Anthrop. Közl. 22. 99–114. 1978.

# INFERENCE CONCERNING THE AGE DISTRIBUTION OF SKELETAL POPULATIONS AND SOME CONSEQUENCES FOR PALEODEMOGRAPHY

by T. Sjøvold

(Osteological Research Laboratory, University of Stockholm, Solna, Sweden)

## Introduction

Contrary to most modern demographic studies, where the age distributions are taken directly from population censuses, one of the main problems of a paleodemographic investigation based on skeletal remains is actually to establish the number of individuals in each age group. Determination of the age at death of an individual from its skeletal remains is always carried out with some uncertainty, depending on the individual variability in the development of age determining characteristic utilized. Even the age of small children can not be estimated without a probable error in the determination of one or more years, with the exception of foetuses, still-born and sucklings dead during the first few months of life. With increasing age the probable error in the age determination increases.

The natural consequence is that individual age determinations generally are given in terms of age intervals, within which limits the true ages of the individuals are regarded to lie, at least with a high degree of probability. The intervals may be reduced to a certain extent depending on how many age determining characteristics are known and on the utilization of such characteristics. Accordingly, the more crude or less well preserved age determining characteristics, the greater the uncertainty of the individual age determinations and the wider the age intervals that must be admitted.

In spite of the development of new and better methods for the determination of individual age at death, skeletal materials for which only rough age determinations can be made still turn up. Such situations occur whenever the material itself is badly preserved, for instance when the skeletal remains are fragmentary or when the individuals are cremated. They also occur when the age determining characteristics are uncertain, and when only a minor number of age determining characteristics can be considered. In such cases it is often only possible to determine each individual's age as being within one of a number of fixed age groups. Because of individual variability, any method for age determination based on skeletal remains will provide an age interval when applied to a given case, and therefore alloction into fixed age groups may be applied under more general circumstances.

### The system of age groups given by Martin and some generalizations

The system of groups of Martin (1914, 1928) is the best known system of fixed age groups into one of which each dead individual may be classified. It consists of the age groups *Infans I* (early childhood), *Infans II* (late childhood), *Juvenilis* (juvenile), *Adultus* (young adult), *Maturus* (old adult) and *Senilis* (senile or old). This subdivision was originally based on the development of the skull, and the limits of each age group were determined by the occurrence of certain dental or cranial developmental stages, with birth as the initial limit. Later the same classification has been widely used for age determinations based on both cranial and postcranial age indicators.

Because of individual variation, the original definitions were only *indicating* the most usual age or age period for the transition from one age group to the next, with the approximate conditions for Europeans as examplis. However, for a useful evaluation of the age determinations for paleodemographic purposes, age limits in years have to be set for each age interval, and in practice an upper bound for the senile age has to be set.

In Table 1 examples of such interpretations are shown, together with the original definitions of Martin. It is seen that not only the limits of the age intervals, but even the range in years of the intervals often diverge. The apparent reason for this divergence in interpretation is assumed discrepancies in time and space between the individual's *chronological age* (counted in years) and the *biological* (skeletal) age, in addition to individual variations. Although living conditions and the genetical constitution may be believed to influence on skeletal ageing, it is difficult, however, to make exact statements of these effects on prehistoric populations for which no written records are available. Many of the age limits set for prehistoric populations are thus based on assumptions which may hardly be controlled. On the other hand, this does not mean that the different age limits set by different authors may not all contain some truth. In fact, one may always find individuals who satisfy any of the different sets of age limits for the age groups. The difficulty arises when one is to generalize for one particular population or another.

Because of individual variation, however, this kind of variation has to be taken into consideration when fixing age limits for each particular age group. Concerning eruption of the first permanent molar, for instance, this in known to take place at the age of five in some individuals, and at the age of seven in others. Thus one individual being actually six years of age may be classified as *Infans I* because the first permanent molar has not erupted, whereas another individual, being also six years old, may be classified as *Infans II* because the tooth *has* erupted. Concerning later, older age groups, the age characteristics are changing gradually with a great amount of individual variation, especially with regard to suture closure. Individuals with more accelerated skeletal ageing may therefore be classified into an age group being too old (according to some subdivision *in years* of the age groups), whereas individuals with more retarded skeletal age may be judged as belonging to an age group being actually too young. As all age limits for Martin's and other age groups systems published until now are based on the principle that when one age group ends, the next one continues, the the individuals running the greatest risk for being classified into an erronous age group are those having their actual chronological age next to the age set as limit between two adjacent age groups.

*Table 1*

Original definitions of age groups and age limits set by different authors
*1. táblázat.* Különböző szerzők eredeti korcsoport- és korhatár-meghatározásai

| Age group *Korcsoport* | Definitions given by MARTIN 1914, 1928 MARTIN *1914, 1928 meghatározásai* | ANGEL 1953 | GEJVALL 1960* | ACSÁDI and NEMES-KÉRI 1970 | ULLRICH 1972* |
|---|---|---|---|---|---|
| *Infans I/Inf. I.* (early childhood) *(korai gyermekkor)* | From the birth to the eruption of the first permanent molar (for Europeans approximately to the 7th year of life). *A születéstől az első maradandó moláris áttöréséig (európaiaknál kb. a 7. életévig).* | 0–4 | 0–7 | 0–6 | 0–6 |
| *Infans II/Inf. II.* (late childhood) *(késői gyermekkor)* | From completed eruption of the first to the completed eruption of the second permanent molar (for Europeans approximately to the 14th year of life). *Az első maradandó moláris teljes áttörésétől a másodikéig (európaiaknál kb. a 14. életévig).* | 5–14 | 8–14 | 7–14 | 7–12 |
| *Juvenilis/Juv.* (juvenile) *(fiatal)* | From completed eruption of the second permanent molar to the closure of the synchondrosis sphenoccipitalis (for Europeans approximately to the 18th or the 22nd year of life). *A második maradandó moláris teljes áttörésétől a synchondrosis sphenooccipitalis záródásáig (európaiaknál kb. a 18. vagy 22. életévig).* | 15–24 | 15–20 | 15–22 | 13–18 |
| *Adultus/Ad.* (young adult) *(fiatal felnőtt)* | All teeth erupted (the third permanent molar does occasionally not erupt) and incipient abrasion of the teeth's chewing facets. All sutures with exception of minor areas still completely open (for Europeans to the close of the third decennium). *Minden fog áttört (a harmadik maradandó moláris néha nem tör át), észlelhető a fogak rágófelületének kezdődő abrasiója. Kisebb területek kivételével minden varrat még teljesen nyitott (európaiaknál a harmadik évtized végéig).* | 25–39 | 21–40 | 23–39 | 19–35 |

*** The original age intervals are changed according to the internationally accepted demographic notation. — *Az eredeti korintervallumok a nemzetközileg elfogadott demográfiai jelölés szerint megváltoztatva.***

*Table 1* (continued) *1. táblázat* (folytatás)

| Age group *Korcsoport* | Definitions given by MARTIN 1914, 1928 MARTIN *1914, 1928 meghatározásai* | ANGEL 1953 | GEJVALL 1960* | ACSÁDI and NEMESKÉRI 1970 | ULLRICH 1972 |
|---|---|---|---|---|---|
| *Maturus/Mat.* (middle adult) *(középkorú felnőtt)* | Marked abrasion of the teeth's chewing facets. Ossification of the sutures, although not to complete obliteration (for Europeans to the close of the fifth decennium). *A fogak rágófelületének határozott abrasiója. A varratok csontosodása, bár még nem a teljes obliterációig (európaiaknál az ötödik évtized végéig).* | 40–59 | 41–60 | 40–59 | 36–50 |
| *Senilis/Sen.* (old adult) *(idős felnőtt)* | Advanced or complete obliteration of the skull sutures. More or less resorbtion of the tooth sockets due to loss of teeth (for Europeans after the 60th year of life). *A koponyavarratok előrehaladott vagy teljes obliterációja. Foghiány következtében az alveolusok kisebb-nagyobb mérvű resorptiója (európaiaknál a 60. életév után).* | 60 | 61 | 60 | 51 |

It may be argued that when the number of individuals is moderately large, the numbers of individuals misclassified according to age group tend to cancel, so that the number of *individuals* assigned to each age group is approximately retained. However, it can be shown mathematically that this assumption is rather improbable or unlikely for population sizes met with in analysis of skeletal populations, especially when the age groups are of unequal length in years and the numbers of individuals actually belonging to each age group according to their chronological age are unequal.

The natural solution to reduce the problem of misclassification is to define the age categories as a system of *overlapping* age groups. Although extremes may be thought to occur without possibility of being detected, such a system is intended to allow for most individual variation, rendering the number of misclassified individuals at a minimum. Because the authors shown in table 1 were chosen to represent also the most extreme variation concerning the limits in years of the different age groups, a generalized MARTIN system based on these four authors will be recommended, with the addition of one new age group, denoted *Infant*, comprising individuals dead during the first year of life, and particularly during the first months of life. This takes care of the infant mortality (Table 2).

With regard to the extreme, the senile group, the upper limit of life is set to 80 years. Frequently this limit is set to 70 or even 60 years, but as ages over 70 occur in early demographic records, these upper limits are obviously set

*Table 2*

**Age limits for the system of age groups given by MARTIN (1914, 1928)***
***2. táblázat.* Korhatárok a MARTIN (1914, 1928)* által megadott korcsoportrendszerhez**

| Age group *Korcsoport* | Range in years of age *Időköz életévekben* | Span in years *Időtartam években* | Overlap in years with preceding age group *Átfedés az előző korcsoporttal, években* |
|---|---|---|---|
| Infant | 1 | 1 | — |
| Infans I | 0–7 | 8 | 1 |
| Infans II | 5–14 | 10 | 3 |
| Juvenilis | 10–24 | 15 | 5 |
| Adultus | 18–44 | 27 | 7 |
| Maturus | 35–64 | 30 | 10 |
| Senilis | 50–79 | 30 | 15 |

* The new age group Infant is added. — *Hozzávéve az új Infant korcsoport*

somewhat too low. For instance, a study of the church records from the village Hallstatt, in Austria, currently undertaken by the present author, displays a very high infant mortality but also a remarkable number of deaths between 70 and 80 years of age among some 30,000 deaths during the 250 year period between 1602 and 1852. The general picture obtained from the study of the church records is that those who survived childhood had a fair chance of dying between 60 and 80 years of age. Similar observatious have been made from studies of church records in Hungary (NEMESKÉRI, personal communication). In Hallstatt, some individuals died at even greater ages than 80, but no one was observed older than 90 years of age. As generally few individuals are classified to senile age when studying skeletal populations, however, the exact upper limit of life is of relatively little importance for paleodemographic research. One should, on the other hand, be aware of the possibility of greatly underestimating the age of very old individuals. Therefore, also, it would be better consequently to make age determinations in terms of wider age intervals instead of proposing fairly exact determination of age, especially with respect to older individuals.

The necessity of allowing for ovelapping age intervals may also be inferred from the following considerations: the fact that one particular individual looks older than another indevidual does not necessarily mean that it *is* older, but it may *probably* be older. If we confine a certain appearence of an age indicator to the latest reached or "oldest" of two successive, overlapping age groups and another to the first reached or "younger" age group, any age indicator will make the transition from the "younger" to the "older" age group at an earlier age of life for some individuals than for others. Some of the individuals of the last named group, maintaining the "young" appearence, may happen to die at a later age than some of the first named group. In this way an individual showing a "young" appearence according to the age indicators may actually be older than another looking "old" according to the age indicators.

These difficulties arise because it is difficult to distinguish the rate of development of an age indicator within a given age group. In fact, if this were not difficult, it would also be possible to distinguish additional or intermediate developmental stages of the age indicator. In addition, the mode of development of each age indicator from the moment the one developmental stage is reached and until the next is made, is not known. In some individuals this inter-stage development may be thought to be gradual, whereas for other there may exist periods of stagnation, followed by sudden, marked changes. On the other hand, the difficulty actually concerns the age intervals during which the transition from one stage to the next takes place, and which we may denote as transition periods. The age group corresponding to the "younger" appearence of the age indicator may therefore be partitioned into one part belonging to the transition period and another, adjacent, non-overlapping part corresponding to a younger age interval. Similarly, the age group corresponding to the "older" appearence of the age indicator may be partitioned into one part corresponding to the transition period and another corresponding to an older age interval. Extending this argument, the age interval corresponding to the "younger" appearence of the age indicator may, in turn, overlap another age interval corresponding to a still "younger" appearence of the age indicator, and the age interval corresponding to the "older" appearence may overlap a still "older" age interval.

## The distribution of years lived by individuals dead within the same age group and estimation of death rates within given age intervals

The distribution of the individual ages at death within each age group is of importance for the calculation of the mean age of the individuals of a given series, and for the construction of paleodemographic life tables. In this connection the situation when ages at death of a number of individuals are determined within the same age limits will be discussed.

ACSÁDI and NEMESKÉRI (1970) claim that "In order to reach a correct figure for the age distribution when ages are given between limits, the number of deaths must be distributed within these limits. For instance, if three people who died at the age 18—20 figure in the series, one dead person must be taken as aged 18, 19 or 20. If on the other hand there is only one person in the series who died in the age interval from 50 to 59, we must recon with 0.1 dead for the various ages (with 0.2 dead with age groups of five years, etc.). When age is defined within very wide limits, such as 'adult age' or 'old age' (i.e. 23-*x* resp. 60-*x* years) the number of cases must be distributed between the lowest and highest age limits."

Although this statement is very general, it clearly demonstrates some fundamental differences between the principle utilized by ACSÁDI and NEMESKÉRI and the present one, and therefore it should be given some comments. Obviously the authors regarded each person's age at death as being secured within the lower and the upper limit of the appropriate age interval, and that the probability that the actual chronological age could be outside this interval is nil or at least negiligible. This is in accordance with the present principle. With regard to the distribution of the dead, however, some formal discrepancies exist.

To demonstrate the difference, the example given in the quotation may be used. Assume that the age of the three individuals may all be secured to

18–20 years. According to the present principle, each individual is regarded to have died *independent* of the two others as either 18, 19 or 20 years of age, although no year of death may be pointed out as a more likely time point of death than the two other years. At this point there is no contrast between the view of ACSÁDI and NEMESKÉRI and the present one. That is, ACSÁDI and NEMESKÉRI do not explicitely claim that the individual deaths are independent. However, according to their principle, it may be shown that they are *not* independent: if the one individual died at, say, the age of 18, the second had to have died at either 19 or 20; say at the age of 19. The the third *had to* have died at the age of 20. Thus the year of death of the third is given by those of the first and the second.

Now the purpose of this allocation of individuals to specific years of death was certainly not to introduce analysis of dependent variables, but a means to simplify the algebraic operations. However, although other kinds of analysis may introduce more mathematical complexity, it is nevertheless necessary, because the simplifications made by ACSÁDI and NEMESKÉRI, in order to make the paleodemographic methods more accessible, actually lead to final demographic statistics which apparently claim to be more exact than they actually are. The reason why it is so is that the uncertainties in the different age determinations are disregarded.

The principle outlined by ACSÁDI and NEMESKÉRI implies that every year within a given age group (in terms of *age interval*) is equally likely to be the year of death of any individual judged to have died within the age group. This is also in accordance with the present model. Thus the possible ways the three individuals referred to in the quotation may have died can be directly counted by listing the different eyually likely combinations. In this case the possible combinations are as follows: all three died at the age of 18, 19 or 20; two at 18 and the third at 19 or 20; two at 19 and one at 18 or 20; two at 20 and the third at 18 or 19; and finally, one at 18, one at 19 and one at 20. Thus the distribution of deaths chosen by ACSÁDI and NEMESKÉRI is only one out of ten equally likely possibilities, and hence the probability that the three individuals actually died in this manner is equal to 0.1, or only 10%. With regard to the number of other possible combinations of deaths, it may be said that the combination with one dead each year is rather unlikely.

The argument may be carried the other way around, as with the single individual in the quotation who had died between 50 and 59 years of age. The claim that we must recon 0.1 dead for the various ages is untenable because of similar reasons as pointed out above. It is quite clear that the individual only died once, during one of the ten possible years. However, because we cannot point out any year as more likely than any other year for the death of the individual, one may say that the *probability* of death of the individual is 0.1 for each year in the ten-year interval (0.2 with age groups of five years, etc.). For any of the three individuals dying within 18–20 years of age the *probability* of dying at either 18, 19 or 20 years of age is similarly 0.33 according to the present model.

The difference between the two models is thus that the present model takes the probability into consideration. This takes fully care of the uncertainty of the individual determinations of the age at death. The wider an age group is, the less the probability that an individual dead within the limits of the age group died any particular year within the corresponding time interval.

Instead of looking at time expressed by whole years, we may look at time as a continuous variable. This may be done because we regard a year as the time lapse from one birthday to the next. Although births and deaths are not quite evenly distributed during a calendar year, these deviations tend to cancel when birthdays are utilized to define the year. One may therefore assume that the distribution of deaths may be approximated to the even (uniform) distribution.

As a corolary of the above said, individual variability (in a broad sense of the word) of the development of age determining characteristics is creating a situation for the paleodemographer that greatly differs from that of modern demography. In the first place, paleodemographic samples constitue fractions of per milles of a modern demographic material, or in favourable cases, they may attain some per milles, and in the second place, the age of each individual is determined within a more or less broad age interval, any time point within such an interval being regarded as equally likely as the time point of death. In other words, the time point of death is rectangularly or uniformly distributed within the appropriate age interval, the age intervals of death forming a more or less overlapping sequence.

If some individuals may be assigned to the same age interval of death, however, it is possible to obtain the distribution of their mean age at death. With regard to the death of one individual, the probability of death is constant throughout the age interval. With two individuals assigned to the same age interval, the distribution of their mean age is *triangularly* distributed (Fig. 1). With three or more individuals, the distribution of the mean age becomes more bell-shaped, strongly resembling the *Gaussian* or *normal* distribution. This is actually a consequence of *the central limit theorem of statistics* which states that the sum, and hence also the mean, of identically and independly distributed variables tends to be distributed in a normal fashion. In the case of the uniform distribution, this convergence towards the normal distribution is very rapid, as indicated above. In fact, the approximation to the normal distribution for this distribution is fairly good for three cases and onwards. In addition, because the original distribution is known, the mean age and its standard devation is readily found.

For construction of demographic as well as paleodemographic life tables the distribution of the dead, that is, the number of dead within each year, five- or ten-year period, or in any sub-division of the time in successive age periods is needed. However, because regard has to be made to the fact that the individual deaths are determined with a great amount of uncertainty, we can not expect that the results of a paleodemographic analysis will be as exact as in the case of modern demographic population studies. Even when five- or ten-year age intervals are utilized, as in the case of most paleodemographic studies until now, these uncertainties are not eliminated, because respect has not been made to the fact that the age determinations do in fact overlap. PETERSEN (1974) argued that modern demographic studies actually are not based on as exact data as apparently believed by many paleodemographers, but that the demographic basis of many countries often is incomplete and the demographic records full of holes for which inference was made in order to make reasonable corrections. These conditions were therefore used as arguments for applying demographic methodology in paleodemography. However, even when rougher modern demographic methods are utilized for a living population, such as

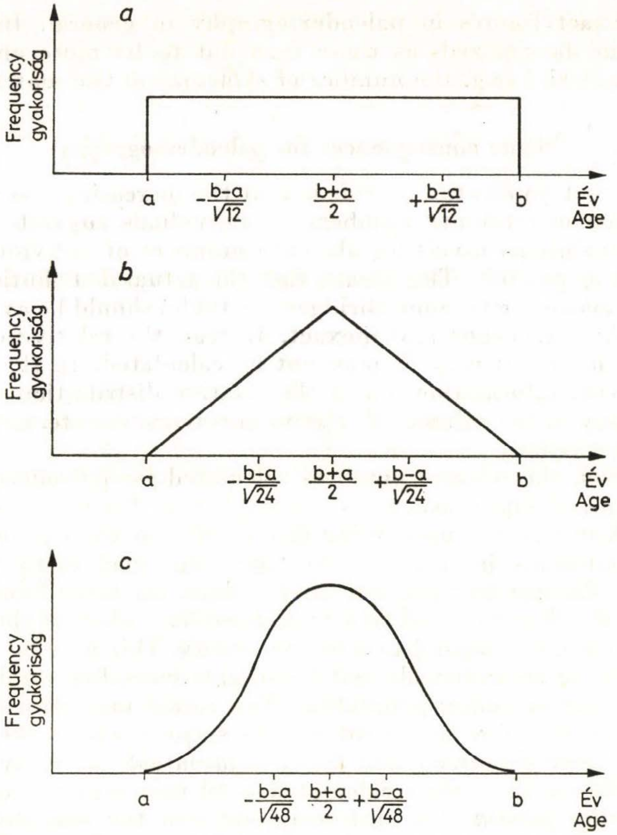


*Fig. 1.* **The distribution function for the age of one dead within a general age interval (a, b) (Fig. 1a) with corresponding mean and standard deviation, for the mean age of two deaths (Fig. 1b) and for the mean age of four deaths (Fig. 1c), both with means and standard deviations**
*1. ábra.* **Az egy (a,b-n belüli) halálozási életkorra eső eloszlásfüggvény (1a ábra) a megfelelő középértékekkel és szórással; két halálozási életkor középértékére (1b ábra) és négy halálozási életkor középértékére (1c ábra)**

**single-census methods based on five- or ten-years intervals (Stolnitz 1956), the errors in individual age determinations will tend to cancel due to the much larger number of individuals in a modern, living population than in most skeletal populations from cemeteries or gravefields.**

**In paleodemography, every age interval may therefore be partitioned into one part which overlaps with adjacent age intervals, and a remaining part which does not. The number of individuals dead within the age interval corresponding to the age group the equals the number of individuals assigned to that age group, plus the individuals from the adjacent age groups who actually died within the age interval. Without going into mathematical detail, it turns out to be very difficult to estimate *exactly* the actual *number* of individuals who died within a given age interval. With increasing sample size, such estimation gets more difficult, because the standard deviation of the estimate increases with sample size. Similar effects turn out to exist for deter-**

mination of exact figures in paleodemography in general. Instead, *relative* numbers should be utilized, as these turn out to be more and more exact when the sample size (e.g. the number of skeletons in the material) increases.

## Some consequences for paleodemography

The most direct implication of this is that the increasing loss of precision of estimates based on absolute numbers of individuals suggests that paleodemographic calculations involving absolute numbers of individuals should be avoided as far as possible. This means that the actual distribution of the dead (the $D_x$-series according to some abridged life table) should be avoided, because it is althogether erroneous and inexact. Instead the relative distribution of the dead (the $d_x$-series) may or may not be calculated. In the case it is not explicitely given, information about the relative distribution of the dead is given implicitely in the column of relative survivorship rate, or the $l_x$ column, by means of recursion.

However, even the relative numbers calculated for paleodemographic purposes are hampered with inexactness, although this diminishes with increasing sample size. Knowing the underlying distribution of the age determinations, however, a confidence interval for the true value may easily be calculated, say, a 95% confidence interval. For the $l_x$-values, the lower bound of the confidence interval will correspond to a high mortality, whereas the upper bound of the interval will correspond to a low mortality. This may be interpreted as a mortality due to unfavourable and favourable mortality conditions, respectively, of the corresponding population. The actual mortality pattern of the population may therefore be regarded to be secured within the limits corresponding to *the least favourable* and *the most favourable mortality pattern of the population*, whereas the values calculated until now may be regarded as the *expected mortality pattern*. The difference between the expected (calculated) values and the extremes is just a function of sample size. Formulas for calculating the different $l_x$-series according to the generalized age group system of MARTIN are given in Table 3. The calculated values refer to the limits of overlap between different age groups (see table 2). This is permissible from the knowledge of demographic theory, the pattern of mortality not being dependent of age intervals spanning exactly the same range of years. The formulas in table 3 also turn out to be the simplest expressions for practical calculations.

This concept can be further applied on other paleodemographic funcions. With regard to the expectations of life at different ages, age intervals are arrived at, instead of single figures, which are most probably erroneous. In the future, therefore, one might probably be accostumed to see mortality curves similar to Fig. 2 and Fig. 3, where the curves enclose areas, expressing how far we can get from given methods of age determination into the demography of a prehistoric population. To reach that stage, we shall probably be forced to reconstruct parts of the population which are missing for one reason or another. Such estimation may be carried out along different lines (e.g. UNITED NATIONS 1963, BOCQUET and MASSET 1977) but it should be born in mind that the estimation has to be carried out from the different patterns of mortality, so that the estimates of a missing part of the population can never be more exact than the estimates based on the existing part.

Formulas for calculation of $l_x$-values according to the generalized age group system of MARTIN (1914, 1928), with standard deviation and 95% confidence limits for each values. The symbols $n_{Inf}$, $n_{Inf\,I}$, $n_{Inf\,II}$, $n_{Juv}$, $n_{Ad}$, $n_{Mat}$ and $n_{Sen}$ denote the number of individuals within the age groups *Infant*, *Infans I*, *Infans II*, *Juvenilis*, *Adultus*, *Maturus* and *Senilis*, according to Table 2, and $n$ is the total number of dead. Confidence limits correspond to the least favourable and the most favourable mortality pattern of the population

*3. táblázat.* Képletek az $l_x$ értékek kiszámítására MARTIN (1914, 1928) általánosított korcsoportrendszere szerint, szórással és 95% konfidencia-határokkal minden egyes értékre. Az $n_{Inf}$, $n_{Inf\,I}$, $n_{Inf\,II}$, $n_{Juv}$, $n_{Ad}$, $n_{Mat}$ és $n_{Sen}$ jelek a korcsoportok egyedszámát jelölik a 2. táblázat szerinti *Infant*, *Infans I*, *Infans II*, *Juvenilis*, *Adultus*, *Maturus* és *Senilis* korcsoportokban, $n$ pedig az elhalálozottak teljes száma. A konfidencia-határok a népesség legkedvezőtlenebb és legkedvezőbb halálozási alakulásának felelnek meg

| $l_x$ | Expected or mean value *Várható vagy középérték* | Standard deviation *Szórás* | Confidence limits *Konfidencia-határok* |
|---|---|---|---|
| $l_0$ | $100{,}00$ | $0$ | $\pm 0$ |
| $l_1$ | $100{,}00 - \frac{100{,}00}{n}(n_{Inf} + 0{,}125\, n_{Inf\,I})$ | $\frac{33{,}07\sqrt{n_{Inf\,I}}}{n}$ | $\pm \frac{50{,}00 + 64{,}82\sqrt{n_{Inf\,I}}}{n}$ |
| $l_5$ | $100{,}00 - \frac{100{,}00}{n}(n_{Inf} + 0{,}625\, n_{Inf\,I})$ | $\frac{48{,}41\sqrt{n_{Inf\,I}}}{n}$ | $\pm \frac{50{,}00 + 98{,}89\sqrt{n_{Inf\,I}}}{n}$ |
| $l_8$ | $100{,}00 - \frac{100{,}00}{n}(n_{Inf} + n_{Inf\,I} + 0{,}300\, n_{Inf\,II})$ | $\frac{45{,}83\sqrt{n_{Inf\,II}}}{n}$ | $\pm \frac{50{,}00 + 89{,}82\sqrt{n_{Inf\,II}}}{n}$ |
| $l_{10}$ | $100{,}00 - \frac{100{,}00}{n}(n_{Inf} + n_{Inf\,I} + 0{,}500\, n_{Inf\,II})$ | $\frac{50{,}00\sqrt{n_{Inf\,II}}}{n}$ | $\pm \frac{50{,}00 + 98{,}00\sqrt{n_{Inf\,II}}}{n}$ |
| $l_{15}$ | $100{,}00 - \frac{100{,}00}{n}(n_{Inf} + n_{Inf\,I} + n_{Inf\,II} + 0{,}333\, n_{Juv})$ | $\frac{47{,}14\sqrt{n_{Juv}}}{n}$ | $\pm \frac{50{,}00 + 92{,}40\sqrt{n_{Juv}}}{n}$ |
| $l_{18}$ | $100{,}00 - \frac{100{,}00}{n}(n_{Inf} + n_{Inf\,I} + n_{Inf\,II} + 0{,}533\, n_{Juv})$ | $\frac{49{,}89\sqrt{n_{Juv}}}{n}$ | $\pm \frac{50{,}00 + 97{,}78\sqrt{n_{Juv}}}{n}$ |
| $l_{25}$ | $100{,}00 - \frac{100{,}00}{n}(n_{Inf} + n_{Inf\,I} + n_{Inf\,II} + n_{Juv} + 0{,}259\, n_{Ad})$ | $\frac{43{,}82\sqrt{n_{Ad}}}{n}$ | $\pm \frac{50{,}00 + 85{,}89\sqrt{n_{Ad}}}{n}$ |
| $l_{35}$ | $100{,}00 - \frac{100{,}00}{n}(n_{Inf} + n_{Inf\,I} + n_{Inf\,II} + n_{Juv} + 0{,}630\, n_{Ad})$ | $\frac{48{,}29\sqrt{n_{Ad}}}{n}$ | $\pm \frac{50{,}00 + 94{,}65\sqrt{n_{Ad}}}{n}$ |
| $l_{45}$ | $100{,}00 - \frac{100{,}00}{n}(n_{Inf} + n_{Inf\,I} + n_{Inf\,II} + n_{Juv} + n_{Ad} + 0{,}333\, n_{Mat})$ | $\frac{47{,}14\sqrt{n_{Mat}}}{n}$ | $\pm \frac{50{,}00 + 92{,}40\sqrt{n_{Mat}}}{n}$ |
| $l_{50}$ | $100{,}00 - \frac{100{,}00}{n}(n_{Inf} + n_{Inf\,I} + n_{Inf\,II} + n_{Juv} + n_{Ad} + 0{,}500\, n_{Mat})$ | $\frac{50{,}00\sqrt{n_{Mat}}}{n}$ | $\pm \frac{50{,}00 + 98{,}00\sqrt{n_{Mat}}}{n}$ |
| $l_{65}$ | $100{,}00 - \frac{100{,}00}{n}(n_{Inf} + n_{Inf\,I} + n_{Inf\,II} + n_{Juv} + n_{Ad} + n_{Mat} + 0{,}500\, n_{Sen})$ | $\frac{50{,}00\sqrt{n_{Sen}}}{n}$ | $\pm \frac{50{,}00 + 98{,}00\sqrt{n_{Sen}}}{n}$ |
| $l_{80}$ | $0$ | $0$ | $\pm 0$ |

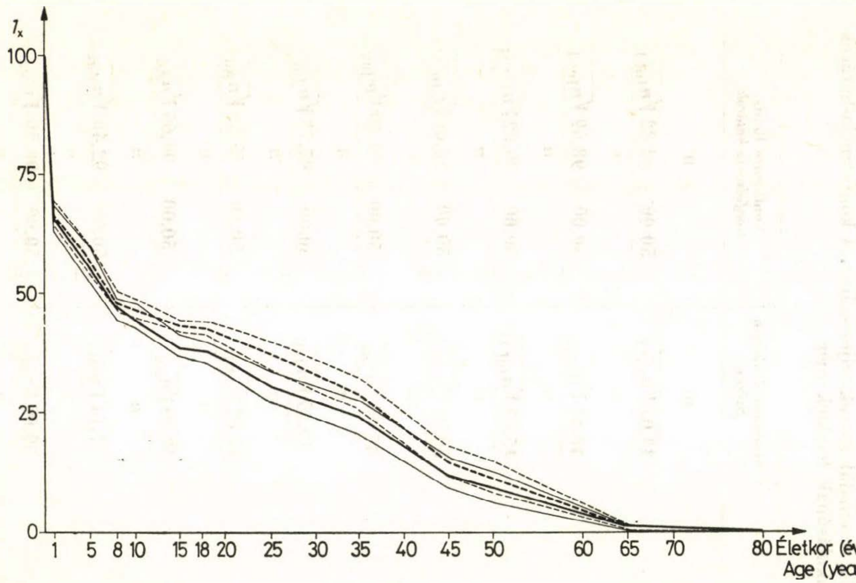


*Fig. 2.* The $l_x$-series of Westerhus population for males (unbroken curves) and females (broken curves) according to the least, the expected and the most favourable mortality pattern of the population (the lower, middle and upper curves, respectively)

*2. ábra.* A Westerhus-i népesség $l_x$ sora férfiakra (folytonos görbék) és nőkre (szaggatott görbék), a népesség legkedvezőtlenebb, várható és legkedvezőbb halálozási alakulása szerint (alsó, középső, ill. felső görbék)

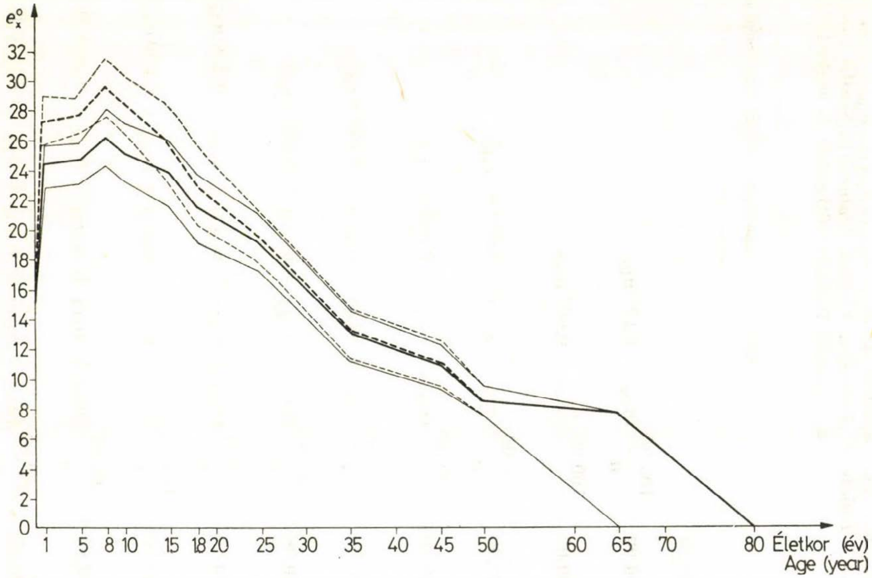


*Fig. 3.* The $e_x$-series of the Westerhus population for males (unbroken curves) and females (broken curves) based on the three patterns of mortality displayed by the $l_x$-series given in Fig. 2. From the age of 50, male and female curves are practically identical

*3. ábra.* A Westerhus-i népesség $e_x$ sora férfiakra (folytonos görbék) és nőkre (szaggatott görbék) a 2. ábrán a halálozás alakulására megadott $l_x$ sorra alapozva. 50 éves kortól a férfiak és nők görbéi gyakorlatilag azonosak

The possibility of reconstructing a population is a very important result for paleodemography. The most obvious use of this result concerns the reconstruction of infant mortality, but similar procedures may be used in order to estimate or adjust the male or female population within certain age groups. For different reasons parts of the adult population may be missing, such as men from a fishing population being lost at sea or, in general, men being killed in warfare their bodies not having been recovered. At least, it should be quite obvious that carrying out a paleodemographic study on a skeletal population without having ascertained that the crude age distribution of the dead is close to the original age distribution, may lead to pure nonsense. At any rate, the results will certainly be of dubious nature. Similar precautions have also to be taken into consideration with respect to age and sex determinations. These and other problems concerning paleodemography have been more extensively discussed by ANGEL (1969), NEMESKÉRI (1972) and MASSET (1973).

Actually, the paleodemographic theory developed in the preceding chapters does not depend on a specified system of preassigned age groups. The main point is that confidence limits for the numbers of survivors is calculated. If, therefore, the sex is properly identified and the probability distributions of the age determinations are known, the theory given may be modified to suit the new conditions under which the paleodemographic calculations are carried out. The important matter is that paleodemographic results are not given as single values, but as intervals reflecting the actual amount of information on which the calculations are based.

It is to be assumed that modern methods for sexing skeletons grew more and more accurate, especially since there are only two sexes, even for juveniles and children. Therefore, the problem of sufficiently exact sex determination may hopefully be solved within not too distant future. More difficult, however, is the problem of exact age determination. The aim of developing methods for age determination being to obtain as exact age determinations as possible (or, more correctly, as narrow age intervals as possible), most contemporary methods claim to be far more accurate than they actually are, e.g. McKERN and STEWART (1957) with regard to *symphysis pubis*, and ACSÁDI and NEMESKÉRI (1970) with regard to the combined method of age determination. McKERN and STEWART's age ranges for the total scores are too narrow to be true with a high degree of accuracy (a confidence of 95% or more). Concerning the combined method by ACSÁDI and NEMESKÉRI, using four indicators simultaneously, the most exact age determinations, giving an age interval of five years, are connected with an exactness of 80–85% only, as pointed out in connection with the tabulation of the method (SJØVOLD 1975). Similar criticism may be directed towards other methods for age determination.

The main problem in connection with age determination is connected with the probability distribution of the age of an individual displaying a certain expression of an age determining characteristic (apart from misjudgements of the phase actually displayed). In general, a normal distribution of the age cannot be assumed since the individual, after having reached the age stage corresponding to that particular expression or score, remains in the same stage from an observational point of view at the age stage corresponding to the next expression is reached. Probably a Poisson or a related distribution is involved, since the fundamental problem is the time for transition from one stage to another. In this way, the procedure of ageing is related to so called Poisson-and Markoff-processes and, in especial, multivariate situations of this kind. The Poisson distribution, as well as other alternative distributions which may be involved (e.g., the expotential, the gamma or even the chi-square distribution) is positively skewed. Applied to a particular stage of age development, this implies that some individuals may retain a "young" appeaience of an age indicator into old age, although most of the individuals undergo a "normal" ageing process, passing from the one ageing stage to the next within a shorter time period. Within the field of multivariate Poisson- and Markoff-processes, however, much remains to be done within the field of statistical theory before methods for age determination can be soundly based on the results from such analyses. Once the proper distribution of single age determinations has been at least approximately determined, calculation of paleodemographic data may proceed on an individual basis, utilizing the confidence limits of the distribution to obtain mortality patterns according to the least, the expected and the most favourable mortality condition of that particular population.

A likely property for an age determination is that the age interval will tend to increase with age. The reason for this may be explained in the following way: Assume that all individuals concerned are judged as adults, say, according to the closure of the sphenoocipital syncondrosis and epiphyseal closure. Then they all belong to the first age stage according to some sequence of expressions or scores. Depending on the intensity of transition to the next age stage, a certain amount of age variation will occur for this transition. The time until the following transition will, in turn, depend on transition intensity with regard to the expression of the next following age stage. But now there was already a certain variation in age when the second age stage was entered. Therefore, the age variation for the second transition is likely to be greater than in connection with the first and so on. This is reflected by the method of McKern and Stewart, and for Acsádi and Nemeskéri for old age. The actual *distribution of ages* for the transition into and out of an age stage should therefore be analysed, both theoretically and empirically.

Also, the possible influence of social or cultural pressure on the transition intensity should be investigated, as this possibility might explain some of the deviation between the biological and the chronological age of individuals not merely explained as individual variation. Hopefully, the fact that the subdivisions into phases or scores expressed by an age indicator primarily reflects the anthropologist's ability to distinguish age development variation is not going to create serious difficulties in this connection.

Because the probability distributions for age determinations remain to be found with respect to modern age determining methods, it follows that proper confidence intervals can not be calculated with sufficient degree of accuracy. Therefore, until these distributions have been properly defined, it appears most reasonable to collect individual age determinations into a system of overlapping age groups for paleodemographic purposes. Such a system of overlapping age groups may, in principle, be made up from case to case, based on the property that, as far as nothing exact is known about the distributions of age determinations within each age group, they may each be regarded as uniformely distributed over the age interval. Correspondingly, the theory of the previous sections may be modified to yield paleodemographic information with regard to the least, the expected and the most favourable mortality pattern of each particular skeletal population.

To conclude this paper, some additional aspects of paleodemography which may be of importance for future research shall be mentioned. Perceiving that a stable population, unlike the stationary population of the life-table, is a developing unit, different aspects of population growth and development may be studied. Until now, few studies of this kind have been esseyed (e.g. BENNETT 1973), but this line of research seems promising as a means of extracting information concerning the development of populations from which only skeletal remains are available. Throughout however, care should be taken to the three different patterns of mortality restricting the mode of development of the population. The essay by the UNITED NATIONS (1968) on stable populations, as well as related papers on that subject, should provide a fairly good base for proceedings in this direction.

## Summary and conclusions

Paleodemographic studies are based on small sample sizes compared with modern demographic studies, and on inaccurate age determinations. Based on inference concerning the nature of the age determinations available, the distribution of the mean age within given age intervals may be derived, emphasizing the amount of information actually contained in the age estimates. Because these are inaccurate, it is found that, in paleodemography, estimates of exact numbers, such as exact numbers of survivors at a given age, or the exact number of years lived by the survivors, turn more and more inprecise with increasing sample size, and calculation of such numbers should therefore be avoided. Instead, only relative numbers should be calculated, since such numbers get more and more exact as the sample size increases.

As a consequence of the small sample sizes and the inaccurate age determinations, the results from a paleodemographic analysis can never be as exact as corresponding, modern demographic data. However, the exactness of the results may be expressed in terms of *the least*, *the expected* and *the most favourable mortality conditions of the population*, based on the knowledge of what is actually known about the age distributions. According to this principle, paleodemographic characteristics are expressed by means of intervals instead of exact figures, the intervals covering the true (but unknown) demographic figure with a high degree of confidence. These intervals shrink towards single numbers with increasing sample size. In this way, both the inaccuracy of the different age determinations as well as the small sample size are accounted for.

Until now, paleodemography has borrowed many of the procedures from modern demography, as paleodemography is in fact demography based on a particular kind of material, utilizing data with properties deviating from that of demography proper. These properties are of a kind that require certain modifications from the modern demographic methodology. With this in mind, it should be possible to combine the knowledge of physical anthropology and osteology with that of demography, so that the conclusion of a paleodemographic study may really reflect the actual knowledge extracted from skeletal remains applied in demographic basis.

*

(Received 11 September 1978)

## References


ACSÁDI, GY.—NEMESKÉRI, J. (1970): *History of Human Life Span and Mortality.* — Akadémiai Kiadó, Budapest.

ANGEL, J. L. (1953): The human remains from Khirokitia. — Appendix II, *in:* DIKAIOS, P. (Ed.): *Khirokitia.* Oxford University Press, Oxford—London.

— (1969): The bases of paleodemography. — Am. J. Phys. Anthrop. *30;* 427—438.

BENNETT, K. A. (1973): On the estimation of some demographic characteristics on a prehistoric population from the American Southwest. — Am. J. Phys. Anthrop. *39;* 223—232.

BOCQUET, J-P.—MASSET, C. (1977): Estimateurs en paléodémographie. L'Homme *17;* 65—90.

GEJVALL, N-G. (1960): *Westerhus. Medieval Population and Church in the Light of Skeletal Remains.* — Håkan Ohlsson, Lund.

MARTIN, R. (1914): *Lehrbuch der Anthropologie in systematischer Darstellung.* — Gustav Fischer Jena.

— (1928): *Lehrbuch der Anhtropologie in systematischer Darstellung.* 2. Auflage, 2. Band. — Gustav Fischer, Jena.

MASSET, C. (1973): La démographie des populations inhumées. — L'Homme *13;* 95—131.

MCKERN, T. W.—STEWART, T. D. (1957): *Skeletal age changes in young American males, analysed from the standpoint of age identification.* — Headquarters Quartermaster Research & Development Command, Quartermaster Research & Development Center, US Army, Nantic, Massachusetts. Technical Report EP-45.

NEMESKÉRI, J. (1972): Die archäologischen und anthropologischen Voraussetzungen paläodemographischer Forschungen. — Praehistorische Zeitschrift *47;* 5—46.

PETERSEN, W. (1975): A demographer's view of prehistoric demography. — Current Anthropology 16; 227—246.

SJØVOLD, T. (1975): Tables of the combined method for determination of age at death given by Nemeskéri, Harsányi and Acsádi. — Anthrop. Közl. 19; 9—22.

STOLNITZ, G. J. (1956): *Life Tables from Limited Data. A Demographic Approach.* — Office of Population Research→ Princeton, New Jersey.

ULLRICH, H. (1972): *Anthropologische Untersuchungen zur Frage der Entstehung und Verwandtschaft der thüringischen, böhmischen und mährischen Aunjetitzer.* — Weimar.

UNITED NATIONS (1963): Factor analysis of sex-age specific death rates. A contribution to the study of the dimensions of mortality. — Department for Economic and Social and Economic Affairs: Population Bulletin of the United Nations *6;* 147—201.

— (1968): *The Concept of a Stable Population.* — Department for Economic and Social Affairs: Population Studies *39.*



*Author's address:* DR. T. SJØVOLD
*A szerző címe:* Osteological Research Laboratory
University of Stockholm
Ulriksdal Royal Castle
S—171 71 Solna, Sweden