Weaning and Early Diet Reconstruction from an Ancient Archaeological Site in California

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Abstract

This study examines weaning practices and early childhood diet at a 3000-year-old archaeological site in the California Delta, CA-SJO-112, or the Bear Creek Site, located in the modern city of Stockton. Human permanent first molars form between the ages 0 and 9 years, and record dietary practices while the tooth is forming. Collagen is extracted from serial samples in first molars, and stable carbon and nitrogen isotopes measured to reconstruct diets across this window of time, which includes the weaning process. The data facilitate comparison of diets of boys vs. girls within the site, and potentially, measures of parental investment in offspring. Data from 8 individuals at CA-SJO-112 are compared to a previous study at a contemporary site 40 km to the east, CA-CCO-548, or the Marsh Creek site. Analyses at the latter site showed that most children were weaned between 3 and 4 years of age, that boys consumed greater amounts of higher trophic-level fish and meat protein than girls, and that girls were weaned at slightly later ages. Data from this study will indicate differences in contemporary sites located in different geographic regions of California and the impact of environmental and cultural patterns on early childhood diets.

Key Words: Stable Isotope analysis; microsampling; gender roles; California Prehistory; age of weaning; dietary reconstruction; first molar, early life history; parental investment

Introduction

Stable isotope analysis of skeletal materials provides insight into ancient human behavior at the scale of the individual, an area of inquiry where other lines of evidence are often unavailable. While analysis of midden constituents can tell us about human behavior at the level of a population and refuse within domestic houses can inform on families, there are few other approaches that allow us to reconstruct individual practices.

Stable isotope analysis is being used to address an increasingly wide range of ancient behaviors, including paleodiet, mobility patterns, and marriage networks (DeNiro 1985; Price and Burton 2012). More recently, stable isotopes have been used to reconstruct age at weaning and early childhood diet in ancient populations (e.g., Eerkens, 2011; Choy et al., 2010; Fuller et al.,2006; Gardner et al., 2011). Age of weaning is one clear indicator of parental investment in offspring. On the one hand, breast milk provides an offspring a reliable and easily digestible source of calories and nutrients and contains important antibodies. On the other hand, its production is a significant energetic investment and reduces the fertility of the mother (Borgerhoff-Mulder, 1992).

Recent studies on the long-term effects of breast milk consumption indicate the value of longer breastfeeding and increased parental investment in the survival and fitness
of offspring. In the evolution of mammals, such benefits must have greatly outweighed the energetic and fertility costs to females (Hinde and Capitanio, 2010; Hinde et al., 2009). However, there is a diminishing value to an offspring over time versus the costs to the mother. Thus, while breastfeeding is extremely valuable to an infant (0-1 year) and greatly increases the probability of survival into adulthood, the increase in probability of survival to adulthood for a toddler receiving breast milk (1-3 years) is less, and even less so for a young child (3+ years). Furthermore, the cost to the mother to produce breast milk remains equally high for an infant versus toddler versus young child. Thus, mothers must balance investing in their offspring through breastfeeding with increased caloric intake (and work) to produce breast milk and lower probability of getting pregnant again (i.e., the number of potential future children).

Variation in weaning practices, including dissimilarity in age of weaning (termination of breast milk consumption), among ancient populations has become of great interest to archaeologists. Behavioral ecological models make predictions about the age of weaning relative to environmental risk. For example, Quinlan (2007) suggests that maternal investment in offspring varies inversely with rate of famine and warfare within a range of modern societies. He found that age of weaning was strongly correlated with pathogen stress, where low and high rates of disease are correlated with earlier weaning, and moderate pathogen stress with the highest average age of weaning. As a result, environmental conditions can have a strong effect on parental investment strategies. As well, individual choices and cultural norms can have strong effects on decisions mothers make on how long to breastfeed their children. Because stable isotope analysis allows archaeologists to estimate age of weaning for individuals in the past, and the archaeological record can provide a long-term perspective on varying rates of disease, warfare, and environmental conditions, it is possible to test Quinlan’s model using archaeological data.

This study focuses on reconstructing the age of weaning in an archaeological population in Central California dating between 3000 and 3300 years ago at the site CA-SJO-112. There is no written history in California hunter-gatherer populations. Thus, archaeological evidence is the only way to reconstruct ancient lifeways. Stable isotope analysis typically complements other analyses from excavated sites, including faunal and paleobotanical analysis, that are used to reconstruct paleodiet. However, in the case of CA-SJO-112, faunal and floral remains were not systematically gathered during excavation. As a result, stable isotope analysis is the major means by which we can estimate the diets of people who lived at this particular site.

**Background**

Biological tissues in the human body are synthesized from ingested food and water. These food and water sources may have different underlying isotopic compositions, or signatures, which are subsequently captured in human biological tissues. Collagen is a protein that helps to form connective tissues, especially in bone and dentin (Tieszen and Fagre, 1993). However, tooth and bone collagen have different formation patterns. In bone, collagen is continually remodeled throughout an individual’s lifetime, with an average replacement/remodel rate of 10-20 years depending on the skeletal element. As a result, isotopic data collected from bone
The approach relies on the assumption that there is a trophic level difference between mother and infant (i.e. hold a different position within the food chain). A breastfeeding infant is expected to be enriched one full trophic level relative to the mother. The research below focuses on nitrogen and carbon isotope ratios as a marker of such dietary shifts. $\delta^{15}N$ in collagen reflects the general tropic levels of protein consumed by an individual, while $\delta^{13}C$ reflects the carbon source of dietary protein. Prior to inclusion of solid foods, when breast milk comprises all of the diet, $\delta^{15}N$ should be at its highest level. During the weaning process, as a child is transitioned away from breast milk and onto a diet consisting of primarily solid foods, $\delta^{15}N$ should drop by approximately 2-4‰, into the range of other adults (Eerkens et al, 2011). Following weaning, $\delta^{15}N$ will reflect the trophic level of the weaning food and early childhood diet. Likewise, $\delta^{13}C$ may show slight changes through the weaning process and into the childhood period if there is a shift in the source of protein. How quickly $\delta^{15}N$ drops depends on how abruptly a child is weaned and the quantity of solid foods incorporated in the diet over time. The source of weaning food will also affect how much the $\delta^{15}N$ value will decline. For example, inclusion of large amounts of plant gruel, especially legumes, will cause $\delta^{15}N$ to drop to very low levels since they are at the bottom of the food pyramid. By contrast, inclusion of large amounts of terrestrial game will cause $\delta^{15}N$ to drop to more intermediate levels as herbivores are one trophic level above plants. Because the roots of first molars continue growing until age 9.5 years and humans are typically weaned well before this age we can follow diets after weaning.
A total of 36 burials and 2 features were excavated and recorded by Olsen (Olsen and Wilson 1964). The most common burial posture is fully extended and face down, but a significant number of burials were placed on their backs or were in other forms of flexure. Fully extended burials in the California Delta are typical of the Early Period (ca. 4500-2500 BP), but are less common later in time. Table 1 lists burials information and grave good statistics for all 36 excavated burials including features one and two (note that some burials contain multiple individuals).

Radiocarbon dates on bone collagen from 8 individuals indicate that the majority of individuals at CA-SJO-112 were interred between approximately 3000 and 3300 BP. This study attempts to reconstruct the age of weaning for eight individuals (table 2).

Methods

The research methods follow those described in Eerkens et al (2011) in order to reconstruct the weaning process. This study examines first molars from eight individuals. Collagen was extracted from the dentin component for δ15N and δ13C stable isotope analysis. Because first molars (M1) erupt early in life, they are often heavily worn in ancient populations. This is especially true in California, which has some of the highest rates of occlusal attrition anywhere in the world (Eerkens et al 2011; Jurmain, 1990). In a few of the samples from CA-SJO-112 (n=4) much of the enamel and some of the underlying dentin within the crown were lost to attrition. In a growing tooth, dentin begins forming at the DEJ and grows in successive layers toward the root. As a result, attrition has removed some of the earliest-growing dentin (i.e., and through the early childhood years by analyzing sections from the root of this tooth.

This study follows Fuller et al (2003) and Eerkens et al. (2011) where first molars were sectioned into serial samples with dentin collagen extracted from each section and measured for δ15N and δ13C. This methodology is based on the fact that dentin grows sequentially from the crown to the root tip over time, allowing the reconstruction of diet over small windows of time during tooth growth. First molars begin growing at the time of birth (age=0) at the DEJ. The crown is typically complete by 2.5-3 years of age, marked by the cementum-enamel junction (CEJ). Apical root tips close around 9.5 years of age (Hillson, 1996). Typically, between 8 and 16 serial samples are extracted per tooth, averaging diet at 0.5-1 year intervals. However, for some teeth with high tooth wear, the early part of this sequence is removed, obliterating some or the entire weaning signal. If enough of the tooth is present, and collagen is reasonably well preserved, a single first molar can be used to reconstruct the entire weaning process as well as a significant part of early childhood diet.

Sample

CA-SJO-112, or the Bear Creek Site, is located on the bank of a small stream, Bear Creek, in the California Delta near present day Stockton (figures 1 and 2). Preliminary investigations in the late 1950s indicated that two-thirds of the site had been destroyed with the remaining one-third available for salvage excavation. William Olsen excavated the remaining one-third of the site in the 1950s because it was continuing to be destroyed due to suburban landscaping. No faunal remains were collected leaving stable isotope analysis as the only means of reconstructing diet at the site.
between age 0 and 1), limiting our ability to reconstruct diet during the earliest stages of life. In some heavily worn teeth where dentin corresponding to a longer period of time (i.e., between age 0 and 3) is missing, the entire weaning signal has been removed.

Each tooth was cut in half to isolate one complete root and adjoining section of the crown, cleaned with distilled water, and then set out to dry for 24 hours and photographed. Each tooth was measured noting the relative location of important landmarks, in particular, the DEJ, if present, the CEJ, and the apical root tip. All enamel was removed and saved for future and ongoing isotopic studies. The remaining cementum and any exposed dentin was also completely removed by abrasion with a drill bit, to remove potential surface contamination including any visible material in the pulp chamber.

Cleaned samples were washed and sonicated in deionized water and immersed in 0.5M HCl for demineralization. HCl was replaced every 1-2 days until the tooth no longer visibly reacted with the HCl solution and was spongy in texture (typically 5-10 days). Following demineralization, the tooth was rinsed with deionized water and sliced with a scalpel into thin parallel sections approximately 1-2mm thick, perpendicular to the central axis of the root. It is evident that these sections cross the growth lines of dentin, especially in the root where growth lines are more angled (see Figure 3). The sampling procedure generated between 8 and 16 serial sections per tooth, depending on the degree of tooth wear and the size of the tooth. Figure 3 shows a hypothetical tooth and the general sampling methodology.

Table 3 presents information on the 8 teeth included in the study, including the length in mm from the root tip to the CEJ and the distance from the CEJ to the occlusal surface (in most cases the DEJ had been partially or completely worn away). The number of serial samples analyzed by mass spectrometry from each tooth is also shown.

Demineralized dentinal sections were then placed in separate glass vials, labeled, and treated with 0.125M NaOH for 24 hours to remove humic contaminants. Samples were then rinsed with dH2O, immersed in pH≈3 water, and placed in an oven at 80°C for 24 hours to solubilize the collagen. Samples were then filtered, with the liquid fraction removed and freeze-dried. Collagen δ15N and δ13C was measure by continuous-flow mass spectrometry at the Stable Isotope Facility at UC Davis.

**Results**

Figures 4-11 show δ15N (in green) and δ13C (in blue) dentin serial sections for the first molars for all eight individuals sampled. δ15N and δ13C are plotted on the vertical axis, while approximate age in years is plotted on the horizontal axis.

δ15N is the main marker used in determining age of weaning, although both δ13C and δ15N help determine early childhood diet. Within the serial samples, δ15N typically begins high on the left, representing the earliest growth remaining on the tooth (ca. age 0-2 depending on the amount of occlusal wear and tooth attrition). The δ15N value at this point is typically 2-3% above the adult solid food diet at this point, and then decreases in all subsequent serial samples (Eerkens et al, 2011). The decreasing δ15N value has been interpreted as a weaning signal, indicating a drop in trophic level from the mother’s breast milk early in the sequence to complementary solid or liquid foods. A 2-3% drop is consistent with what would be expected for a single
trophic level decrease (Minagawa and Wada, 1984). The data from figures 4-11 indicate considerable variation in the presence of a weaning signature as well as the rate of decreasing breast milk and age of completion.

In some cases, such as burials 4, 9, 16, and 17, a weaning signature is not clearly defined. That is, there is no indication of a 2-3% drop in δ15N used to indicate a reduction in breast milk consumption. The lack of a weaning signature can be attributed to severe occlusal wear most likely due to the age at which the individual died. In individuals that do not show clear signs of weaning, conclusions regarding age at which breast milk consumption was terminated cannot be reached. It is only possible to state that weaning must have happened prior to the age represented by the first serial sections. Although the age of weaning cannot be determined with accuracy, these burials still provide valuable information regarding early childhood diet.

Burial 4 (figure 4) is an individual of indeterminate sex. This individual died between the ages of 12 and 20 years old. This burial shows no significant indications of weaning. This is most likely due to occlusal wear, which removed early-growing layers of dentin where the weaning signature should have been. Weaning for this individual occurred before 27.6 months of age (2.3 years), the youngest serial sample available for analysis.

Burial 9 (figure 5) is another example of an individual where a weaning signature is not present. Similar to burial 4 this can be attributed to significant wear on the occlusal surface of the tooth. This individual is a female who died between the ages of 30 and 40 years old. Weaning for this individual occurred before 22.8 months or 1.9 years of age.

Burial 16 (figure 6), a male who died between 50 and 60 years, has no clear weaning signature present. Weaning for this individual occurred before 14.4 months of age (1.2 years).

Burial 17 (figure 7), a female who died between the ages of 40 and 50 years, also lacks a weaning signal due to occlusal wear. Weaning in this case happened later in childhood before 38.4 months or 3.2 years of age.

In the cases of burials 4, 9, 16 and 17, weaning is not shown in either δ15N or δ13C isotopes. This lack of a weaning signature can be attributed to wear on the occlusal surface of the M1 tooth. Information regarding the definite age of weaning cannot be reached. It is however, possible to determine an age in which weaning occurred before. This is done using the earliest available serial sample. The remaining teeth, discussed below, all showed a clear weaning signal, as expected.

Burial 11A (figure 8) is a female who died between the ages of 30 and 40 years old. This burial shows evidence of abrupt weaning before the CEJ formed. This means that the termination of breast milk occurred abruptly before the development of the CEJ at 2.8 years of age (33.6 months). We estimate that this individual was weaned at 36 months of age or 3 years old.

Burial 20 (figure 9) is a female who died around the age of twenty years. This burial also shows evidence of abrupt weaning before the CEJ formed (approximately 2.5-3 years of age). This individual was weaned relatively early at 13 months of age or 1.1 years old.

In some cases the cause for termination of breast milk is unclear. Burial 23 (figure 10) represents an individual whose sex is indeterminate. This individual died in early adolescence between the ages of 14-17. This burial shows evidence of two weaning
signatures. One occurs at 1 years old with resumed consumption of breast milk at 1.6 years of age and complete termination of breast milk at 2.7 years. This disruption in breast milk consumption can be attributed to various scenarios, including stress on the individual or the mother. The cause of stress is unknown in this individual. Age of weaning is approximated at 1 years old.

Burial 26i3 (figure 11) represents a possible male who died late in life around age 60 years. Nitrogen isotopes indicate this individual was weaned at 3.4 years old. This individual shows a significant increase $\delta^{15}N$ values over early childhood particularly around age 7.

**Discussion**

It should be noted that serial samples used in the analysis of these eight individuals are not mutually exclusive in the time and growth they represent. First molars begin growing at birth at the DEJ. This landmark is often absent in samples due to occlusal wear. The crown in the first molar completes growing between the ages of 2.5 and 3 (Hillson, 1996), set at 2.75 years of age at the CEJ in this study. Using an average dentin crown height of 4.8 mm (DEJ-CEJ distance) rate of growth was calculated to 1.75 mm/year, with completion of growth at 9-9.5 years of age. A linear rate of growth between the CEJ and root tip was assumed resulting in 1.87 mm/year in the root. (Note: actual rates of growth vary between individuals)

In this study a time average growth rate, especially in the root was used to calculate significant events within early years of life. Eerkens et al (2011) applied information about growth and percentage of growth overlap to model four different weaning scenarios and how they would appear in serial sections of a tooth. These scenarios include abrupt (before or after CEJ) or gradual (before or after CEJ) transition (weaning) based on the rate at which $\delta^{15}N$ decreases (see figure 12).

Four burials sampled from SJO-112 show the drop in $\delta^{15}N$ associated with a weaning signature, 11A, 20, 23, and 26 ind 3. Of these, three follow a pattern characterized as abrupt (Eerkens et al., 2011), while one, burial 26 ind 3, appears to have been more gradual.

There is still however; a great deal of variation in weaning behavior within the SJO-112 sample. This finding is in line with previous studies among modern societies where there is tremendous intra-population variation in weaning (Sellen, 2006). While a significant percentage of individuals in this sample experience abrupt weaning before the CEJ formed, there is significant variation in age of weaning between individuals. For example, burials 20 and 23 experienced weaning between 12 and 13 months of age, while burial 11A was weaned closer to 3 years old. Future analysis on a larger sample size is needed to indicate whether these four are typical of this site in general. However, the majority of individuals with a weaning signature experienced abrupt weaning, with a known average age of weaning at 25.5 months.

Robert Quinlan (2007) discusses the correlation between environmental conditions and parental investment in an offspring, including specifically the age of weaning. His model suggests that basic parental care benefits offspring, but extrinsic risk creates substantial diminishing returns to parental effort.
There is a ‘saturation’ point (Smax) beyond which fitness does not respond to additional parental care. If extrinsic risk is high, then parents reach Smax at lower levels of effort. Hence, channeling resources away from parenting into mating effort or additional offspring should enhance fitness when extrinsic risk is high. But, if extrinsic risk is low, then the saturation point of parental care is high and responsive parenting can have important influence on a child’s survival and ultimate success. In sum, tradeoffs between mating and parenting efforts, or offspring quality and quantity, depend on whether environmental hazards can be avoided by increasing parental effort (Quinlan, 2007). This model is reproduced in Figure 13 below.

In a series of modern populations, Quinlan showed that age of weaning increased as pathogens increased to moderate levels (see Figure 13. However, age of weaning decreased again at higher pathogen levels. Parental investment decreased with high and low levels of pathogen stress. This means that when environmental conditions are of high or low quality parental investment decreases, at moderate environmental conditions parental investment increases to maximum investment.

SJO-112 has an estimated average age of weaning of 25.6 months. This is much lower than estimates at a contemporary site in California, CA-CCO-548, where the average age of weaning found by using identical methods was calculated at 43 months (Eerkens and Bartelink 2013) (see Table 5). CA-CCO-548 or “Marsh Creek” is an archaeological site that lies on the western edge of the Sacramento-San Joaquin Delta in Central California, on the banks of Marsh Creek. Radiocarbon dates estimate the age of this site as 3000-4000 BP. Though in a different geographical location in California, this site is contemporary in time to SJO-112.

Results suggest early age of weaning at SJO-112, and furthermore, lower parental investment. Using the Quinlan model of parental investment, environmental conditions at SJO-112 can be interpreted as either of higher or lower quality than CCO-548. It is unclear whether environmental conditions reflected a productive high quality or an unproductive low quality environment. Yet, it is clear individuals at SJO-112 experienced earlier weaning, with lower parental investment. Burials with interesting δ15N and δ13C signatures provide insight into environmental conditions at CA-SJO-112. Burials 11A and 23 show signs of multiple weaning signatures, meaning multiple decreases and increases in δ15N in the first year of life. The termination of breast milk at early ages has implications for infant stress, and, furthermore, indications of a poor environment.

As at SJO-112, there is significant variation in weaning behavior at CA-CCO-548. There is a large time spread among the individuals sampled by Eerkens and Bartelink (2013) at Marsh Creek (almost 600 years). This is a possible explanation for variation in weaning behavior. It is just as likely; however, that variation surrounding weaning practices is due to intra-population variation. SJO-112 also shows evidence of variation, yet there is not a large time span to account for this variation.

Information presented in Table 6 indicates several possible differences between male and female individuals at SJO-112. First, female individuals seem to have been weaned abruptly more often. Both male and female individuals differ slightly in δ15N and δ13C levels. Differences in δ15N and δ13C seem to be based on the
individual level and not a sex-based pattern. CA-CCO-548 shows considerable differences in sex based weaning patterns. First, females were completely weaned at a slightly older age, on average, than males. Males and females also differed consistently in their average δ15N values at all ages, with males always having more elevated values. Thus, these males started life consuming protein from higher trophic levels than females, a pattern that appears to have continued throughout their lives (Eerkens and Bartelink, 2013). This pattern does not seem to hold at CA-SJO-112. Instead, boys and girls seem to have been consuming protein from roughly equal trophic levels, both during and after weaning.

**Conclusion**

The purpose of this study has been to reconstruct age of weaning and early dietary composition at an archaeological site in the California Delta. Age of weaning is a clear indicator of parental investment in early childhood. Although age of weaning at SJO-112 showed inter-individual variation, estimated age of weaning on average was determined to be 2.1 years of age. This is significantly earlier than a contemporaneous site in California, and earlier than ethnographic documentation of 20th century hunter-gatherer groups (Crittenden et al., 2013; Barry and Paxson, 1971).

Parental investment at CA-SJO-112 is dramatically lower than expected to ensure child survival into adulthood. Survival and fitness of offspring is strongly correlated to parental investment (i.e. breast milk consumption). The limited parental investment can be attributed to two different scenarios: high quality environment with rich resource availability or poor environmental conditions in which parental investment is low (Quinlan, 2006). Evidence from SJO-112 may indicate a poor environment. In particular, two burials show evidence of multiple weaning signatures within the first two years of life. This multiple weaning signature can potentially be attributed to infant or parental stress due to environmental conditions, as does the early age of weaning documented in the other individuals.

High levels of variation in age of weaning are documented throughout the individuals sampled for this study. There is not a high level of variation between individuals of differing sex, meaning there is little to no variation between sexes or no sex differentiation in early childhood. This pattern is different from a contemporary site in California, CA-CCO-548, in which there are significant differences in early childhood diet between boys and girls.

Although age of weaning remained relatively consistent, the data show significant differences between individuals. The majority of individuals with obvious weaning signatures were weaned abruptly yet one individual was weaned gradually. The source of the weaning food in most cases appears to have been a low trophic level food with little or no marine-derived protein. All of the eight individuals were buried with some grave goods, indicating a relatively egalitarian social structure.

Environmental conditions can have a strong effect on parental investment strategies; however, individual choices and cultural norms can also have strong effects on the breastfeeding of children. Stable isotope analysis has provided a way to test parental investment strategies by documenting age of weaning. There is clearly still much to learn about parental investment as it is related to age of weaning in ancient populations. A larger sample size is needed to further document the patterns recognized at SJO-112. A study of diet
later in the lifetime of individuals is necessary to determine if the egalitarian pattern noticed continues through adolescence and into adulthood. This could be accomplished by stable isotope analysis of serial sections in third molars. There is still much to learn through the examination of the life histories of specific individuals from the past.

Acknowledgments
A great thank you goes to Dr. Jelmer Eerkens for his constant guidance, input, and patience without which this project would have been impossible. I would also like to thank Alex Greenwald for her hands on assistance throughout data collection and analysis. I also wish to thank the UC Davis Stable Isotope Facility for assistance with the stable isotope work.
Figures and Tables

![Map of SJO-112 & contemporary site CCO-548](image1)

![Google Earth image of SJO-112 & darker soil that may represent the remains of the midden](image2)

<table>
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<th>Without grave goods</th>
<th>Totals</th>
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Table 1. Presents data for all individuals excavated.
Table 3: Size and measurements for each tooth in this study, and number of isotopic serial samples analyzed.

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<tr>
<th>Burial</th>
<th>Tooth</th>
<th>Root tip – CEJ (mm)</th>
<th>CEJ-Occlusal surface (mm)</th>
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* This column reports the number of isotopic samples actually run. All teeth were cut into 13-17 sections, but in some instances collagen had to be combined from adjacent apical sections to ensure enough collagen for reliable δ¹⁵N and δ¹³C isotope measurement. (Ectoco, 2011)

Figure 3: Example of sampling method, with ten serial samples from root tip (A) to crown (J). Dentine in white with approximate angles of growth lines.
Figure 4: Burial 4 Comparison of δ15N and δ13C

Figure 5: Burial 9 Comparison of δ15N and δ13C

Figure 6: Burial 16 Comparison of δ15N and δ13C
Figure 7: Burial 17 Comparison of $\delta^{15}$N and $\delta^{13}$C

Figure 8: Burial 11A Comparison of $\delta^{15}$N and $\delta^{13}$C

*Note: for burials such as this with multiple decreases and subsequent increases in Nitrogen levels the first drop in Nitrogen is used to calculate age of weaning.

Figure 9: Burial 20 Comparison of $\delta^{15}$N and $\delta^{13}$C

Figure 10: Burial 23 Comparison of $\delta^{15}$N and $\delta^{13}$C

Figure 11: Burial 26I3 Comparison of $\delta^{15}$N and $\delta^{13}$C
Figure 12: Models of weaning and resulting sampling curves (Eerkens et al, 2011)
Figure 13: Quadratic associations between pathogen stress and parental effort. (Quinlan, 2007)

Table 5: burial and age of weaning information for SJO-112 and CCO-548

<table>
<thead>
<tr>
<th>Total number of burials</th>
<th>SJO-112</th>
<th>CCO-548</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Average age of weaning (yrs)</td>
<td>2.1</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Table 6: Average of isotope dietary measures by sex at CA-SJO-112 and CA-CCO-548

<table>
<thead>
<tr>
<th>Site</th>
<th>Burial</th>
<th>Sex</th>
<th>δ¹⁵N pre-weaning high</th>
<th>δ¹⁵C pre-weaning</th>
<th>δ¹⁵N of weaning food</th>
<th>δ¹⁵C of weaning food</th>
<th>Avg. δ¹⁵N age 7-9</th>
<th>Avg. δ¹⁵C age 7-9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9</td>
<td>F</td>
<td>12.2</td>
<td>-21.1</td>
<td>9.0</td>
<td>-21.3</td>
<td>10.4</td>
<td>-21.5</td>
</tr>
<tr>
<td></td>
<td>11A</td>
<td>F</td>
<td>12.2</td>
<td>-21.1</td>
<td>9.0</td>
<td>-21.3</td>
<td>10.4</td>
<td>-21.5</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>M</td>
<td>12.2</td>
<td>-21.1</td>
<td>9.0</td>
<td>-21.3</td>
<td>10.4</td>
<td>-21.5</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>F</td>
<td>9.8</td>
<td>-20.2</td>
<td>9.8</td>
<td>-20.2</td>
<td>9.3</td>
<td>-19.9</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>F</td>
<td>9.8</td>
<td>-20.2</td>
<td>9.8</td>
<td>-20.2</td>
<td>9.3</td>
<td>-19.9</td>
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<tr>
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<td>23</td>
<td>Indct</td>
<td>10.7</td>
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<td>9.2</td>
<td>-20.7</td>
<td>8.7</td>
<td>-20.5</td>
</tr>
<tr>
<td></td>
<td>26I3</td>
<td>M</td>
<td>10.6</td>
<td>-20.8</td>
<td>9.9</td>
<td>-20.6</td>
<td>9.6</td>
<td>-20.3</td>
</tr>
<tr>
<td>CCO-548</td>
<td>Female</td>
<td>Avg.</td>
<td>9.7</td>
<td>-19.5</td>
<td>6.9</td>
<td>-20.0</td>
<td>8.4</td>
<td>-20.0</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>Avg.</td>
<td>12.2</td>
<td>-19.8</td>
<td>9.2</td>
<td>-20.1</td>
<td>10.2</td>
<td>-19.9</td>
</tr>
</tbody>
</table>

Note: SJO-112 breaks down data into individual burials. CCO-548 is an average of all burials divided by males and females used in study.
References Cited


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