

Chapter 10

DEMOGRAPHIC AND HEALTH CHANGES DURING THE TRANSITION TO AGRICULTURE IN NORTH AMERICA

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Abstract: What were the consequences of Neolithic demographic transition on population's health? The paradigmatic question asked by Mark Cohen 30 years ago is revisited: did biological stresses, which are indicators of a population's well being, increase with the transition to agriculture? Data on four North American skeletal biological markers; dental caries (31 archeological sites), porotic hyperostosis (33 sites), cribra orbitalia (22 sites) and femur length sexual dimorphism (22 sites), used as proxy for stature; are set in the same chronological framework and related to the two-stage Neolithic demographic transition? How did they co-vary? Caries frequency increase one thousand years before the transition to agriculture. This pattern probably indicates the broadening of the diet range during the time before agriculture takes place as well as the addition of sugar in the diet. As soon as the transition to agriculture takes place, and fertility increases, the prevalence of anemia markers increases and stature sexual dimorphism decreases. Overall, the picture confirms the hypothesis of biological stresses, during the transition

INTRODUCTION

The signal of a hitherto unnoticed demographic process has been detected from bioarchaeological data from about a hundred cemeteries in Europe, North Africa and North America, during the shift from forager to horticulture-farming societies. This signature is characterized by an abrupt increase in the proportion of immature skeletons over a period of 600–700 years. This indicates a notable increase in the crude birth rate and beyond that in fertility. This process has been termed the Neolithic Demographic Transition (Bocquet-Appel and Naji 2006; Bocquet-Appel, 2002). This

signature was detected thanks to a representation of the data in a relative chronological scheme, i.e. relative to the local introduction of the new economic system, and not in the usual absolute (calendrical) chronology. The change in the chronological frame of analysis, which is obtained by a simple subtraction, has the effect of ordering spatio-temporally scattered bioarchaeological data relatively to the onset of the agriculture transition only, specifically the transition whose impact we are seeking to measure. This device has enabled us to compare archaeological sites globally and not simply pairwise, as is usually the case. The approach is discussed at length elsewhere (Bocquet-Appel and Naji 2006; Bocquet-Appel and Dubouloz 2003; Bocquet-Appel 2002; Bocquet-Appel and Paz de Miguel Ibanez, 2002). The use of a relative chronological frame is not exclusive to paleodemographic data and can be applied to many other archaeological variables (e.g. Bandy, 2005). Because the different data are set within a common chronological frame, their covariations can be readily observed, as in juxtaposed time series, which are usually difficult to observe with archaeological data. Having detected the Neolithic Demographic Transition by employing this approach, we are now interested in seeking and interpreting signals produced by other relevant categories of cultural and biological data that can contribute to an understanding of the economic transition as a whole, as a systemic shift. Beyond the demographic impact of the economic transition we have already demonstrated, what were its effects, and at what tempo, on socio-political organization, cultural production and the health of populations? Among the variables representing socio-political organization, a first tempo has already become apparent, at a global geographical scale, concerning the appearance of the earliest systems of large, stable villages, over an average time duration of about 1000 years (Bandy, 2006). This is followed by a leveling-off of the birth rate during the Neolithic Demographic Transition, which is estimated at above 50%. Finally, a tempo of approximately 2000 years was necessary for the spontaneous emergence of supra-local political units, interpreted as chiefdoms (Bandy, 2005, 2006). Other archaeological markers such as increasing numbers of LBK culture enclosures in Northern and North-Eastern Europe (Bocquet-Appel and Dubouloz 2004) are linked to the population explosion of the Neolithic Demographic Transition. What of the bioarchaeological variables? In this article, we return to the paradigmatic question raised by Cohen (1977) 30 years ago: did biological stress, a negative indicator of the population's well being, increase with the transition to agriculture (Cohen 1997, 1989; Cohen and Armelagos 1984; Larsen, 1995)? And if so, how did the timing of this process relate to the two stages of the Neolithic

Demographic Transition, as postulated in its original formulation (Bocquet-Appel, 2002)? To answer this question, data on four skeletal biological indicators from about 57 North-American cemeteries were collected and superimposed over the frame of the economic shift and the pattern of the Neolithic Demographic Transition.

MATERIALS AND METHODS

The North American database has been updated by adding 23 new sites, 12 foragers and 11 farmers (Figure 1). The new profile compensates the low density of points, in the dt zone preceding the introduction of the economic change, of the figure previously published (Bocquet-Appel and Naji 2006). Criteria for selecting these sites are the same with 2 exceptions:

- i) The small number of forager sites made us discard the criteria: « *excavation of at least 50% of the evaluated cemetery size* » (Bocquet-Appel and Naji 2006:342). This was necessary in order to ensure an adequate sample size. Additionally, these sites often have a large number of analyzed skeletons. For these sites, the criterion of selection is not an issue of excavated percentage, but an issue of the absolute number of excavated skeletons. If this number is large, regardless of a small excavated surface area, the skeletal sample can be considered a representative sample of the living population.
- ii) An upper limit to ${}_{15}P_5$ high values was estimated through its correspondence in terms of TFR, by using the 45 pre-industrial life tables demographic model (Bocquet-Appel, 2002; Bocquet-Appel and Naji, 2006:356) and the relation used by Coale; Demeny, Vaughan (1983). Sites falling above this limit were eliminated from the sample.

The new profile (Figure 1) is slightly different than a previous published one (2006): in the $dt = -2000$ to -1000 zone, the profile clearly has a bump, rising from 23% to 25% before rapidly decreasing to reach its minimum value of 19%, around 200 years before the introduction of the economic change. The profile then increases abruptly to reach the value of 29% at $dt = 1200$ years. One has to mention however, that few sites are present after $dt = 1000$ since we include only sites predating western contact. The continuation and possible termination of the profile is therefore not evident in the chart. The tempo is thus, for the moment, underestimated if we consider $dt = 1000$ to be the end of the profile. Presently, the bump in the pre-transition zone does not have a clear explanation. It could be an artefact

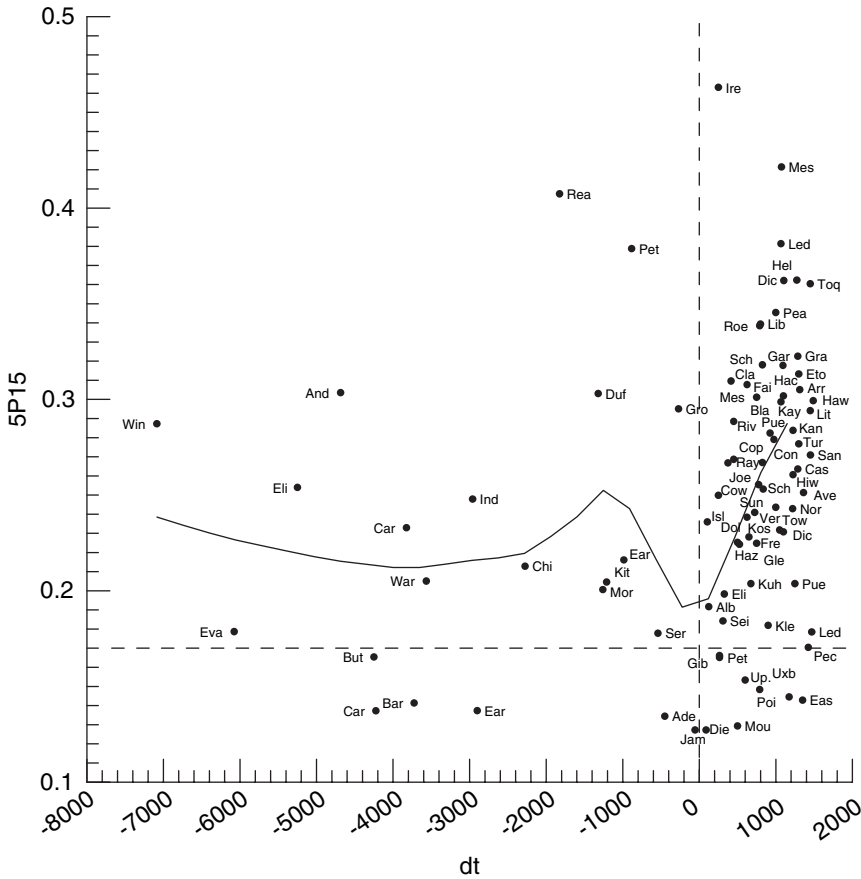


Figure 1: Changes in the proportion of immature skeletons aged 5 to 19 years (abbreviated as 15p5) during the transition from foraging to horticulture-farming, represented by *dt*

of site sampling, or it could also be due to a real effect of increased fertility for the sedentary or semi-sedentary shell-midden foragers (Bocquet-Appel and Naji 2006; Bocquet-Appel 2006), related to their putative low mobility.

The data on common biological indicators were gathered from the literature (see references in Figures 2–5). The indicators are frequencies for: i) dental caries (31 sites, see Figure 2), ii) porotic hyperostosis (33 sites, see Figure 3), iii) cribra orbitalia (22 sites, see Figure 4) and iv) sexual dimorphism in maximum femur length, used as a proxy for stature (22 sites, see Figure 5). The main reason for selecting these indicators was the frequent publication of the relevant data in bioarchaeological analyses, as well as the fact that these indicators are regularly used in population comparisons. It

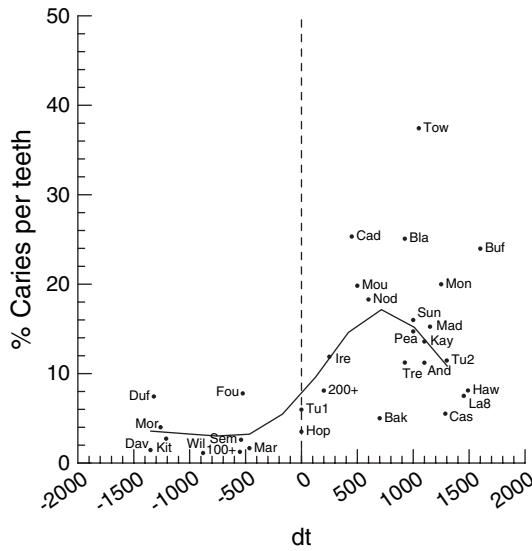


Figure 2: Frequencies of caries during the transition from foraging to horticulture-farming, represented by *dt*. (References: Anderson, 1968; Black, 1979; Butler, 1971; Driscoll, 2001; Martin et al., 1991; Powell, 1988; Ryan, 1977; Sciulli, 2002; Steckel and Rose 2002; Vradenburg, 1999)

should be noted however, that there are relatively few published cemeteries with a statistically significant sample of more than 30 observations and that the criteria used to establish frequencies are not entirely uniform, despite apparent agreement among authors. In this study, each indicator is based on a sample of at least 20 individuals (or, more accurately, 20 observations), or, in the case of dental caries, 640 teeth (20 individuals *32 teeth). To make up for the small number of sites matching our criteria, we sometimes combined data from several sites defined by archaeologists as culturally and geographically homogenous.

The frequency of dental caries is defined as the percentage calculated over all the *permanent* teeth in individuals in a given sample, i.e. those 6 years of age or more on average. The frequency of porotic hyperostosis (related to external table of the parietal bones) and cribra orbitalia (orbital region of the frontal bones) is defined as the percentage calculated over all the relevant bones observed in subadults. The heterogeneity of the age classes used by various authors to define “subadults” must be pointed out here, since the upper limit of the age group is variously given as “< 18 years”, “< 16 years”, “< 1 years”, “subadults”, “children”. As for the lower age limit of the group, the lack of any definition in most cases

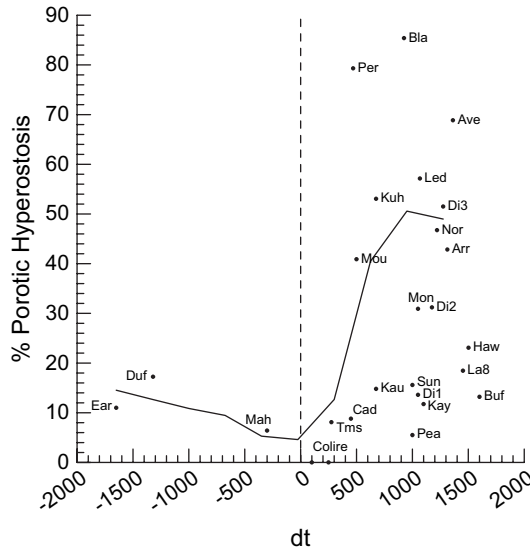


Figure 3: Frequencies of porotic hyperostosis during the transition from foraging to horticulture-farming, represented by *dt*. (References: Atwell, 1991; Burnett, 1999; Goodman et al., 1984; Martin et al., 1991; Milner and Smith 1990; Palkovich, 1980; Reinhard et al., 1999; Rose et al., 1984; Ryan, 1977; Steckel and Rose 2002; Williams, 2005)

does not allow the well-known under-representation of the 0–4 year age class to be addressed satisfactorily. This lack of accuracy prevents ready comparisons between sites and weakens the information drawn from these indicators. This study uses only individuals of 16 years of age and under, and assumes that the frequently used “subadult” category is equivalent to the “< 16 years” age group. Maximum femur length ($N \geq 20$, for each sex, i.e. 40 individuals at least) was recorded directly except in 2 cases (Madisonville and “Middle woodland”) where the inverse regression of femur length to stature was used (Sciulli and Giesen 1993).

These indicators were then placed within the relative chronology (*dt*) through their C14-calibrated BP dates or, if these were missing, through their cultural chronologies as defined by the authors. Interpreting the variations in these biometric characteristics invokes the so-called “osteological paradox” which has been discussed at length elsewhere (see for example Wright and CJ. Yoder Cassady 2003; Cohen, 1997; Wood et al., 1992) and which we shall only briefly address here in the light of the observed pattern of the Neolithic Demographic Transition (see Figure 1). The paradox is based in part on variations in the shape of an age distribution, caused by variations

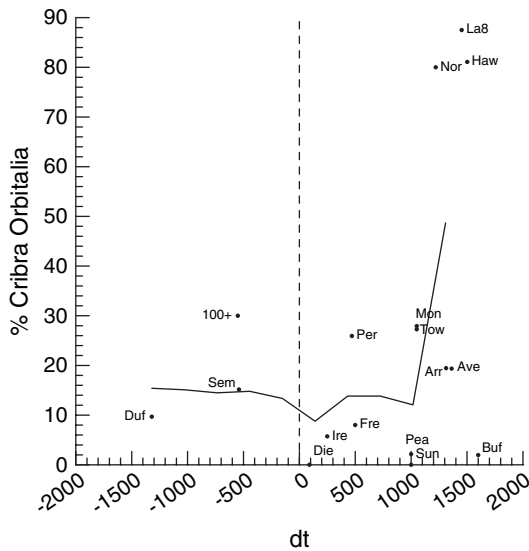


Figure 4: Frequencies of cribra orbitalia during the transition from foraging to horticulture-farming, represented by dt . (References: Anderson, 1968; Driscoll, 2001; Larsen, 2002; Milner and Smith 1990; Owsely and Bruweldheide 1997; Palkovich, 1980; Steckel and Rose 2002; Williams, 2005)

in the population's growth rate. It should be noted that if the frequency of an indicator is calculated relatively to individuals in the same age class, then its frequency will be independent from the age distribution and will be called, in the remainder of this article, its *incidence*.

The profile of variation in the frequency of caries in dt is shown in Figure 2. As is well known (Larsen, 1995; Turner, 1979), the occurrence and increased frequency of caries predates the shift to agriculture, as Figure 2 also shows. Where $dt = -1500$ years, the frequency is low, at around 3–4%. It then rises with a change of slope at around $dt = -500$ years. However, this early increase in caries frequency is somewhat suspect since there are no data points in the crucial period between -500 and 0 dt . Caries frequency levels off at around 17% at $dt = 700$ – 800 years, and eventually drops to around 11% at $dt = 1300$ years. While the increase of caries frequency with the transition to agriculture is a robust pattern, the subsequent decline is produced by very low values for three sites from the south-western United States (Hawikku and San Cristobal) and northern Mexico (Casas Grandes). Residents of these sites employed stone grinding implements, which are known to reduce caries frequency (Larsen, 1995:188; Powell, 1985).

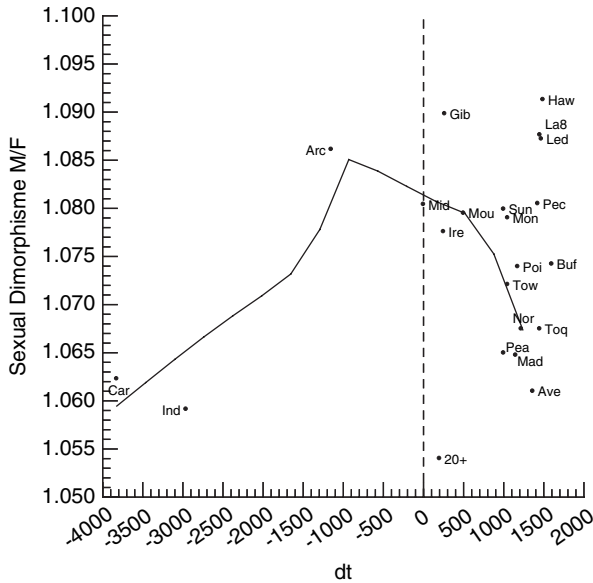


Figure 5: Sexual dimorphism for the femur during the transition from foraging to horticulture-farming, represented by *dt*. (References: Bennett, 1973; Boyd, 1986; Buikstra, 1976; Driscoll, 2001; Herrmann, 2002; Hooton, 1930; Milner and Smith 1990; Powell, 1988; Sciulli, 2002; Steckel and Rose 2002)

If the data had represented *incidences* as defined above instead of total frequencies, for juvenile age classes for example, then the impact of a potential increase in life expectancy could have been ruled out, but this cannot be done with the data from the literature. Theoretically, there are three alternative interpretations of the profile observed: i) increased dietary carbohydrate intake (Turner, 1979; Larsen, 1997) during the transition, reflecting a notable change in the hunters' diet; ii) higher life expectancy and therefore a larger number of surviving individuals who could have developed caries (Wood et al., 1992); iii) both possibilities together. The interpretation of the profile is therefore conditional, where the impact of diet is concerned, upon the assumption that longevity (probability of death) remained approximately constant, and, symmetrically, regarding the impact of longevity, upon a carbohydrate intake that also remained approximately constant. The situation is more complex for the impact of both variables. With this hypothesis, caries frequency and life expectancy increase, perhaps simultaneously but not necessarily so. Although the reorganization of the hunters' meat-based diet is a certainty, mortality data is lacking. We have nevertheless assumed that mortality remained much the same during the

transition. This leads us to the naive explanation that the increase in caries frequency resulted from an increase in dietary carbohydrate intake.

We follow Blom et al. (2005) in interpreting porotic hyperostosis as a skeletal manifestation of marrow hyperplasia produced by iron deficiency anemia in childhood. It is now widely recognized that early interpretations of the condition as reflecting an iron-deficient diet were premature (Blom et al., 2005; Holland and O'Brien 1997; Kent, 1986; Larsen, 1995; Stuart-Macadam, 1992). The condition is instead more appropriately understood as a product of marrow hyperplasia, which itself has a complex and multifactorial etiology. Contributing factors can include diet, but also congenital conditions, and, importantly for our purposes, parasites and infectious disease. Following an extensive study of skeletal material from Peru, Blom et al. conclude that "environmental stressors, such as parasites or disease, rather than specific dietary practices were more likely to be associated with childhood anemia in these coastal Andean samples" (2006:166; see also Kent, 1986; Walker, 1986).

Understood in this fashion, porotic hyperostosis therefore may be read as an admittedly imperfect index of pathogen load in the human environment, and therefore a generalized indicator of health. The incidence of porotic hyperostosis in our sample increases with the transition to agriculture (see Figure 3). Porotic hyperostosis incidence was roughly 8–10% during the forager period. An increase in incidence is apparent with the transition to agriculture at $dt = 0$. However, a truly dramatic increase in porotic hyperostosis incidence takes place some centuries after the agricultural transition, beginning at $dt = 300$ and increasing rapidly to a peak and stabilising at 40% at $dt = 1000$. The effect of the agricultural transition on porotic hyperostosis incidence was therefore not immediate but was rather delayed for some centuries. This pattern may reflect the fact that dense human settlements and high regional population densities, both expected to be associated with increases in the pathogen load of populations, did not appear immediately at $dt = 0$, but were a somewhat delayed product of the rapid population growth of the NDT.

Cribra orbitalia is a condition similar to porotic hyperostosis, affecting the orbits rather than the cranial vault. It is understood to be an early manifestation of porotic hyperostosis, with a similar etiology (Blom et al., 2005:153; Stuart-Macadam, 1989). The profile of variation in the frequency of cribra orbitalia (see Figure 4), which hovers between 10% and 20%, does not correlate directly with the economic shift. The frequency increases abruptly some time after the onset of the economic shift, at around $dt = 1000$. This delayed increase in incidence is therefore in some ways similar to that of

porotic hyperostosis, discussed above. However, the time frame involved is much longer.

Additionally, the pattern is suspect because the abrupt increase at $dt = 1000$ is produced entirely by the high values for three sites: San Cristobal, Hawikku and Norris Farm. In order to eliminate the hypothesis of these sites being outliers, we tried to understand why their frequencies were so high by looking for a common explanatory factor other than pathological frequency, such as geographical location (two sites are from the NM and one from IL) or analytical bias (two sites were studied by Stodder (Stodder et al., 2002) and one by Milner and Smith, 1990), but with no result. Furthermore, some studies (see Larsen, 1997 for a summary) provide evidence of a variable relationship between the regions of the skull where cribra orbitalia occurred. For these reasons, we will refrain from imputing significance to the observed pattern of cribra orbitalia incidence at present.

The profile of variation in sexual dimorphism in maximum femur length is used as a proxy variable for stature (see Figure 5). We know that stature estimators from the literature, based on reference samples, are biased by the same errors as techniques for age estimation (Bocquet-Appel, 1981: 214). The best estimator, up to a constant, is therefore the bone segment which contributes the most to stature: the femur. The large number of studies showing a correlation between stature and the variation of overall living conditions, since the nineteenth century and during world conflicts (see: Arora, 2005; Steckel, 1992; Eveleth and Tanner 1976), are sufficiently convincing to make it unnecessary to call on other major factors. Furthermore, it is well known that sexual dimorphism increases in times of abundance and decreases in times of scarcity (Baten and Murray 2000; Komlos, 1994; Nicholas and Oxley 1993; Tanner, 1962). Even though the data-points indicating forager populations (Figure 5) are sparse and relatively scattered, we can see that the profile does not indicate an increase in dimorphism during the transition, but a decrease. This pattern is indicative of a qualitative degradation of nutrition, which is associated with health. Furthermore, as was the case with porotic hyperostosis incidence, the decline in stature sexual dimorphism displays a delay relative to the agricultural transition, with a dramatic decline evident at $dt = 500$. Though the theoretical linkage between pathogen load and sexual dimorphism is not obvious, this pattern could possibly be explained in the same manner as the delayed increase in porotic hyperostosis incidence.

HEALTH AND DEMOGRAPHY

The Neolithic Demographic Transition has been postulated as a two-stage process (Bocquet-Appel, 2002). The first stage was characterized by a dramatic increase in human fertility, and a resultant surge in the rate of population growth, coincident with the transition to agriculture. This stage has been documented by previous publications (Bocquet-Appel, 2002; Bocquet-Appel and Naji 2006). The second stage was characterized by an increase in mortality, produced by an increase in infectious disease and parasite infestation. This second stage is theorized to have been related to increases in regional population density and in the size of human settlements, in turn produced by the rapid growth of the first stage. The increase in mortality in the second stage resulted in a decrease in the rate of population growth. This decrease was documented in a preliminary fashion using archaeologically measured rates of population growth in three regions of Latin America (Bandy, 2005). Bandy's data show that the decrease in population growth in the second stage, at least for the areas in his sample, took place between $dt = 600$ and $dt = 800$ (Bandy, 2005:S113).

Figure 6 displays archaeologically reconstructed population growth rates for five prehistoric cases, relative to the NDT. Three of these cases are described by Bandy (2005): Oaxaca, the Basin of Mexico, and the Titicaca Basin. Two other cases have been added from published archaeological sequences. The first is for Southwestern Colorado, and the second for the Ontario Iroquoians. The Colorado data is based on a series of momentary population estimates by Richard Wilshusen, (1999a,b; Lipe and Varien 1999), while the Iroquoian growth rates are taken from Gary Warrick's dissertation (1990, Table 47). Each point represents a momentary estimate of population growth. A regression line was fitted using the Loess technique, in the same manner as employed for the paleopathological data. The fitted line clearly shows the same pattern reported by Bandy: rapidly increasing population growth prior to $dt = 500$, with decreasing population growth (but not population decline) between $dt = 500$ and $dt = 800$. The rate of population growth stabilizes after $dt = 800$ between 0.1% and 0.2% annually.

Several of the classes of paleopathological data collated and presented here have direct relevance to this second stage of the Neolithic Demographic Transition. The two-stage model predicts that human disease and parasite

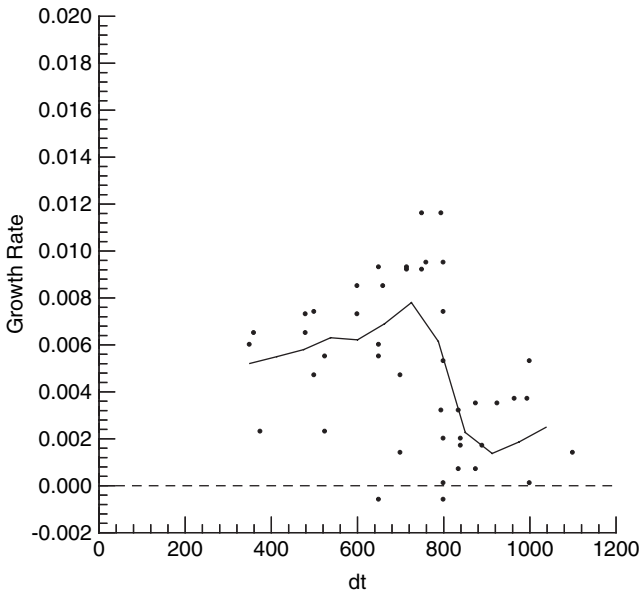


Figure 6: Rates of population growth in five archaeological sequences, relative to dt . The two-stage pattern is evident; (References: Bandy, 2005; Lipe and Varien 1999; Wilshusen, 1999a,b; Warrick, 1990)

levels will increase during the second stage of the transition, at the same time that the rate of population growth declines. The model therefore predicts that incidence of porotic hyperostosis and cribra orbitalia, interpreted as measures of disease and parasite infestation, will remain low for several centuries after the beginning of the Transition and will subsequently increase between $dt = 500$ and $dt = 800$.

Figure 7 displays the signals of porotic hyperostosis, cribra orbitalia, and dental caries. While caries frequency increases at $dt = 0$ or before, dramatic increases in the incidence of porotic hyperostosis and cribra orbitalia are evident during the second stage of the NDT (figure 6), between $dt = 500$ and $dt = 800$. These results are consistent with the predictions of the two-stage model of the NDT, suggesting that the emergence of high pathogen loads did not occur immediately with the transition to agriculture but was rather a threshold phenomenon related to the high population densities achieved only some 500–1000 years after the transition had already taken place. The first epidemiological transition (Barrett et al., 1998) was therefore associated with the second stage of the NDT.

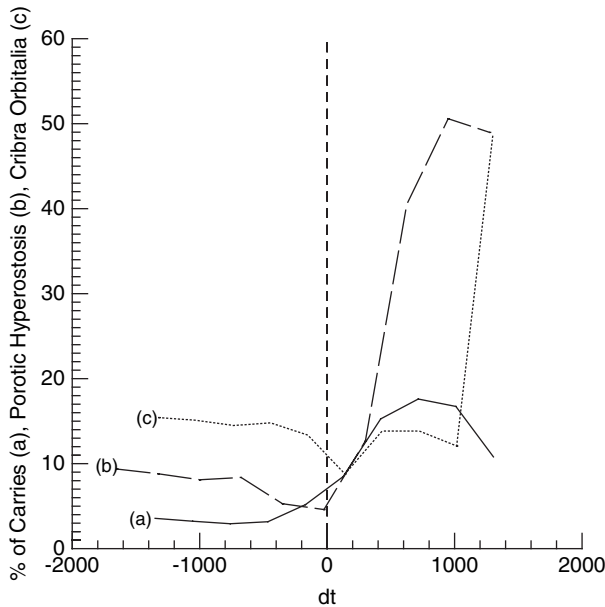


Figure 7: Frequencies of caries (a) porotic hyperostosis (b) and cribra orbitalia (c) relative to dt

CONCLUDING REMARKS

Relatively to the timing of the transition to agriculture and assuming that life expectancy at 6 years of age (roughly the average age for the first permanent molars) remained approximately unchanged during the transition, the frequency of caries increases at $dt = -1000$ years. This pattern probably indicates a broadening dietary range before the advent of agriculture, and the addition of sugars in dietary intake (Flannery, 1969). Furthermore, after the farming economy appeared, there is evidence of: i) an immediate explosion in the birth rate and, underlying this, in fertility (see Figure 1), probably as a by-product of a sedentary economic system; ii) a delayed increase in the incidence of anaemia indicators. iii) a delayed decrease of stature sexual dimorphism, which may be the continuation of a trend that had already appeared during the forager period. The overall pattern clearly confirms the hypothesis of biological stress during the transition (Cohen, 1989; Cohen and Armelagos 1984; Larsen, 1995). Significantly, however, it also confirms the two-stage model of the NDT and of a delayed mortality increase between $dt = 500$ and $dt = 800$. The forager system sustained a population with

a very low demographic density (Bocquet-Appel et al., 2005), and apparently qualitatively better nourished, but the system was fragile to stochastic environmental fluctuations. This pattern is strikingly different from the farming system, which, at the peak of its emergence might have sustained a population with a local demographical density that may have been 1000 times higher or more than in the earlier period. The population, though qualitatively less well nourished and less healthy, was sustained nonetheless by a system that had foreseeable potential for economic production and was therefore probably more robust than the previous one to stochastic fluctuations.

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