.081	0.067	0.071	0.221	0.245	0.299	0.356
Leo	0.082	0.051	0.063	0.067	0.203	0.256	0.318	0.367
Steckel	0.134	0.082	0.056	0.043	0.199	0.302	---	---
C&D_{w1}	0.551	0.070	0.053	0.070	0.186	0.234	0.287	0.396
Woods₂₀	0.493	0.097	0.056	0.090	0.265	0.287	0.300	0.348
Italy₁₈₇₂	0.443	0.063	0.032	0.037	0.103	0.115	0.140	0.219
Russia₁₈₉₆₋₉₇	0.453	0.068	0.027	0.027	0.074	0.094	0.131	0.212

Source: I. BARBIERA, M. CASTIGLIONI, G. DALLA-ZUANNA (CIT. IN NOTE 1).

Figure 2. Probability of dying by age 5-59: comparing Leo with the median, the first and the third quartiles of 75 European cemeteries used during 0-1349 AD



⁴ Barbiera, I., Castiglioni, M., & Zuanna, G. D. (2016). "Missing women in the Italian middle ages? Data and interpretation", in Huebner, S. R., & Nathan, G. (Eds.) *Mediterranean Families in Antiquity: Households, Extended Families, and Domestic Space*, 283-309.

Source: I. BARBIERA, M. CASTIGLIONI, G. DALLA-ZUANNA (CIT. IN NOTE 1).

Table 5. Life-tables estimated starting from the remains in the Leobersdorf cemetery (see table 3), under the hypothesis of stationary population. In italics the imputed data.

	0-4	5-19	20-39	40-59	60+
HIGH. Level 1 of C&D_w table (e₀=20) for child mortality (age 0-4) and e₆₀					
Males					
q_x	<i>0.570</i>	0.188	0.252	0.569	1.000
l_x	100,000	42,957	34,889	26,110	11,254
d_x	57,043	8,068	8,779	14,856	11,254
L_x	271,828	583,845	609,994	373,649	112,545
e_x	19.5	39.1	31.4	18.6	8.7
Females					
q_x	<i>0.532</i>	0.154	0.561	0.567	1.000
l_x	100,000	46,836	39,624	17,413	7,541
d_x	53,164	7,212	22,212	9,872	7,541
L_x	287,344	648,452	570,370	249,537	75,409
e_x	18.3	33.0	22.6	18.7	9.4

As is known, if the population is stationary, once the life-tables are known it is immediate to estimate other parameters of the demographic dynamics: the birth rate and the death rate are $1/e_0$; the average number of children per woman can be estimated as $20 \times 2l_0/F L_{20-39}$. According to the level of child mortality, Leo's fertility rate fluctuates between 5.4 and 7.0 children per woman, with birth and death rates between 40.4 and 52.9‰ (see **Table 6**, constructed from the values in **Table 5**).

Table 6. Estimation of birth rate (b), death rate (d) and mean number of children per woman (TFR) for population using the Leobersdorf cemetery, by level of child mortality, under the hypothesis of stationary population

	b = d ‰	TFR
HIGH	52.9	7.0
MEDIUM	45.5	6.0
LOW	40.4	5.4