ELSEVIER

Journal of Archaeological Science 34 (2007) 451–462

Journal of Archaeological SCIENCE

http://www.elsevier.com/locate/jas

Seasonality and paleodiet in the Chiribaya polity of southern Peru

Kelly J. Knudson [a,*], Arthur E. Aufderheide [b], Jane E. Buikstra [c]

[a] *Center for Bioarchaeological Research, School of Human Evolution and Social Change, PO Box 872402, Arizona State University, Tempe, AZ 85287-2402, USA*

[b] *Department of Pathology, University of Minnesota Medical School Duluth, Duluth, MN, USA*

[c] *Center for Bioarchaeological Research, Arizona State University, Tempe, AZ, USA*

Received 12 May 2006; received in revised form 29 June 2006; accepted 2 July 2006

Abstract

In the Andes, the complex Chiribaya polity, or *señorío*, was composed of economically specialized groups. Previous carbon and nitrogen isotope analyses of archaeological human bone from Chiribaya-affiliated sites have effectively demonstrated socioeconomic specialization and variability in paleodiet among different Chiribaya-affiliated sites. The present study complements earlier paleodietary analyses of Chiribaya populations by supplementing them with carbon and nitrogen isotope analyses of archaeological human hair from the two Chiribaya-affiliated sites of Chiribaya Alta and El Yaral. These new data demonstrate that seasonal variability in the consumption of marine products and C_4 plants such as maize was quite high for some individuals buried at Chiribaya-affiliated sites. In addition to elucidating the complex patterns of Chiribaya seasonality, this study contributes to the growing body of knowledge of archaeological analyses of human hair for paleodiet.

Keywords: Carbon isotopes; Nitrogen isotopes; Hair; Andes

1. Introduction

Previous paleodietary research on the Chiribaya polity of southern Peru has very effectively demonstrated socioeconomic specialization and variability in paleodiet among different Chiribaya-affiliated sites (Tomczak, 2003). However, these data from archaeological human bone samples have focused on paleodiet averaged over the last years of an individual's life. The present study complements Tomczak's (2003) earlier paleodietary analyses of the Chiribaya by supplementing it with carbon and nitrogen isotope analyses of archaeological human hair from the two Chiribaya-affiliated sites of Chiribaya Alta and El Yaral. This provides valuable information on seasonality in Chiribaya paleodiet, and demonstrates that seasonal variability in the consumption of marine products and C_4 plants such as maize was quite high for some individuals buried at Chiribaya-affiliated sites. This study also contributes to the growing body of knowledge of archaeological analyses of human hair.

2. The Chiribaya polity of the south central Andes

Previous research on the Chiribaya of southern Peru has elucidated the sociopolitical complexity of this Late Intermediate Period polity (Buikstra, 1995; Jessup, 1990; Lozada Cerna and Buikstra, 2002, 2005; Martinson et al., 2002; Owen, 1998; Reycraft, 2000, 2005; Rice, 1993; Sutter, 2000; Umire Alvarez and Miranda, 2001; Williams et al., 1990; Zaro and Umire Alvarez, 2005). Excavations in residential and mortuary sectors at the Chiribaya-affiliated sites of Chiribaya Alta, Chiribaya Baja, San Gerónimo, and El Yaral, as well as previous cranial modification and light stable isotope studies of archaeological human bone, all support the hypothesis that the Chiribaya were organized into smaller economically specialized groups that were part of a larger *señorío* (Fig. 1) (Buikstra et al., 2005; Lozada Cerna and Buikstra, 2002, 2005; Tomczak, 2003).

* Corresponding author. Tel.: +1 480 965 6213; fax: +1 480 965 7671.
E-mail address: kelly.knudson@asu.edu (K.J. Knudson).

0305-4403/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jas.2006.07.003

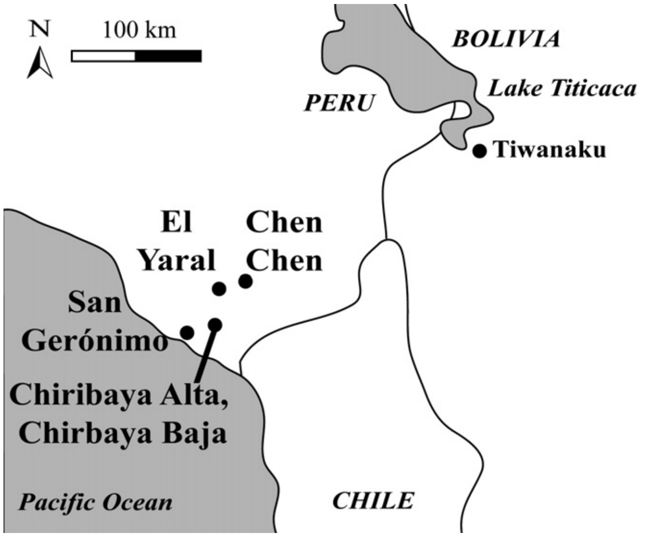

Fig. 1. Map of the south central Andes with the Chiribaya-affiliated sites of El Yaral, San Gerónimo, Chiribaya Alta, and Chiribaya Baja and the Tiwanaku-affiliated site of Chen Chen.

Two Chiribaya-affiliated sites were included in this study, Chiribaya Alta and El Yaral. The site of Chiribaya Alta is clearly the largest Chiribaya-affiliated site, and may be the regional political center (Fig. 2) (Rice, 1993). Chiribaya Alta is located 7 km from the Pacific Ocean where it overlooks the Ilo Valley (Buikstra, 1995). In addition to nine cemeteries that vary spatially and temporally, Chiribaya Alta also contains a number of domestic units, plazas, terraces, and a defensive wall (Buikstra, 1995). It is possible that Chiribaya elites from other communities were buried at Chiribaya Alta, as is seen at the Andean ceremonial center of Pachacamac (Lozada Cerna, 1998; Lozada Cerna and Buikstra, 2002).

More than 305 burials with 372 individuals from intact and disturbed tombs were recovered from the nine Chiribaya Alta cemeteries. Of these 372 individuals, 147 were complete enough for inclusion in previous biodistance and cranial modification studies (Lozada Cerna and Buikstra, 2002). Of this subset, 85 individuals were included in previous bone carbon and nitrogen isotope analyses (Tomczak, 2003), and 12 individuals were included in Knudson's enamel and bone strontium isotope analyses.

In contrast to Chiribaya Alta, the site of El Yaral is located approximately 50 km from the Pacific Ocean (Buikstra, 1995). There, it is surrounded by Tiwanaku-affiliated sites like Chen Chen, and it is one of the few Chiribaya-affiliated sites in the Moquegua Valley. It is also smaller than Chiribaya Alta, and consists of residential terraces and a large mortuary component (Fig. 3) (Lozada Cerna and Torres Pino, 1991; Rice, 1993; Wheeler et al., 1995). Excavations in the mortuary component of El Yaral uncovered 99 individuals buried in cist tombs in a flexed position (Buikstra, 1995). The number and types of mortuary artifacts are limited when compared to Chiribaya Alta, although gender-based specialization is apparent (Buikstra, 1995). Of the 99 individuals buried at El Yaral, 74 were buried with Chiribaya-style artifacts and have been included in previous skeletal analyses and paleodiet studies (Tomczak, 2003), 47 were included in previous biodistance and cranial modification studies (Lozada Cerna, 1998; Lozada Cerna and Buikstra, 2002), and four were included in Knudson's residential mobility studies.

3. Archaeological analyses of human hair

Although limited to archaeological sites with exceptional preservation, analyses of archaeological human hair to identify seasonal trends in paleodiet have become increasingly common (Fernández et al., 2003; Macko et al., 1999a,b; O'Connell

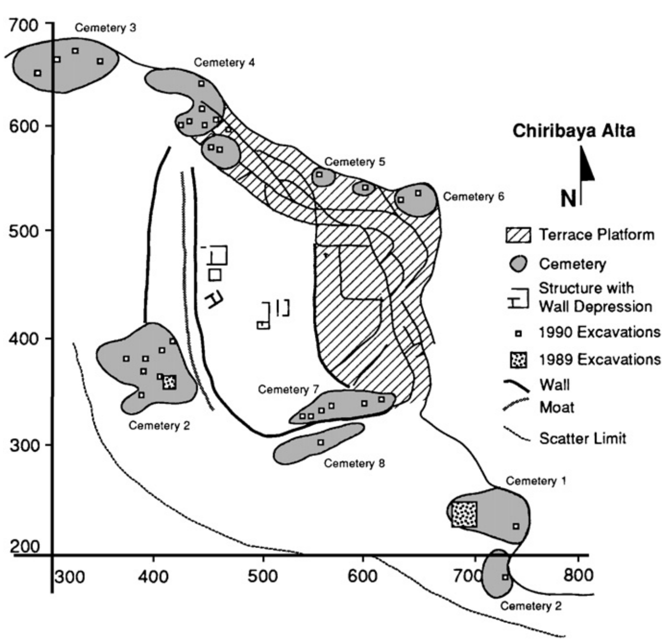

Fig. 2. Site map of Chiribaya Alta (from Buikstra, 1995: 256).

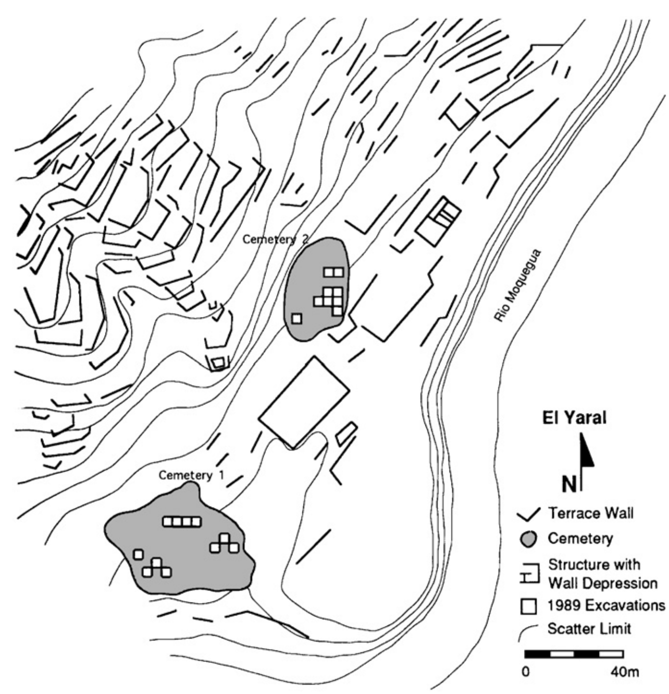

Fig. 3. Site map of El Yaral (from Buikstra, 1995: 257).

and Hedges, 1999a,b; O'Connell et al., 2001; Panarello et al., 2003; Roy et al., 2005; Sandford and Kissling, 1993; Schwarcz and White, 2004; White, 1993; Wilson et al., 1999). These studies build on earlier research on archaeological human hair that utilized trace element concentrations to identify pathologies and paleodiet (Benfer et al., 1978; Grupe and Dorner, 1989; Kowal et al., 1991; Sandford et al., 1983). In addition, some researchers have used non-human hair to examine short-term climatic changes and seasonal changes in diet (e.g. Iacumin et al., 2005; Schoeninger et al., 1998, 1999).

Most paleodiet research using light stable isotopes utilizes archaeological bone samples and, to a lesser extent, tooth enamel samples, to identify broad paleodietary trends (e.g. Balasse, 2002; Cox et al., 2001; Lee-Thorp et al., 2003; Richards et al., 2003, 2006; Spielmann et al., 1990; Tykot and Staller, 2002). However, analyses of archaeological human hair can provide a much more fine-grained resolution of seasonality. Individual human hair follicles experience independent growth cycles and, during active growth, approximately 0.2–0.5 mm of hair are produced by an individual hair follicle each day (Robbins, 2002; Sandford and Kissling, 1993; Valkovic, 1988a). Although growth rates vary according to hair texture and seasonal variations, on average hair grows approximately 1 cm per month (Randall and Ebling, 1991; Valkovic, 1988a). In addition, human hair contains 44–46% carbon (in weight) and 13–14% nitrogen (in weight) (Roy et al., 2005; Valkovic, 1988b). Therefore, carbon and nitrogen isotopic analyses of 1–2 cm hair samples can provide dietary information for approximately 1–2 months of food consumption. This hypothesis has been tested and supported with modern control populations with known diets (Macko et al., 1999a; McCullagh et al., 2005; Petzke et al., 2005; Sharp et al., 2003; Sponheimer et al., 2003).

In addition to its utility in identifying diet on a much smaller temporal scale than studies that utilize bone collagen, hair is much more resistant to diagenetic contamination than bone collagen. Bone collagen can be altered by hydrolysis, deamination, and decarboxylation (Macko and Engel, 1991). Hair, on the other hand, is composed of α-keratins, hydrophobic proteins that are resistant to degradation (Lubec et al., 1987; Robbins, 2002). The structure of α-keratins also assists in their resistance to diagenetic contamination as the α-helix is tightly packed and very stable (Lubec et al., 1987; Macko et al., 1999a; Robbins, 2002). Numerous studies have demonstrated the retention of the original amino acid composition, and of carbon and nitrogen isotope signatures, in archaeological hair samples (Lubec et al., 1987; Macko and Engel, 1991; Macko et al., 1999a; Roy et al., 2005). Although the nitrogen and carbon isotopes in hair faithfully reflect the diet of an individual, a decrease in $\delta^{15}N$ values during gestation has been documented in the hair of pregnant women (Fuller et al., 2004, 2005).

4. Paleodietary analyses through carbon and nitrogen isotopes: a brief introduction

Isotopic data from archaeological human remains have been successfully employed for almost 30 years, and have provided much valuable information about paleodiet (e.g. Ambrose, 1993; Ambrose and Krigbaum, 2003; Katzenberg, 2000; Pate, 1994; Schoeninger, 1989; Sillen et al., 1989; Staller et al., 2006). Briefly, analyses of stable isotopes of carbon can determine relative amounts of C_4 and C_3 plants in an individual's diet from their bone collagen and hydroxyapatite, while nitrogen isotopes can elucidate the role of marine and freshwater food consumption (DeNiro and Epstein, 1978, 1981; Schoeninger and DeNiro, 1984). The carbon isotopic composition of plants reflects the photosynthetic pathways used in CO_2 conversion. Plants that use the C_4, or Hatch–Slack, pathway generally have $\delta^{13}C$ compositions between -9 and $-14‰$ while plants that use the C_3, or Calvin, pathway have $\delta^{13}C$ values between -30 and $-35‰$ (Katzenberg, 2000). In contrast, marine plants typically convert bicarbonate, which has a $\delta^{13}C$ value of approximately 0‰, instead of atmospheric CO_2 (Ambrose et al., 1997). Although carbon isotope values in marine resources are approximately $\delta^{13}C = -20.0‰$, there is considerable variability according to species and locale (Katzenberg, 2000; Keegan and DeNiro, 1988; Schoeninger and DeNiro, 1984). Nitrogen isotopes in an organism reflect the nitrogen sources in the diet, and vary by trophic level. Marine sources are generally $\delta^{15}N = +6.0‰$ and terrestrial sources are lower and are typically $\delta^{15}N = 0.0‰$; each trophic level is generally enriched by 3‰ moving up the food chain (DeNiro and Epstein, 1981; Minagawa and Wada, 1984).

The Ilo and Moquegua Valleys of southern Peru provide a wide variety of resources that can be identified using carbon and nitrogen isotope analyses. While nitrogen isotopes can distinguish products from the rich marine ecosystem, carbon isotopes can distinguish the utilization of the C_4 crop, maize. However, since nitrogen isotopes can vary according to climate, and $\delta^{15}N$ in particular is enriched in arid environments, it is important to examine the isotopic composition of the local foodweb (Ambrose, 1991). Tieszen and Chapman (1992) analyzed a variety of terrestrial and marine plants and animals from northern Chile, an area environmentally similar to the Ilo and Moquegua Valleys of southern Peru. Mean $\delta^{13}C = -25.1‰$ for C_3 plants, mean $\delta^{13}C = -12.9‰$ for C_4 plants, and marine products had intermediate $\delta^{13}C$ between the C_3 and C_4 plants (Tieszen and Chapman, 1992). Terrestrial animals, including camelids, had more negative values, and averaged $\delta^{13}C = -22.5‰$ (Tieszen and Chapman, 1992). The $\delta^{15}N$ values of the marine resources were much higher than those of the terrestrial resources. For example, mean $\delta^{15}N = 19.2‰$ for fish, mean $\delta^{15}N = 18.0‰$ for vertebrates, and mean $\delta^{15}N = 17.9‰$ for invertebrates (Tieszen and Chapman, 1992).

5. Laboratory methodology for light stable isotope analyses

5.1. Sampling strategy for Chiribaya Alta and El Yaral

At both Chiribaya Alta and El Yaral, large samples of human remains had been included in previous bioarchaeological analyses (Lozada Cerna and Buikstra, 2002; Tomczak, 2003). However, the sample size for our isotopic analysis of archaeological hair was constrained by the preservation of hair samples that were many centimeters long. Five individuals from Chiribaya Alta and five individuals from El Yaral were chosen based on preservation, and consist of subadult and adult females and males from a variety of mortuary sectors (Table 1).

5.2. Laboratory methodology for light stable isotope analyses

Hair samples were initially prepared by Aufderheide in the Department of Pathology at the University of Minnesota Medical School Duluth. For each individual sampled, a scalp fragment approximately 5 by 3 cm with at least one long braid was removed. The braid was unwound and the hair was combed so that each individual hair shaft was parallel to the others. Then, the braid was wrapped in gauze, stapled at 2-cm intervals, and then suspended in a 1000-mL cylinder filled with absolute ethanol. After the gauze-wrapped hair was dry, the hair samples were obtained by transecting the gauze and its contained hair at the pre-measured 2-cm intervals. Each 2-cm hair sample, which consisted of multiple, parallel hairs from the same braid, was finely diced with a single-edged razor blade, stored in a separate glass vial, and numbered consecutively with Sample Number 1 representing the first 2-cm interval adjacent to the scalp. We assume that this sampling procedure will in fact underestimate the temporal variability in $\delta^{13}C_{keratin}$ and $\delta^{15}N$ values since the growth phases in adjacent hairs may not be identical. However, other scholars have detected temporal shifts using light stable isotopes through the analysis of adjacent hairs rather than using single hair strands (O'Connell and Hedges, 1999a,b; Schwarcz and White, 2004).

Bone samples from the same individuals were also sampled for carbon and nitrogen isotope analysis. Cortical bone samples from the same individuals were taken from a cross-section of the mid-diaphysis of the femur or tibia. Before analysis, approximately 1 mm of the surface periosteum was removed with a Dremel electric drill equipped with an aluminum oxide abrasive wheel.

Carbon and nitrogen isotopes were then analyzed by M. Chapman and L. Tieszen in the Mass Spectrometry Laboratory in the Department of Biology at Augustana College. Samples were prepared according to Tieszen and Chapman's previously published methodology (Tieszen and Chapman, 1992; Tieszen et al., 1992). Briefly, samples were washed in distilled water, extracted in chloroform and methanol, dried, and weighed. Collagen pseudomorphs were obtained by incubating the sample in 0.5 M EDTA. In order to test for the presence of bioapatite carbonate, 0.5 M HCl was added to the pseudomorph and observed under a 10^{-2} torr vacuum. Pseudomorphs were then extracted in 0.125 M NaOH and dried.

Collagen and keratin samples were combusted in a Carlo Erba CHN analyzer and CO_2 and N_2 gases were separated in a chromatographic column monitored by a thermal conductivity detector. Carbon dioxide for isotopic analyses was passed from the Carlo Erba CHN analyzer to a triple trapping system of the SIRA 10 isotope ratio mass spectrometer (IRMS). The carbon sample was standardized against PeeDee belemnite (PDB) carbonate standard as follows: $\delta^{13}C = ((((^{13}C/^{12}C_{sample})/(^{13}C/^{12}C_{standard}))/(^{13}C/^{12}C_{standard})) - 1) \times 1000$.

Nitrogen isotopes were measured similarly although CO_2 and H_2O were removed through an ascarite column preceding the trap and nitrogen was adsorbed on silica gel at liquid nitrogen temperature as the helium carrier gas transported it through the trapping system. The nitrogen sample was standardized against atmospheric nitrogen (air) as follows: $\delta^{15}N = ((((^{15}N/^{14}N_{sample})/(^{15}N/^{14}N_{standard}))/(^{15}N/^{14}N_{standard})) - 1) \times 1000$.

Samples were tested for diagenetic alteration using C:N ratios and percent of carbon and nitrogen. As shown in Table 2, the range of molar C:N for the bone samples analyzed from these individuals was C:N = 3.18–3.30; this suggests that the bones were not contaminated by carbon from lipids. The range of C:N for the hair samples analyzed from these individuals was C:N = 3.47–4.03, which also implies that little diagenetic contamination occurred. The percent yields of carbon and nitrogen were also close to the expected values, which are 44–46% carbon (in weight) and 13–14% nitrogen (in weight) for hair (Roy et al., 2005; Valkovic, 1988b).

Given the rare and valuable nature of the hair samples, replicate samples were only performed on bone samples. However, replicate analyses of bone samples demonstrate the reproducibility of the analysis (Table 1). Long-term precision is better than $\delta^{13}C = 0.1‰$ and $\delta^{15}N = 0.5‰$ at Augustana College. Finally, bone and hair samples from the same individuals were compared using the following formulas: $\Delta^{13}C_{hair-bone} = \delta^{13}C_{keratin\ (hair)} - \delta^{13}C_{collagen\ (bone)}$ and $\Delta^{15}N_{hair-bone} = \delta^{15}N_{keratin\ (hair)} - \delta^{15}N_{collagen\ (bone)}$.

Table 1
Contextual information on individuals sampled from Chiribaya-affiliated sites

Site	Sector	Specimen number	Feature number	Burial number	Age	Sex
Chiribaya Alta	3	CHA-1000	1000	301	25–35	F
Chiribaya Alta	3	CHA-3854	3854	331	45±	M
Chiribaya Alta	6	CHA-2291	2291	610	45±	F
Chiribaya Alta	9	CHA-2059	2059	901	55–60	F
Chiribaya Alta	7	CHA-2728	2728	728	25–28	M
El Yaral	1	M8-10024	10024	101F	18–21	F
El Yaral	1	M8-10200	10200	137	20–22	F
El Yaral	2	M8-10593	10593	246	30–35	M
El Yaral	2	M8-10427	10427	229	32–40	M
El Yaral	2	M8-10360	10360	216	6.5	U

6. Carbon and nitrogen isotope data from Chiribaya-affiliated sites

6.1. The Ilo Valley site of Chiribaya Alta

As shown in Fig. 4, $\delta^{13}C_{keratin}$ data from human hair segments from Chiribaya Alta show variability in seasonal consumption of C_3 and C_4 plants as well as variability between consumption levels of different individuals (Fig. 4, Table 3).

Table 2
Carbon and nitrogen data from human bone samples from Chiribaya-affiliated sites

Site	Specimen number	% yield	$\delta^{13}C_{collagen}$ (‰)	$\delta^{15}N$ (‰)	% C	% N	C:N (mole %)	$\delta^{13}C_{apatite}$ (‰)	Collagen/apatite spacing
Chiribaya Alta	CHA-1000	20.62	−13.8	15.9	45.9	16.9	3.18	−9.5	4.33
Chiribaya Alta	CHA-1000 (repeat)	20.04	−13.8	NA	NA	NA	NA	−9.3	NA
Chiribaya Alta	CHA-3854	NA	NA	NA	NA	NA	NA	NA	NA
Chiribaya Alta	CHA-2291	20.04	−14.1	15.8	44.3	16.2	3.20	−8.0	6.08
Chiribaya Alta	CHA-2059	22.54	−18.7	12.4	46.0	16.3	3.29	−14.9	3.83
Chiribaya Alta	CHA-2059 (repeat)	35.10	−18.7	12.5	43.9	15.6	3.29	NA	NA
Chiribaya Alta	CHA-2728	18.80	−12.1	19.0	46.2	16.3	3.30	−7.3	4.76
El Yaral	M8-10024	20.75	−17.8	12.2	44.2	16.3	3.17	−14.9	2.94
El Yaral	M8-10200	19.75	−12.7	15.8	45.5	16.2	3.28	−9.4	3.32
El Yaral	M8-10200 (repeat)	19.75	−12.7	NA	NA	NA	NA	NA	NA
El Yaral	M8-10593	21.17	−15.6	13.7	44.7	16.2	3.22	−11.1	4.51
El Yaral	M8-10427	20.97	−14.0	10.3	47.2	17.1	3.23	−9.5	4.51
El Yaral	M8-10360	21.61	−14.1	10.7	46.0	16.6	3.24	−9.2	4.91

Three individuals have relatively small seasonal differences in $\delta^{13}C_{keratin}$ values (CHA-1000, CHA-2728, and CHA-2291). These three individuals also have $\delta^{13}C_{keratin}$ values that range between approximately $\delta^{13}C_{keratin} = -13.0$‰ and $\delta^{13}C_{keratin} = -15.0$‰. Based on Tieszen and Chapman's (1992) reconstruction of the isotope ranges in northern Chilean foodwebs, these values are within the range of measured C_4 plants values and terrestrial animals. This implies that the protein sources in these individuals' diets were C_4 plants and/or terrestrial animals. The values also correspond to marine plant and/or marine animal consumption, which will be discussed below.

In contrast, there are two individuals who exhibit large changes in $\delta^{13}C_{keratin}$ values as one moves along the hair shaft (CHA-3854 and CHA-2059) (Fig. 4, Table 3). The most dramatic changes are seen in 26 cm of hair from CHA-2059, an adult female (Fig. 4, Table 3). The highest values are seen in the hair segments within 6 cm of her scalp and the hair segments within 22–24 cm from her scalp; these values are $\delta^{13}C_{keratin} = -12.1$‰ to -13.1‰. This implies that the protein sources in this woman's diet in approximately the last six months before death were dominated by C_4 plants, presumably maize. Similarly, high maize consumption is seen in the period of approximately 22–26 months before death, according to the $\delta^{13}C_{keratin}$ values in this woman's hair. However, the intervening months show a gradual decrease and then increase in $\delta^{13}C_{keratin}$ values. The lowest $\delta^{13}C_{keratin}$ values are $\delta^{13}C_{keratin} = -18.9$‰, which occur in the hair segments 12–16 cm from her scalp. These values imply that C_4 plants were less important sources of protein during these periods of hair growth, and that protein sources at this time were instead C_3 plants and terrestrial animals. A similar pattern is seen in the $\delta^{13}C_{keratin}$ values measured in hair segments from CHA-3854. In this individual, there is a range of $\delta^{13}C_{keratin} = -15.1$‰ to -19.5‰, with the lowest value measured in the hair segment 16–18 cm from the scalp.

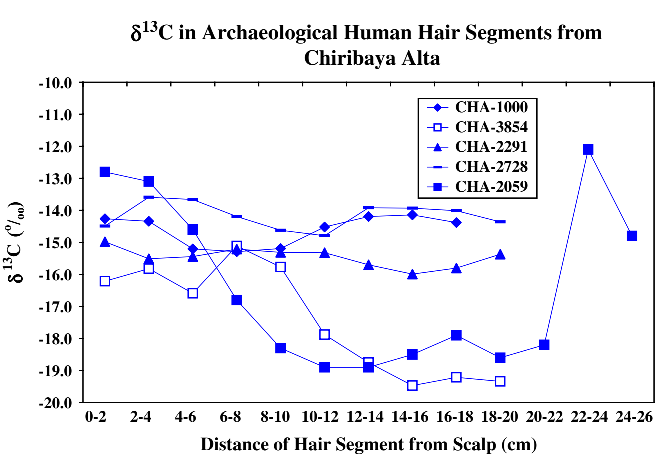

Fig. 4. Carbon isotope data from Chiribaya Alta hair samples.

The nitrogen isotope trends seen in human hair from Chiribaya Alta are similar to the carbon isotope trends (Figs. 4 and 5, Table 3). The same three individuals have relatively small seasonal differences in $\delta^{15}N$ values (CHA-1000, CHA-2728, and CHA-2291). As shown in Fig. 5, these three individuals have relatively high $\delta^{15}N$ values that range from approximately $\delta^{15}N = 15.0$–18.5‰. These high $\delta^{15}N$ values correspond to the $\delta^{15}N$ values that Tieszen and Chapman (1992) measured in marine animals in northern Chile. The high $\delta^{15}N$ values in the 20 cm of hair that was measured imply that these three individuals buried at Chiribaya Alta consumed large amounts of marine animals during the periods of approximately the last 18–20 months of their lives.

One other individual buried at Chiribaya Alta exhibited lower $\delta^{15}N$ values, although the $\delta^{15}N$ did not change dramatically along the hair shaft (CHA-3854) (Fig. 5, Table 3). For CHA-3865, $\delta^{15}N$ along the hair shaft ranged from $\delta^{15}N = 12.6$–14.1‰. These lower $\delta^{15}N$ values imply that this adult male consumed larger amounts of marine plants and/or smaller amounts of marine animals during the last months of his life when compared to other individuals buried at Chiribaya Alta.

Finally, there is one individual buried at Chiribaya Alta who exhibits a wider range of $\delta^{15}N$ values in different hair segments (CHA-2059) (Fig. 6, Table 3). This adult female also exhibited the most dramatic changes in $\delta^{13}C_{keratin}$ values in her hair, and $\delta^{15}N$ values are similarly variable. In the first 2 cm of hair from her scalp, $\delta^{15}N = 18.2$‰. Nitrogen isotope

Table 3
Carbon and nitrogen data from human hair samples from Chiribaya-affiliated sites

Site	Laboratory number	Specimen number	Distance from scalp (cm)	$\delta^{13}C_{keratin}$ (‰)	$\delta^{15}N$ (‰)	% C	% N	C:N (mole %)
Chiribaya Alta	CHA-1000-1	CHA-1000	0–2	−14.3	16.9	40.9	13.7	3.48
Chiribaya Alta	CHA-1000-2	CHA-1000	2–4	−14.3	17.3	40.3	13.5	3.47
Chiribaya Alta	CHA-1000-3	CHA-1000	4–6	−15.2	16.7	42.1	14.1	3.48
Chiribaya Alta	CHA-1000-4	CHA-1000	6–8	−15.3	16.3	41.8	13.9	3.51
Chiribaya Alta	CHA-1000-5	CHA-1000	8–10	−15.2	16.4	42.5	14.1	3.53
Chiribaya Alta	CHA-1000-6	CHA-1000	10–12	−14.5	16.0	41.6	13.9	3.50
Chiribaya Alta	CHA-1000-7	CHA-1000	12–14	−14.2	16.8	42.4	14.0	3.53
Chiribaya Alta	CHA-1000-8	CHA-1000	14–16	−14.1	16.9	42.6	14.0	3.56
Chiribaya Alta	CHA-1000-9	CHA-1000	16–18	−14.4	17.7	43.0	14.1	3.56
Chiribaya Alta	CHA-3854-1	CHA-3854	0–2	−16.2	14.1	44.8	13.6	3.85
Chiribaya Alta	CHA-3854-2	CHA-3854	2–4	−15.8	12.7	45.2	14.0	3.75
Chiribaya Alta	CHA-3854-3	CHA-3854	4–6	−16.6	13.2	45.0	14.0	3.76
Chiribaya Alta	CHA-3854-4	CHA-3854	6–8	−15.1	13.3	41.9	13.1	3.74
Chiribaya Alta	CHA-3854-5	CHA-3854	8–10	−15.8	13.0	44.9	13.9	3.77
Chiribaya Alta	CHA-3854-6	CHA-3854	10–12	−17.9	13.1	44.9	13.6	3.86
Chiribaya Alta	CHA-3854-7	CHA-3854	12–14	−18.8	12.7	45.0	13.5	3.89
Chiribaya Alta	CHA-3854-8	CHA-3854	14–16	−19.5	13.1	45.0	13.4	3.91
Chiribaya Alta	CHA-3854-9	CHA-3854	16–18	−19.2	13.4	44.6	13.7	3.81
Chiribaya Alta	CHA-3854-10	CHA-3854	18–20	−19.3	13.1	43.3	13.4	3.76
Chiribaya Alta	CHA-2291-1	CHA-2291	0–2	−15.0	18.0	40.4	12.9	3.65
Chiribaya Alta	CHA-2291-2	CHA-2291	2–4	−15.5	18.1	39.5	12.6	3.67
Chiribaya Alta	CHA-2291-3	CHA-2291	4–6	−15.4	18.1	41.4	13.6	3.56
Chiribaya Alta	CHA-2291-4	CHA-2291	6–8	−15.2	18.2	40.7	13.3	3.56
Chiribaya Alta	CHA-2291-5	CHA-2291	8–10	−15.3	18.2	42.1	13.8	3.55
Chiribaya Alta	CHA-2291-6	CHA-2291	10–12	−15.3	18.1	42.7	14.1	3.54
Chiribaya Alta	CHA-2291-7	CHA-2291	12–14	−15.7	18.3	42.5	13.8	3.58
Chiribaya Alta	CHA-2291-8	CHA-2291	14–16	−16.0	17.8	41.2	13.9	3.47
Chiribaya Alta	CHA-2291-9	CHA-2291	16–18	−15.8	17.6	41.0	13.6	3.51
Chiribaya Alta	CHA-2291-10	CHA-2291	18–20	−15.4	18.2	42.5	14.0	3.55
Chiribaya Alta	CHA-2059-1	CHA-2059	0–2	−12.8	18.2	46.4	15.0	3.61
Chiribaya Alta	CHA-2059-2	CHA-2059	2–4	−13.1	17.7	46.1	15.1	3.57
Chiribaya Alta	CHA-2059-3	CHA-2059	4–6	−14.6	16.4	46.2	15.3	3.52
Chiribaya Alta	CHA-2059-4	CHA-2059	6–8	−16.8	15.1	44.3	14.8	3.48
Chiribaya Alta	CHA-2059-5	CHA-2059	8–10	−18.3	13.0	45.8	15.3	3.48
Chiribaya Alta	CHA-2059-6	CHA-2059	10–12	−18.9	12.3	45.6	15.2	3.49
Chiribaya Alta	CHA-2059-7	CHA-2059	12–14	−18.9	12.6	43.7	14.5	3.51
Chiribaya Alta	CHA-2059-8	CHA-2059	14–16	−18.5	12.4	45.3	15.2	3.47
Chiribaya Alta	CHA-2059-9	CHA-2059	16–18	−17.9	12.3	46.9	15.6	3.51
Chiribaya Alta	CHA-2059-10	CHA-2059	18–20	−18.6	12.4	45.3	15.0	3.51
Chiribaya Alta	CHA-2059-11	CHA-2059	20–22	−18.2	13.8	45.6	15.0	3.53
Chiribaya Alta	CHA-2059-12	CHA-2059	22–24	−12.1	15.4	45.6	15.0	3.55
Chiribaya Alta	CHA-2059-13	CHA-2059	24–26	−14.8	16.6	45.5	14.6	3.63
Chiribaya Alta	CHA-2728-1	CHA-2728	0–2	−14.5	18.0	43.2	14.0	3.59
Chiribaya Alta	CHA-2728-2	CHA-2728	2–4	−13.6	18.2	42.7	14.1	3.53
Chiribaya Alta	CHA-2728-3	CHA-2728	4–6	−13.7	18.4	42.5	14.0	3.54
Chiribaya Alta	CHA-2728-4	CHA-2728	6–8	−14.2	18.2	44.3	14.5	3.57
Chiribaya Alta	CHA-2728-5	CHA-2728	8–10	−14.6	18.5	44.6	14.6	3.56
Chiribaya Alta	CHA-2728-6	CHA-2728	10–12	−14.8	18.4	44.3	14.4	3.58
Chiribaya Alta	CHA-2728-7	CHA-2728	12–14	−13.9	18.6	44.4	14.4	3.58
Chiribaya Alta	CHA-2728-8	CHA-2728	14–16	−13.9	18.2	44.4	14.5	3.58
Chiribaya Alta	CHA-2728-9	CHA-2728	16–18	−14.0	18.6	44.5	14.4	3.61
Chiribaya Alta	CHA-2728-10	CHA-2728	18–20	−14.4	18.5	44.7	14.3	3.64
El Yaral	M8-10024-1	M8-10024	0–2	−18.4	14.4	43.1	14.4	3.49
El Yaral	M8-10024-2	M8-10024	2–4	−18.2	13.6	42.7	13.6	3.66
El Yaral	M8-10024-3	M8-10024	4–6	−18.0	13.4	41.7	13.4	3.63
El Yaral	M8-10024-4	M8-10024	6–8	−17.1	13.7	43.5	13.7	3.71
El Yaral	M8-10024-5	M8-10024	8–10	−17.1	13.5	42.5	13.5	3.67
El Yaral	M8-10024-6	M8-10024	10–12	−17.6	13.6	43.2	13.6	3.71
El Yaral	M8-10024-7	M8-10024	12–14	−17.1	14.3	42.6	14.3	3.47
El Yaral	M8-10024-8	M8-10024	14–16	−17.2	13.9	42.5	13.9	3.56
El Yaral	M8-10024-9	M8-10024	16–18	−17.9	13.8	42.5	13.8	3.59
El Yaral	M8-10024-10	M8-10024	18–20	−17.0	13.8	42.4	13.8	3.58

(*continued*)

Table 3 (*continued*)

Site	Laboratory number	Specimen number	Distance from scalp (cm)	$\delta^{13}C_{keratin}$ (‰)	$\delta^{15}N$ (‰)	% C	% N	C:N (mole %)
El Yaral	M8-10200-1	M8-10200	0–2	−16.8	11.6	40.0	12.3	3.80
El Yaral	M8-10200-2	M8-10200	2–4	−16.0	11.7	40.8	12.6	3.79
El Yaral	M8-10200-3	M8-10200	4–6	−14.9	12.3	40.7	12.5	3.81
El Yaral	M8-10200-4	M8-10200	6–8	−13.9	13.1	43.4	13.5	3.76
El Yaral	M8-10200-5	M8-10200	8–10	−13.2	15.5	44.0	13.8	3.71
El Yaral	M8-10200-6	M8-10200	10–12	−13.9	16.7	42.5	13.4	3.70
El Yaral	M8-10200-7	M8-10200	12–14	−15.0	17.4	43.9	13.8	3.72
El Yaral	M8-10200-8	M8-10200	14–16	−15.0	17.8	42.7	13.2	3.78
El Yaral	M8-10200-9	M8-10200	16–18	−15.3	17.0	40.1	12.2	3.82
El Yaral	M8-10200-10	M8-10200	18–20	−14.4	16.0	41.1	12.5	3.83
El Yaral	M8-10200-1	M8-10593	0–2	−15.2	13.3	44.2	14.1	3.66
El Yaral	M8-10200-2	M8-10593	2–4	−15.7	13.9	45.7	14.3	3.73
El Yaral	M8-10200-3	M8-10593	4–6	−15.7	14.1	44.1	14.3	3.60
El Yaral	M8-10200-4	M8-10593	6–8	−15.8	13.6	43.4	14.1	3.59
El Yaral	M8-10200-5	M8-10593	8–10	−15.6	12.9	43.3	14.1	3.59
El Yaral	M8-10200-6	M8-10593	10–12	−14.8	12.8	44.1	14.4	3.56
El Yaral	M8-10200-7	M8-10593	12–14	−14.4	12.3	44.6	14.5	3.58
El Yaral	M8-10200-8	M8-10593	14–16	−14.0	13.0	44.4	14.3	3.62
El Yaral	M8-10200-9	M8-10593	16–18	−13.7	13.5	42.9	14.1	3.55
El Yaral	M8-10200-10	M8-10593	18–20	−13.9	13.4	42.8	14.0	3.56
El Yaral	M8-10427-1	M8-10427	0–2	−16.5	11.9	40.9	13.2	3.61
El Yaral	M8-10427-2	M8-10427	2–4	−16.5	11.9	40.8	13.3	3.58
El Yaral	M8-10427-3	M8-10427	4–6	−16.1	11.6	40.3	13.4	3.50
El Yaral	M8-10427-4	M8-10427	6–8	−15.1	11.4	38.2	13.1	3.40
El Yaral	M8-10427-5	M8-10427	8–10	−14.6	11.7	39.2	13.5	3.40
El Yaral	M8-10427-6	M8-10427	10–12	−14.5	11.9	38.5	13.0	3.46
El Yaral	M8-10427-7	M8-10427	12–14	−14.6	12.3	40.7	13.6	3.49
El Yaral	M8-10427-8	M8-10427	14–16	−14.8	13.1	40.6	13.5	3.51
El Yaral	M8-10427-9	M8-10427	16–18	−15.1	14.0	41.5	13.7	3.54
El Yaral	M8-10427-10	M8-10427	18–20	−14.8	13.2	41.8	13.6	3.58
El Yaral	M8-10360-1	M8-10360	0–2	−13.9	14.2	43.0	13.5	3.73
El Yaral	M8-10360-2	M8-10360	2–4	−15.4	12.1	44.8	13.0	4.03
El Yaral	M8-10360-3	M8-10360	4–6	−16.2	10.6	44.8	13.9	3.76
El Yaral	M8-10360-4	M8-10360	6–8	−16.8	10.2	45.1	14.2	3.70
El Yaral	M8-10360-5	M8-10360	8–10	−15.2	11.5	44.0	14.0	3.65
El Yaral	M8-10360-6	M8-10360	10–12	−15.5	12.2	43.4	14.3	3.53
El Yaral	M8-10360-7	M8-10360	12–14	−16.3	13.2	42.2	14.1	3.50
El Yaral	M8-10360-8	M8-10360	14–16	−15.5	12.8	42.7	14.0	3.57
El Yaral	M8-10360-9	M8-10360	16–18	−16.2	12.7	43.4	14.0	3.61

values then steadily drop to $\delta^{15}N = 12.3‰$ in the hair segment 10–12 cm from her scalp, and then increase to $\delta^{15}N = 16.6‰$ in the hair 24–26 cm from her scalp. Therefore, this woman consumed the highest amounts of marine animals in approximately the last 2 months of her life, and again in the period of approximately 20–26 months before death.

6.2. The Moquegua Valley site of El Yaral

At El Yaral, $\delta^{13}C_{keratin}$ values are generally more negative than those measured from hair from individuals buried at Chiribaya Alta (Fig. 7, Table 3). In addition, while there is variability in the $\delta^{13}C_{keratin}$ values in different hair segments analyzed from the same individual, particularly M8-10200, the range of values measured in one individual are smaller than those measured in a single individual at Chiribaya Alta. This implies that the $\delta^{13}C$ values of protein sources are more homogenous over time at El Yaral. The $\delta^{13}C_{keratin}$ values measured in hair segments at El Yaral correspond to the use of C_3 plants or terrestrial animals. These values could also correspond to the consumption of marine plants or freshwater fish; this hypothesis will be tested and discussed below.

Compared to the $\delta^{15}N$ values measured in hair samples from Chiribaya Alta, the hair samples from El Yaral have generally lower $\delta^{15}N$ values. The majority of $\delta^{15}N$ values in hair from individuals buried at El Yaral range from $\delta^{15}N = 10.2–14.3‰$ (Fig. 8, Table 3). These values correspond to a diet that is lower in marine animals and may include the consumption of marine plants, terrestrial animals and freshwater fish (Tieszen and Chapman, 1992). However, one individual (M8-10200) exhibits greater variability in $\delta^{15}N$ values, and particularly shows an increase in $\delta^{15}N$ values in the last 8–20 cm of the hair shaft. The $\delta^{15}N$ values range from $\delta^{15}N = 15.5–17.8‰$ and imply this individual consumed greater amounts of marine animals during the period of approximately the 8–20 months before death than in approximately the last 8 months before death.

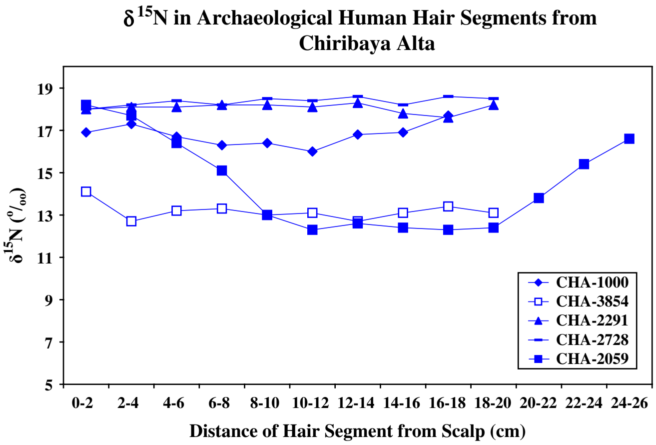

Fig. 5. Nitrogen isotope data from Chiribaya Alta hair samples.

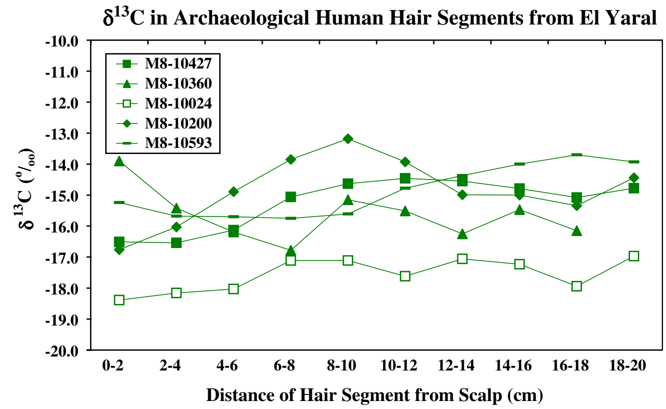

Fig. 7. Carbon isotope data from El Yaral hair samples.

7. The behavior of carbon and nitrogen in Chiribaya samples

Other scholars have argued that there is a 1–2‰ enrichment in $\delta^{13}C_{keratin}$ values and a 2–3‰ enrichment in $\delta^{15}N$ values when compared to bone collagen (McCullagh et al., 2005). Comparison of bone and hair values from the individuals included in this study suggests that there is a 1.0‰ enrichment in $\delta^{13}C_{keratin}$ values and $\delta^{15}N$ values in hair compared to bone values. While mean $\Delta^{13}C_{\text{hair-bone}} = 1.7 \pm 1.6‰$ ($n = 10$, 1σ) for the first segment of hair 0–2 cm from the scalp, by the sixth segment of hair 10–12 cm from the scalp, mean $\Delta^{13}C_{\text{hair-bone}} = 1.0 \pm 0.8‰$ ($n = 10$, 1σ). Similarly, mean $\Delta^{15}N_{\text{hair-bone}} = 2.4 \pm 1.8‰$ ($n = 10$, 1σ) for the first segment of hair 0–2 cm from the scalp and mean $\Delta^{15}N_{\text{hair-bone}} = 1.0 \pm 0.7‰$ ($n = 10$, 1σ) for the sixth segment of hair 10–12 cm from the scalp.

8. Discussion: Chiribaya seasonality

Analysis of carbon isotopes in hair samples from individuals buried at Chiribaya Alta shows values similar to those published in previous paleodietary studies. Based on previous $\delta^{13}C_{collage}$ of archaeological human bone from Chiribaya Alta, mean $\delta^{13}C_{collagen} = -13.1 \pm 1.9‰$ ($n = 85$, 1σ) and mean $\delta^{13}C_{apatite} = -9.0 \pm 1.7‰$ ($n = 49$, 1σ) (Tomczak, 2003). Carbon isotope values from Chiribaya Alta bone samples correspond to both C_4 plants and marine products, although there is much variability in the carbon isotope values from Chiribaya Alta bone (Tomczak, 2003). However, our work has demonstrated that some individuals at Chiribaya Alta had quite variable $\delta^{13}C_{keratin}$ values in hair segments that formed over approximately the last 2 years of life. Bone samples from these individuals shows that $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ values reflect the hair values. For example, $\delta^{13}C_{collagen} = -18.7‰$ in bone from CHA-2059, and the lowest hair value measured for CHA-20590 was $\delta^{13}C_{keratin} = -18.9‰$ in hair located 12–16 cm from the scalp (Table 2). However, mean $\delta^{13}C_{keratin} = -16.4 \pm 2.6‰$ ($n = 13$, 1σ) (Table 4). In other words, the bone value masked the changes in $\delta^{13}C_{keratin}$ values throughout the last years of this individual's life.

Nitrogen isotope values from Chiribaya Alta hair samples are also similar to previously published values. Previous paleodietary studies on nitrogen isotopes on archaeological human bone from Chiribaya Alta showed that mean $\delta^{15}N = 17.8 \pm 3.4‰$ ($n = 85$, 1σ) (Tomczak, 2003). The

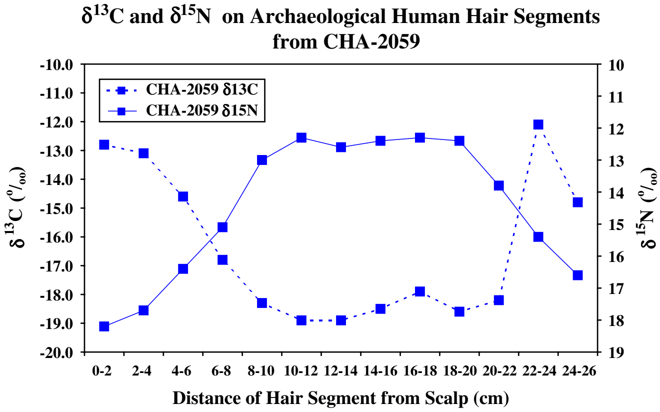

Fig. 6. Carbon and nitrogen isotope data from CHA-2059.

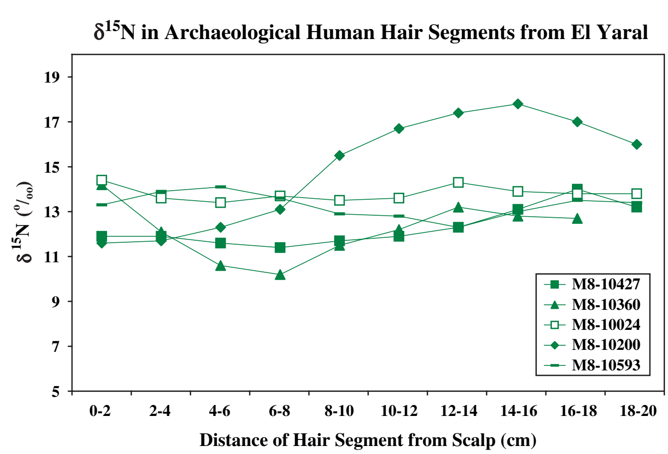

Fig. 8. Nitrogen isotope data from El Yaral hair samples.

Table 4
A comparison of mean carbon and nitrogen data from human hair and carbon and nitrogen values in bone samples from Chiribaya-affiliated sites

Site	Specimen number	Mean $\delta^{13}C_{keratin}$ (‰)	$\delta^{13}C_{collagen}$ (‰)	Mean $\delta^{15}N_{keratin}$ (‰)	$\delta^{15}N_{collagen}$ (‰)
Chiribaya Alta	CHA-1000	−14.6	−13.8	16.8	15.9
Chiribaya Alta	CHA-2291	−15.5	−14.1	18.1	15.8
Chiribaya Alta	CHA-2059	−17.4	−18.7	14.5	12.4
Chiribaya Alta	CHA-2728	−14.2	−12.1	18.4	19.0
El Yaral	M8-10024	−17.6	−17.8	13.8	12.2
El Yaral	M8-10200	−14.8	−12.7	14.9	15.8
El Yaral	M8-10593	−14.9	−15.6	13.3	13.7
El Yaral	M8-10427	−15.3	−14.0	12.3	10.3
El Yaral	M8-10360	−15.6	−14.1	12.2	10.7

hair keratin and bone collagen values imply that individuals buried at Chiribaya Alta had access to marine products, but that some individuals had less access and that at least one individual exhibited seasonal variability in marine food consumption. Interestingly, the highest variability in both $\delta^{13}C_{keratin}$ and $\delta^{15}N$ values was found in the same individual, CHA-2059 (Fig. 6). The lowest $\delta^{15}N$ values are found in hair segments 8–20 cm from the scalp, which implies that this individual consumed fewer marine products in approximately the last 8–20 months before death. Similarly, in this individual the lowest $\delta^{13}C_{keratin}$ values occur in the hair segments 12–16 cm from her scalp. These values imply that there was a period of approximately 8–20 months before death when this individual consumed larger amounts of C_4 plants such as maize at the same time that she consumed smaller amounts of marine products. This is the clearest case of seasonal differences in Chiribaya diet.

The observed intra- and inter-individual variability in $\delta^{13}C_{keratin}$ and $\delta^{15}N$ values in hair from Chiribaya Alta could be explained by a number of different environmental, social, and political factors. There are no clear sex differences in these variable patterns of seasonal differences in $\delta^{13}C_{keratin}$ and $\delta^{15}N$ values, and adult females and males exhibit both low and high variability in their $\delta^{13}C_{keratin}$ and $\delta^{15}N$ values in hair. However, there may be temporal trends in seasonal variability at Chiribaya Alta. The most variability in hair $\delta^{13}C_{keratin}$ and $\delta^{15}N$ values is seen in an adult female who was buried in cemetery 9 (CHA-2059), which dates to AD 850–1150, along with cemeteries 1, 2, 4, and 5 (Lozada Cerna and Buikstra, 2002). The earliest calibrated radiocarbon dates at Chiribaya Alta are found in cemeteries 3 and 7, which date to approximately AD 750–850 (Lozada Cerna and Buikstra, 2002), and one individual from cemetery 3 exhibits variability in $\delta^{13}C_{keratin}$ values (CHA-2728). Finally, the youngest cemeteries at Chiribaya Alta, cemeteries 6 and 8, date to AD 105–1150 (Lozada Cerna and Buikstra, 2002). Seasonal variability does not seem to be large during this time period. If the variability seen in seasonal paleodietary trends is due to temporal factors, it could be the result of poor harvests caused by El Niño events, or less trade due to changes in economic and social relationships.

It may also be the case that variability in Chiribaya Alta hair samples reflects residential mobility and movement between different environmental and/or geologic zones. Future strontium and oxygen isotope analysis of enamel, hair and bone from these individuals could test this hypothesis. Finally, it is possible that the observed intra- and inter-individual variability reflects social practices. For example, it is possible that certain individuals did not have the social networks necessary to provide a steady supply of marine and agricultural products throughout the year.

This variability in $\delta^{13}C_{keratin}$ values in hair was not observed at El Yaral, where $\delta^{13}C_{keratin}$ values were more homogeneous over 20 cm of hair growth, or approximately the last 20 months before death. Previous paleodietary studies on carbon isotopes on archaeological human bone collagen from El Yaral showed that mean $\delta^{13}C_{collagen} = -14.0 \pm 1.6‰$ ($n = 27$, 1σ) and mean $\delta^{13}C_{apatite} = -8.3 \pm 1.1‰$ ($n = 4$, 1σ) (Tomczak, 2003). Tomczak (2003) interpreted these data as a greater reliance on terrestrial foods at El Yaral than at other Chiribaya-affiliated sites, and pointed out that the data could be explained by a diet made up of C_4 carbohydrates and C_3 protein sources. As shown in Tables 2 and 4, the $\delta^{13}C_{collagen}$ and $\delta^{13}C_{apatite}$ values from bone generated in this study are similar to Tomczak's values.

At El Yaral, previous paleodietary studies on nitrogen isotopes on archaeological human bone from El Yaral showed that mean $\delta^{15}N = 11.8 \pm 2.0‰$ ($n = 27$, 1σ) (Tomczak, 2003). Based on bone $\delta^{15}N$ values, Tomczak (2003) argued that inhabitants of El Yaral consumed more terrestrial and less marine products than inhabitants of Chiribaya-affiliated sites on the coast. Hair $\delta^{15}N$ values were generally similar to the bone values (Table 4), and implied that most individuals included in this study from El Yaral (M8-10427, M8-10360, and M8-10024) did not consume large amounts of marine products. However, one adult male buried at El Yaral (M8-10200) consumed higher amounts of marine products during the period of approximately the last 8–20 months of his life, based on $\delta^{15}N$ in hair; this individual also consumed variable amounts of C_4 plants, and had the highest $\delta^{13}C_{keratin}$ values in hair that was 10–12 cm from his scalp. Tomczak measured $\delta^{15}N = 14.0‰$ in this individual's bone, while this analysis generated $\delta^{15}N = 15.8‰$ (Table 2). Although bone collagen values provided a very useful paleodiet average, analysis of this individual's hair shows a surprising amount of variability in marine food consumption. It is possible that this individual received marine products traded from the coast, unlike most of the inhabitants at El Yaral. It is also possible that this individual moved between the coast, where he consumed marine products, and the mid-valley region near El Yaral, where he consumed more terrestrial foods. If this is the case, then this individual appears to have returned to El Yaral in approximately the last 8 months of his life and was then buried there. Comparing the strontium and oxygen isotopes of dental and skeletal elements that formed at earlier times in this individual's life as well as in his last months will allow us to explore patterns of movement at different stages of his life and to thus more fully understand his life history.

9. Conclusion

In conclusion, carbon and nitrogen isotope analyses of archaeological human hair from Chiribaya Alta and El Yaral have demonstrated seasonal variation in the consumption of marine products and C_4 plants such as maize. Interestingly, seasonal variations are not uniform between the 10 individuals included in this study. The most seasonal variation is observed in individuals who had been buried at Chiribaya Alta. When compared to other Chiribaya-affiliated sites, Chiribaya Alta also exhibits the most variability in mortuary artifact assemblages, cranial modification styles, carbon and nitrogen bone collagen values, and enamel and bone strontium isotope ratios (Lozada Cerna and Buikstra, 2002; Tomczak, 2003). The seasonal variability in $\delta^{13}C_{keratin}$ and $\delta^{15}N$ values in human hair at Chiribaya Alta may result from increased access to resources from a variety of ecological zones, or it may support the hypothesis that Chiribaya Alta was a burial ground for individuals from a variety of Chiribaya sites. Although most individuals sampled from El Yaral exhibited homogeneity in the $\delta^{13}C_{keratin}$ and $\delta^{15}N$ values during the last months of their lives, at least one individual buried at El Yaral consumed large amounts of marine products before death, despite his burial in an inland site where most individuals consumed a largely terrestrial diet.

Acknowledgements

This paper would not have been possible without the generous assistance of a number of scholars. Drs Michael Chapman and Larry Tieszen provided sample analysis. In addition, the authors gratefully acknowledge the National Science Foundation (BNS89-20769). Permission to export the samples from Peru was granted by the Instituto de Cultura and facilitated by Dra Sonia Guillen.

References

Ambrose, S.H., 1991. Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. Journal of Archaeological Science 18, 293–317.

Ambrose, S.H., 1993. Isotopic analysis of paleodiets: methodological and interpretive considerations. In: Sandford, M.K. (Ed.), Investigations in Ancient Human Tissue: Chemical Analyses in Anthropology. Gordon and Breach Science Publishers, Langhorne, PA, pp. 59–130.

Ambrose, S.H., Butler, B.M., Hanson, D.B., Hunter-Anderson, R.L., Krueger, H.W., 1997. Stable isotopic analysis of human diet in the Marianas Archipelago, Western Pacific. American Journal of Physical Anthropology 104, 343–361.

Ambrose, S.H., Krigbaum, J., 2003. Bone chemistry and bioarchaeology. Journal of Anthropological Archaeology 22, 193–199.

Balasse, M., 2002. Reconstructing dietary and environmental history from enamel isotopic analysis: time resolution of intra-tooth sequential sampling. International Journal of Osteoarchaeology 12, 155–165.

Benfer, R.A., Typpo, J.T., Graf, V.B., Pickett, E.E., 1978. Mineral analysis of ancient Peruvian hair. American Journal of Physical Anthropology 48, 277–282.

Buikstra, J.E., 1995. Tombs for the living … or … for the dead: the Osmore ancestors. In: Dillehay, T. (Ed.), Tombs for the Living: Andean Mortuary Practices. Dumbarton Oaks, Washington, DC, pp. 229–279.

Buikstra, J.E., Tomczak, P., Lozada Cerna, M.C., Rakita, G.F.M., 2005. Chiribaya political economy: a bioarchaeological perspective. In: Rakita, G.F.M., Buikstra, J.E., Beck, L.A., Williams, S. (Eds.), Interacting with the Dead: Perspectives on Mortuary Archaeology for the New Millennium. University Press of Florida, Gainesville, FL, pp. 66–80.

Cox, G., Sealy, J., Schrire, C., Morris, A., 2001. Stable carbon and nitrogen isotopic analyses of the underclass at the colonial Cape of Good Hope in the eighteenth and nineteenth centuries. World Archaeology 33, 73–97.

DeNiro, M.J., Epstein, S., 1978. Influence of diet on the distribution of carbon isotopes in animals. Geochimica et Cosmochimica Acta 25, 495–506.

DeNiro, M.J., Epstein, S., 1981. Influence of diet on the distribution of nitrogen isotopes in animals. Geochimica et Cosmochimica Acta 45, 341–351.

Fernández, J., Panarello, H.O., Schobinger, J., 2003. The Inka mummy from Mount Aconcagua: decoding the geographic origin of the messenger to the deities by means of stable carbon, nitrogen, and sulfur isotope analysis. Geoarchaeology 14, 27–46.

Fuller, B.T., Fuller, J.L., Sage, N.E., Harris, D.A., O'Connell, T.C., Hedges, R.E.M., 2005. Nitrogen balance and $\delta^{15}N$: why you're not what you eat during nutritional stress. Rapid Communications in Mass Spectrometry 19, 2497–2506.

Fuller, B.T., Fuller, J.L., Sage, N.E., Harris, D.A., O'Connell, T.C., Hedges, R.E.M., 2004. Nitrogen balance and $\delta^{15}N$: why you're not what you eat during pregnancy. Rapid Communications in Mass Spectrometry 18, 2889–2896.

Grupe, G., Dorner, K., 1989. Trace elements in excavated human hair. Zeitschrift fur Morphologie und Anthropologie 77, 297–308.

Iacumin, P., Davanzo, S., Nikolaev, V., 2005. Short-term climatic changes recorded by mammoth hair in the Arctic environment. Palaeogeography, Palaeoclimatology, Palaeoecology 218, 317–324.

Jessup, D., 1990. Rescate arqueológico en el museo de sitio de San Gerónimo, Ilo. Trabajos Arqueologicos en Moquegua, Peru 3, 150–165.

Katzenberg, M.A., 2000. Stable isotope analysis: a tool for studying past diet, demography and life history. In: Katzenberg, M.A., Saunders, S.R. (Eds.), Biological Anthropology of the Human Skeleton. Wiley-Liss New York, pp. 305–328.

Keegan, W.F., DeNiro, M.J., 1988. Stable carbon- and nitrogen-isotope ratios of bone collagen used to study coral-reef and terrestrial components of prehistoric Bahamian diet. American Antiquity 53, 320–336.

Kowal, W., Beattie, O.B., Baadsgaard, H., Krahn, P.M., 1991. Source identification of lead found in the tissues of sailors from the Franklin Arctic expedition of 1845. Journal of Archaeological Science 18, 193–203.

Lee-Thorp, J.A., Sponheimer, M., van der Merwe, N.J., 2003. What do stable isotopes tell us about hominid dietary and ecological niches in the Pliocene? International Journal of Osteoarchaeology 13, 104–113.

Lozada Cerna, M.C., 1998. The Señorio of Chiribaya: a bioarchaeological study in the Osmore Drainage of Southern Peru. Doctoral dissertation, Department of Anthropology, University of Chicago.

Lozada Cerna, M.C., Buikstra, J.E. El Señorío de Chiribaya en la Costa sur del Perú. Lima, 2002.

Lozada Cerna, M.C., Buikstra, J.E., 2005. *Pescadores* and *labradores* among the *señorío* of Chiribaya in southern Peru. In: Reycraft, R.M. (Ed.), Us and Them: Archaeology and Ethnicity in the Andes. The Cotsen Institute of Archaeology, University of California at Los Angeles Los Angeles, pp. 206–226.

Lozada Cerna, M.C., Torres Pino, E. Mortuary excavations at La Yaral, southern Peru, unpublished manuscript, 1991.

Lubec, G., Nauer, G., Seifert, K., Strouhal, E., Porteder, H., Szilvassy, J., Teschler, M., 1987. Structural stability of hair over three thousand years. Journal of Archaeological Science 14, 113–230.

Macko, S.A., Engel, M.H., 1991. Assessment of indigeneity in fossil organic matter: amino acids and stable isotopes. Philosophical Transactions of the Royal Society of London: Biological Sciences 333, 367–374.

Macko, S.A., Engel, M.H., Andrusevich, V., Lubec, G., Connell, T.C.O., Hedges, R.E.M., 1999a. Documenting the diet in ancient human populations through stable isotope analysis of hair. Philosophical Transactions of the Royal Society of London: Biological Sciences 354, 65–76.

Macko, S.A., Lubec, G., Teschler-Nicola, M., Andrusevich, V., Engel, M.H., 1999b. The Ice Man's diet as reflected by the stable nitrogen and carbon isotopic composition of his hair. FASEB Journal 13, 559–562.

Martinson, E., Reinhard, K., Buikstra, J.E., Dittmar de la Cruz, K., 2002. The pathoecology of Chiribaya parasitism. Memorias do Instituto Oswaldo Cruz 98, 195–205.

McCullagh, J.S.O., Tripp, J.A., Hedges, R.E.M., 2005. Carbon isotope analysis of bulk keratin and single amino acids from British and North American hair. Rapid Communications in Mass Spectrometry 19, 3227–3231.

Minagawa, M., Wada, E., 1984. Stepwise enrichment of 15N along food chains: further evidence and the relation between $\delta^{15}N$ and animal age. Geochimica et Cosmochimica Acta 48, 1135–1140.

O'Connell, T.C., Hedges, R.E.M., 1999a. Investigations into the effect of diet on modern human hair isotopic values. American Journal of Physical Anthropology 108, 409–425.

O'Connell, T.C., Hedges, R.E.M., 1999b. Isotopic comparison of hair and bone: archaeological analyses. Journal of Archaeological Science 26, 661–665.

O'Connell, T.C., Hedges, R.E.M., Healey, M.A., Simpson, A.H.R.W., 2001. Isotopic comparison of hair, nail and bone: modern analyses. Journal of Archaeological Science 28, 1247–1255.

Owen, B., 1998. Chiribaya y sus antecedentes en el Valle de Ilo. In: Wise, K. (Ed.), Moquegua: Los Primeros Doce Mil Años. Policrom Arequipa, Peru, pp. 67–82.

Panarello, H.O., Valencio, S.A., Schobinger, J. 2003. Comparison of carbon isotope variations on hair of two Inca mummies from Chuscha and Aconcagua mounts, Argentina. IV South American Symposium on Isotope Geology.

Pate, F.D., 1994. Bone chemistry and paleodiet. Journal of Archaeological Method and Theory 1, 161–209.

Petzke, K.J., Boeing, H., Klaus, S., Metges, C.C., 2005. Carbon and nitrogen stable isotopic composition of hair protein and amino acids can be used as biomarkers for animal-derived dietary protein intake in humans. Journal of Nutrition 135, 1515–1520.

Randall, V.A., Ebling, F.J., 1991. Seasonal changes in human hair growth. British Journal of Dermatology 124, 146–151.

Reycraft, R.M., 2000. Long-term human response to El Niño in south coastal Peru. In: Bawden, G., Reycraft, R.M. (Eds.), Environmental Disaster and the Archaeology of Human Response. Maxwell Museum of Anthropology, pp. 99–120.

Reycraft, R.M., 2005. Style change and ethnogenesis among the Chiribaya of far south coastal Peru. In: Reycraft, R.M. (Ed.), Us and Them: Archaeology and Ethnicity in the Andes. The Cotsen Institute of Archaeology, University of California at Los Angeles Los Angeles, pp. 54–72.

Rice, D.S., 1993. Late Intermediate Period domestic architecture and residential organization at La Yaral. In: Aldenderfer, M.S. (Ed.), Domestic Architecture, Ethnicity, and Complementarity in the South-Central Andes. University of Iowa Press Iowa City, pp. 66–82.

Richards, M.P., Fuller, B.T., Molleson, T., 2006. Stable isotope palaeodietary study of humans and fauna from the multi-period (Iron Age, Viking and Late Medieval) site of Newark Bay, Orkney. Journal of Archaeological Science 33, 122–131.

Richards, M.P., Price, T.D., Koch, E., 2003. Mesolithic and Neolithic subsistence in Denmark: new stable isotope data. Current Anthropology 44, 288–295.

Robbins, C.R., 2002. Chemical and Physical Behavior of Human Hair. Springer-Verlag, New York.

Roy, D.M., Hall, R., Mix, A.C., Bonnichsen, R., 2005. Using stable isotope analysis to obtain dietary profiles from old hair: a case study from Plains Indians. American Journal of Physical Anthropology 128, 444–452.

Sandford, M.K., Kissling, G.E., 1993. Chemical analyses of human hair: anthropological applications. In: Sandford, M.K. (Ed.), Investigations of Ancient Human Tissue: Chemical Analyses in Anthropology. Gordon and Breach Science Publishers, New York, pp. 131–166.

Sandford, M.K., Van Gerven, D.P., Meglen, R.R., 1983. Elemental hair analysis: new evidence on the etiology of cribra orbitalia in Sudanese Nubia. Human Biology 55, 831–844.

Schoeninger, M.J., 1989. Reconstructing prehistoric human diet. In: Price, T.D. (Ed.), The Chemistry of Prehistoric Human Bone. Cambridge University Press, Cambridge, pp. 38–67.

Schoeninger, M.J., DeNiro, M.J., 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochimica et Cosmochimica Acta 48, 625–639.

Schoeninger, M.J., Iwaniec, U.T., Nash, L.T., 1998. Ecological attributes recorded in stable isotope ratios of arboreal prosimian hair. Oecologia 113, 222–230.

Schoeninger, M.J., Moore, J., Sept, J.M., 1999. Subsistence strategies of two "Savanna" Chimpanzee populations: the stable isotope evidence. American Journal of Primatology 49, 297–314.

Schwarcz, H.P., White, C.D., 2004. The grasshopper or the ant?: cultigen-use strategies in ancient Nubia from C-13 analyses of human hair. Journal of Archaeological Science 31, 753–762.

Sharp, Z.D., Atudorei, V., Panarello, H.O., Fernandez, J., Douthitt, C., 2003. Hydrogen isotope systematics of hair: archeological and forensic applications. Journal of Archaeological Science 30, 1709–1716.

Sillen, A., Sealy, J.C., van der Merwe, N.J., 1989. Chemistry and paleodietary research: no more easy answers. American Antiquity 54, 504–512.

Spielmann, K.A., Schoeninger, M.J., Moore, K., 1990. Plains-Pueblo interdependence and human diet at Pecos Pueblo, New Mexico. American Antiquity 55, 745–765.

Sponheimer, M., Robinson, T., Ayliffe, L., Roeder, B., Hammer, J., Passey, B., West, A., Cerling, T., Dearing, D., Ehleringer, J., 2003. Nitrogen isotopes in mammalian herbivores: hair ^{15}N values from a controlled feedings study. International Journal of Osteoarchaeology 13, 80–87.

Staller, J., Tykot, R., Benz, B., 2006. Histories of Maize: Multidisciplinary Approaches to the Prehistory, Linguistics, Biogeography, Domestication, and Evolution of Maize. Academic Press, New York.

Sutter, R.C., 2000. Prehistoric genetic and cultural change: a bioarchaeological search for the pre-Inka altiplano colonies in the coastal valleys of Moquegua, Peru and Azapa, Chile. Latin American Antiquity 11, 43–70.

Tieszen, L.L., Chapman, M. Carbon and nitrogen isotopic status of the major marine and terrestrial resources in the Atacama Desert of northern Chile. In: Proceedings of the First World Congress on Mummy Studies, 1992, pp. 409–425.

Tieszen, L.L., Iversen, E., Matzner, S. Dietary reconstruction based on carbon, nitrogen, and sulfur stable isotopes in the Atacama Desert, northern Chile. In: Proceedings of the First World Congress on Mummy Studies, 1992, pp. 427–441.

Tomczak, P., 2003. Prehistoric diet and socio-economic relationships within the Osmore Valley of southern Peru. Journal of Anthropological Archaeology 22, 262–278.

Tykot, R.H., Staller, J.E., 2002. The importance of early maize agriculture in coastal Ecuador: new data from La Emerenciana. Current Anthropology 43, 666–677.

Umire Alvarez, A., Miranda, A. Chiribaya de Ilo: Un Aporte de su Difusión. Consejo Nacional de Ciencia y Tecnología, Arequipa, 2001.

Valkovic, V., 1988a. Human Hair. In: Fundamentals and Methods for Measurement of Elemental Composition, vol. I. CRC Press, Boca Raton, FL.

Valkovic, V., 1988b. Human Hair. In: Trace-Element Levels, vol. II. CRC Press, Boca Raton, FL.

Wheeler, J.C., Russel, A.J.F., Redden, H., 1995. Llamas and alpacas: pre-conquest breeds and post-conquest hybrids. Journal of Archaeological Science 22, 833–840.

White, C.D., 1993. Isotopic determination of seasonality in diet and death from Nubian mummy hair. Journal of Archaeological Science 20, 657–666.

Williams, S.R., Clark, N.R., Buikstra, J.E., 1990. Excavaciones de los cementerios de Estuquiña, sur del Peru. Trabajos Arqueologicos en Moquegua, Peru 3, 95–123.

Wilson, A.S., Edwards, H.G.M., Farwell, D.W., Janaway, R.C., 1999. Fourier transform Raman spectroscopy: evaluation as a non-destructive technique for studying the degradation of human hair from archaeological and forensic environments. Journal of Raman Spectroscopy 30, 367–373.

Zaro, G., Umire Alvarez, A., 2005. Late Chiribaya agriculture and risk management along the arid Andean coast of southern Perú, A.D. 1200–1400. Geoarchaeology 20, 717–737.