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Diverse and Dynamic Dietary Patterns in Early Colonial Cuba: New Insights from Multiple Isotope Analyses

Jason E. Laffoon , Roberto Valcárcel Rojas, Darlene A. Weston, Menno L. P. Hoogland, Gareth R. Davies, and Corinne L. Hofman

The European conquest and colonization of the Caribbean precipitated massive changes in indigenous cultures and societies of the region. One of the earliest changes was the introduction of new plant and animal foods and culinary traditions. This study presents the first archaeological reconstruction of indigenous diets and foodways in the Caribbean spanning the historical divide of 1492. We use multiple isotope datasets to reconstruct these diets and investigate the potential relationships between dietary and mobility patterns at multiple scales. Dietary patterns are assessed by isotope analyses of different skeletal elements from the archaeological skeletal population of El Chorro de Maíta, Cuba. This approach integrates carbon and nitrogen isotope analyses of bone and dentine collagen with carbon and oxygen isotope analyses of bone and enamel apatite. The isotope results document extreme intrapopulation dietary heterogeneity but few systematic differences in diet between demographic/social groups. Comparisons with published isotope data from other precolonial and colonial period populations in the Caribbean indicate distinct dietary and subsistence practices at El Chorro de Maíta. The majority of the local population consumed more animal protein resources than other indigenous populations in the Caribbean, and their overall dietary patterns are more similar to colonial period enslaved populations than to indigenous ones.

Keywords: diet, isotope analysis, colonialism, indigenous, Cuba

La conquista y colonización europea del Caribe precipitó cambios masivos en las culturas y sociedades indígenas de la región. Uno de estos fue la introducción de nuevos alimentos vegetales y animales y de tradiciones culinarias. En este trabajo se presenta la primera reconstrucción arqueológica de dietas indígenas y prácticas alimenticias en el Caribe, en el contexto de la ruptura histórica iniciada con el arribo europeo en 1492. Se utilizan múltiples conjuntos de datos isotópicos para reconstruir la dieta y analizar las posibles relaciones entre ésta y los patrones de movilidad a diversas escalas. Los patrones dietarios se evalúan mediante análisis de isótopos de diferentes elementos óseos humanos del sitio El Chorro de Maíta, Cuba. El enfoque integra el análisis de isótopos de carbono y nitrógeno de colágeno de hueso y dentina y el análisis de isótopos de carbono y oxígeno de apatita de hueso y esmalte. Los resultados documentan una heterogeneidad alimentaria intrapoblacional extrema, pero pocas diferencias sistemáticas en la dieta entre los grupos demográficos / sociales. Las comparaciones con los datos isotópicos de otras poblaciones precoloniales y coloniales del Caribe, indican prácticas alimentarias y de subsistencia distintas en El Chorro. La mayor parte de la población local consumió más recursos de proteínas animales que otras poblaciones indígenas en el Caribe y sus patrones dietarios generales son más similares a los de las poblaciones esclavizadas del período colonial.

Palabras clave: dieta, análisis de isótopos, colonialismo, indígenas, Cuba

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Profound changes in indigenous Caribbean foodways have occurred in the last five centuries. The movement of various plant- and animal-based foods between the Old and New Worlds is one of the central themes of the “Columbian Exchange” (Crosby 1972). The quantity and diversity of peoples, pathogens, things, ideas, and foods that comprise the Columbian Exchange and the impacts that they have had on the course of history are well documented in broad strokes (Denevan 1992; Sauer 1966), but our current understanding of this general story is lacking in many critical details. Key research questions that remain unresolved are the dating of the introduction of various foods to different areas, the timing and routes by which they were dispersed, the speed by which new foods and knowledge of food production were incorporated into indigenous foodways, the various factors that contributed to the adoption of certain foods and not others, and how these changing and dynamic culinary traditions varied over space and time both within and between various Amerindian populations.

Patterns of continuity and change in foodways related to cross-cultural encounters in the Caribbean have been previously explored using a broad array of archaeological and historical data (Deagan 2004; Keegan and Hofman 2017; Newsom and Wing 2004; Rouse 1992; Sauer 1966). Although stable isotope methods have been widely applied to human paleodiet studies in the Caribbean for both the precolonial (Chinique de Armas et al. 2015, 2016, 2017; Keegan and DeNiro 1988; Krigbaum et al. 2013; Laffoon and de Vos 2011; Laffoon et al. 2013, 2016, 2017; Mickleburgh and Laffoon 2018; Norr 2002; Pestle 2010, 2013; Stokes 1998) and late colonial periods (Schroeder et al. 2009; Sparkes et al. 2012; Varney 2003), they have yet to be used to investigate the critical period spanning the historical divide or the early colonial period. This lacuna is unfortunate because isotopic analyses of human remains are particularly well suited for paleodietary studies, being ideal for tracking rapid changes in dietary practices both within and between individuals and for exploring variation in diets within and between different social groups at multiple scales using a bottom-up approach. This type of information

concerning indigenous diets is almost entirely neglected in the documentary record of the early colonial period.

In this study we examine patterns in carbon and nitrogen isotopes in dentine and bone collagen, as well as in carbon and oxygen isotopes in enamel and bone apatite, to reconstruct childhood and adult diets at the site of El Chorro de Maíta, Cuba (Figure 1). The analyzed skeletons primarily date to the crucial phase spanning the contact and early colonial periods of the Caribbean that witnessed the arrival of the Spanish, the invasion and colonization of Cuba, and the imposition of the *encomienda* system of forced labor on the indigenous populations of the island. We use the patterning in the stable isotope results at multiple scales—in conjunction with archaeological, osteoarchaeological, zooarchaeological, and historical evidence—to explore the complex interrelationships between diet and mobility among this indigenous community and how existing patterns were affected after AD 1492. The main research aims of this study are to reconstruct patterns of indigenous foodways at the site of El Chorro de Maíta, to investigate changes in dietary practices in early colonial contexts of the Caribbean, to explore potential intrapopulation differences in responding to changing social and ecological conditions, and to assess possible linkages between dietary and mobility patterns at multiple scales.

Investigating Indigenous Diets

Site Background and Context

This study focuses on the burial population of the site of El Chorro de Maíta, on the northern coast of eastern Cuba. The cemetery portion of the site was primarily excavated in the 1980s under the direction of José Guarch Delmonte (1990, 1996) and was originally interpreted as an essentially indigenous space of precolonial character with an ephemeral contact period component and without an important link with Europeans. Subsequent archaeological research over the last few decades conducted by Roberto Valcárcel Rojas and colleagues has provided important new insights into many aspects regarding the site. This research at the site identified nonfunerary contexts including domestic spaces and

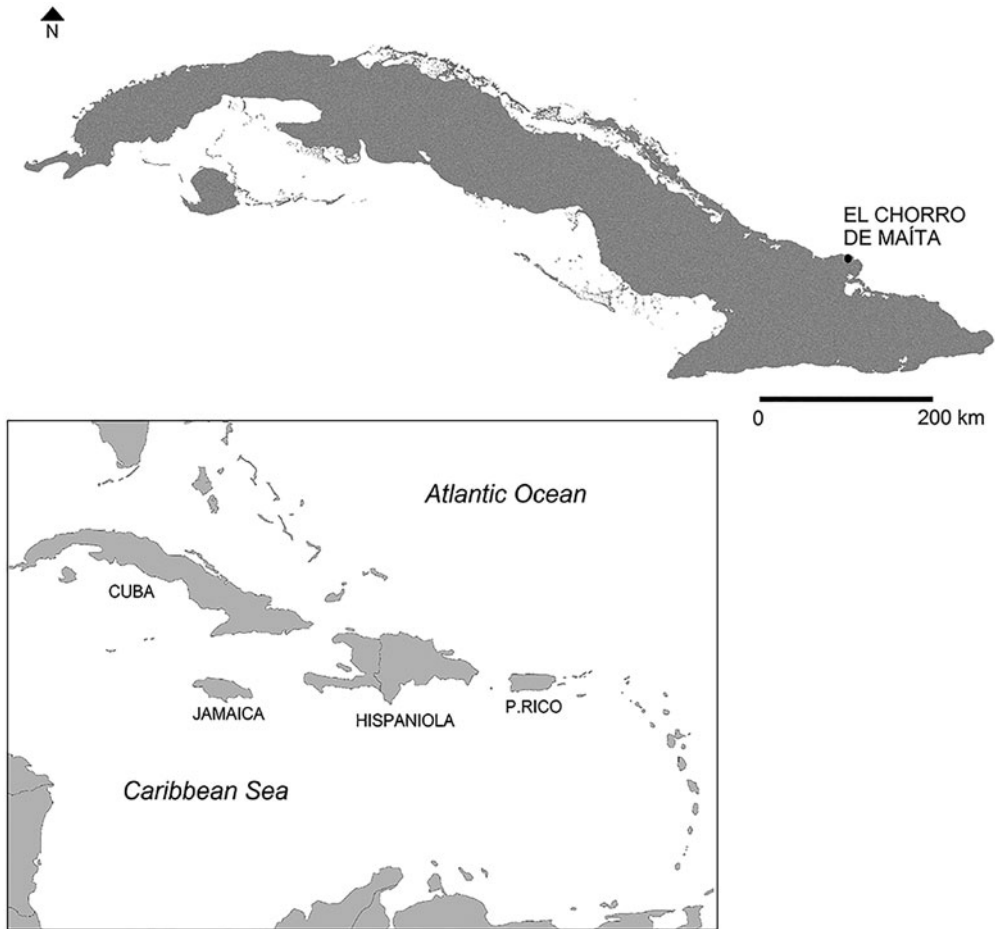


Figure 1. Map of Cuba showing the location of the site El Chorro de Maíta.

refuse deposits, indicating an indigenous occupation beginning around the thirteenth century AD. Pottery, European metallic artifacts, and pig remains appear in the final layers of occupation mixed with indigenous materials. In the fifteenth and sixteenth centuries AD, the settlement was organized around a central area in which a cemetery was located (Valcárcel Rojas 2016).

Several unique aspects of the site and burial population make it ideally suited for the aims of the current study, including the fact that the skeletal population is one of the largest (MNI = 133; Weston and Valcárcel Rojas 2016) and most well-researched indigenous populations in the insular Caribbean; it is also one of the only indigenous Caribbean populations whose dating can be definitively linked to the early colonial period (ca. AD 1500–1550). A large suite of

radiocarbon dates including extensive direct dating of many of the skeletons indicates that most individuals have 2-sigma date ranges spanning the historical divide (Bayliss et al. 2012; Valcárcel Rojas 2012, 2016). It is therefore impossible to assign most individuals to either the precontact or postcontact period based on radiocarbon dates alone. A detailed analysis of the calibrated radiocarbon dates, including the use of Bayesian modeling, suggests that the dates are concentrated in the contact or early colonial period (Bayliss et al. 2012; Valcarcel Rojas 2016:194). Additional evidence that many of the burials date to this period includes the widespread presence of domestic pig (*Sus scrofa*) bones, European pottery, and metal artifacts recovered from graves (Valcárcel Rojas 2016), in addition to the extended supine (Christian-style) placement of

the body for many of the burials (Valcárcel Rojas 2012; Valcárcel Rojas et al. 2011, 2013).

Recent osteoarchaeological investigations (Weston and Valcárcel Rojas 2016) revealed important new insights into health and demography at the site, including a mortality profile consistent with a catastrophic episode such as an epidemic. Furthermore, large concentrations of burials associated with indigenous (Meillacan) pottery found at this site do not occur at indigenous sites in Cuba, where burial areas generally comprise few individuals predominantly in cave sites, or elsewhere in precolonial Antilles. In addition, the lack of secure chronological indicators of precontact burials, the diverse ethnic and geographical origins observed in the mortuary population (Valcárcel Rojas et al. 2011), and taphonomic and demographic indicators that point to catastrophic mortality (Weston and Valcárcel Rojas 2016) suggest that the cemetery itself is predominantly a colonial phenomenon resulting from Indigenous–European interactions; however, the possibility that it could include a small nucleus of precolonial burials cannot be ruled out (Valcárcel Rojas 2016; Weston and Valcárcel Rojas 2016). The indigenous population of the site was rapidly incorporated into the Spanish system (*encomienda*) of forced labor in the first decades of the sixteenth century AD (Valcárcel Rojas 2012, 2016; Valcárcel Rojas et al. 2013).

Zooarchaeological research conducted to date has focused on specific components of the site, and in terms of MNI the terrestrial mollusks are the most abundant (Pérez Iglesias 2007, 2008, 2010, 2011). Nevertheless, the principal contributions to the biomass came from fishing, followed by hunting hutia, a small native rodent, and collecting mollusks (Pérez Iglesias 2008). Thus, the quantitative faunal analyses indicate that marine fish and various small mammals such as hutia (*Capromys pilorides*, *Mysateles melanurus*) and cave rats (*Boromys offella*, *Boromys torrei*) constituted the core of the animal-based nutrition (Rodríguez Arce 1987; Valcárcel Rojas 2016). Importantly the faunal analyses also revealed the presence of domestic pig remains at the site and provided clear evidence for processing (butchery marks) of these animals for consumption (Pérez Iglesias and Valcárcel

Rojas 2014). Because of the biases of the faunal record, questions nevertheless remain concerning how rapidly introduced foods were incorporated into indigenous diets, their importance to caloric intake, and variation in the relative contributions of different foods to individual diets. Although caution is warranted in the use of trace element data from archaeological bone (Burton and Price 2000), previous analysis of trace element concentrations from El Chorro de Maíta (Taylor 1990) revealed variable patterns consistent with the consumption of both marine and vegetable foods, thereby indicating varied omnivorous diets.

Stable Isotopes and Dietary Reconstruction

Carbon isotope values ($\delta^{13}\text{C}$) vary between different types of plants based on the different photosynthetic pathways used to fix atmospheric carbon (Smith and Epstein 1971). Most plant species use the C_3 cycle (Calvin-Benson) and have lower $\delta^{13}\text{C}$ values, whereas a minority use either the C_4 (Hatch-Slack) or CAM (Crassulacean acid metabolism) cycles and possess significantly higher $\delta^{13}\text{C}$ values (Bender 1971; Smith and Epstein 1971). In the precolonial Caribbean, maize (*Zea mays*) was one of the only widespread and economically important C_4 crops (Newsom and Wing 2004), although other regionally available C_4 (amaranths, chenopods) and CAM (agave, pineapple) plants may have been occasionally consumed (Pestle 2010). Recent microbotanical (starch grain) research has further highlighted the early appearance (ca. 7800 BP) and widespread consumption of maize in the precolonial insular Caribbean (e.g., Mickleburgh and Pagán-Jiménez 2012; Pagán-Jiménez 2013; Pagán-Jiménez et al. 2015). Carbon isotopes also vary between terrestrial and marine ecosystems based on differences in their primary carbon sources (DeNiro and Epstein 1978; Schoeninger and DeNiro 1984), with the former possessing much lower $\delta^{13}\text{C}$ values than the latter.

Nitrogen isotope values ($\delta^{15}\text{N}$) in plants are generally low compared to animals because $\delta^{15}\text{N}$ is enriched stepwise between each trophic level in a food chain such that herbivores, omnivores, and carnivores possess increasingly higher $\delta^{15}\text{N}$ (DeNiro and Epstein 1978, 1981). Marine

ecosystems also generally have enriched $\delta^{15}\text{N}$ values relative to terrestrial ones, given that marine plants possess higher $\delta^{15}\text{N}$ and that there are usually more trophic levels in marine ecosystems (DeNiro and Epstein 1978; Schoeninger et al. 1983). Although the combination of higher $\delta^{15}\text{N}$ and higher $\delta^{13}\text{C}$ values among marine ecosystems is such that coupled carbon and nitrogen isotopes can often be used to distinguish between marine and terrestrial food sources (Hedges and Reynard 2007), the coral reef ecosystems of the Caribbean region include many fish species with lower than expected $\delta^{15}\text{N}$ values (similar to terrestrial animals). This limits the usefulness of this isotopic proxy for distinguishing between terrestrial and marine protein consumption (Keegan and DeNiro 1988).

The main principle of dietary reconstruction via stable isotope analysis is that the isotopic composition of consumed foods is reflected in the tissues of consumers (DeNiro and Epstein 1976). The earliest applications of stable isotope methods for paleodietary studies focused on inferring long-term changes in diet based on carbon isotopes in human bone collagen (Vogel and van de Merwe 1977). Over the last four decades, stable isotope approaches have become widely used and invaluable tools in archaeological research. Because of preferential routing (Fernandes et al. 2012; Krueger and Sullivan 1984), carbon isotopes in collagen primarily reflect dietary protein, whereas carbon isotopes in bone (or enamel) apatite reflect the average of all three macronutrient components (carbohydrates, fats, and proteins) within the diet (Ambrose and Norr 1993; Tieszen and Fagre 1993).

Previous Isotopic Research

All strontium isotope ($^{87}\text{Sr}/^{86}\text{Sr}$) data ($n = 88$) and a small subset of the enamel carbon ($\delta^{13}\text{C}$) and oxygen ($\delta^{18}\text{O}$) isotope data ($n = 12$) from El Chorro de Maíta discussed herein were previously reported (Laffoon 2012; Laffoon et al. 2013; Valcárcel Rojas et al. 2011). In combination with other lines of evidence, these isotope results revealed a high proportion of nonlocal migrants (25%) with diverse natal origins (Figure 2). Based on the combined evidence, most of these nonlocals probably originated from elsewhere in the Caribbean, possibly even

from other locations on Cuba, although two individuals exhibited considerable evidence indicating long-distance mainland origins. For individual CM72B, an adult female, the evidence for nonlocal origins includes deviant burial treatment; tall stature relative to the local population; exotic cranial and dental modification styles; and nonlocal enamel strontium, oxygen, and carbon isotope values. Based on this evidence, it was proposed that this individual probably originated from Mesoamerica (Valcárcel Rojas et al. 2011). A recent dual isotope provenance approach applied to this individual's combined strontium and oxygen isotope signatures confirms that lowland Mesoamerica is one of the few places in the tropical Americas from where this individual could have originated (Laffoon et al. 2017). For individual CM45, an adult male, the evidence for nonlocal origins includes a burial position that is atypical for indigenous Antilleans; grave inclusions of brass aglets (clothes fasteners) of European origin (Cooper et al. 2008; Martín-Torres et al. 2007; Valcárcel Rojas 2016); cranial metrics indicative of likely African ancestry; and highly elevated enamel isotope values of strontium, oxygen, and carbon that excluded the possibility of Antillean origins. Based on the overall evidence this individual was interpreted as a first-generation migrant from Africa (Valcárcel Rojas et al. 2011).

In addition to the extensive suite of radiocarbon dates, a preliminary dataset of associated stable isotope results has also been reported for this burial population (Bayliss et al. 2012). This preliminary bone collagen carbon and nitrogen isotope data have confirmed both a high degree of dietary variation and tentative links between nonlocal origins and nonlocal dietary practices.

Materials and Methods

Materials

The sampling strategy used for this study focused on both bone and dentine collagen and bone and enamel bioapatite (structural carbonate). This strategy permitted explorations of age-based variation in dietary practices, including changes occurring within the life of a single individual

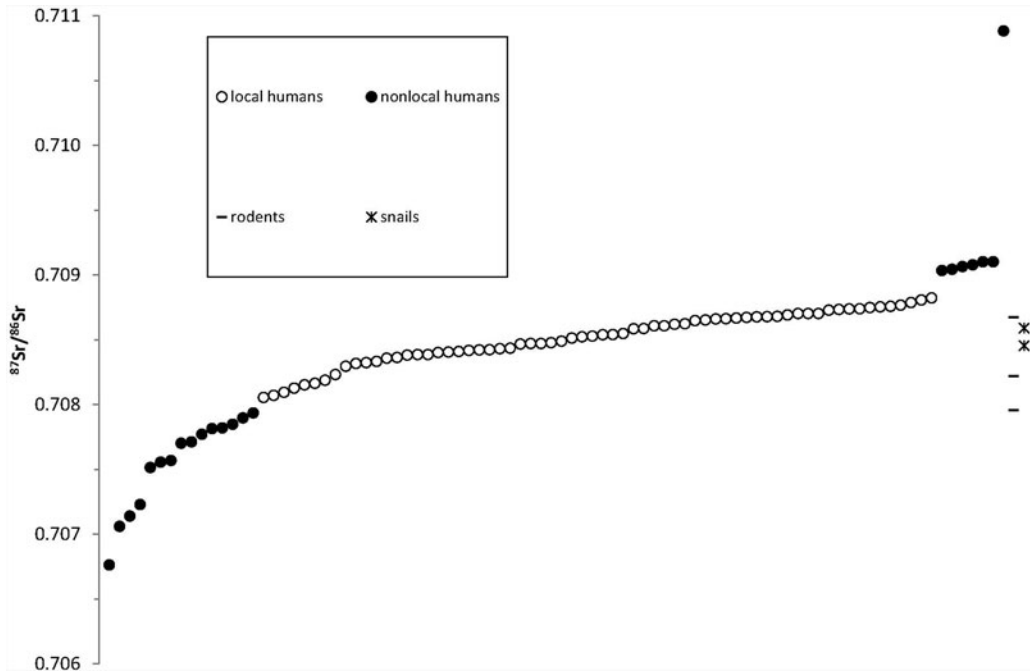


Figure 2. Plot of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios from El Chorro de Maíta showing locals (white symbols) and nonlocals (black symbols). (Data sources: Laffoon 2012; Valcárcel Rojas et al. 2011.)

from a life-history perspective (e.g., Laffoon et al. 2018; Sealy et al. 1995). Sampling of dental elements targeted premolars for consistency and to avoid the complicating effects of breastfeeding inputs; however, in several cases other teeth were also sampled when intact premolars were not available. Enamel and dentine samples were taken from the same dental elements. Bone samples were primarily derived from long bone fragments. All samples were processed at the Stable Isotope Laboratory, Faculty of Science, at Vrije Universiteit Amsterdam.

Methods

Bone and teeth samples were cleaned by mechanically removing the outer surface, which is the most susceptible to diagenetic alteration (Budd et al. 2000). The extraction of collagen from bone and dentine followed standard protocols for archaeological skeletal materials (Ambrose 1990; Brown et al. 1988). Samples were demineralized in 0.6 M HCl at 4°C for several days, rinsed to neutral with ultrapure water (Milli-Q), treated with 0.125 M NaOH for 20 hours, rinsed to neutral again, gelatinized in

pH = 3 HCl at 80°C for 48–72 hours, separated with Ezee (Elkay) filters, frozen, and lyophilized. The processing of bone and enamel apatite samples for isotope analyses included a chemical pretreatment procedure (Bocherens et al. 2011), which involved washing in 2.5% bleach (NaOCl) rinsing, and then leaching in Ca-acetate buffered acetic acid (CH_3COOH , pH = 4.75). Carbon and nitrogen isotope measurements were conducted on a ThermoQuest IRMS Delta XP-plus interfaced to a Flash elemental analyzer. International standards (USGS40, USGS41, IAEA-310(A) and IAEA-NO3) were used for sample calibration, with long-term reproducibility of standards of $\pm 0.1\text{‰}$ (1SD) for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. Carbon and oxygen isotope measurements were conducted on a Finnigan DeltaPlus IRMS coupled with a Gasbench II; long-term reproducibility of the international reference material (NBS19) is $\pm 0.1\text{‰}$ (1SD) for $\delta^{13}\text{C}$ and $\pm 0.2\text{‰}$ (1SD) for $\delta^{18}\text{O}$. Stable isotope results are reported in the δ notation, in parts per thousand (‰) relative to the international VPDB (carbon and oxygen) and AIR (nitrogen) standards.

Results

Quality Control Indicators

The sampling information and isotope results are presented in Supplemental Table 1. Not all isotope proxies are available for every individual because some did not possess suitable intact dental elements, whereas others had poor bone preservation (and are not considered further). For all samples reported here, multiple quality control indicators suggest overall good preservation of collagen material with C:N ratios within the range (2.9–3.6) reported for nonaltered bone and with wt.% carbon and wt.% nitrogen higher than 13.0% and 4.8%, respectively (Ambrose 1990; DeNiro 1985). Collagen yields were variable for bone collagen, ranging from 2.5% to 26.2% (mean: 7.6%), and for dentine collagen, ranging from 1.8% to 16.5% (mean: 8.5%) but consistent with those reported for precolonial Caribbean populations (Pestle and Colvard 2012). Collagen stable isotope values tended to remain consistent for collagen yields higher than 1% (Ambrose 1990). Unlike for bone collagen, there is no general consensus concerning quality-control indicators for bone apatite (Shin and Hedges 2012), but given its known susceptibility to multiple diagenetic processes (Koch et al. 1997), we used general and pairwise comparisons of bone and enamel carbon ($\delta^{13}\text{C}_{\text{apat}}$ and $\delta^{13}\text{C}_{\text{enam}}$) and oxygen ($\delta^{18}\text{O}_{\text{apat}}$ and $\delta^{18}\text{O}_{\text{enam}}$) to test for potential postmortem alteration of biogenic isotope values. We also considered the bone apatite isotope data as supplementary to the other isotope proxies and focused our interpretations on the more robust collagen and enamel isotope datasets.

Enamel and Bone Apatite Results: Carbon and Oxygen

Summary statistics of isotope results for all samples and for specific subgroups based on sex, age, and origins are presented in Supplemental Table 2. Enamel and bone apatite carbon and oxygen isotope values are plotted in Figure 3. The mean $\delta^{13}\text{C}_{\text{enam}}$ for all individuals is $-11.4 \pm 0.9\text{‰}$ (-15.5‰ to -9.7‰ , $n=69$), and the mean $\delta^{18}\text{O}_{\text{enam}}$ is $-3.7 \pm 0.7\text{‰}$ (-5.4‰ to -2.0‰). These statistics exclude the two non-local individuals (CM45, CM72B) with long-

distance (mainland) origins, who possess $\delta^{13}\text{C}_{\text{enam}}$ (-5.1‰ and -3.7‰) and $\delta^{18}\text{O}_{\text{enam}}$ values (-5.4‰ and -3.7‰), respectively: these values are highly elevated both relative to the local population and compared to all other Caribbean archaeological populations (Laffoon et al. 2013).

The mean $\delta^{13}\text{C}_{\text{apat}}$ for all samples is $-10.5 \pm 0.6\text{‰}$ (-12.3‰ to -8.7‰ , $n=41$), and the mean $\delta^{18}\text{O}_{\text{enam}}$ is $-6.3 \pm 0.5\text{‰}$ (-7.2‰ to -5.4‰). The mean $\delta^{13}\text{C}_{\text{enam}}$ and mean $\delta^{13}\text{C}_{\text{apat}}$ are broadly similar, and the corresponding ranges display a high degree of overlap. In contrast, the mean $\delta^{18}\text{O}_{\text{enam}}$ and mean $\delta^{18}\text{O}_{\text{apat}}$ differ by 2.6‰ with the latter consistently lower than the former and almost no overlap in the range of values. There is a statistically significant difference between both $\delta^{13}\text{C}_{\text{enam}}$ and $\delta^{13}\text{C}_{\text{apat}}$ $t(102) = -3.81$, $p < 0.001$, and between $\delta^{18}\text{O}_{\text{enam}}$ and $\delta^{18}\text{O}_{\text{apat}}$ $t(103) = 23.29$, $p < 0.001$.

We identified intra-individual variation in apatite isotope values by comparing enamel and bone apatite isotope values from the same individuals (Figure 4). For the vast majority of individuals, $\delta^{13}\text{C}_{\text{enam}}$ is more negative than $\delta^{13}\text{C}_{\text{apat}}$, but the offset ($\Delta^{13}\text{C}_{\text{enam-apat}}$) between them is highly variable, with a mean of $-1.1 \pm 1.2\text{‰}$ (-5.0‰ to $+1.8\text{‰}$, range: 6.8‰). Intra-individual offsets in oxygen isotope values ($\Delta^{18}\text{O}_{\text{enam-apat}}$) are larger (mean: $2.4 \pm 0.8\text{‰}$) than those observed for $\Delta^{13}\text{C}_{\text{enam-apat}}$ but with reduced variation (1.0‰ to 4.7‰). The variability in $\Delta^{13}\text{C}_{\text{enam-apat}}$, including both negative and positive values, was previously documented for both animals and humans, but its possible causes are not well understood (Laffoon et al. 2016; Loftus and Sealy 2012).

Dentine and Bone Collagen Results: Carbon and Nitrogen

Dentine and bone collagen isotope values are plotted in Figure 5. The mean $\delta^{13}\text{C}_{\text{dent}}$ for all individuals is $-17.7 \pm 1.3\text{‰}$ (-19.0‰ to -12.2‰ , $n=35$), and the mean $\delta^{15}\text{N}_{\text{dent}}$ is $13.8 \pm 1.3\text{‰}$ (10.2‰ to 15.7‰). The mean $\delta^{13}\text{C}_{\text{coll}}$ is $-17.6 \pm 2.1\text{‰}$ (-22.8‰ to -9.8‰ , $n=44$), and the mean $\delta^{15}\text{N}_{\text{coll}}$ is $13.2 \pm 1.4\text{‰}$ (8.5‰ to 14.9‰). The two individuals with documented long-distance origins (CM45 and CM72B) were excluded from these summary

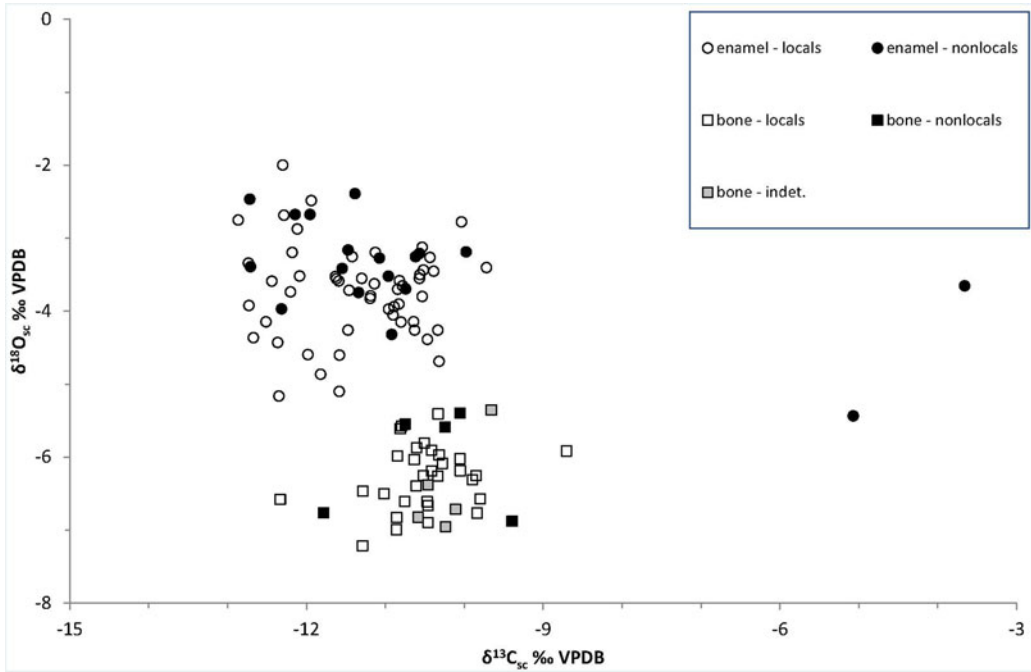


Figure 3. Plot of enamel and bone apatite $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values from El Chorro de Maíta. (Data sources: Laffoon et al. 2013 and this study.)

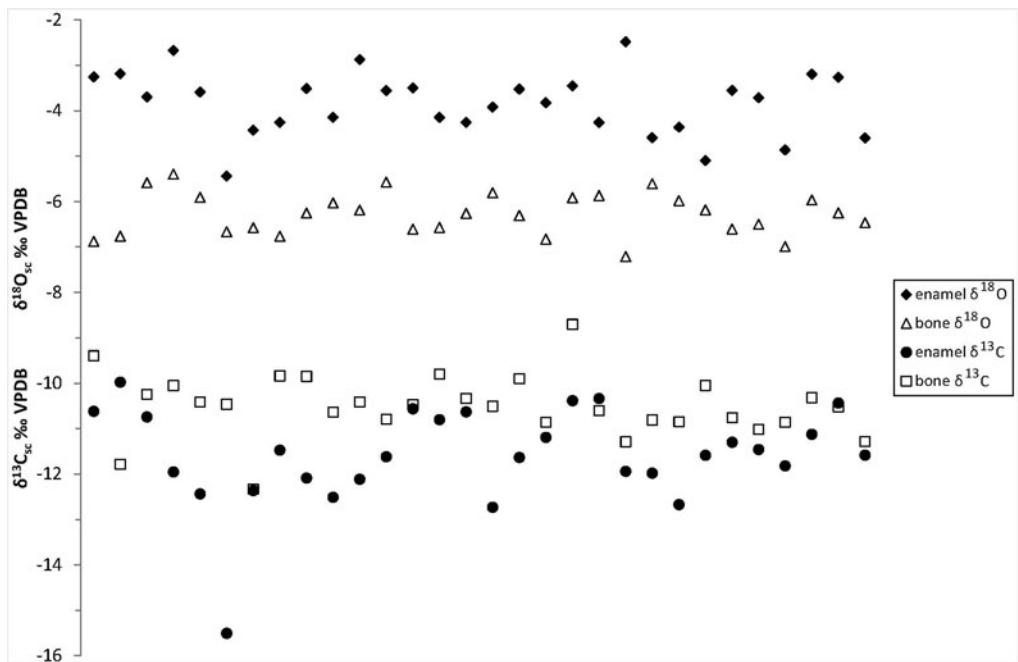


Figure 4. Paired enamel ($\delta^{13}\text{C}_{\text{enam}}$ and $\delta^{18}\text{O}_{\text{enam}}$) and bone apatite ($\delta^{13}\text{C}_{\text{apat}}$ and $\delta^{18}\text{O}_{\text{apat}}$) isotope values of the same individuals from El Chorro de Maíta.

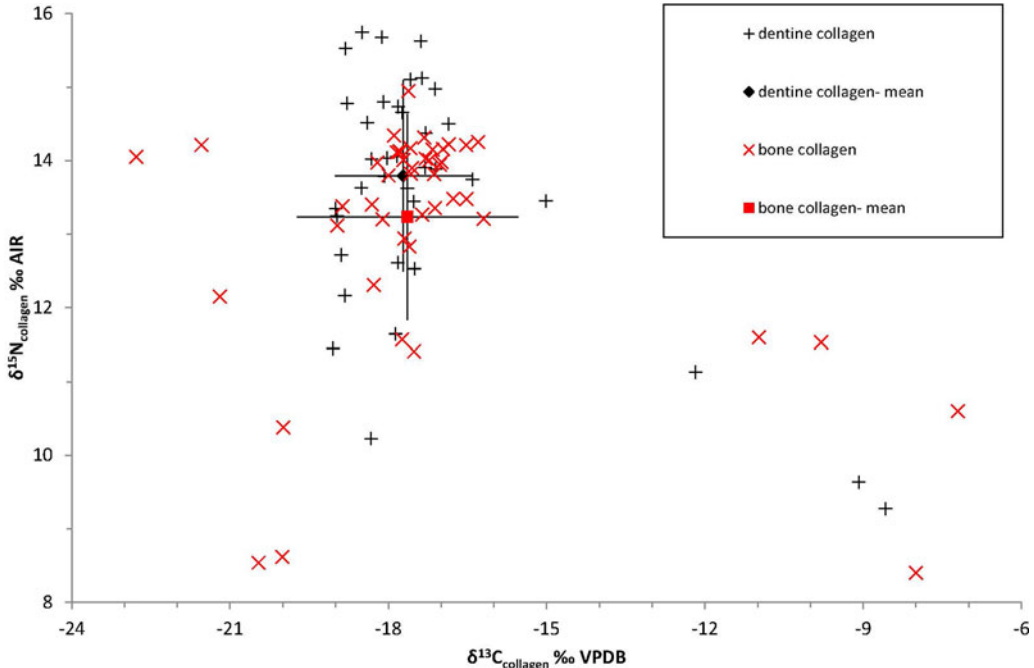


Figure 5. Plot of dentine collagen ($\delta^{13}\text{C}_{\text{dent}}$ and $\delta^{15}\text{N}_{\text{dent}}$) and bone collagen ($\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$) isotope values from El Chorro de Maíta.

statistics because their collagen isotope values are extreme outliers and are highly elevated for both dentine, $\delta^{13}\text{C}_{\text{dent}}$ (-9.1‰ and -8.6‰) and $\delta^{15}\text{N}_{\text{dent}}$ (9.6‰ and 9.3‰), and bone collagen $\delta^{13}\text{C}_{\text{coll}}$ (-7.2‰ and -8.0‰) and $\delta^{15}\text{N}_{\text{coll}}$ (10.6‰ and 8.4‰), respectively (Bayliss et al. 2012). Overall, the dentine and bone collagen datasets possess similar mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, differing by less than 1‰ , and there is a high degree of overlap in the ranges of values, although the bone collagen dataset possesses a greater range of values for both $\delta^{13}\text{C}$ ($>15\text{‰}$) and $\delta^{15}\text{N}$ ($>6\text{‰}$). The collagen isotope dataset exhibits notably extreme variability, which is far greater than that reported for other indigenous populations in the Caribbean.

Intra-individual differences in collagen isotope values based on paired dentine and bone samples (Figure 6) are on average quite small, with mean offsets of 0.3‰ for $\Delta^{13}\text{C}_{\text{dent-coll}}$ and 0.7‰ for $\Delta^{15}\text{N}_{\text{dent-coll}}$. Nevertheless, there is considerable variation among these offsets, with $\Delta^{13}\text{C}_{\text{dent-coll}}$ varying from -1.8‰ to $+4.8\text{‰}$ (range: 6.6‰) and $\Delta^{15}\text{N}_{\text{dent-coll}}$ varying from -2.8‰ to $+7.1\text{‰}$ (range: 9.9‰). It is

noteworthy that the direction of the offset is also quite variable, with roughly equal proportions possessing positive and negative offsets.

Discussion

Dietary Reconstructions

Owing to the high variance and extremely large ranges of the stable isotope data overall, and of the collagen isotope data in particular, it is difficult to make broad generalizations about the entire sample population. Nevertheless several trends are apparent. For example, we derived estimates of whole-diet carbon isotope values ($\delta^{13}\text{C}_{\text{whole diet}}$) by subtracting 10.1‰ from the enamel and bone apatite $\delta^{13}\text{C}$ values (Fernandes et al. 2012), reflecting the average (whole dietary) intake of the childhood and adult periods, respectively. The $\delta^{13}\text{C}_{\text{whole diet}}$ values of the majority of the dataset fall within the range of C_3 plants, indicating a predominance of C_3 resources in the plant component of the diet, but several samples have $\delta^{13}\text{C}_{\text{whole diet}}$ values falling at the edge or just outside of the range of values reported for C_3 plants in the Caribbean.

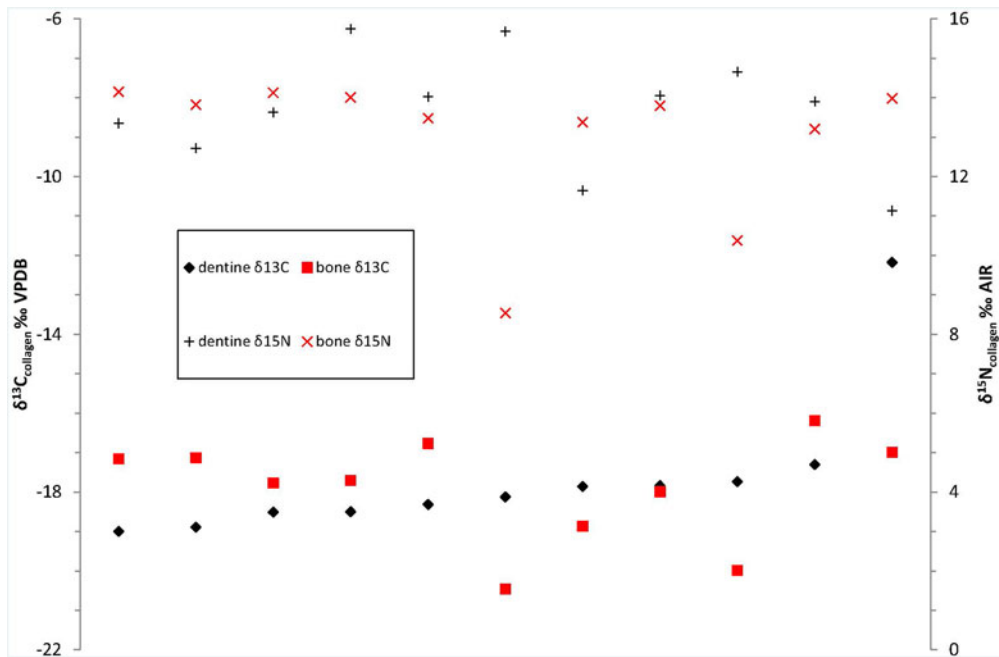


Figure 6. Paired dentine ($\delta^{13}\text{C}_{\text{dent}}$ and $\delta^{15}\text{N}_{\text{dent}}$) and bone collagen ($\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$) isotope values of the same individuals from El Chorro de Maíta.

This likely indicates minor contributions of C_4 , marine resources, or both (Mickleburgh and Laffoon 2018). These patterns are consistent with the ecology of Cuba and the broader Caribbean region, which is dominated by C_3 plants and where only a limited number of C_4 (such as maize) or CAM plants (agave, pineapple) have been documented as human food sources (Newson and Wing 2004; Pestle 2010). Individuals CM45 (African origin) and CM72B (Mesoamerican origin) have highly elevated $\delta^{13}\text{C}_{\text{whole diet}}$ estimates calculated from their $\delta^{13}\text{C}_{\text{enam}}$ values, indicating a predominance of C_4 resources during childhood, likely from their respective consumption of sorghum/millet and maize (Laffoon et al. 2013).

Turning to assessments of intra-individual variation in isotope values, a few clear patterns emerge. First, there are at least two possible explanations for the systematic differences between the enamel and bone oxygen isotope values: (1) the $\delta^{18}\text{O}_{\text{enam}}$ are elevated relative to bone $\delta^{18}\text{O}_{\text{apat}}$ owing to the influence of breastfeeding, because breastmilk is expected to be elevated in $\delta^{18}\text{O}$ (Britton et al. 2015), and (2) the

$\delta^{18}\text{O}_{\text{apat}}$ values are systematically offset by post-mortem alteration or issues of sample treatment and data calibration (Pestle et al. 2014). The enamel and bone apatite $\delta^{18}\text{O}$ values have been used to calculate drinking water oxygen isotope ($\delta^{18}\text{O}_{\text{dw}}$) values by first converting to the VSMOW scale using the formula of Coplen (1988) and then applying the calculation of Chenery and colleagues (2012). Comparison of these $\delta^{18}\text{O}_{\text{dw}}$ values with the range of precipitation $\delta^{18}\text{O}$ for the circum-Caribbean (International Atomic Energy Agency/World Meteorological Organization 2016; Laffoon et al. 2017; Terzer et al. 2013) indicates a high degree of overlap with $\delta^{18}\text{O}_{\text{dw}}$ values derived from the El Chorro de Maíta $\delta^{18}\text{O}_{\text{enam}}$ dataset but not the $\delta^{18}\text{O}_{\text{apat}}$ dataset. As such, and because enamel is generally considered a more reliable sample substrate for oxygen isotopic analyses (Sponheimer and Lee-Thorp 1999), we conclude that the bone oxygen isotope data are unreliable and do not consider them further.

Estimates of the protein component of the diet (Figure 7) are derived by applying the conversion formula from Pestle and colleagues (2015) to

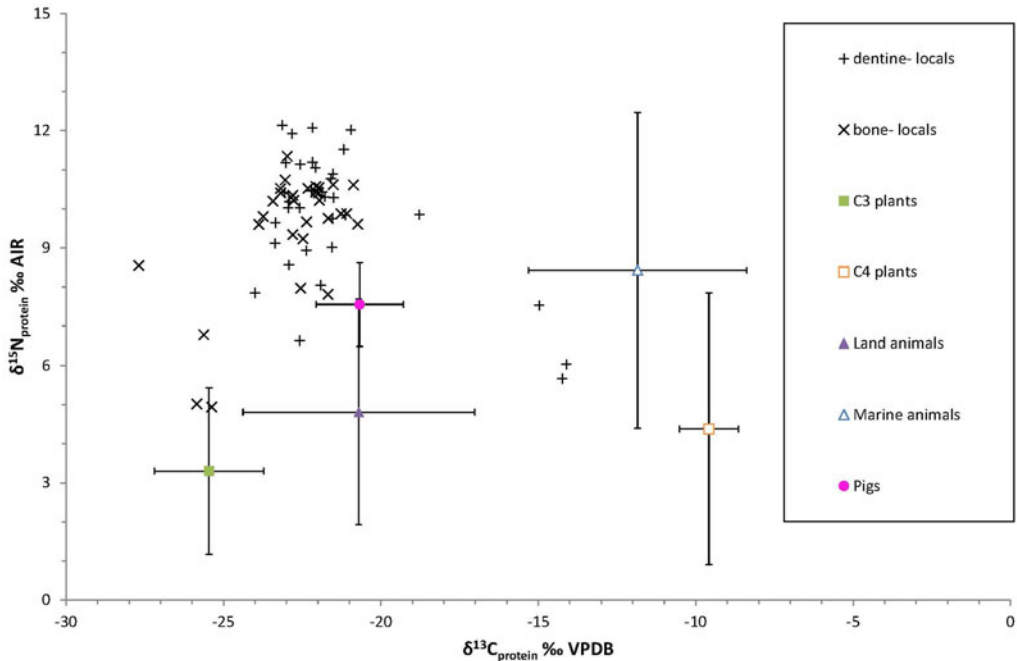


Figure 7. Estimated protein carbon isotope values ($\delta^{13}\text{C}_{\text{protein}}$) derived by applying the conversion formula from Pestle and colleagues (2015) to combined collagen and apatite carbon isotope values, plotted against estimated protein nitrogen isotope values ($\delta^{15}\text{N}_{\text{protein}}$) derived by subtracting 3.6‰ from collagen nitrogen isotope values. (Faunal isotope data sources: Pestle 2010; Stokes 1998.)

obtain $\delta^{13}\text{C}_{\text{protein}}$, and by subtracting 3.6‰ from dentine and bone $\delta^{15}\text{N}$ values to obtain $\delta^{15}\text{N}_{\text{protein}}$, as suggested by various studies (Ambrose 2002; DeNiro and Epstein 1981). When compared to the mean (\pm SD) of plant (C_3 and C_4) and animal (land and marine) food groups available in the precolonial Caribbean (Pestle 2010), the estimated $\delta^{13}\text{C}_{\text{protein}}$ values of the local population overlap considerably with the range of $\delta^{13}\text{C}$ for both C_3 plants and land animals but not with C_4 plants or marine animals. In contrast, the $\delta^{15}\text{N}_{\text{protein}}$ values of the majority of samples overlap primarily with the range of $\delta^{15}\text{N}$ in (pelagic) marine animals. Therefore, the estimated protein diet at the site does not match well with any of these four specific native Caribbean food groups. It should be noted that (combined) low carbon and high nitrogen consumer collagen isotope values have been interpreted as reflecting the consumption of freshwater fish in certain archaeological contexts (e.g., Harrison and Katzenberg 2003), but no archaeological, faunal, or textual evidence

indicates that this is a feasible primary food source at El Chorro de Maíta.

Abundant historical records document both the early arrival and rapid expansion of domestic pig populations within the Spanish colonies of the Caribbean (del Río Moreno 1996). Domestic pigs are expected to have low $\delta^{13}\text{C}$ owing to a reliance on C_3 plants, in addition to moderately enriched $\delta^{15}\text{N}$, due to omnivory. A small dataset ($n=9$) of pig dentine collagen stable isotope values (mean $\delta^{13}\text{C}_{\text{dent}} = -20.7 \pm 1.4\text{‰}$; mean $\delta^{15}\text{N}_{\text{dent}} = 7.6 \pm 1.1\text{‰}$) from various sites in the Caribbean displays this pattern, with isotope values that are comparable to the main cluster of local El Chorro de Maíta individuals. There is nevertheless considerable variation in the estimated protein isotope values, which indicates substantial diversity in the relative contributions of these different food groups to individual diets. In general terms, these comparative data are consistent with the combined human stable isotope results, indicating mixed diets incorporating plants and marine and terrestrial animals but

with a major contribution from the meat of domestic livestock (pigs) to the protein component of the diet for the majority of the local population.

Intrapopulation Variation

The observed diversity in dietary practices evidenced by the stable isotope data is at least partially explained by the large numbers of nonlocals within the population and their highly diverse origins. This diversity is most evident in the isotope values of individuals CM45 and CM72B who appear to have been highly reliant on C_4 plants but is also found in several individuals with very low $\delta^{13}C_{\text{protein}}$ and $\delta^{15}N_{\text{protein}}$ values approaching a pure C_3 plant diet. Notably, three out of the four most depleted $\delta^{13}C_{\text{protein}}$ values are from juveniles, whereas three out of the four most enriched $\delta^{13}C_{\text{protein}}$ values are from nonlocals. Given that the nonlocals CM45 and CM72B also have deviant bone collagen isotope values, they probably died before their bones could equilibrate to the local dietary pattern. This is consistent with the high rates of mortality among enslaved individuals in colonial times and the potentially catastrophic mortuary profile of the El Chorro de Maíta cemetery population (Weston and Valcárcel Rojas 2016). Nevertheless, statistical tests based on sex, age, geographic origins, or cranial modifications only identified significant differences in $\delta^{15}N_{\text{dent}}$ for two variables. Specifically, there are statistically significant differences in $\delta^{15}N_{\text{dent}}$ based on *age*, with juveniles having significantly higher values ($M = 14.6\text{‰}$, $SD = 0.7$) than adults ($M = 13.1\text{‰}$, $SD = 2.9$); $t(34) = 3.65$, $p < 0.001$; and based on *origins*, with locals having significantly higher $\delta^{15}N_{\text{dent}}$ ($M = 14.2\text{‰}$, $SD = 1.3$) than nonlocals ($M = 11.8\text{‰}$, $SD = 2.6$); $t(12) = 4.23$, $p = 0.001$.

The differences in $\delta^{15}N_{\text{dent}}$ between juveniles and adults are notable because the values in both groups should in principle reflect roughly the same ages of formation. Given that the sampling of teeth for dentine collagen targeted the later-forming distal tips of the roots to avoid possible influences of breastmilk consumption on measured isotope values, it is not likely that a breastfeeding effect could account for the enriched dentine $\delta^{15}N$ values of either group. By contrast, the observed differences in $\delta^{15}N_{\text{dent}}$ between

adults and juveniles may reflect differential survivorship, with the former representing survivors and the latter nonsurvivors (e.g., Beaumont et al. 2013). If so, this specific data pattern might indicate a possible link between childhood malnutrition (indicated by elevated $\delta^{15}N_{\text{dent}}$) and mortality (juvenile age at death; Gowland 2015), but more research is required to explore this in greater depth.

Large differences in $\delta^{15}N_{\text{dent}}$ relative to different (natal) geographic origins could result if local individuals, particularly local juveniles, born and raised during the imposition of the *encomienda* system, would have had access to higher trophic level food sources during childhood. Nonlocal individuals, by contrast, could have had quite different dietary habits in their youth, which would be preserved in their dentine stable isotope signals and reflect the food cultures of their various homelands. Yet it should be noted that it is somewhat questionable to treat nonlocals of diverse origins as a coherent statistical group for the sake of comparisons, given the diversity of origins suggested by the isotopic, archaeological, and bioarchaeological evidence (Laffoon 2016).

Several patterns are evident concerning the observed differences between enamel and bone apatite $\delta^{13}C$ values. For the vast majority of individuals, $\delta^{13}C_{\text{enam}}$ is lower than $\delta^{13}C_{\text{apat}}$. The generally lower $\delta^{13}C_{\text{enam}}$ values could result from a breastfeeding effect or simply reflect minor age-related differences in dietary intake over time. Interestingly, the slight offset between $\delta^{13}C_{\text{enam}}$ and $\delta^{13}C_{\text{apat}}$ is also apparent for juvenile individuals, potentially owing to differences in the time spans represented by the two sample types. Importantly, the differences between these two datasets are not statistically significant either at the scale of the entire sample or for paired tooth-bone samples of the same individuals, and the degree of intra-individual offsets is highly variable. Such patterning could also perhaps be explained by differential diagenesis of bone samples if, for example, some bone apatite samples were more isotopically altered than others. Nonetheless, the lack of systematic differences between the enamel and bone apatite carbon isotope values and the fact that all but three of the latter fall within the range of the

former would seem to suggest a lack of diagenetic alteration in the $\delta^{13}\text{C}_{\text{apat}}$ dataset, thus indicating a high degree of correspondence between childhood and adult diets.

In fact, although large intra-individual differences were observed for paired enamel-bone and paired dentine-bone samples for several individuals, this large variability was not limited to nonlocals. This pattern could result from a limitation of the strontium isotope method itself, which cannot identify nonlocals originating from isotopically similar regions (false negatives); alternatively it could indicate that large-scale dietary changes also occurred among some locals. This second possibility would not be too surprising, considering (1) that many other regions of Cuba (and the Caribbean in general) possess similar ranges of bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ (Laffoon et al. 2012) and given (2) the documented diversity of dietary practices on such a large, and ecologically and culturally diverse, island as Cuba (Chinique de Armas et al. 2016). Lastly, the relatively limited range (ca. 4‰) of enamel/apatite $\delta^{13}\text{C}$ values contrasts sharply with the enormous range (ca. 13‰, excluding nonlocals) of dentine/bone collagen $\delta^{13}\text{C}$, possibly indicating a greater diversity of protein diets compared to whole diets.

Interpopulation Variation

Placing the isotopic datasets within a broader regional context, we compared the collagen isotope data with several precolonial and colonial period populations from the Caribbean (Figure 8). Starting with intra-island comparisons, the local El Chorro de Maíta population has higher values for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ than most other indigenous Cuban populations, with the notable exception of Canímar Abajo. Although the locals at El Chorro de Maíta and the Canímar Abajo population have overlapping $\delta^{13}\text{C}$ ranges, the mean $\delta^{15}\text{N}$ is more than 2‰ higher for the former. At Canímar Abajo, diets are purported to have been heavily reliant on plant and shellfish resources (Chinique de Armas et al. 2016), which may account for their relatively lower $\delta^{15}\text{N}$ values. Turning to comparisons with precolonial Caribbean populations, the El Chorro de Maíta dataset also possesses a broadly similar range of collagen $\delta^{13}\text{C}$

values but elevated $\delta^{15}\text{N}$ values compared to other indigenous populations from across the Antilles. In fact, the combined collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for El Chorro de Maíta display little overlap with any of the indigenous populations from Cuba or the insular Caribbean more broadly. The higher $\delta^{15}\text{N}$ values at El Chorro de Maíta indicate a larger relative contribution of animal protein, the consumption of higher trophic level animal resources compared to other precolonial Caribbean populations, or both.

This conclusion is supported by comparing the El Chorro de Maíta results with several colonial-era populations from the Caribbean (Figure 8). In terms of combined collagen carbon and nitrogen isotope values, the local El Chorro de Maíta population is comparable to some, but not all, colonial period enslaved African populations within the Antilles; for example, at English Harbour, Antigua, and Harney, Monserrat (Sparkes et al. 2012; Varney 2003). In contrast, other enslaved African populations from the colonial-era Caribbean such as Ste. Marguerite, Guadeloupe (Sparkes et al. 2012), and Newton Plantation, Barbados (Schroeder et al. 2009), possess considerably higher collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values than El Chorro de Maíta. The combined collagen isotope values at these latter two sites are more consistent with higher rates of marine protein consumption. Interestingly, the enamel and bone apatite $\delta^{13}\text{C}$ values at El Chorro de Maíta are broadly similar in both precolonial and colonial period Caribbean populations and display much less spatial or temporal variation than collagen $\delta^{13}\text{C}$ values (Stokes 1998). One plausible explanation for these observations is that there was a pronounced change in protein diets across the historical divide but comparatively less change to the plant component of diets (at least in terms of the relative proportions of C_3 and C_4 plants).

In summary, the overall patterns in stable isotope results at El Chorro de Maíta and other colonial period sites in the Caribbean reflect greater access to terrestrial animal protein sources during the colonial period, likely as the result of the introduction and dispersal of European domestic livestock within extensive colonial economic systems. The incorporation of Old World domestic livestock such as pigs into dietary regimes that

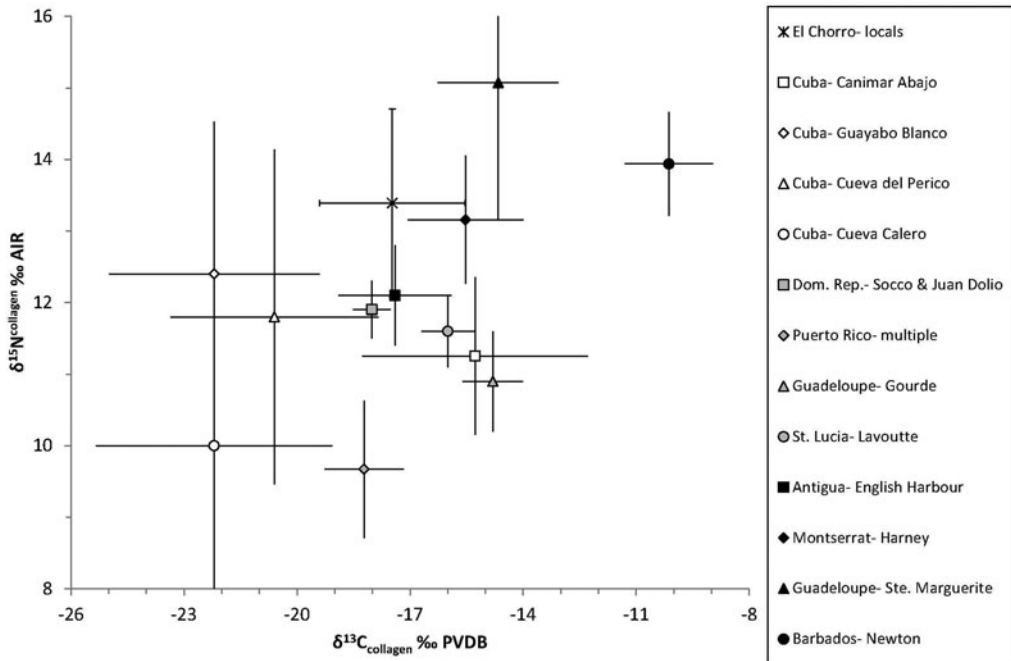


Figure 8. Bone collagen stable isotope values ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) from El Chorro de Maíta compared to precolonial (indigenous) populations from Cuba and to precolonial (indigenous) populations from elsewhere in the Antilles, and late colonial period (enslaved) populations from the Antilles (black symbols). (Data sources: Chinique de Armas et al. 2016; Laffoon and de Vos 2011; Laffoon et al. 2016; Pestle 2010; Schroeder et al. 2009; Sparkes et al. 2012; Stokes 1998; Varney 2003.)

were predominantly indigenous oriented is consistent with the observed patterning of the stable isotope and zooarchaeological data at El Chorro de Maíta. This is evidenced by the general lack of difference in enamel/apatite $\delta^{13}\text{C}$ values between El Chorro de Maíta and other indigenous Caribbean populations, the intermediate collagen $\delta^{13}\text{C}$ values indicating mixed diets of plant and animal proteins, and especially the elevated $\delta^{15}\text{N}$ values at El Chorro de Maíta that correspond well with those observed for domestic pigs in the Antilles. This pattern may also reflect a broader regional trend by which specific Old World animals were fairly rapidly incorporated into New World subsistence economies during the early years of Spanish colonization of the Caribbean (del Río Moreno 1996).

Conclusions

In this article we presented a large corpus of stable isotope data from the burial population of El Chorro de Maíta, Cuba, and provided

new insights into dynamic patterns of dietary diversity and change during the first generations of the colonization of the New World. The combined isotope results, particularly collagen isotope results, indicate extremely diverse diets at El Chorro de Maíta among not only nonlocal individuals but also within the local population. There are many possible reasons why the local indigenous population may have had highly variable diets in the early colonial period, including but not limited to differences in social status, socioeconomic relations, work activities or occupations, and access to food sources, as well as the possibility that the cemetery includes individuals who did not reside at the site but originated from other places in Cuba, or beyond, with distinct dietary habits and culinary traditions.

A few long-distance immigrants, including one originating from Mesoamerica (CM72B) and one from Africa (CM45), had correspondingly distinct dietary habits. Therefore, the multiple isotope proxies indicate that some nonlocals either maintained the dietary patterns of their

homelands after migration or more likely died before their tissues could equilibrate to local dietary patterns. There are nevertheless very few systematic differences between different social groups based on demographic factors (sex and age) or geographic origins (locality). The significant differences in dentine nitrogen isotope values between juveniles and adults and between locals and nonlocals reflect not only the correlation of these variables but also the possibility that locally born juveniles who died in the sixteenth century had distinctly different diets than did other groups within this burial population. This conclusion is supported by the fact that a number of individuals possess pronounced (intra-individual) differences in isotope values from different sample types (paired enamel-bone or dentine-bone samples), including several locally born individuals. These patterns may record individuals who experienced large-scale dietary changes over life courses spanning the historical divide between precolonial and colonial times.

Large-scale chronological changes in dietary patterns are also indicated by the greater similarity of the El Chorro de Maíta isotope results to certain enslaved African populations, rather than to other precolonial populations from Cuba or the Caribbean in general. Thus, differences in dietary practices at multiple scales from the individual to the population level suggest relatively rapid (within ca. 50 years) transitions in indigenous foodways. Although the highly variable human isotope data and general lack of comparative baseline (foodweb) isotopic data for the site make it difficult to generalize about dietary reconstructions, the majority of locals at El Chorro de Maíta seem to have consumed mixed diets dominated by a combination of C_3 plants and terrestrial animal proteins. Nevertheless, the moderately elevated apatite and collagen isotope values are not consistent with pure C_3 diets and suggest smaller but substantial contributions of C_4 plants, seafood, or both. Pork is a likely source of the consumed terrestrial animal protein based on the combined historical, zooarchaeological, and isotopic evidence, but the consumption of meat from other imported domestic livestock cannot be ruled out. The totality of evidence thus

suggests that under the *encomienda* system the indigenous community at this site obtained rapid access to newly introduced foods either via provisioning by Europeans, the hunting of feral pigs, or even the raising of domestic pigs themselves.

Overall, the high diversity in diets documented at El Chorro de Maíta cannot clearly be attributed to any single cause and probably results from the interplay of a multitude of factors including temporal, social, cultural, demographic, and idiosyncratic variables. Several unresolved questions concerning various aspects of dietary and subsistence patterning at El Chorro de Maíta will be addressed in future research. These include expanding the baseline foodweb stable isotope data for both the precolonial and colonial period sites on Cuba, quantifying dietary inputs using Bayesian multiple source mixing models, investigating temporal changes in weaning practices via serial sampling and stable isotope analyses of dentine collagen, and conducting compound-specific isotope analyses (CSIA) of individual amino acids to disentangle the relative influences of terrestrial and marine food sources. Lastly, it is our hope that the research framework developed for this study can be applied to investigate the continuity and change of indigenous lifeways in the face of culture contact, conquest, and colonization at other sites within the Caribbean and the Americas more broadly.

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Data Availability Statement. All data generated or analyzed during this study are included in this published article.

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Supplemental Table 1. Sample Information and Isotope Results from El Chorro de Maíta, Cuba.

Supplemental Table 2. Statistical Summary of Stable Isotope Data from El Chorro de Maíta, Cuba.

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