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Intra-Population Variation in Anemia Status and Its Relationship to Economic Status and Self-Perceived Health in the Mexican Family Life Survey: Implications for Bioarchaeology

Barbara A. Piperata,[1]* Mark Hubbe,[1,2] and Kammi K. Schmeer[3]

[1]*Department of Anthropology, The Ohio State University, Columbus, OH 43210*
[2]*Instituto de Investigaciones Arqueológicas y Museo, Universidad Católica del Norte, San Pedro de Atacama, Chile*
[3]*Department of Sociology, The Ohio State University, Columbus, OH*

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ABSTRACT Recently scholars have advocated for the use of a critical biocultural approach in bioarchaeology, where osteological and dental markers of stress are used to understand the broader biosocial context of past populations. However, the ability to accomplish this task rests on the assumption that ultimate-level environmental stressors and well-being in the past can be reconstructed from the prevalence of pathologies in skeletal collections. Here we test this assumption using anemia prevalence in the Mexican Family Life Survey. Specifically we test three hypotheses: (1) that individuals sharing the same household are more likely to share anemia status; (2) anemia status is a predictor of economic status (a common proxy for broader environmental context); and (3) anemia status is related to self-rated health. Results demonstrate that: anemia status was not commonly shared between household members; there was a significant overlap in economic status between anemic and nonanemic individuals (i.e., anemia poorly predicted economic status) and; while anemia status was associated with self-perceived health, the majority of those who reported poor health were nonanemic while a significant number of those who reported very good health were anemic. We argue that these findings are likely related to variation in individual frailty, which is shaped by biological and cultural risk factors. Therefore, we advocate for greater incorporation of individual frailty into bioarchaeological investigations, and, in effort to overcome some of the difficulties associated with this task, increased use of data from living populations and greater collaboration between bioarchaeologists and human biologists. Am J Phys Anthropol 155:210–220, 2014. © 2014 Wiley Periodicals, Inc.

Bioarchaeology is the scientific study of archaeological human remains with the intent to better understand the "life ways" of past human populations (Larsen, 1997). Life ways is a deliberately broad term meant to capture many of the key areas of bioarchaeological inquiry which include reconstructing patterns of behavior such as burial practices, social organization, daily activities, and the division of labor, mobility, population structure (i.e., paleodemography) as well as health and disease (Larsen, 1997; Buikstra, 2006). Early bioarchaeological investigations tended to focus on describing individual skeletons or skeletal assemblages. However, by the latter half of the 20th century, the subfield, like others within anthropology, became more hypothesis-driven and problem-oriented as it was influenced by the work of scholars such as Binford and Washburn (Buikstra, 2006), as well as by new human biology research being conducted as part of the Human Biological Program (Leslie and Little, 2003; Dufour, 2006). As part of this shift, a better appreciation for and interest in understanding the processes through which the environment shapes the human condition, particularly health and well-being, emerged. Goodman (1998) has referred to this as a shift towards a "processual bioarchaeology". Initially, the term environment was often limited to its physical attributes, such as geography and associated plant and animal resources. However, by the 1990s bioarchaeologists began arguing for a broader conception of the environment. In their edited volume, Goodman and Leatherman (1998) made a strong case that any effort to understand variation in human health must consider the physical as well as social elements (economic and political forces) of the environment, as well as appreciate the dialectical interactions human groups have with their broader environmental context. In adopting this new critical biocultural approach, bioarchaeologists placed greater emphasis on connecting identifiable dental and skeletal pathologies to their underlying proximate cause(s), as well as on using them to reconstruct the broader environmental context in which individuals lived [see Busch and Zvelebil (1991) for a series of articles on the biocultural approach in skeletal biology].

Although a critical biocultural approach has proven powerful for explaining intra-population variation in health and disease among living populations (Dressler, 1995; Leatherman, 1996; Singer, 2001; McDade, 2002;

*Correspondence to: Barbara A. Piperata, Department of Anthropology, The Ohio State University, Smith Lab Room 4054, 174 West 18th Avenue, Columbus, OH 43210. E-mail: piperata.1@osu.edu

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Worthman and Kohrt, 2005) its application in bioarchaeology is clearly more challenging (Armelagos and Van Gerven, 2003). In fact, a number of scholars have raised concerns regarding our ability to reconstruct life-ways and health in the past based on skeletal samples (e.g., Wood et al., 1992; Schulz, 2001; Walker et al., 2009). These critiques have mostly focused on limitations derived from the nature of skeletal samples, in other words, the idea that the characteristics of dead individuals are representative of those who survived (e.g., Wood et al., 1992) and the fact that the cause of many osteological markers of stress are multifactorial making it difficult to attribute them to a specific proximate stressor (Schulz, 2001; Walker et al., 2009). An additional limitation is our inability to observe the dynamic interactions between humans and their physical, biotic and social environments in the past. This makes it difficult to identify ultimate-level causal pathways that link the broader environment to human health.

Data collected from living human or other animal populations can prove useful in addressing some of these concerns. For example, clinical and experimental data have proved particularly important in identifying the proximate etiology of many common osteological markers of stress (Kreshover et al., 1954; Ortner and Putschar, 1981; Stuart-Macadam, 1987a, 1987b; Goodman et al., 1991; Aufderheide and Rodriguez-Martin, 1998). While such data have certainly strengthened the discipline and assisted researchers in narrowing the range of potential environmental stressors affecting past populations, they are less useful for advancing our ability to address the more recent call of Goodman and Leatherman (1998) for a more critical biocultural approach where skeletal markers of stress are used to discuss the broader environmental conditions in which past populations lived and the pathways that link ultimate-level factors to variation in health in the past. Our goal in this article is to explore how data on living populations, including large-scale epidemiological datasets, can be used to uncover new, as well as test hypothesized associations between skeletal markers of stress and the broader biocultural context (i.e., ultimate causalities) and life ways of past human populations. To do this, we analyze data from a large representative sample of the Mexican population that allows us to simultaneously explore broad aspects of the biosocial environmental context, objective measures of individual health status, as well as individuals' perceived health status. This study focuses on anemia as the dependent variable or marker of stress, due to the fact that it (1) is associated with specific skeletal stress markers and (2) was and continues to be a major health issue among human populations.

Anemia, proximate, and ultimate causality

Of the numerous skeletal markers used to discuss systemic stress and assess overall health in past populations, porotic hyperostosis (PH) and cribra orbitalia (CO) are two of the most frequently observed in the archaeological record (Walker et al., 2009). On the proximate level, these conditions are the result of hypertrophy of the diploë or spongy bone that forms the internal structure of the cranial vault and superior border of the eye orbits. While some infectious diseases and scurvy can result in similar skeletal markers, in most cases PH and CO are considered to be the result of increased demand for erythrocyte (red blood cell) production during childhood, when these sites serve as the primary centers of erythropoiesis. Increased demand for red blood cell production is often the result of anemia, defined as low hemoglobin concentration, red-cell count, or packed cell volume which impairs oxygen delivery to tissues (Warrell et al., 2003). Anemia is caused by increased erythrocyte loss (hemolytic anemia) and/or impaired proliferation or ineffective maturation of erythrocytes. While over 200 different hemolytic anemias (e.g., sickle cell, thalassemias, cancer, toxin exposure) are recognized (Walker et al., 2009), they are not the most common types of anemia. Instead, most cases of anemia are due to the lack of haemopoetic nutrients critical for normal erythrocyte production and maturation. Iron is an integral component of the hemoglobin molecule, required for hemoglobin synthesis, as well as the formation of mature erythrocytes. Thus, inadequate iron levels result in reduced erythropoiesis and can cause anemia (Walker et al., 2009). This relationship has led to anemia and iron-deficiency anemia being used synonymously in the bioarchaeological and public health literatures. However, in a detailed and sophisticated discussion of the etiology of PH and CO, Walker et al. (2009) challenge the idea of associating these stress markers with iron deficiency and suggest that other micronutrient deficiencies, as well as infections, were more likely the cause of the anemia that resulted in PH and CO (although see Oxenham and Cavill, 2010 and McIlvaine, 2013 for counter arguments). Similar caution has been raised in discussions of the current global rate of anemia. In a recent review, McClean et al. (2009) stated that less than half of the estimated 1.62 billion cases of anemia worldwide are due to iron deficiency and argued that, to better address this public health concern, attention should be given to other potential causes. These include deficiencies in folic acid (Vitamin B9) and Vitamin B12 which are required for erythrocyte synthesis and maturation. Inadequate intakes of these nutrients result in megaloblastic anemia where red blood cells are produced but are malformed with enlarged nuclei due to impaired DNA synthesis. In addition, Vitamin C is important due to its role in enhancing absorption of the haemopoetic nutrients. Polyphenols, phytates, and calcium are also important to consider as these substances impede the absorption of Vitamins B9 and B12 (Balarajan et al., 2011). Finally, infectious diseases, especially intestinal parasites (e.g., hookworm), can contribute to anemia by reducing micronutrient absorption, as well as by increasing blood loss (Balarajan et al., 2011). Overall, current data suggest that PH and CO are most likely due to megaloblastic anemia, and that the most significant proximate risk factors for this type of anemia are insufficient access to key micronutrients (low intake and/or poor absorption) and infectious disease burden.

While clinical studies have provided critical information on the proximate causes of anemia, multi-factorial, biocultural models inform discussions of the more distant, or ultimate-level factors that place individuals at risk (Balarajan et al., 2011). Inadequate access to needed micro-nutrients and risk of infectious disease are shaped by the individual's immediate environmental context which includes the household and immediate vicinity. The household is recognized as the basic unit of production and consumption (Wilk, 1997). It is here that access to food (land, income), knowledge of dietary needs (education) and sanitary conditions, as well as cultural beliefs and practices come together to shape individual

TABLE 1. Demographic characteristics of the sample

Age	Female	Male	Total
Children (0–4 years)	1389	1356	2745
Children (5–11 years)	2432	2418	4850
Children (12–14 years)	1108	1056	2164
Adults (15–49 years)	6731	5042	11773
Pregnant women (15–49 years)	226		
Old adults (50+ years)	2023	2274	4297
Total	15047	12877	27924

dietary and work patterns. This immediate context is influenced by broader physical and biotic aspects of the environment which shape the types and amounts of food produced and pathogen exposure. The socio-political context affects both the biotic (land use, access to resources) and social aspects (wealth distribution, social inequality, cultural practices) of individuals' lives. Generally, studies show a pattern of increased rates of anemia being associated with poorer living conditions, for which economic status is often used as a proxy (WHO, 2008). Lastly, regardless of whether the focus is on proximate or ultimate levels of causality, the fact that age, sex, and reproductive status affect nutritional requirements, as well as access to resources, means that even within the same physical, biotic, and social environment not all individuals are at equal risk of developing anemia. Globally, the highest rates of anemia are found among young children (0–5 years) (~48%) and women of reproductive age, especially those who are pregnant (15–49 years) (>30%) (WHO, 2008).

While there remains some discussion regarding our ability to associate PH/CO with a specific proximate stressor (Schulz, 2001; Walker et al., 2009; Oxenham and Cavill, 2010; McIlvaine, 2013), most agree anemia, especially megaloblastic anemia and anemia caused by infectious disease burden, is a significant contributor to the incidence of these pathological conditions. Less well-evaluated is our ability to use the prevalence of anemia in bioarchaeological contexts to reconstruct the biosocial context (ultimate-level pathways) and discuss how this pathology impacted daily life in past human populations. Testing these relationships is an important step in determining the scope and limitations of how bioarchaeological samples can be used to discuss life in the past and thus respond to the call for a more critical biocultural bioarchaeology (Goodman and Leatherman, 1998). To contribute to this discussion, we use data gathered as part of the Mexican Family Life Survey (MxFLS) to explore the relationship between an individual's anemia status and the environmental conditions in which they live, as well as their self-perceived health. On the basis of current models of anemia risk, we tested the following hypotheses:

1. Individuals sharing the same environment share similar anemia risk. Our rationale is based on the idea that if individual health status is a reflection of the physical and social environmental context, a central assumption of bioarchaeological investigations, then members of the same household should be more likely to share anemia status.
2. Economic status, commonly used as a proxy measure for one's environmental context, is a significant predictor of anemia risk. Similar to hypothesis one, our rationale here is based on the common idea that health status reflects the individual's broader environmental context, with poor health being related to lower economic status due to its association with poor infrastructure and limited access to resources needed to maintain health.
3. An individual's anemia status is related to their perception of their own health and dietary quality, as well as their work capacity. If anemia affects the daily life of an individual, then we should expect those with anemia to rate their health and well-being, as measured through proxies such as overall health, diet quality and ability to conduct daily activities, more poorly than those without anemia. While this hypothesis deals with perceived health, a dimension of human life that cannot be assessed among past populations, it has direct relevance to bioarchaeological studies. A major assumption of the discipline is that osteological lesions represent markers of stress that impacted the lives of individuals in perceivable ways. Thus, the prevalence of these lesions in skeletal assemblages is commonly used to discuss broader aspects of well-being in the past. (e.g., Larsen, 1997; Buikstra, 2006).

MATERIAL AND METHODS

Sample

The Mexican Family Life Survey (MxFLS) is a longitudinal database that includes socioeconomic, demographic and health indicators collected from a nationally representative sample of the Mexican population (Rubacalva and Teruel, 2006). The first wave of the survey was conducted in 2002 and includes information on ~35,000 individuals living in 8,440 households from 150 communities. The health assessment included information on weight, height, hip circumference, hemoglobin levels, and blood pressure measures of household members, as well as a series of questions aimed at assessing adults' perceived health which included their overall health, diet quality, and ability to conduct normal daily activities. The combination of the economic, objective health measures, including anemia status, and self-perceived health questions makes the MxFLS one of the largest studies available to investigate the association between anemia status, economic and environmental conditions and perceptions of well-being.

To be included in this study, each individual needed to have data on their anemia status, responses to the self-perceived health questions and information that allowed us to link them to their household, as economic status was based on an index of household condition and assets (see below). In addition, we limited our analysis to data from the MxFLS 2002 wave since sample size was significantly larger than it was for the 2005 wave. Applying these inclusion criteria left us with an analytical sample of 27,924 individuals (Table 1). Detailed information on the data collection protocol and questionnaire is available on the MxLFS website (http://www.ennvih-mxfls.org/) and in Rubacalva and Teruel (2006).

Study variables

Anemia status was assessed via the collection of data on hemoglobin levels from individual participants. We defined anemia using the WHO cutoff values (2008), which consider sex, age, reproductive status, and altitude of residence of the individual (Table 2). Communication with MxFLS staff confirmed that reported hemoglobin values were corrected for the individuals' altitude of residence. Our decision to transform the hemoglobin data into discrete categories (nonanemic, mild, moderate, and severe anemia) is due to our interest in making these data as comparable as possible to bioarchaeological data where osteological markers of stress are usually treated as dichotomous variables (e.g., presence/absence of PH/CO). We recognize that the specific WHO cut-offs used here have not been directly related to the osteological lesions used to identify PH/CO in skeletal samples and that clinical data (Stuart-Macadam, 1987a) suggest that the lesions are probably associated with more severe forms of anemia. By using all anemic individuals (including mild cases) we are taking a conservative approach. If mild-anemia, which is quite common, cannot be used as a good proxy of broader environmental quality, more severe forms (which are relatively rare) should follow the same patterns (see Table 3 for further support that severity does not change the patterns observed with mild anemia).

Economic status was calculated at the household level. A household wealth index was developed using Principal Component Analysis following the method developed by Filmer and Pritchett (2001). Physical aspects of the household such as wall and floor materials, piped water, electricity, sanitation, as well as household assets were considered. Using 21 of these variables and the correlations between them, the first principal component, i.e., the axis that captured most of the variation in the data, was used as a linear index of economic status. Individual economic status was then determined by linking each individual to their respective household. The same protocol was used by Schmeer (2013) in a study of the relationship between changes in parental union status and child anemia using both waves of the MxFLS.

Information on self-perceived health was only available for adults. The questions included the individuals' assessment of their overall health and dietary quality and responses were collected as ordinal variables (very good, good, average, bad, or very bad). Data on activity performance or work capacity were gathered from two questions. The first asked if the individual felt they could carry a heavy bucket and the second asked if they could walk 5 km. Responses were collected as ordinal variables (yes, yes with difficulty, and could not do it).

Statistical analyses

To test our first hypothesis, that individuals sharing the same environment would share similar anemia status, we first identified all households with at least one anemic individual. Using this sub-sample of households, we then looked at the degree to which members sharing the same home also shared anemia status. To take into account the fact that age and sex make some individuals more biologically susceptible to being anemic, we looked at several comparisons that crossed age and sex categories (husband/wife; mother/child; between siblings). Matches, where both individuals in the comparison shared anemia status, provide support for the idea that markers of health are good predictors of environmental context, whereas mismatches do not provide support for this idea and demand alternative explanations for the observed intra-household variation. For each of these comparisons, the observed frequencies of matched/mismatched pairs were compared with the expected frequencies in a random distribution simulated from 1,000 permutations.

TABLE 2. Hemoglobin values used to diagnose anemia at sea level (g/l)[a]

Age	Nonanemia	Mild anemia	Moderate anemia	Severe anemia
Children (0–4 years)	>110	100–109	70–99	<70
Children (5–11 years)	>115	110–114	80–109	<80
Children (12–14 years)	>120	110–119	80–109	<80
Nonpregnant women (15+ years)	>120	110–119	80–109	<80
Pregnant women	>110	100–109	70–99	<70
Men (15+ years)	>130	110–129	80–109	<80

[a] Hemoglobin cut-off levels based on WHO (2008), individual values corrected for altitude of residence.

To test our second hypothesis, that anemia status is related to economic status, assessed through the wealth index described above, we linked each individual to their household. The economic status of anemic individuals was compared with that of nonanemic individuals. Student's *T*-tests were used to test for significant differences between groups. However, due to the large sample size used here, there is a high probability of observing some kind of over-fitting of the data (i.e., statistical differences are found, although they are not necessarily meaningful). To account for this, we also calculated the percentage of anemic individuals that fell below the 5th percentile of the nonanemic SES distribution. In addition to comparing differences between groups in the entire sample, we also tested for differences between age and sex categories (males, females, adult males, adult females, sub-adult males, and sub-adult females).

Finally, to test our third hypothesis, that anemia status influences one's perception of their own health, dietary quality and ability to conduct everyday activities, we tabulated the frequency of anemic individuals according to their responses to the questions regarding their self-perceived health, their health in relationship to others in their community and their dietary quality, as well as their assessment of their performance in common activities, as discussed above. Chi-square tests were used to identify differences in anemia frequency between categories.

All statistical analyses were performed in R (R Core Team, 2013) with functions written by one of us (MH) for this article. While the WHO (2008) provides cutoff values for classifying anemic individuals based on their level of severity (mild, moderate, severe), here we group individuals simply as anemic or nonanemic since preliminary analyses showed that severity level did not affect the outcomes of any of the comparisons.

RESULTS

Anemia in the Mexican Family Life Survey

Table 3 summarizes the prevalence of anemia among individuals, according to sex and age. As a whole, 14.6% of the sample had hemoglobin values that classified them as anemic. Of all sub-groups, children under the age of 5 and adult women (18–49 years) had the highest rates of anemia (26.4% and 20.1%, respectively). Compared with adult men, adult women were four-times more likely to be anemic. Importantly, we did not find

TABLE 3. Frequency of anemia in the Mexican Family Life Survey (MxFLS)

	Mild			Moderate			Severe			Total		
Age (years)	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
0–4.9	15.12% (210/1,389)	16.08% (218/1,356)	15.59% (428/2,745)	9.94% (138/1,389)	10.18% (138/1,356)	10.05% (276/2,745)	0.36% (5/1,389)	0.37% (5/1,356)	0.36% (10/2,745)	25.77% (358/1,389)	26.99% (366/1,356)	26.38% (724/2,745)
5–11.9	4.56% (111/2,432)	5.38% (130/2,418)	4.97% (241/4,850)	5.72% (139/2,432)	6% (145/2,418)	5.86% (284/4,850)	0.21% (5/2,432)	0.17% (4/2,418)	0.19% (9/4,850)	10.69% (260/2,432)	11.7% (283/2,418)	11.2% (543/4,850)
12–14.9	6.95% (77/1,108)	6.16% (65/1,056)	6.56% (142/2,164)	5.14% (57/1,108)	1.89% (20/1,056)	3.56% (77/2,164)	0.27% (3/1,108)	0.47% (5/1,056)	0.37% (8/2,164)	12.64% (140/1,108)	9.00% (95/1,056)	10.86% (235/2,164)
15–17.9	9.36% (89/951)	6.88% (60/872)	8.17% (149/1,823)	4.42% (42/951)	1.38% (12/872)	2.96% (54/1,823)	0.21% (2/951)	0.11% (1/872)	0.16% (3/1,823)	14.2% (135/951)	8.49% (74/872)	11.46% (209/1,823)
Pregnant teen	15.15% (5/33)			9.09% (3/33)			0% (0/33)			24.24% (8/33)		
Breastfeeding teen	0% (0/7)			42.86% (3/7)			0% (0/7)			42.86% (3/7)		
Not pregnant teen	9.22% (84/911)			3.95% (36/911)			0.22% (2/911)			13.61% (124/911)		
18-49.9	9.52% (641/6,731)	3.99% (201/5,042)	7.15% (842/11,773)	9.09% (612/6,731)	0.81% (41/5,042)	5.55% (653/11,773)	0.76% (51/6,731)	0.12% (6/5,042)	0.48% (57/11,773)	20.13% (1355/6,731)	5.04% (254/5,042)	13.67% (1609/11,773)
Pregnant adult	13.72% (31/226)			12.83% (29/226)			0.44% (1/226)			27.43% (62/226)		
Breastfeeding adult	13.75% (22/160)			15.63% (25/160)			0.63% (1/160)			30.63% (49/160)		
Nonpregnant adult	9.27% (588/6,345)			8.79% (558/6,345)			0.77% (49/6,345)			19.61% (1,244/6,345)		
>50	6.43% (130/2,023)	14.07% (320/2,274)	10.47% (450/4,297)	8.6% (174/2,023)	2.9% (66/2,274)	5.59% (240/4,297)	0.53% (13/2,436)	0.28% (6/2,133)	0.42% (19/4,569)	16.31% (330/2,023)	17.5% (398/2,274)	16.94% (728/4,297)
Total	9.01% (1,356/15,047)	7.27% (936/12,877)	8.21% (2,292/27,924)	7.72% (1,162/15,047)	3.28% (422/12,877)	5.67% (1,584/27,924)	0.53% (79/15,047)	0.21% (27/12,877)	0.38% (106/27,924)	17.78% (2676/15,047)	10.97% (1412/12,877)	14.64% (4,088/27,924)

TABLE 4. Results of the intra-household comparisons: mother–child, husband–wife, siblings

	Anemic child	Nonanemic child
Anemic mother	12.89% (480/3,725)	56.64% (2,100/3,725)
Nonanemic mother	30.74% (1,145/3,725)	
	Anemic husband	Nonanemic husband
Anemic wife	8.47% (98/1,157)	22.21% (257/1,157)
Nonanemic wife	69.32% (802/1,157)	
	Siblings	
Matching anemic siblings	9.14% (1053/11,525)	
Mismatching siblings	90.86% (10,472/11,525)	

TABLE 5. Results of the comparisons between anemia status and SES index in the MxFLS

	All individuals	Women	Men	Subadult females	Subadult males	Adult females	Adult males
Anemic							
SES index	−0.178 ± 1.945	−0.053 ± 1.859	−0.006 ± 2.075	−0.275 ± 1.947	−0.345 ± 2.069	0.055 ± 1.804	−0.488 ± 2.083
N	4,088	2,676	1,412	893	818	1,783	594
Nonanemic							
SES index	−0.026 ± 1.880	−0.046 ± 1.901	−0.406 ± 1.857	−0.203 ± 2.000	−0.115 ± 1.924	0.059 ± 1.824	0.076 ± 1.801
N	23,836	12,371	11,465	4,987	4,884	7,384	6,581
Student t-test							
T	−4.3299	0.1761	6.5498	0.9314	2.798	0.0783	6.0994
P	<0.0001	0.8602	<0.0001	0.3519	0.0053	0.9376	<0.0001
Anemic below 95% CI of nonanemic individuals							
Number of individuals	275	145	127	52	68	92	62
Frequency	6.73%	5.42%	8.99%	5.82%	8.31%	5.16%	10.44%

any differences in rate of anemia between male and female children. Pregnancy (27.4%) and breast-feeding (30.6%) also increased the risk of being anemic in this sample, although the number of individuals in these reproductive states was rather small (226 and 160 women, respectively).

Hypothesis 1: Intra-household variation in anemia status

The results of the within-household analyses are summarized in Table 4. Of all mother–child pairs, only 12.9% were matches where both mother and child shared anemia status. We ran 1,000 permutations in order to estimate the likelihood of a mother and child sharing anemia status by chance alone. The expected upper 95th percent confidence interval (CI) was 10.5% and the maximum obtained was 11.5%. Thus, while the observed results are higher than expected by chance alone, they are only slightly higher.

For the husband–wife comparisons, the percentage of matches was smaller (8.5%) than found among the mother–children comparisons. While the frequency is higher than the upper 95th percent CI generated from the random permutations (7.9%), it is still smaller than the maximum obtained by chance (8.9%).

For the sibling comparisons, sexes were grouped together since previous analyses showed no sex differences in anemia status among children (Table 1). As with the previous analyses, the frequency of matches is low (9.1%), although it is ∼3% higher than the upper 95th percent CI (5.5%) and maximum frequency (5.8%) obtained from the random permutations.

Hypothesis 2: Relationship between Anemia and Economic Status

Table 5 provides descriptive information on the wealth index (measure of economic status) and reports the results of comparisons between anemic and nonanemic individuals by economic status. Among males (adults and children), the wealth index was significantly lower among anemic individuals than nonanemic individuals. However, among females (adults and children) we found no significant difference in wealth index between those with and without anemia. To evaluate the practical meaning of using economic status to predict anemia status, Table 5 also reports the frequency of anemic individuals whose wealth index fell below the lower 95th percent CI of the nonanemic wealth index distribution. Despite significant differences in wealth status between anemic and nonanemic individuals, the frequency of anemic individuals falling below the nonanemic 95th percent CI was surprisingly low, ranging from 5.2% to 10.4%. The significant degree of overlap is illustrated in Figure 1.

Hypothesis 3: Relationship between anemia status and self-perceived health and diet

The final set of analyses tested the association between anemia status and self-perceived health and diet, as well as work capacity. These results are summarized in Table 6 and Figures 2 through 5. In all cases, there was a clear trend of decreasing self-perceived health and diet quality and increased prevalence of anemia (all Chi-square *P*-values <0.001; Table 6). For overall health, anemia frequencies ranged from 8.1% among individuals who reported having very good health to 33.9% among those who assessed their health as being very-bad (Fig. 2). In terms of dietary quality, the prevalence of anemia ranged from 12.5% among those who reported having very good diets to 21.7% among individuals who reported their dietary quality as being very bad (Fig. 3). In relating anemia status and one's perceived ability to conduct normal daily activities or work capacity, such as carrying a load or walking 5 km, we found that among those who felt they could accomplish these tasks, ~12% were anemic, whereas, among those who reported being unable to conduct these activities, the rate of anemia was ~24% (Figs. 4 and 5).

Despite the observed trends, it is worth noting the significant number of anemic individuals who classified their own health and diet as being very good or good, as well as the large number of people who were nonanemic, yet viewed their health and diet as poor. For example, almost 10% of individuals who rated their health and diet as very good or good were anemic while ~75% of those who reported having very bad or bad health and diet were nonanemic. A similar trend was observed with the work capacity data (Figs. 4 and 5). The majority of those who reported not being able to conduct these basic daily tasks were not anemic. These data suggest that anemia status and self-rated health and well-being are not as tightly linked as perhaps expected.

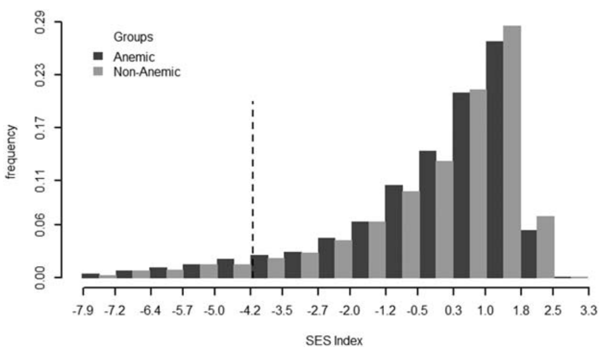

Fig. 1. Frequency of anemia according to economic status index. The dashed line indicates the lower 5th percentile of the economic status index for nonanemic individuals.

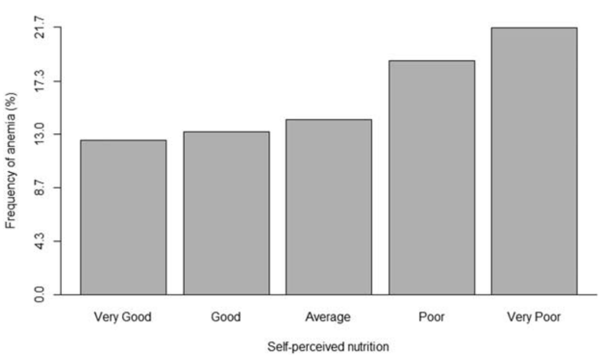

Fig. 2. Frequency of anemia by individual self-rated nutritional status.

DISCUSSION

Over the past few decades a number of scholars have advocated for a critical biocultural bioarchaeology (Goodman and Leatherman, 1998; Armelagos and Van Gerven, 2003; Buikstra 2006), where skeletal and dental markers of stress are used to better understand the immediate, as well as broader biosocial context in which past populations lived. This conceptual framework advanced bioarchaeological research by moving the discipline beyond descriptive studies and better aligning it with other subdisciplines within anthropology actively applying a biocultural perspective to understanding human health. Importantly, the ability to apply this biocultural approach rests on the assumption that broad, ultimate-level environmental causes of stress in the past, as well as their meaning in terms of well-being, can be reconstructed from the prevalence of dental and osteological pathologies in skeletal collections. In the cases of porotic hyperostosis (PH) and cribra orbitalia (CO), researchers have linked the prevalence of these pathologies to rates of anemia (proximate stressor) in the population, as well as used them to make inferences regarding broader aspects of lifestyle and stress in the past (e.g., Stuart-Mcadam, 1991, 1992; Holland and O'Brien, 1997; Blom et al., 2005). However, the results presented here, using data from a large, representative sample of the Mexican population (MxFLS), call into question our ability to accurately use anemia status, or skeletal markers of anemia such as PH and CO, to speak about the broader environmental context in which individuals lived.

Whether we are considering its proximate or ultimate causal pathways or its prevalence in skeletal or living populations, anemia is a complex disease. This is demonstrated in the MxFLS where the relationship between an individual's anemia status and their environmental context proved far from straightforward. Using common, means-based statistical approaches, the data indicate that, in fact, it was more common for anemic individuals to share the same household and that there was a significant association between anemia status and economic status, as well as measures of self-perceived health, diet quality and work capacity in this sample. However, these statistical approaches failed to capture the large degree of variation present within the analytical categories created to understand the relationship between anemia status and the broader environmental context and well-being of the individuals in the study. While the

TABLE 6. Frequency of anemic individuals in the MxFLS according to individual self–perceived health status, diet quality and work capacity

	Very Good	Good	Regular	Bad	Very Bad
Overall health	8.1% (60/681)	12.7% (967/6,640)	15.3% (1,128/6,269)	20.7% (183/701)	33.9% (21/41)
Diet quality	12.6% (65/453)	13.2% (1,003/6,581)	14.2% (1,094/6,613)	19.0% (161/686)	21.7% (26/94)
	Can do it easily	Can do it with difficulty	Cannot do it		
Carry heavy bucket	12.0% (255/1,863)	18.1% (200/903)	75.3% (667/219)		
Walk 5 km	12.8% (258/1,753)	16.7% (193/963)	23.7% (223/717)		

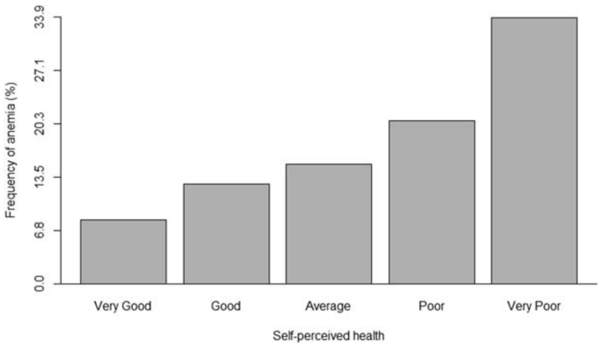

Fig. 3. Frequency of anemia by individual self-rated health status.

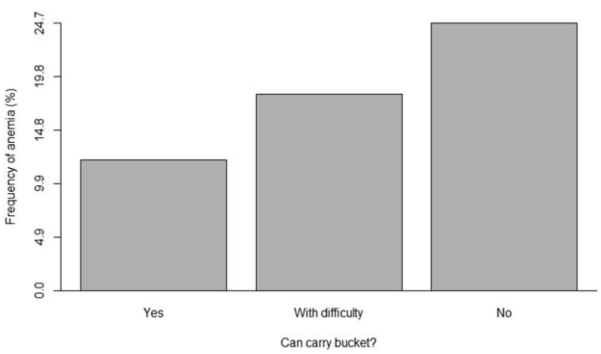

Fig. 4. Frequency of anemia by self-perceived work capacity: carrying a bucket.

frequency of anemic individuals sharing a household was higher than expected by chance, this association was weak in practical terms. Regardless of which individuals were compared (mother/child, spouses, siblings), the frequency of matches never surpassed 12.9%, meaning that in the vast majority of cases (~87%) anemic individuals were far more likely to share a home with nonanemic individuals. In addition, the relationship between wealth or economic status, a widely used proxy for broader environmental quality, and anemia status was quite weak. In other words, we found a high degree of overlap in economic status among anemic and nonanemic individuals, clearly evident in Figure 1. In fact, less than 10% of anemic individuals had wealth index values below the lower 95th percent confidence interval of nonanemic individuals (Table 5). Finally, our attempt to relate anemia status to measures of self-perceived health and work capacity illustrate that the impact anemia has on an individual's lived experience is not that meaningful, albeit statistically significant. Between 8 and 12% of those who considered themselves to be very healthy or very well-nourished, were also anemic. Conversely, among those who categorized themselves as very unhealthy or very poorly nourished, the vast majority (>66%) were nonanemic.

Taken together, these results illustrate that variation within each of the analytical categories was considerably greater than between them. This is likely due to variation in individual frailty. In demography, the term individual frailty is used to discuss unmeasured biological risk factors (e.g., genetic) that contribute to heterogeneity in susceptibility to death (Vaupel et al., 1979). This

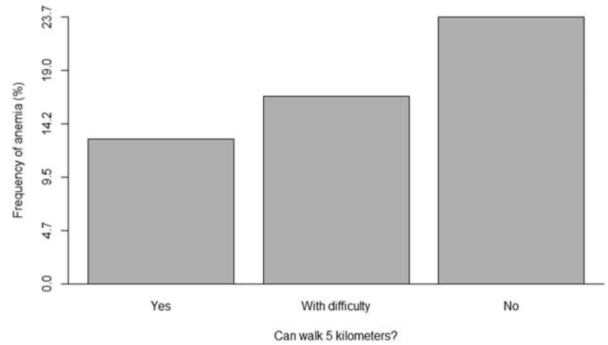

Fig. 5. Frequency of anemia by self-perceived work capacity: walk 5 km.

concept was employed by Wood et al. (1992) in discussing concerns over the use of skeletal samples to estimate population health ("osteological paradox"). Despite the bias introduced by the osteological paradox, few studies have attempted to address it analytically, largely due to the difficulty of incorporating additional, individual-level variation (i.e., frailty) into analyses of small archaeological samples. The data presented here show, empirically, that individual frailty likely plays a considerable role in anemia risk, which, if ignored, can lead to invalid conclusions about the broader socioeconomic environment and lived experiences of past human populations based on anemia status.

Thus, we argue that while the incorporation of individual frailty into bioarchaeological studies is challenging, it is imperative that we consider the factors that contribute to such frailty in order to more critically assess the meaning of the presence of PH and CO, as well as increase the reliability of our conclusions regarding past environmental conditions on an individual's life derived from skeletal data. However, compared with previous discussions of individual frailty, we argue that it should be conceptualized more broadly to include not only biological risk of disease but also the cultural factors that can exacerbate or diminish biological risk (see also Goodman and Armelagos, 1989). Data from living human populations (human biology, public health), but especially data from studies that incorporate a critical biocultural approach, can be particularly useful for exploring the factors that lead to observed variation in frailty.

Intra-population variation: A biocultural perspective on individual frailty in anemia risk

Similar to published global health data (WHO, 2008), in the MxFLS we found that young children (0–5 years) and women of reproductive age (15–49 years) had the highest rates of anemia and that pregnancy and lactation further increased risk of anemia in adult women. The lowest rates were found among adult men. The reason for these findings is likely related to both biological and social/cultural vulnerability which combine to create variation in risk or individual frailty.

Because of rapid growth during the early years of life, young children's nutritional needs, including micronutrients, are relatively high considering their body size. On average, infants are born with iron stores to last approximately 4–6 weeks. After this point they must have sufficient iron in their diets to meet their relatively high needs. In addition, it is also during this period of rapid growth that children experience the stressful process of weaning and must adjust to the adult diet (Sellen, 2007). In some contexts, this can include reliance on carbohydrate and fiber-rich foods and low consumption of protein and micronutrient-rich foods (Onyango et al., 1999). With relatively small guts, children may be unable to ingest sufficient micronutrients before feeling satiated. For example, scholars working in the Amazon have suggested that poor linear growth in children may be attributed, in part, to inadequate macro and micronutrient intakes due to the fact that the dietary staple, manioc, is energy-dense and high in fiber but low in protein and fat, as well as micronutrient-poor (Dufour, 1992; Piperata, 2007). Furthermore, both through the consumption of foods other than breast milk and increased mobility, young children also increase their interaction with the bio-physical environment and thus increase their risk of coming in contact with pathogens that may compromise iron absorption or contribute to blood loss (Bundy et al., 1988; Kirwan et al., 2009).

In addition to their increased biological vulnerability, cultural factors may also place young children at greater risk of anemia. In some societies, data indicate that children are denied meat and vegetables, foods rich in the micronutrients required for erythropoiesis. This can be due to temporary food taboos meant to protect children from foods locally classified as too strong or dangerous (Odebiyi, 1989; Holmes et al., 2007). Under other circumstances, children may simply not be prioritized at mealtimes. Instead, nutrient-rich foods are reserved for the most economically active members of the household (Abdullah and Wheeler, 1985; Engle and Nieves, 1993). Conversely, in other settings, data indicate that children are preferentially fed and thus potentially protected from micronutrient deficiencies (Kaiser and Dewy, 1991; Leonard, 1991; Graham, 1997; Kramer, et al., 1997; Piperata et al., 2013). In cases of food scarcity, there is evidence that adults, particularly women, tend to buffer children (Fitchen, 1987; Kaiser and Dewey, 1991; Radimer et al., 1992; Piperata et al., 2013). While this cultural practice may potentially protect children from nutritional deficiencies they may place women at increased risk (Piperata et al., 2013).

For women of reproductive age (14–49 years), menstruation, pregnancy, and lactation all increase micronutrient needs including those associated with anemia such as vitamins B9 and B12, as well as iron (Whitney and Rolfes, 1999). In addition to their biological vulnerability, women may also be at increased risk of suffering deficiencies of key micronutrients associated with anemia due to their lower social status in the household (Pelto, 1987; Gittelsohn et al., 1997) and their tendency to protect children from dietary shortages, despite their own increased needs, as discussed above. In fact, in a review of the global literature on intra-household food distribution, Haddad et al. (1996) concluded that age and gender affect access to nutrient-dense more than energy-dense foods. Finally, taboos that restrict women's access to meat and other nutrient-dense foods during pregnancy (Ferro-Luzzi, 1980a) and lactation (Ferro-Luzzi, 1980b; Santos-Torres and Vasquez-Guribay, 2003; Piperata, 2008) have the potential to increase their vulnerability to developing anemia.

Finally, the complex relationship we found between anemia status and self-perceived health, diet quality and work capacity is also important considering the tendency to use rates of PH and CO to assess the impact of anemia on an individual's life in the past (e.g., Stuart-Mcadam, 1991, 1992; Holland and O'Brien, 1997; Blom et al., 2005). In terms of self-perceived health and work capacity, this may be partially explained by the fact that, of the micronutrients that contribute to the development of anemia, only iron deficiency has been demonstrated to impair work capacity. Yet, iron deficiency is responsible for less than 50% of all anemia cases (McClean et al., 2009) and, as argued by Walker et al. (2009), likely not the cause of PH/CO. This is critical for estimating the impact of PH and CO on the lived experiences of individuals in the past. In addition, one's lived experience, an aspect of quality of life, is culturally constructed. In the case of diet, one's ideals regarding dietary quality are shaped by local norms and beliefs which may not conform to nutritional recommendations. Under such circumstances we should not expect to find a strong relationship between one's assessment of their quality of life (e.g., diet quality) and anemia status. These issues raise questions regarding the degree to which anemia can be used as a marker of the broader environmental context.

Taking these biological and social/cultural factors into consideration it is clear that based on their life-history stage, not all members of a society or household are at equal risk of developing anemia. Young children are consistently identified as being the segment of the population most at risk of anemia due to their biological and, depending on the setting, cultural vulnerability. Considering this variation and the fact that PH and CO are indicative of anemia in childhood, caution should be used in assessing the broader environmental context of the population based on the prevalence of these skeletal pathologies among sub-adults.

Consequently, any bioarchaeological study that includes the prevalence of anemia as a proxy to establish the biocultural context of the individuals or populations being studied will require a more in depth consideration of individual frailty. In addition, it is critical to note that individual frailty affects multiple stress markers in similar ways. For example, pregnancy increases one's susceptibility to both anemia and dental caries (Lukacs, 1996, 2011; Lukacs and Largaespalda, 2006). For this reason, we argue that the multi-marker approach, often adopted by bioarchaeologists (Larsen 1997, and references therein) as a strategy to deal with the complex etiologies of individual markers of stress, will not allow us to fully overcome the limitations introduced by individual frailty.

While we recognize that the inclusion of individual frailty is challenging in bioarchaeological studies, the results reported here make a strong case for the acknowledgement of its role when drawing conclusions about the proximate, as well as broader environmental conditions in which past populations lived based on the prevalence of skeletal and dental pathologies. To address this limitation, the first step will be to identify biological vulnerability and incorporate this knowledge into the interpretation of the prevalence of the skeletal pathologies being considered. Then, using archaeological data, historical records, and cultural and human biology-oriented studies among living populations, researchers can explore potential biocultural factors that may have placed individuals at risk of disease in the past. In the case of PH and CO, this ethno-bioarchaeological approach would include data on the typical diet and any differences in consumption pattern based on age and/or gender, especially if they are likely to lead to low intakes of hemopoietic nutrients or if they are high in phytates (whole grains, legumes, nuts, seeds), phenols (e.g., caffeine), and calcium (dairy products) known to impede the absorption of hemopoeitic nutrients. While this approach has been adopted by some scholars [Dobney and Goodman (1991) for an example], the data presented here make the case for its wider use within the discipline and the further integration of bioarchaeological and human biology research, keeping in mind social differences, including social complexity, between the past and present populations being compared. Finally, large-scale databases such as the MxFLS provide a useful tool for testing hypotheses regarding the contribution of individual frailty to observed variation in disease risk which can then be applied to studies of past populations. However, such databases do not replace the need for detailed critical biocultural studies that have the power to elucidate how frailty is created. While others have focused on the biological side of frailty (e.g., Wood et al., 1992), in this paper we argue that frailty is created by the interaction of biology and culture. The power of the MxFLS dataset is its size which allowed us to uncover the patterns discussed in this article. It does not, however, help us to understand them.

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