Transition Analysis as a Method of Age Estimation: A Reevaluation from an Anthropological Perspective

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Paleodemographic age-at-death distributions have long been criticized for their deviations from known human mortality patterns (Bocquet-Appel y Masset 1982)(Howell, 1976). In general terms, preindustrial populations across time and space share certain commonalities in regards to the age-specific force of mortality. Mortality is high in infants and young children but falls off rapidly to a lifetime low in late childhood and early adolescence. Mortality remains low throughout early and middle adulthood and then begins to accelerate rapidly at later ages (Weiss 1973; Wood, et al. 1992). This is not to say that mortality is invariable across populations. Populations do show variation in terms of the levels of excess mortality in early childhood or senescence. The age at which juvenile mortality begins to decline or senescent mortality begins to rise may also differ (Wood et al. 2002: 138).

Paleodemographers, however, have typically reported unexpectedly low infant mortality and adult age-specific mortality that is abnormally high and that accelerates rapidly from age 15 to 50, resulting in few individuals surviving into old age (Milner, et al. 2000). Howell (1976, 1982) and Bocquet-Appel and Masset (1982) have noted that age-at-death distributions, constructed from skeletal remains, typically look significantly different than those produced by historical demographers, even though the historical and archaeological samples may not be that far removed in time. Some anthropologists assert that mortality patterns in archaeological populations were significantly different than
those observable in historic and modern anthropological populations (Meindl 2003). However, it has been demonstrated conclusively that traditional aging methods suffer from methodological problems that affect the accuracy of adult age estimates (Bocquet-Appel y Masset 1982, Konigsberg y Frakenberg 1992, 1994, Konigsberg, et al. 1997). In order to evaluate whether substantial variation in the human mortality experience occurred over time, we must first resolve these methodological impediments to adult age estimation.

Transition analysis (Bolsen, et al. 2002) is an adult aging method that addresses the problem of age mimicry of the reference sample, and it offers a means of improving age estimates that is still applicable to relatively small sample sizes. Transition analysis relies on age-related information collected from five different cranial sutures, the pubic symphysis, and the iliac portion of the sacroiliac joint using the scoring system established by Boldsen et al. (2002). These data are then entered into a computer program (ADBOU), which weights this osteological information in an appropriate way, and calculates a maximum likelihood estimate of age using Bayes’ Theorem and either a uniform prior probability or an archaeological prior probability, which will be explained below. Age-related data from the cranial sutures, pubic symphysis, and auricular surface are weighted based upon the accuracy and precision of the age estimates they produce. If skeletal elements are missing or incomplete, transition analysis allows for age estimates using only the features that are observable.
The uniform prior probability assumes that all ages are equally likely to be represented in the age-at-death distribution of the population. Clearly, this is not a theoretically-valid assumption, as some age groups are much more likely to be represented in a skeletal sample than others.

One of the most significant benefits of transition analysis is the promise of improved estimates of age for older adults (Boldsen et al., 2002). In the past, this has been a problematic issue in paleodemography, and many methods of adult age estimation have an open-ended terminal age category, such as 55+. While these open-ended categories acknowledge the difficulties of accurately aging older individuals, they also limit the information regarding senescent mortality that can be obtained from the skeletal sample. The transition analysis program includes age information from various parts of the skeleton that aid in aging older adults. In particular, characteristics such as posterior iliac exostoses, which are more likely to be present at advanced ages, address deficiencies in traditional aging methods in estimating the ages of the very oldest members of the population.

Recently, we published a work (Kreger Bullock, et al. 2013) where we apply this method to the series of Cholula and San Gregorio Atlapulco, the results indicate a number of individuals who survived past the age of 80. In the case of the series of San Gregorio, which is to be
discussed in this paper, results are presented in Figure 1, which shows the comparison between the distribution obtained from the application of transitional analysis and the distribution published by Hernandez (2006b), who obtained it by applying the traditional standards for age at death estimation.

Using traditional techniques to estimate age, mortality is concentrated between the third and fourth decade of life with low survival after fifty years, there is no representation of individuals beyond age 65. In contrast, the age at death distribution, constructed using transitional analysis, shows low mortality in young and middle-age and a significant part of the population survives to age 70. Others survived to age 90 and beyond.

Given these results we need to answer the following questions:
1) Does the historical and archaeological research on San Gregorio supports these results?
2) What do we know about the impact of epidemic disease and living conditions on these people?
3) In the past did they use to live into old age? What do bioarchaeological and ethnographic studies say?

1) San Gregorio Atlapulco, Xochimilco

The series of San Gregorio Atlapulco was recovered between 1993 and 1995, from an archaeological salvage work at the Ejido of the same name, when residential buildings were constructed there. When archaeologists arrived, the large platform that was possible to see in the center of the field was already 90% destroyed, only the remaining 10% was excavated; 384 human burials were recovered in good condition (Ávila 1995). Burials correspond to the time of contact (XVI century) anthropological data confirm the indigenous origin of these individuals (Karam Tapia 2012: 112).

In the sixteenth century, San Gregorio was a small village that depended on Xochimilco. Gonzalez (1996), who also participated in the excavation of site, suggests that during prehispanic times it was a temporary activity area, but after the Conquest and as a result of declining lake levels in 1524, the region was permanently populated by neighbors from Tlahuac and Xochimilco.

Their subsistence pattern has been characterized as intensive agriculture. They were the builders of chinampas and main food providers of the capital of the Aztec empire. Their population should have been large enough to provide the required workforce. According to the results of research conducted on this series, workloads, disease and continuing times of famine, ravaged this city, where survival was difficult, given the damp and unhealthy environment on the banks of Lake Xochimilco and the insects that were part of that environment (Hernandez Espinoza 2006a Enriquez Medrano 1999).
From a paleodemographic focus, Hernandez (2006b) analyzed the age distribution of death, noting that the high proportion of infants and young adults in the sample are not only indicators of a population with high population growth but also a population with low survival at young ages, as calculated life expectancy for this population is 17 years at birth.

No one knows, for sure, if in this site was located at the ancient Ermita of San Gregorio Atlapulco and the old hospital of the Immaculate Conception, built to catechize the Indians and to offer them relief from epidemics that hit this town in the sixteenth century, especially the plagues in 1548-1549, 1554 and the 1576 smallpox epidemic (Nieto Chapa, 1957: 147-148). According to the compiled data archives for the Parish Church of Xochimilco and the distribution of the burials, you can see "corridors" between groups of burials (see Figure 1). Initially we thought they were buried in the atrium of the Ermita and possibly died as the victims of some of the epidemics mentioned, given the high subadult representation in this series.

However, in a recent review of pathological lesions present in these burials, the presence of trauma and cut marks was evident on most individuals tested, so our hypothesis now focuses, on the possibility that we have a massacre. The cuts marks on skulls and limbs are consistent with weapons carried by Spaniards. Bibliographic review is still in process, so we cannot yet identify to which of all the indigenous massacres these remains pertain to; what is certain is that the age-at-death distribution of these the skeletons, actually corresponds to the age distribution of the once living population. Consequently, the age-at-death distribution obtained from seriation methodology and traditional physical anthropology techniques is more consistent with this information than that obtained from transitional analysis.

**Elderly survival in the past**
Data from ancient populations, in both prehistoric and historic Europe and Asia, show that only a small proportion of the population lived beyond 50, most died at about sixty or seventy years old. In the case of the Middle East (Southern Levant), Hershkovitz and Gopher (2008), studied hundreds of skeletons that came from a hunter-gatherer series of Natufian period (15,000 to 12,000 a. P.) and pre-ceramic sedentary groups from the Neolithic (from 12,000 to 8350 a. P). For the former the estimated life expectancy at birth, assuming they are stationary population, is 24.6 years, while for the latter it is 25.4 years. The average age at death of adult individuals represented in the series is 32.1 years to the hunter-gatherers (37.6 years for men and 30.1 years for women) and 31.2 years for the pre-ceramic group (men 32.2 and 35.5 for women) (Hershkovitz and Gopher 2008: 445). Bagnall and Frier (1995), based on censuses from the second to third century AD.C. in Roman Egypt, found that only about one fifth of women lived from adolescence to age 60. The average life expectancy at birth was 25.60 and 22.5 for men and women respectively. At 30 years old this indicator is 22.23 and 24.998 respectively, therefore the probability of survival beyond the age of fifty was very low. From the study of Chinese genealogies, Zhao (1995) shows that very few people reached the age of 95 years and life expectancy at ages 30 and 50, were lower than those estimated by Coale and Demeny (1966) in their model West table, level 5, which are 28.3 and 16.9 years, respectively, for women. Séguy et al. (2008: 97), for the series Frénouville Cemetery (Calvados, France, dated between the third century and VII d. C.) estimate that life expectancy at age 30 was 31.1 years and at 80, only four years. In England during the sixteenth and seventeenth centuries, Wrigley et al. (1997) indicate that adult mortality was very volatile in the sixteenth century. Life expectancy at age 25 was 30 years, that is, an individual at that age could expect to live to 55, with a probability of survival at 50%, and in earlier periods men at age 20 had a life expectancy of 27 years on average. In this same country, but using life tables with
historical data, Thatcher (1995) finds that in the eighteenth century the probability of living to age 100 was 1 in 100,000. This same author also constructed life tables for ages over fifty years, and the results indicated that only between 40% and 50% survived to 70 years, and only 10-20% to 80 years.

Wilmoth (1995), whose main objective was to estimate the proportion of centenarians, concludes that they should be present with what he calls the birth of civilization, not because mortality had decreased, but because the world’s population was big enough. Like Zhao, Wilmoth found that high levels of adult mortality have been present until the last couple of centuries and that life expectancy at age 50 was, on average, only about 14 years. This author points out that the first reliable mortality tables, (Coale and Demeny 1966) mark a life expectancy at birth of 33.4 for men and 35.5 for women, but in the industrial era. Therefore, for the European and Asian cases from the pre-modern era, the chances of survival to age 75 was very low, and that historical patterns under specific circumstances resulted in survival to sixty years and in some cases, only to forty.

In the case of America, Curet (2005: 185-219) studied the prehispanic Antilles population, where he presents some paleodemographic data for three sites. The indicator of interest here is the average life expectancy at birth and at thirty years, and, for the oldest site, Tibe (100-600 d. C.), these indicators are 28.5 years at birth and 7.794 years at age 30; Punta Candelero (400-600 d. C.), 32.9 and 12.1 years respectively, and Paso del Indio (1200 to 1500 dc) at birth 19.7 years and at age 30, only 10.2 years.

For prehispanic populations of Ohio and Kentucky, United States, Meindl et al. (1998) and Mensforth (1990) estimate these same indicators for several Late Archaic period sites, whose life expectancy at birth was between 30 and 37 years. At age 30, life expectancy is reduced to 15 years on average.

For prehispanic Mexico, we have information of several series from different cultural horizons, which are presented in Table 1, with
information on life expectancy at birth ($E_0$), at age 30 ($E_{30}$); the survivorship probability ($l_0$), average of age of living population (AA) and the proportion of adults who survived beyond age 50 (S). Survival was low and few survived past sixty.

<table>
<thead>
<tr>
<th>Series</th>
<th>Chronology</th>
<th>$E_0$</th>
<th>$E_{30}$</th>
<th>$l_0$</th>
<th>AA</th>
<th>S (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tlatilco</td>
<td>Preclassic (*)</td>
<td>20.7</td>
<td>10.8</td>
<td>0.366</td>
<td>29.6</td>
<td>10.7</td>
</tr>
<tr>
<td>Cuicuilco</td>
<td>Preclassic</td>
<td>25.9</td>
<td>10.5</td>
<td>0.550</td>
<td>29.9</td>
<td>6.3</td>
</tr>
<tr>
<td>Monte Albán</td>
<td>Classic (**)</td>
<td>23.4</td>
<td>8.1</td>
<td>0.476</td>
<td>28.6</td>
<td>6.2</td>
</tr>
<tr>
<td>Tlajinga 33</td>
<td>Classic</td>
<td>24.8</td>
<td>27.4</td>
<td>0.345</td>
<td>29.3</td>
<td>7.7</td>
</tr>
<tr>
<td>Jaina</td>
<td>Classic</td>
<td>17.4</td>
<td>18.3</td>
<td>0.320</td>
<td>28</td>
<td>13.0</td>
</tr>
<tr>
<td>Palenque</td>
<td>Classic</td>
<td>25.1</td>
<td>8.77</td>
<td>0.466</td>
<td>26.8</td>
<td>3.4</td>
</tr>
<tr>
<td>Chac Mool</td>
<td>Classic</td>
<td>20.2</td>
<td>16.0</td>
<td>0.524</td>
<td>33.6</td>
<td>24.3</td>
</tr>
<tr>
<td>Chac Mool</td>
<td>Postclassic (***)</td>
<td>20.6</td>
<td></td>
<td></td>
<td>31.6</td>
<td>19.9</td>
</tr>
<tr>
<td>Xcaret</td>
<td>Postclassic</td>
<td>15.4</td>
<td>6.4</td>
<td>0.361</td>
<td>31.6</td>
<td>19.0</td>
</tr>
<tr>
<td>Cholula</td>
<td>Postclassic</td>
<td>23.9</td>
<td>9.8</td>
<td>0.480</td>
<td>29.3</td>
<td>7.7</td>
</tr>
</tbody>
</table>

(*) 1500 a.C. – 0 d. C.  (**) 0-900 d.C  (***) 1000–1521 d.C.

The Mexican colonial period was characterized by constant outbreaks of varying etiology, which primarily impacted the indigenous population, and to a lesser extent mestizos and Europeans with greater immunity because of new viruses and bacteria. Among the Indians, unsanitary living conditions, malnutrition, strenuous working hours and environmental conditions, leading to a state of biological fragility that prevented them from surviving to old age. Although in the parish and civil records we can find people whose age at death was nearly 100 years, it doesn’t mean that all individuals survived to that age.

**Is it the techniques or the reference population?**
We agree that the trend of paleodemographic studies is to rejuvenate the population, because of the standards used; however, we would also suggest not to fall into the other extreme, of making them too old.

The main point of this work is the comparison of two age distributions obtained from different techniques and according to the authors of this method, it comes down to osteological techniques used to estimate age.
Analyzing in detail the results for the series of San Gregorio, we present some results obtained with this new method by omitting some of the skeletal indicators. Figure 2 shows the distribution obtained by transitional analysis without the indicators observed in the skull, that is, the extent of cranial suture obliteration (Bolsen, et al. 2002: 103).

![Figure 2](san_gregorio_atlapulco_age_at_death_distribution_based_on_craneal_suture_obliteration.png)

From: Bullock et al. 2013

Mortality is now concentrated in young adults, at ages 15-25, after this point frequencies decrease until age 80. You can see two spikes, one at the age of forty and one to sixty-five.

When the distribution is obtained from the information of the pubic symphysis (Bolsen, et al. 2002: 97-98) (Figure 3), the shape changes, mortality is concentrated now, with greater frequency, on individuals at
ages 15-19, 20-24, 35-39 and 60-64. There are no individuals in the age groups 45-49 and 85-89.

From: Bullock et al. 2013

Using information derived from the iliac auricular facet and the posterior iliac (Bolsen, et al. 2002: 100-103) (figure 4), mortality is concentrated in the age group of 15-19, diluted to 105 and more, with three spikes, one in the group 25-29, 70-74 and another less pronounced at 85-89 years.
The transitional analysis program (Adbou) includes two types of distributions, the so-called uniform distribution, which is based on the assumption that there is an equal probability of all ages and the "archaeological distribution." The latter assigns ages based on seventeenth century Danish rural mortality; hence ages beyond 80 are rare (Figure 5), while the uniform distribution assumes that all adult ages are equally likely to be represented. Mathematically, the effect of the uniform prior probability is that it overages individuals in the oldest part of the age-at-death distribution, resulting in some individuals being aged up to 110. The two are similar up to the age group 50-55 years, but from there the trend curve changes. The archaeological distribution shows an increase in the intensity of mortality up to age 70; thereafter it decreases to 85, that is to say, all indicators used coded
information to the 85-89 age group. The uniform distribution dilutes the effects of mortality from age 70 until the age group 110 years, which for a population like San Gregorio, is obviously not consistent. However, this extension of survival up to age 110 is purely a mathematical effect of the uniform prior probability.

The answer lies in the assumption that ancient populations had mortality experiences equal to those of modern preindustrial populations. Contemporary populations experience the force of mortality differently, as their physical and social environments are different from those of ancient populations. According to the theory of senescence (Ossa and Crews 2006), the body aging process begins when the accumulation of physical disability and chronic illness do not make it feasible to continue living. Historical data accumulated on the lives of indigenous people at time of Spaniard contact and then during the Colonial period, rarely give arguments for survival to ages older than
Given these results, we still think that the best method to get an estimate of the appropriate age is serialization, using the technique of morphological changes in the auricular iliac facet, which proved to be the most effective even in transitional analysis.

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