

# Sex-Biased Weaning and Early Childhood Diet Among Middle Holocene Hunter–Gatherers in Central California

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**ABSTRACT** This article evaluates age of weaning and early childhood diets of eight males and nine females from a Middle Holocene (4300–3000 BP) site in Central California, CA-CCO-548. All individuals died as adults.  $\delta^{15}\text{N}$  values from serial sections of dentin collagen in first molars suggest females were fully weaned, on average, by 3.6 years of age, about 0.4 years later than males in the sample, suggesting possible greater parental investment in female offspring. However, throughout childhood females consumed lower trophic-level foods than males. This could indicate greater investment in males through

provisioning of higher quality foods, or alternatively, some degree of independent foraging by males starting as early as 2 to 3 years of age. Even as adults, these same males and females consumed a different range of foods as indicated by their bone collagen  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values. Overall, the data suggest children were enculturated early into their respective gendered diets, with girls consuming greater amounts of plant foods and boys consuming greater amounts of higher-trophic level fish and meat protein. *Am J Phys Anthropol* 152:471–483, 2013. © 2013 Wiley Periodicals, Inc.

Humans are unique among primates in terms of child investment and weaning practices. Not only is there extreme variation between and within particular societies, but offspring are typically weaned at much earlier ages than non-human primates, such as great apes. For example, accounting for differences in growth rates and life history effects, humans breastfeed on average less than half as long as our close relatives, chimpanzees and gorillas (Dettwyler, 2004; Kennedy, 2005).

Early human weaning and the nature of early childhood diets, as well as high interindividual variation in such practices, has been used to speculate on a number of evolutionary processes in our species' past (Trivers, 1974; Blurton-Jones, 1986; Sellen and Smay, 2001; Stearns, 1992; Kaplan, 1996; Borgerhoff-Mulder, 1992, 2001; Piperata, 2009). These processes often pit the costs of longer breastfeeding to parents, especially mothers, against benefits to offspring. Breast milk is a significant energetic investment for a mother. It can negatively impact her health, require her to work harder to obtain calories, take away from time she could be working (opportunity costs), and decrease her ability to get pregnant again, lowering her fertility and overall fitness, as well as that of her male partner (Delgado et al., 1982; Borgerhoff-Mulder, 1992; Riordan, 2005; Sellen, 2006; Piperata and Mattern, 2011). On the other hand, breast milk provides a child with a reliable and easily digestible source of calories and nutrients. Empirical evidence suggests that extended breastfeeding offers long-term benefits to children, such as increased stature, better cognitive capabilities (e.g., higher IQ), greater immunity to some diseases, and lower rates of obesity (Taren and Chen, 1993; Mortensen et al., 2002; Schack-Nielsen and Michaelsen, 2006), effects also seen in non-human primates (Hinde et al., 2009). For these reasons, the age at which a mother weans a child has often been used as a proxy measure of parental investment in offspring (Stuart-Macadam and Dettwyler, 1995; Humphrey, 2010).

Research in human behavioral ecology suggests that parents will reduce their investment in children in environments where increased parenting does not increase the probability of offspring survival. For example, Quinlan (2007) shows that mothers will breastfeed longer in environments where rates of infectious disease are moderate, but not low or high, because in the latter extended breastfeeding will not significantly decrease mortality. Likewise, the Trivers–Willard hypothesis suggests that parents employ a sex-biased investment strategy in offspring if one of the sexes has a higher potential for reproductive success (Trivers and Willard, 1973; Cronk, 2007). In particular, when resources are plentiful and there is room for population growth, the Trivers–Willard hypothesis predicts greater investment in male offspring, and when resources are in short supply greater investment in females. Other social factors may also predispose parents to invest more in one sex over another (Higginson and Aarson, 2011).

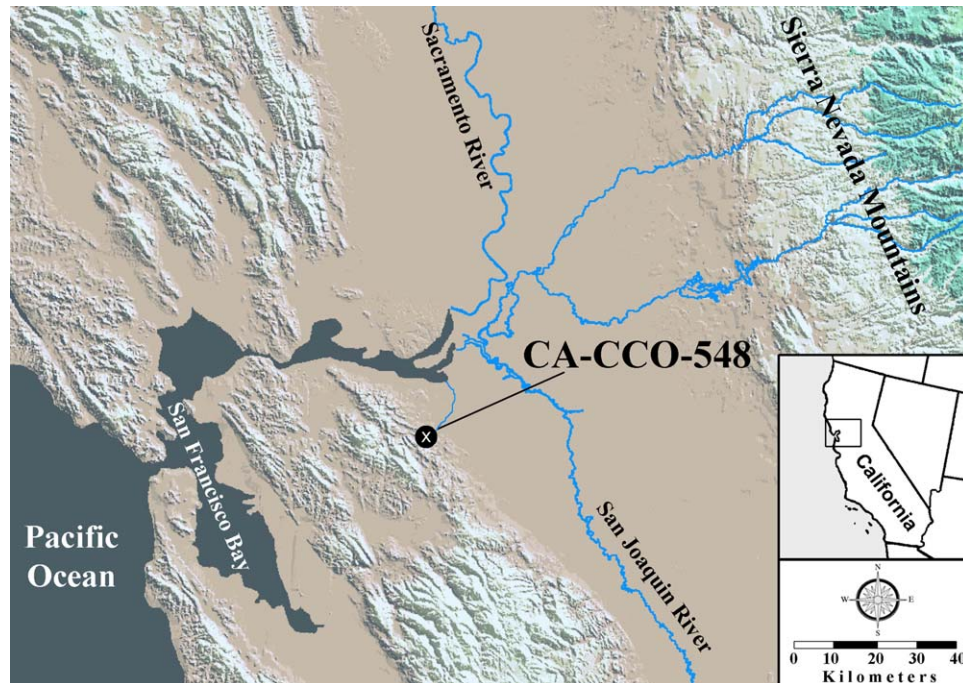
The majority of the data used in making such arguments about weaning and parental investment strategies comes from cross-cultural studies of extant populations. For a number of reasons that have been extensively discussed elsewhere (Foley, 1995; Irons, 1998), modern societies may not be good analogues for

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**Fig. 1.** Map of Central California showing location of CA-CCO-548 and geographic features discussed in text. [Color figure can be viewed in the online issue, which is available at [wileyonlinelibrary.com](http://wileyonlinelibrary.com).]

the environments in which such behaviors evolved. Moreover, the majority of weaning studies have been conducted among agricultural and industrial populations. Although there are exceptions (Barry and Paxson, 1971; Hill and Hurtado, 1996; Blurton-Jones et al., 1994, 1997; Howell, 1999; Kaplan et al., 2000; Konner, 2005; p 57; Scelza and Bliege-Bird, 2008), significantly less is known about weaning and early childhood diets in hunter-gatherer populations. Because there are so few hunter-gatherer groups around the world today, and because many modern behaviors have evolutionary roots in hunting and gathering settings, reconstructing weaning behaviors from ancient hunter-gatherer populations provides an important and independent data set to test anthropological, evolutionary, and ecological hypotheses about parental investment strategies. Indeed, much recent research has sought to estimate weaning and early childhood diets in ancient populations (Katzenberg and Pfeiffer, 1995; Wright and Schwarz, 1998, 1999; Mays, 2003; Clayton et al., 2006; Fuller et al., 2006a, 2006b; Dupras et al. 2007; Choy et al., 2010; Eerkens et al., 2011; Nehlich et al., 2011).

For our purposes, we define the weaning process as a series of transitions, beginning with exclusive suckling, a period of declining milk consumption in conjunction with the introduction of complementary foods, followed by the complete cessation of breastfeeding (Lewis, 2007; p 99; McDade, 2011; p 10). We refer to dietary patterns after the weaning process as the “early childhood” diet. We reconstruct childhood dietary behavior for individuals by extracting dentin collagen from first molar serial sections, following recently developed serial sampling methods (Fuller et al., 2003; Eerkens et al., 2011; Beaumont et al., 2012). Our case study is a Middle Holocene site in Central California, CA-CCO-548, or the Marsh Creek Site (Fig. 1). Nitrogen isotope ratios in collagen extracted from serial first molar dentin samples allow us

to reconstruct the weaning process for individuals who survived into adulthood, as well as estimate the trophic level of weaning and post-weaning foods, especially dietary protein. Carbon isotope ratios allow us to estimate the input of marine protein to the diet. From this information we can compare weaning behavior for males and females, as we do here, but also high status and low status, tall and short, and other subsets of individuals within a burial population. Furthermore, although we do not address the issue here, it would also be possible to compare early childhood dietary isotopes of those who died in childhood vs. those who survived (although in the former we would lack sex information). Such an analysis might give insight into the cause of childhood mortality, or perhaps, rule out diet as a significant predictor of early death.

## BACKGROUND

CA-CCO-548 currently lies on the edge of the California Delta along a small perennial waterway, Marsh Creek (Fig. 1). The site was excavated between 2003 and 2008 as part of a mitigation project for a housing development and nearly 500 burials were recorded and excavated (Wiberg, 2010). Although there is earlier and later occupational debris at the site, including unexcavated portions, radiocarbon dating and temporally diagnostic artifacts place the cemetery component at the end of the Middle Holocene, between approximately 4300 and 3000 BP. This fits with what has been referred to as the Early Period in Central California (Beardsley, 1954; Bennyhoff and Hughes, 1987; Meighan, 1987; Groza, 2002).

Regionally, the Middle Holocene was a time of significant cultural change in Central California. This period marks the onset of more sedentary villages with internal or adjacent cemeteries, the construction of large and permanent domiciles, the transition to a plant-intensive

subsistence economy, and a notable increase in the number of recorded sites suggesting regional population increase. Analyses of the midden constituents from CA-CCO-548 support many of these notions, showing occupants were residentially stable, that heavy and often immobile plant processing tools (e.g., mortars, pestles, millingstones) were common, and that acorns and small seeds were a staple component of the diet (Stevens et al., 2009; Wiberg, 2010). Given the importance of plant foods in the diet, the amount of skill and training required to become efficient in extracting and processing plant resources, and the tremendous amount of labor involved in processing plant resources, especially acorn (see Bock, 2005), women must have played a critical economic role in Early Period societies (see also McGuire and Hildebrandt, 1993; Jones, 1996). Indeed, ethnographic accounts highlight women's roles as gatherers throughout Central California and the dominance of plant foods in local subsistence economies (Willoughby, 1963; Wallace, 1978; Jackson, 1991).

Furthermore, analyses of strontium isotopes indicate that CA-CCO-548 inhabitants had a preference for matrilineal post-marital residence, especially between 3900 and 3500 cal BP (Jorgenson, 2012.). A comparison of  $^{87}\text{Sr}/^{86}\text{Sr}$  in early-forming teeth versus bone indicates that the majority (~80%) of immigrants to the site in this interval were males. Although there are many reasons to change residence, marriage in late teenage years, after most teeth have fully formed, is a major one that would lead to the type of pattern documented in the  $^{87}\text{Sr}/^{86}\text{Sr}$  results. A matrilineal post-marital residence pattern is consistent with what we expect for a gathering-intensive society that lacked significant levels of warfare (Ember and Ember, 1971; Ember, 1975). Given the importance of female labor, it may have been desirable to keep related women together in the same village. Efficient gathering is a knowledge-intensive skill that requires transmission of information and individual learning (i.e., practice) to master. In this respect, there is an advantage if women can stay in their natal village, where they learn about efficient gathering in the local environment from their female relatives. Moreover, if productive gathering tracts were owned, women might inherit access to them from their kin, again leading to a preference for keeping related women in the same village. Small overall population size during the Early Period likely meant that villages had to practice some degree of exogamy. For these reasons, inhabitants at CA-CCO-548 may have preferred matrilineality when inter-village marriages took place.

This post-marital residence data supports the hypothesis that females and their labor were economically important in Early Period societies in Central California. In matrilineal societies, daughters stay in their natal villages and continue to provide food and other support to their aging parents. These factors can influence parents, especially mothers, to bias their investment in offspring to favor daughters who will stay over sons who will leave. As mentioned above, age at weaning and the quality of early childhood diet are two measures of parental investment in offspring. Consequently, our central hypothesis in this analysis is that females were breastfed for a longer period of time than males, and that they may have consumed food from higher trophic levels. This difference should be most pronounced in the burials dating between 3900 and 3500 cal BP at CA-CCO-548.

## APPROACH AND METHODS

Biological tissues in the human body are synthesized from the foods we consume and water we drink. These food and water sources may have different isotopic compositions, which are reflected in bulk stable isotope values in human tissues. Collagen is a protein that helps to form connective tissues, including bone and dentin, and is synthesized mainly from ingested protein (Ambrose and Norr, 1993; Tieszen and Fagre, 1993; Schwarcz, 2000); [see recent review in Froehle et al. (2010) and Kellner and Schoeninger (2007)]. In bone, collagen is continually remodeled throughout the lifetime of an individual, with an average replacement of about 10-20 years, depending on the skeletal element (Manolagas, 2000; Hedges et al., 2007). Isotopic data from bone collagen, then, informs on the diet of an individual, primarily the protein source consumed during the last decades of life before death. Teeth, on the other hand, do not remodel, and thus preserve a signature of dietary behavior over the temporal window during which the dental tissues formed. For permanent first molars, this temporal window begins at about birth, when the crown begins to form, and ends around age 9.5 years, when the apical roots are completely formed (Hillson, 1996; Dean and Vesey, 2008). Because dentin includes significant amounts of collagen, and makes up the interior portion of the crown as well as the majority of the root, we can isolate, extract, and analyze collagen from teeth. In the case of first molars, this collagen tells us about diet during the first 9.5 years of life (Dean et al., 1993; Liversidge et al., 1993; Hillson, 1996; Dean and Vesey, 2008).

Moreover, teeth do not form as a whole, but instead accrue tissue in a predictable way over time. As a result, we can narrow our temporal windows on diet even further by focusing our analyses on serial sections of the tooth that were forming at different times. Dentinal tissue forms in nearly horizontal layers in the crown much like sedimentary strata (but with oldest layers at the top), and in concentric cones (with truncated tops) in the root. Overall, dentinal tissue accumulates from the dentin-enamel junction (DEJ) toward the apex during tooth development (Hillson, 1996). Some secondary and tertiary dentin can be deposited within a tooth later in life, after tooth formation, and is laid down along the walls of the pulp chamber (Beaumont et al., 2012). However, the relative mass of secondary dentin is minor compared with the mass of primary dentin in the crown and root, and in many cases it is possible to remove much of this secondary dentin by reaming out the pulp chamber.

To reconstruct the weaning process, we follow the methods described in our previous research (Eerkens et al., 2011), which built on earlier work by Fuller et al. (2003). In short, this process includes sampling a first molar with at least a portion of the crown preserved as well as a complete root. Rates of tooth wear were extreme in prehistoric California (Jurmain, 1990; Bartelink, 2006; Kolpan, 2009; Grant, 2010; Blake, 2011) and many individuals from CA-CCO-548 did not have first molars appropriate to be included in this study.

First molars were photographed and measured, noting in particular the location of the DEJ, if present, and cementum-enamel junction (CEJ). Teeth were then cut to isolate one complete root and adjoining section of the crown, cleaned (including removing any visible material from the pulp chamber), and all cementum and enamel was removed by abrasion with a drill bit. Cleaned



TABLE 1. Demographic data, tooth wear, and adult (bone) collagen isotopic data for study sample

Burial no.	Sex	Age at death	Tooth	Wear score <sup>1</sup>	<sup>14</sup> C date	Median <sup>14</sup> C calibrated	Bone $\delta^{13}\text{C}$ (‰)	Bone $\delta^{15}\text{N}$ (‰)
14	Female	45–50	RM <sup>a</sup>	7	3,170	3,252	–19.5	9.9
38	Male	45–55	LM <sup>a</sup>	7	3,640	3,836	–19.8	12.4
59	Male	25–35	RM <sup>a</sup>	5	3,010	3,135	–20.9	10.1
79	Male	25–35	LM <sup>a</sup>	6	–	–	–19.6	9.9
87	Female	20–30	LM <sup>a</sup>	2	3,075	3,155	–19.6	9.3
92	Male	30+	LM <sup>a</sup>	7	3,540	3,690	–19.5	9.8
107	Male	34–45	LM <sup>a</sup>	5	3,505	3,650	–19.5	8.8
109	Female	35+	RM <sup>a</sup>	7	3,465	3,604	–19.5	8.8
154	Female	30–50	RM <sup>a</sup>	6	3,375	3,514	–20.0	8.2
180	Female	25–35	RM <sup>a</sup>	6	3,500	3,653	–19.8	7.9
183	Female	18+	LM <sup>a</sup>	6	3,350	3,472	–19.7	7.9
202	Male	20–25	LM <sup>a</sup>	4	2,985	3,060	–20.4	9.7
214	Female	50+	LM <sup>a</sup>	7	3,375	3,443	–18.7	9.2
236	Female	40–50+	RM <sup>a</sup>	7	3,450	3,555	–19.1	8.9
249	Female	35–45+	RM <sup>a</sup>	7	3,400	3,538	–20.1	7.7
294	Male	18+	LM <sup>a</sup>	6	3,580	3,739	–19.2	10.6
308	Male	40–50	RM <sup>a</sup>	7	3,515	3,706	–20.5	9.0

<sup>a</sup> Wear = attrition stage as reported in Wiberg (2010), and given according to system described in Smith (1984).

samples were washed and sonicated in deionized water and immersed in 0.5M HCl at 1°C for demineralization. HCl was replaced every 1 to 2 days until the tooth no longer visibly reacted with the solution and was spongy in texture (~5–14 days). Following demineralization, the tooth was rinsed and sliced with a scalpel into thin parallel sections approximately 1 to 2 mm thick, perpendicular to the central axis of the root. While these sections cross growth lines, we are able to partly correct for this effect by estimating how much of each serial section overlaps with the previous and subsequent section (Eerkens et al., 2011). Demineralized sections were then placed in separate glass vials and treated with 0.125M NaOH for 24 h to remove humic contaminants. Samples were then rinsed with dH<sub>2</sub>O, immersed in pH ≈ 3 water, and placed in an oven at 80°C for 24 h to solubilize the collagen. Sectioned samples were centrifuged, with the liquid fraction removed and freeze-dried. Collagen  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  was measured by continuous-flow mass spectrometry (PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer) at the Stable Isotope Facility at UC Davis. Long-term standard deviation of analysis of solid materials is 0.2‰ for  $\delta^{13}\text{C}$  and 0.3‰ for  $\delta^{15}\text{N}$ . The atomic C/N ratio and the percent collagen yield are also reported in Table 2, and are useful indicators of sample quality (DeNiro, 1985; van Klinken, 1999; Weber et al., 2005).

Typically, we were able to generate between 8 and 12 serial sections per tooth, depending on the degree of tooth wear and the size of the tooth. Because we needed 1 mg of collagen for each run on the mass spectrometer, in some cases we had to combine collagen from successive serial sections to reach this amount. We rejected a small number of sections because they did not produce C/N ratios in the acceptable range of 2.9 to 3.6, indicating degraded collagen (DeNiro, 1985; van Klinken, 1999; Weber et al., 2005). Overall, we averaged between 7 and 8 serial sections with adequate collagen preservation per tooth across the 17 individuals included in the study.

Carbon and nitrogen isotopes of human bone collagen are highly dependent on the source of protein consumed by an individual. In foodwebs,  $\delta^{15}\text{N}$  increases by about 2 to 4‰ with each trophic level (Minagawa and Wada, 1984; Schoeninger, 1985). A child that is completely

dependent on breast milk for protein will display enriched  $\delta^{15}\text{N}$  over its mother by one trophic level, as has been shown in both controlled studies as well as in archaeological studies of human bone collagen of infants (Fogel et al., 1989; Katzenberg et al., 1996; Schurr, 1997; Herring et al., 1998; Fuller, et al. 2006a,2006b; Nehlich et al., 2011). However, as a child is weaned on solid foods,  $\delta^{15}\text{N}$  decreases to reflect a more “adult-like” diet, similar in composition to its mother. How quickly  $\delta^{15}\text{N}$  drops depends on how abruptly a child is weaned and the quantity of solid foods incorporated in the diet over time. The source of the weaning food will also affect how much the  $\delta^{15}\text{N}$  value will decline. Children weaned on low-trophic level foods such as plant gruels will have lower  $\delta^{15}\text{N}$  than children weaned on a mix of meat and plant products. By analyzing serial sections of collagen from tooth dentin, we can follow the weaning process from high  $\delta^{15}\text{N}$  in preweaning times to more adult-like diets, as well as the general trophic levels of foods consumed across this process. Further, 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 through the early childhood years.

Carbon isotopes show similar but dampened trophic-level effects (Fuller et al., 2006a,2006b). More importantly,  $\delta^{13}\text{C}$  in collagen can help discriminate sources of dietary protein. In other regions,  $\delta^{13}\text{C}$  is a good indicator for the importance of C<sub>3</sub> vs. C<sub>4</sub> photosynthesizing plants in the diet (see Farquhar et al., 1989). For example, in North America  $\delta^{13}\text{C}$  is particularly effective in estimating the dietary importance of the C<sub>4</sub> plant maize (Schoeninger 2009). In Central California, there are few economically important C<sub>4</sub> plants (Bartelink, 2006; Eerkens et al., 2013). Instead,  $\delta^{13}\text{C}$  is effective at discriminating between terrestrial and marine sources of dietary protein (Schoeninger and DeNiro, 1984). Particularly important in this category are anadromous salmon, which can be caught in non-coastal locations, but carry a marine  $\delta^{13}\text{C}$  signature in their tissues.

## RESULTS

We attempted to reconstruct childhood dietary practices from first molars for 20 individuals at CA-CCO-548

TABLE 2. C and N isotope data and C/N ratios for serial sections for each burial (and sex)

Burial	Median age for section	$\delta^{13}\text{C}_{\text{‰}}$	$\delta^{15}\text{N}_{\text{‰}}$	C/N ratio	Burial	Median age for section	$\delta^{13}\text{C}_{\text{‰}}$	$\delta^{15}\text{N}_{\text{‰}}$	C/N ratio
14(F)	8.7	-19.8	5.7	3.1	38(M)	8.5	-21.5	12.1	3.1
14	7.4	-19.8	5.7	3.1	38	6.9	-22.1	12.8	3.5
14	6.4	-19.9	6.0	3.1	38	5.9	-22.0	11.8	3.4
14	5.3	-19.3	6.2	3.1	38	4.6	-21.8	10.9	3.2
14	4.3	-18.9	6.4	3.1	38	3.0	-21.8	10.3	3.1
14	3.3	-19.0	7.2	3.1	38	2.3	-21.5	10.5	3.1
14	2.0	-18.8	7.6	3.1	38	1.8	-21.4	11.2	3.1
14	0.6	-18.9	7.9	3.1					
59(M)	8.9	-19.93	8.7	3.2	79(M)	8.9	-18.61	10.2	3.3
59	7.8	-19.75	8.5	3.2	79	7.8	-19.11	10.0	3.4
59	6.7	-20.20	8.0	3.3	79	6.7	-19.46	9.1	3.3
59	5.6	-20.20	8.4	3.3	79	5.8	-19.56	8.9	3.3
59	4.4	-20.09	9.1	3.2	79	5.0	-19.52	9.2	3.3
59	3.6	-20.14	10.2	3.2	79	4.0	-19.37	9.2	3.3
59	3.0	-20.23	11.1	3.2	79	3.2	-19.39	9.9	3.3
59	2.5	-20.24	13.0	3.2	79	2.2	-19.42	11.0	3.3
59	1.9	-20.15	13.7	3.2	79	0.8	-19.52	11.9	3.3
59	1.3	-19.80	14.0	3.2					
87(F)	8.4	-19.7	10.4	3.4	92(M)	7.8	-20.7	9.5	3.6
87	6.9	-19.7	10.6	3.3	92	5.6	-20.6	11.5	4.4
87	6.1	-20.0	9.8	3.3	92	4.4	-19.8	11.3	4.0
87	5.4	-20.1	9.6	3.4	92	3.3	-19.8	11.0	3.9
87	4.6	-19.9	9.2	3.4	92	1.6	-19.6	12.6	4.0
87	3.9	-19.8	8.4	3.4					
87	3.1	-19.7	8.3	3.4					
87	1.6	-19.4	9.6	3.4					
87	0.5	-19.9	10.8	3.4					
107(M)	8.5	-19.2	7.6	3.2	109(F)	8.0	-20.9	6.1	3.2
107	4.8	-19.5	7.9	3.6	109	6.6	-20.3	6.0	3.2
107	2.2	-19.2	8.1	4.0	109	5.2	-20.1	5.8	3.2
107	1.0	-19.6	8.2	3.7	109	3.0	-19.8	5.9	3.3
107	0.2	-19.2	10.5	3.8	109	1.8	-20.8	5.9	3.3
					109	1.0	-20.0	8.2	3.3
154(F)	8.8	-20.1	9.2	3.2	180(F)	8.7	-20.0	8.7	3.2
154	7.8	-19.9	9.1	3.1	180	7.2	-20.8	11.1	3.1
154	7.1	-19.6	8.6	3.1	180	5.8	-19.7	8.8	3.3
154	5.8	-20.0	9.2	3.1	180	4.7	-19.7	8.6	3.5
154	5.1	-19.9	8.6	3.0	180	3.8	-20.7	6.9	3.1
154	4.4	-20.2	9.3	3.0	180	2.9	-20.4	9.5	3.5
154	3.8	-20.3	10.2	3.1	180	2.6	-20.7	9.6	3.3
154	3.1	-20.9	10.1	3.0	180	2.0	-20.1	10.1	3.1
154	1.9	-20.9	10.8	3.1	180	1.2	-19.7	9.6	3.0
154	0.5	-20.9	11.4	3.1					
183(F)	8.7	-20.4	4.0	3.2	202(M)	8.0	-20.8	11.3	3.3
183	6.4	-20.5	5.3	3.2	202	6.3	-20.9	11.3	3.3
183	5.3	-20.7	8.3	3.2	202	4.9	-20.6	10.9	3.3
183	4.3	-20.3	10.3	3.4	202	4.2	-20.2	11.0	3.3
183	3.3	-19.7	11.2	3.3	202	3.6	-20.0	11.2	3.3
183	1.9	-19.1	11.3	3.3	202	3.0	-20.5	11.5	3.3
					202	2.5	-21.2	12.6	3.3
					202	1.9	-21.2	13.2	3.2
					202	1.3	-20.9	12.4	3.2
					202	0.8	-20.7	13.2	3.1
214(F)	9.0	-18.9	10.0	3.3	236(F)	8.8	-19.4	7.9	3.2
214	8.1	-18.9	8.5	3.2	236	7.7	-19.2	8.0	3.2
214	7.1	-19.1	9.3	3.3	236	6.8	-20.0	7.8	3.2
214	6.1	-19.1	8.0	3.2	236	5.9	-20.1	8.6	3.2
214	5.2	-19.2	7.5	3.3	236	5.0	-20.2	8.6	3.2
214	4.2	-19.0	9.1	3.3	236	3.7	-20.3	9.3	3.2
214	3.2	-19.3	4.6	3.1	236	1.9	-20.1	9.9	3.2
214	2.5	-19.2	6.6	3.1					
214	1.6	-19.2	8.3	3.2					
249(F)	8.3	-20.3	9.4	3.0	294(M)	4.4	-19.3	10.6	3.2
249	6.5	-20.5	9.3	3.0	294	3.3	-19.5	9.1	3.3
249	5.6	-21.0	9.6	3.0	294	2.3	-18.8	11.2	3.3

TABLE 2. *Continued*

Burial	Median age for section	$\delta^{13}\text{C}_{\text{‰}}$	$\delta^{15}\text{N}_{\text{‰}}$	C/N ratio	Burial	Median age for section	$\delta^{13}\text{C}_{\text{‰}}$	$\delta^{15}\text{N}_{\text{‰}}$	C/N ratio
249	5.0	-20.9	9.6	3.0	308(M)	6.7	-19.5	11.4	3.6
249	4.2	-20.7	9.5	3.1	308	4.9	-19.6	10.9	3.4
249	3.0	-19.6	8.6	3.0	308	4.4	-19.8	10.4	3.5
249	2.5	-19.4	9.0	3.0	308	3.7	-19.8	10.0	3.3
249	1.9	-19.0	9.1	3.0	308	3.0	-19.8	9.0	3.5
249	1.2	-19.1	8.0	3.0	308	2.5	-19.5	10.8	3.5
249	0.3	-18.5	9.6	3.0	308	1.6	-19.3	11.4	3.0
294	0.5	-18.8	13.0	3.3					

with known sex. Of these, 17 had collagen preservation sufficient to allow for estimation of the weaning process, including 9 females and 8 males. All these individuals survived into adulthood. We also have  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  data on bone collagen for these individuals, allowing us to compare the time series of childhood diet to an average adult diet (representing the last ~10–20 years of life). Furthermore, 16 of the 17 have associated radiocarbon dates on bone collagen, giving us excellent control over chronological age within the sample. Table 1 provides basic data about the samples included in this study.

Table 2 presents  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values from the study. From the serial sections, an estimate of diet over the first nine years can be reconstructed, including the weaning process if enough of the crown exists. If weaning occurred early in life (i.e., before age 2 years), this proved difficult given tooth wear in most teeth. In the remainder of the article we primarily focus on patterns in  $\delta^{15}\text{N}$  which correlate most strongly to weaning, though  $\delta^{13}\text{C}$  values are also presented and evaluated in light of the transition from breast milk to complementary foods.

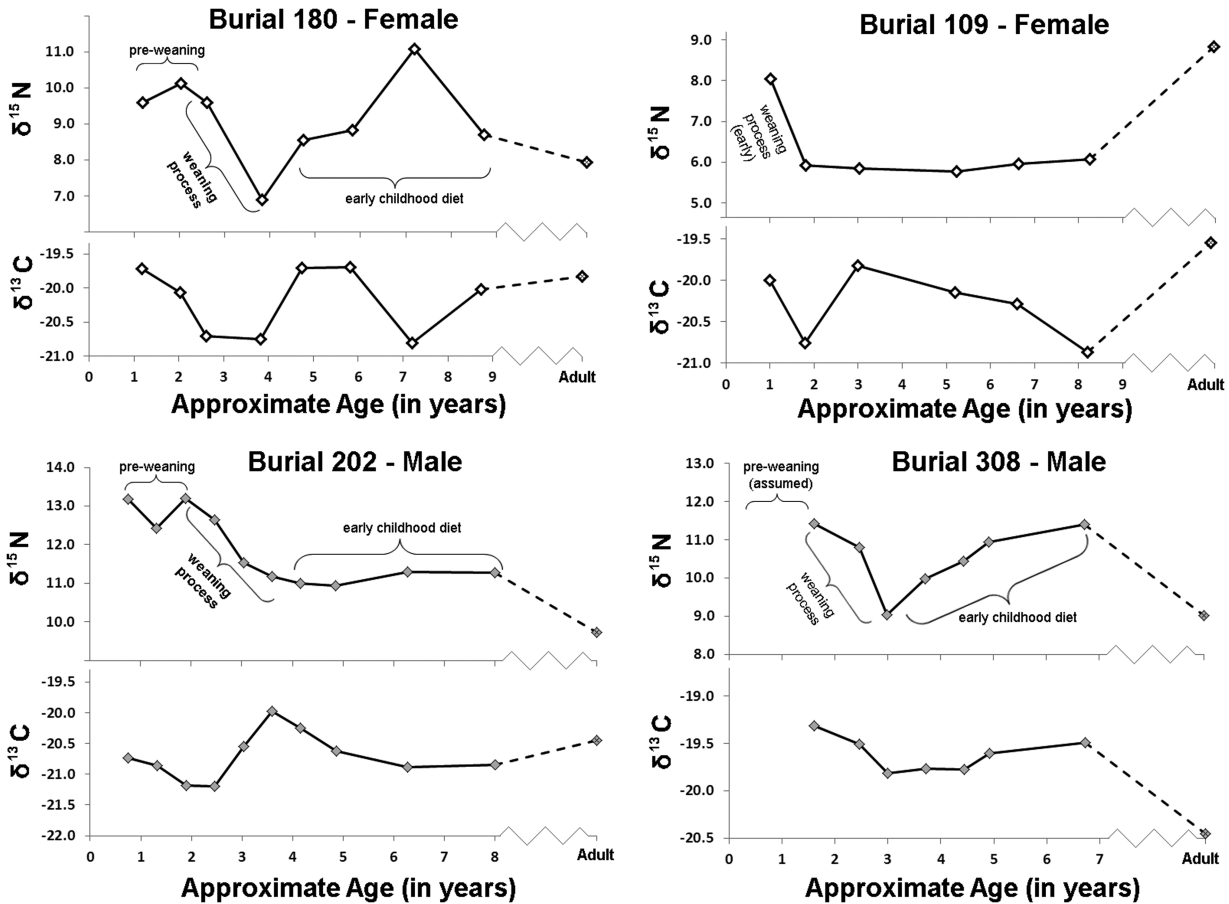
The data from CA-CCO-548 indicate a diversity of diets among children, indeed, much greater than the variation seen among adults. In general,  $\delta^{15}\text{N}$  values are highest in the coronal sections and then decline to their lowest values in the serial sections just below the crown, though occasionally this happens within the crown, and more rarely, well into the root. The decline in  $\delta^{15}\text{N}$  values varies between 2 and 6‰ across this transition, which would be expected for a 1 to 2 trophic level reduction in the source of dietary protein. Often,  $\delta^{15}\text{N}$  values have already decreased from expected levels in the uppermost coronal sections (closest to the occlusal surface) we sampled, indicating that the weaning process had already started in these sections. This is likely due to tooth wear, which resulted in the removal of the earliest-forming dentin that accumulated when the individual was only consuming breast milk, but before the commencement of the weaning process.

Carbon isotopes in the serial sections follow a similar pattern to the  $\delta^{15}\text{N}$  values, but with two notable differences. First, the  $\delta^{13}\text{C}$  values only drop 0.5 to 1.0‰ during the weaning process, and second, the  $\delta^{13}\text{C}$  values seem to decrease at an earlier age than the  $\delta^{15}\text{N}$  values. Significantly, both these findings duplicate patterns observed by Fuller et al. (2006b) in stable isotope studies of fingernail and hair samples from living human infants during the weaning process. Thus, our findings support those of Fuller et al. that carbon, like nitrogen, is subject to trophic-level fractionation effects, though the magnitude is much less than nitrogen. Fuller et al. (2006b) speculate that the slight temporal lag of decreasing  $\delta^{15}\text{N}$  values behind  $\delta^{13}\text{C}$  values is a byproduct of weaning foods that are rich in carbohydrates but low in protein,

causing a greater dilution in the carbon pool relative to nitrogen of infants. They note, however, that more detailed investigations are needed to verify this hypothesis. Our data are not a direct test of this hypothesis, but as discussed below, are certainly in agreement with this interpretation. Carbohydrate-rich plant gruels are a likely source for the weaning foods of many individuals.

After reaching a minimum,  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values often increase again in the apical root sections associated with ages after 5 to 6 years. This is the pattern we would expect if a child consumed high levels of breast milk early in life (age 0–2 years), was slowly weaned from breast milk with low trophic-level foods (e.g., gruel made from acorns or seeds), and then began consuming high trophic-level protein and solid food after age 5–6 years, approaching an adult-like diet after 7 years of age. Again, the absolute decrease in the  $\delta^{13}\text{C}$  values (typically 0.5–1.5‰) is less than the  $\delta^{15}\text{N}$  values (typically 2–6‰). Using a different approach based entirely on bone collagen, Waters-Rist and colleagues (2011) record a very similar childhood dietary trajectory among hunter-fisher-gatherers in the Cis-Baikal region of Siberia.

While this is the typical pattern, we did encounter a range of dietary curves in the study. Figure 2 plots four exemplary dietary curves (two females, two males), showing the range of shapes encountered in the study (see Eerkens et al., 2011 for additional examples). For each individual (i.e., quadrat),  $\delta^{15}\text{N}$  values are shown on top and  $\delta^{13}\text{C}$  values are below. Serial samples from teeth are shown as points connected by a solid line, while the adult bone collagen value is shown on the far right of each sequence, connected to the teeth serial samples by a dotted line. For example, the upper left panel of Figure 2 shows a “typical” dietary curve, for Burial 180, a female 25–35 years of age at death. As an adult, this female consumed foods that produced bone collagen values of 7.9‰ and -19.8‰ for  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ , respectively. The dentin  $\delta^{15}\text{N}$  value in the crown of her M1 is significantly elevated, near 10‰, well above her adult diet, while the  $\delta^{13}\text{C}$  value was approximately the same in childhood as in adulthood. However, in dentinal sections corresponding to ages 2.5 to 3.8 years, the  $\delta^{15}\text{N}$  values dropped markedly, to a low of 6.8‰, and the  $\delta^{13}\text{C}$  value dropped to -20.8‰, which we reconstruct as the weaning process for this female. After 4 years of age, her dietary protein increased markedly in trophic level, increased again to levels even above the pre-weaning diet by age 7.2 years, and then decreased again around age 8.5 years to approximately the level found in the adult bone collagen. Likewise, the  $\delta^{13}\text{C}$  value increased to pre-weaning levels around age 4.5 years and then decreased again around age 7.0 years, before approaching the adult value by age 8.5 years.



**Fig. 2.** N and C stable isotope values of serial sections from first molar dentin (points connected by solid line) and adult bone (far right, connected by dotted line) for two females (top half) and two males (bottom half).

By contrast, Burial 109, also a female, shows a very different pattern. This female appears to have been weaned abruptly and at an early age, by age 1.8 years, and on quite low trophic-level foods. As an adult she consumed foods that produced a bone collagen  $\delta^{15}\text{N}$  value of 8.8‰ and  $\delta^{13}\text{C}$  value of  $-19.5$ ‰, while her weaning food produced a  $\delta^{15}\text{N}$  value around 6.0‰ and a  $\delta^{13}\text{C}$  value of  $-20.8$ ‰. Further, while  $\delta^{13}\text{C}$  values increased again following weaning, her post-weaning diet did not cause a rebound in  $\delta^{15}\text{N}$  values in the early childhood years. Instead, the  $\delta^{15}\text{N}$  values remained low through at least 8 years of age.

Burial 202, a male, consumed high trophic-level pre-weaning foods ( $\delta^{15}\text{N}$  value near 13.0‰), and was weaned more gradually between the ages of 2 and 4 years on foods that were still above his adult  $\delta^{15}\text{N}$  value (9.2‰); he continued eating these foods through age 8 years. His  $\delta^{13}\text{C}$  values fluctuated less dramatically, decreasing only 0.5‰ at the beginning of the weaning process, and notably, before the  $\delta^{15}\text{N}$  value dropped, increasing slightly during the last stages of the weaning process, and then leveling off at adult bone  $\delta^{13}\text{C}$  values around age 6 years.

Finally, although the earliest-forming dentin in the crown was missing due to attrition, Burial 308, also a male, shows a “typical” dietary pattern similar to that of Burial 180. In fact, a comparison of Burials 308 and 180 highlights many of the overall trends in the larger data set from CA-CCO-548. Patterns in, and absolute values of,  $\delta^{13}\text{C}$  are quite similar in the two burials. However,

$\delta^{15}\text{N}$  values suggest that Burial 308 was completely weaned at a slightly earlier age (age 3.0 years) while Burial 180 was weaned later, by age 3.9 years. At the same time, Burial 308 was weaned on higher trophic level foods, with a  $\delta^{15}\text{N}$  value of 9.0‰, while Burial 180 was weaned on foods closer to 6.8‰. Likewise, the average  $\delta^{15}\text{N}$  value of the early childhood diet for Burial 308 was about 1 to 2‰ higher than for Burial 180.

From the data in Table 2, we estimated several attributes regarding childhood diet. First, when enough coronal sections were available ( $n = 11$  individuals) we estimated the overall length of the weaning process (in years). Second, for all the burials ( $n = 17$ ) we also estimated the age at which  $\delta^{15}\text{N}$  values drop to a minimum, which we equate with the termination of breast milk input. Finally, we calculated the isotopic composition of foods at various points in the life cycle, including the preweaning food (the maximum  $\delta^{15}\text{N}$  value and corresponding  $\delta^{13}\text{C}$  values in the coronal sections), the composition of the weaning food (i.e., the minimum  $\delta^{15}\text{N}$  and corresponding  $\delta^{13}\text{C}$  values), and the average isotopic value after 7 years of age. Averages and standard deviations for these measures are given in Table 3, for males and females separately. Probability values for a Mann–Whitney  $U$  Test comparing the distribution of values for males and females are also given. This test is a nonparametric equivalent to an independent sample  $t$ -test but does not assume the data are normally distributed.



TABLE 3. Average (and standard deviation) of isotope dietary measures by sex at CA-CCO-548

Sex	Count	Average length of weaning process (yrs)	Average age at completion of weaning process (yrs)	Average $\delta^{15}\text{N}$ of preweaning food	Average $\delta^{13}\text{C}$ of preweaning food	Average $\delta^{15}\text{N}$ of weaning food	Average $\delta^{13}\text{C}$ of weaning food	Average $\delta^{15}\text{N}$ at age 7-9	Average $\delta^{13}\text{C}$ at age 7-9	Average $\delta^{15}\text{N}$ as adult	Average $\delta^{13}\text{C}$ as adult
Female	9	2.3 (1.6)	3.6 (1.4)	9.7 (1.4)	-19.5 (0.9)	6.9 (1.5)	-20.0 (0.6)	8.4 (2.2)	-20.0 (0.6)	8.7 (0.8)	-19.6 (0.4)
Male	8	1.3 (1.0)	3.2 (1.8)	12.2 (1.2)	-19.8 (0.7)	9.2 (1.1)	-20.1 (0.8)	10.2 (1.5)	-19.9 (0.9)	10.0 (1.1)	-19.9 (0.6)
Mann-Whitney U		0.38	0.61	0.002	0.36	0.002	1.0	0.24	0.42	0.008	0.82
Bartlett's HOV		0.52	0.56	0.41	0.38	0.28	0.31	0.32	0.31	0.28	0.38

Standard deviation values given in parentheses. Mann-Whitney U and HOV tests report P values.

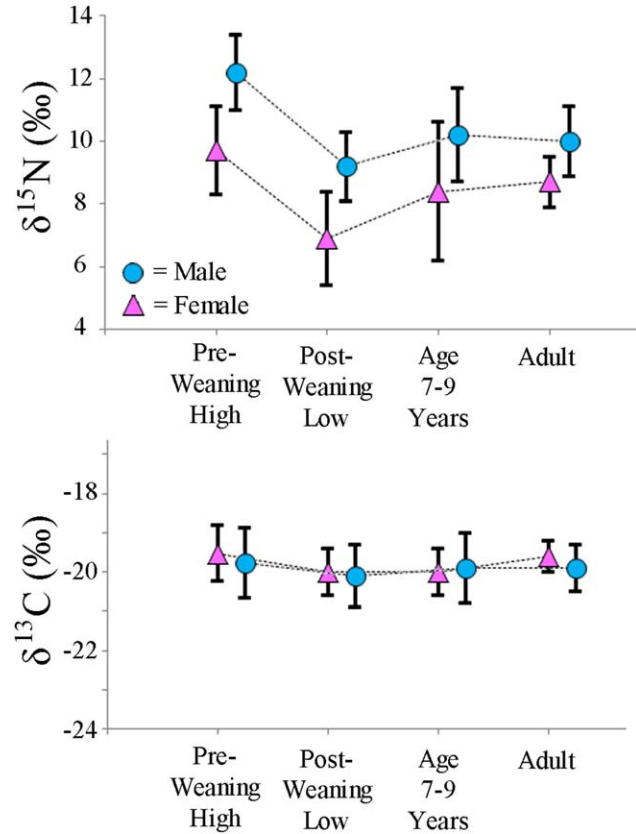


Fig. 3. Average N and C isotopic life histories for males (circles) and females (triangles) at CA-CCO-548. Bars show one standard deviation around sample mean. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Table 3 and Figure 3 indicate several notable patterns. First, females were weaned over a longer time frame than males, and were completely weaned at a slightly older age, on average. These differences are not statistically significant by a Mann-Whitney U test; however, we note that our sample sizes are small and additional sampling will be necessary to determine if this pattern holds for a larger sample.

Second, males and females differ consistently in their average  $\delta^{15}\text{N}$  values at all ages, with males always having more elevated values. Differences in  $\delta^{15}\text{N}$  values between the sexes are significant for the pre-weaning high, the post-weaning low, and the adult diet, as indicated by Mann-Whitney U tests. Thus, these males started life consuming protein from higher trophic levels than females, a pattern that appears to have continued throughout their lives, though the absolute difference between males and females decreases with age.

By contrast,  $\delta^{13}\text{C}$  values vary little across the population as a whole, either by sex (Table 3) or age (childhood mean =  $-20.0\text{‰} \pm 0.7\text{‰}$ ; adulthood mean =  $-19.7\text{‰} \pm 0.5\text{‰}$ ). As discussed below, the lower (i.e., more negative)  $\delta^{13}\text{C}$  values indicate that resources enriched in  $^{13}\text{C}$  (e.g., marine resources,  $\text{C}_4$  plants) did not play an important role in diets at CA-CCO-548.

Third, there tends to be higher interindividual variation in diets in childhood compared with adulthood, and slightly greater variation among females than males,



with the exception of the age at completion of the weaning process (and all the  $\delta^{13}\text{C}$  measures). Bartlett's tests for homogeneity of variance, also reported in Table 3, do not indicate that the differences in variation are statistically significant between males and females for any measure, though again, sample sizes are small.

Fourth, males and females show similar life history trajectories in their  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values. Thus, for both sexes,  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values begin elevated, above the average level of adult females (where, presumably, their lactating mothers were as well).  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values reach a minimum around age 4 to 6 years, and then rebound again by ages 7 to 9 years, approaching values similar to adults. While the overall trajectory is the same, the absolute values are different between males and females. Male pre-weaning  $\delta^{15}\text{N}$  values begin, on average, 3.5‰ higher than bone collagen from adult females, consistent with an increase that is more than one trophic level above where we believe their mothers were. By contrast, female pre-weaning  $\delta^{15}\text{N}$  values (i.e., the maximum values in coronal sections before the weaning decline) are only 1‰ above the average of adult female bone values, a trophic level decrease of less than one during weaning. We expected boys and girls to show similar  $\delta^{15}\text{N}$  values in their pre-weaning diets, at approximately 2 to 3‰ above the adult female average, reflecting breast milk as the major source of dietary protein. Instead, these starting  $\delta^{15}\text{N}$  values suggest that young boys and girls (ca. age 1–3 years) were already including significant amounts of complementary foods in their diets, but notably, that these foods were drawn from very different sources (i.e., males from sources elevated in, and females depleted, in  $^{15}\text{N}$ , but both similar in  $^{13}\text{C}$ ).

## DISCUSSION

Results for sex-biased parental investment in children at CA-CCO-548 are mixed. Based on the assumed economic importance of female labor and an apparent preference for matrilocality, we expected greater investment in female than male offspring. Although there is a general trend suggesting that males may have ceased consumption of breast milk at a slightly younger age, the difference is not statistically significant within our small sample, particularly given the range of variation within the population. In addition, the length of the weaning process was longer for female offspring in our sample, on average, but again was not statistically significant. These trends are supportive of our central hypothesis, but larger sample sizes are clearly needed to fully evaluate these patterns of parental investment.

By contrast, the type of foods on which children were weaned was demonstrably different. The overall low (i.e., more negative)  $\delta^{13}\text{C}$  values observed in dentinal collagen indicate that marine-derived protein played a minor role in the diets of all individuals throughout childhood, both males and females (see Eerkens et al., 2013; p 3272). Using a linear mixing model based on data in Bartelink (2006), marine carbon is estimated to comprise between 0% (corresponding to minimum observed  $\delta^{13}\text{C}$  in dentine =  $-22.1\text{‰}$ ) and 23% (maximum  $\delta^{13}\text{C}$  =  $-18.5\text{‰}$ ) of the protein budget during these years. However, even these estimates are too high as they ignore the slight enrichment of  $\delta^{13}\text{C}$  in breast milk (see discussion below; we are unable to adjust the percent marine contribution values downward because we cannot know the relative contribution of breast milk vs. other foods to the protein budget

from the data at hand). By contrast,  $\delta^{13}\text{C}$  of adult bone collagen in a sample of individuals living on the Central Californian Pacific Coast averages  $-13.4 \pm 0.4\text{‰}$  (estimated 57% marine carbon contribution using the same mixing model), and on San Francisco Bay, an estuary with significant freshwater input,  $\delta^{13}\text{C}$  of adult bone collagen averages  $-16.4 \pm 1.9\text{‰}$  (estimated 37% marine carbon contribution) (Bartelink, 2006). However small the amount, the marine carbon at CA-CCO-548 likely came from consumption of anadromous salmon and sturgeon, and occasional importation of marine/estuarine shellfish. Faunal remains from the site show that salmon and sturgeon comprise just 0.7% of the total fish bone assemblage, and marine/estuarine species just 2% by weight of the shellfish assemblage (Wiberg, 2010). These figures support the notion that terrestrial environments comprised the dominant source of protein for CA-CCO-548 foragers, both in childhood and as adults.

While the  $\delta^{13}\text{C}$  value is similar between boys and girls, the  $\delta^{15}\text{N}$  value is decidedly not. Foods consumed by females during and after the weaning process had lower  $\delta^{15}\text{N}$  values relative to males. Combined with the  $\delta^{13}\text{C}$  data, the isotopic signature in the post-weaning tooth sections for females is consistent with protein derived mainly from  $\text{C}_3$  plant-based products, such as acorn gruel, with a small contribution animal protein. On the other hand, the  $\delta^{15}\text{N}$  value of the average weaning food for males was approximately one trophic level (2.3‰) higher than females, consistent with greater input of animal protein. This suggests that these males were weaned on foods that included a greater amount of freshwater fish, terrestrial meat, and/or particular cuts of meat that are higher in  $\delta^{15}\text{N}$ . For example, brain and liver are typically enriched in  $^{15}\text{N}$  relative to muscle and blood from the same animal (Vanderklift and Ponsard, 2003). Likewise, brackish and freshwater fish available in the California Delta have  $\delta^{15}\text{N}$  tissue values that range between 9.5‰ and 18‰ (see data summarized in Eerkens et al., 2013).

We assume that foods enriched in  $^{15}\text{N}$  are higher in quality. We also assume that fish and/or terrestrial meat are harder to acquire than plant resources. Under these assumptions, the  $\delta^{15}\text{N}$  value of the weaning foods suggests a result contradicting our central hypothesis. Thus, by this measure, male children are receiving greater parental investment than female children, counter to the result from the estimates of the age at which weaning was complete. In pre-weaning years, the absolute difference between males and females in  $\delta^{15}\text{N}$  is 2.5‰, post-weaning it is 2.3‰, by age 7–9 years it is 1.8‰, and as adults it is just 1.3‰. Thus, the male–female difference gradually decreases with age but is significantly different, on average, even in adulthood.

Together, the data suggest that females, like males, began their lives breastfeeding, but were including at least some plant foods very early in life, complementing breast milk. Girls may have been breastfed for a longer period of time but were eventually fully weaned on much lower trophic-level foods than males. Girls continued eating lower trophic-level foods through their juvenile years and even into adulthood. By contrast, boys were fully weaned earlier in life, but began consuming higher trophic level protein during and after the weaning process, leading to elevated  $\delta^{15}\text{N}$  values. They continued eating these higher trophic-level foods through their adult years.

To our knowledge, such sex-based differences in childhood diet have not been recorded in other archaeological

populations. For example, Rietsema and Vercellotti (2012) record isotopically similar childhood diets for males and females in a medieval population in Italy. Likewise, Fuller et al. (2003) report similar values for males and females in dentinal collagen of canine teeth at the medieval site of Wharram Percy in Yorkshire, UK. In line with our results, both of these studies show significant interindividual variation in childhood dietary practices. In any case, these studies suggest that biological differences between boys and girls are unlikely to explain the observed sex differences. At the same time, and apart from the sex-linked differences, the overall dietary life history trajectory at CA-CCO-548 is remarkably similar to hunter-gatherers in the Cis-Baikal region of Siberia (Waters-Rist et al., 2011).

We propose that elevated  $\delta^{15}\text{N}$  values in the life history of males at CA-CCO-548 arose through one of three behavioral means. First, it is possible that mothers of boys consumed a different suite of foods while they were nursing, one enriched in higher-trophic level foods. They would then pass this enriched nitrogen on to their sons in the form of breast milk. We find this explanation the least likely of the three, as we are unaware of examples in modern hunter-gatherers where females alter their diet according to the sex of their nursing offspring. Moreover, mothers may be nursing more than one child at a time (albeit one more intensively than others), and the sex of the children in those cases may have been mixed.

Second, and more likely, the differences could relate to explicit sex-biased provisioning by parents. Under this explanation, the diets of breastfeeding boys were supplemented with higher quality foods by their parents, a pattern that continued into post-weaning years. For example, boys in camp may have been encouraged to eat more meat and/or higher-quality animal parts such as brain and liver, relative to girls. As well, young boys may have occasionally accompanied their fathers or other adult males on short hunting bouts (i.e., a few hours), within a few kilometers of camp. Time spent away from the camp, where presumably their mothers or other female relatives were located, may have encouraged the earlier weaning we observed. During these hunting bouts, boys could have consumed increased quantities of terrestrial meat and/or fish relative to girls. Likewise, young girls may have stayed closer to the village site and/or accompanied their mothers on foraging bouts. During such activities, girls may have consumed higher quantities of plant products such as berries and gruels made out of acorns, seeds, and roots, among others, resulting in lower  $\delta^{15}\text{N}$  values. This sort of argument has been proposed elsewhere to explain differential rates of dental caries between males and females (Walker, 1988; Walker and Hewlett, 1990; though see Lukacs and Largaespada, 2006 for biologically mediated explanations for differences in dental caries).

In any case, if parents were explicitly provisioning boys with higher quality foods, this explanation runs counter to our hypothesis of increased investment in female offspring. It is, however, consistent with the Trivers-Willard hypothesis, which suggests that populations with room to grow will increase investment in boys. Much research shows that regional populations in Central California grew markedly during the Late Holocene (Rosenthal et al., 2007), just after the cemetery at CA-CCO-548 was in use.

Third, and we think most likely, it is possible that the differences relate less to explicit provisioning by parents,

but more to self-provisioning by children. If foraging and self-provisioning began at an early age in this population, and the nature of such foraging was sex-biased, with girls focusing on plants and boys on small animals, the isotopic patterns we describe could emerge. For example, while girls may have collected berries, nuts, or leafy greens for their own consumption, boys may have focused on capturing small-bodied prey, such as frogs, turtles, snakes, and lizards. The latter items are typically ignored by adults due to low return rates, but are a readily available resource for child foragers and have elevated  $\delta^{15}\text{N}$  values. Such self-foraging by children has been observed in some ethnographic studies among hunter-gatherers, showing that children can be effective foragers and can provide a significant component of their dietary intake (Hawkes et al., 1995; Blurton-Jones et al., 1997; Bird and Bliege Bird, 2005; p 135; Bock, 2005), though in some populations children do little self-foraging (Blurton-Jones et al., 1994). Such sex-biased self-foraging by children, precisely along the lines we observe at CA-CCO-548, has recently been reported among the Hadza as well (Crittenden et al., 2013). In that study, juvenile boys were observed to consume significantly more calories while out foraging, especially small game and honey, than young girls.

Importantly, and in keeping with our central hypothesis, such self-foraging could, in fact, represent less investment by parents in male offspring if boys were encouraged to acquire their own foods away from camp, while girls were provisioned with processed and carbohydrate-rich plant gruels in camp. Additionally, self-foraging may have helped young girls and boys acquire knowledge about the local environment and ecology, honing their gathering and hunting skills at an early age. These hypotheses can only be robustly evaluated with a larger data set and additional osteological and isotopic analyses.

Regardless of which of the three scenarios above is correct, we believe that the sex differences likely reflect a process of gender enculturation in the population. Girls and boys likely acquired the skills they would need as adult women and men early in life, and in the process, consumed a different suite of resources. Indeed, early gender enculturation is commonly observed cross-culturally (Montgomery, 2010), and often includes differential access to food. Osteological data do not indicate significant nutritional stress at CA-CCO-548; for example the prevalence of enamel hypoplasia defects and possible scars of anemia (cribra orbitalia, porotic hyperostosis) were low (Wiberg, 2010). Nor is there evidence that females consistently died at earlier ages or experienced higher rates of periosteal bone reactions. Thus, the sex differences in diet do not appear to have had deleterious effects on either males or females. Instead, the differences may be the byproduct of where children were located (e.g., in camp or out foraging) as they were acquiring the skills they would need as adults. Because males and females would need different skills as adults, they may have been learning in different settings, and in the process, consuming different suites of foods in those locations.

## CONCLUSIONS

We were able to document a late average age of weaning in a 3000- to 4000-year-old archaeological site in Central California. Although some children were completely weaned as early as 1 to 2 years of age, and

others as late as 5 to 6 years, the average age at which breast milk input ceased was between 3 and 4 years (average = 3.4 years for all individuals). This is close to but slightly later than what has been documented in ethnographic studies of 20th century hunter-gatherer groups (Barry and Paxson, 1971; Konner, 2005; p 57). In this respect, the data support the notion that mothers at CA-CCO-548 invested significant energy in breastfeeding their children to ensure their survival into adulthood. At the same time, significant input of solid food began by 1 to 2 years of age. We cannot determine whether the source of this food was parental provisioning, self-foraging, or a combination of the two factors.

The data are equivocal about sex-biased parental investment. On the one hand, there is a trend showing that females in our sample were generally weaned over a longer period of time, and on average about 0.4 years later than males (12% later than males). The female-male differences are not statistically significant, but this pattern is at least consistent with our central hypothesis of greater investment in female offspring. On the other hand, males in our sample consumed higher trophic level foods, suggesting greater investment in boys. This would be consistent with a population with room to grow, as seems to have been the case in prehistory. However, as we have discussed, it is not clear whether parents provided these higher quality foods, which would suggest greater investment, or if boys self-foraged and acquired these resources on their own, in which case there may have been less investment. Larger sample sizes will be needed to better evaluate this hypothesis.

Even controlling for sex, there is high interindividual variation in age of weaning and the isotopic composition of childhood diet. The significance of this variation remains unclear. In addition to increasing the sample size, future studies will be directed at examining the long-term outcomes of these childhood dietary practices, which may explain some of this variation. For example, we aim to examine whether the age of weaning and the composition of childhood diet had predictable effects on stature, longevity, and/or rates of pathological conditions, within a particular sex. As well, we aim to examine whether wealth, as measured by associated grave goods, and immigration status, as measured by strontium and oxygen isotopes (i.e., immigrant or local; see Jorgenson, 2012), is correlated with childhood dietary patterns. Such additional contextual data may help shed light on the significance of the high interindividual variation.

Finally, we were also able to document meaningful differences in the diets of male and female children at CA-CCO-548. Our previous analyses of stable nitrogen isotopes in adult bone had shown slight, but statistically significant differences in the diets of mature males and females (Bartelink et al., 2010). Boys were consistently drawing their protein from higher trophic levels than females. Data from the first molars show that these dietary differences began early in life, typically by age 1 to 3 years. We believe these differences relate to early enculturation into a society marked by a sexual division of labor, allowing boys and girls to acquire important hunting, fishing, and gathering skills. Such learning may have taken children to different parts of the landscape, where they were involved in different activities, including consumption of isotopically distinct foods. The dietary difference between the sexes was more pronounced earlier in life and diminished as individuals matured into adults.

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