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## HOMO - Journal of Comparative Human Biology

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# Dento-alveolar lesions and palaeodietary inferences from the Paso Alsina 1 site (eastern Pampean–Patagonian transition, Argentina)<sup>☆</sup>

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### ARTICLE INFO

#### Article history:

Received 10 March 2010

Accepted 13 June 2011

### ABSTRACT

Several archaeological researches in northeastern Patagonia and southeastern Pampas have evaluated various indicators of the diets of hunter-gatherers who inhabited these regions during the Late Holocene, including the role of plant foods. Dental analysis is an important way to introduce new information about subsistence. In this sense, the objective of this work is to document and interpret dento-alveolar lesions in an osteological sample recovered from the Paso Alsina 1 archaeological site (eastern Pampean–Patagonian transition, Argentina). This paper will explore the oral health status of individuals and discuss palaeodietary information of hunter-gatherers that inhabited the lower valley of the Colorado River during the final Late Holocene (ca. 500 years BP). The site is defined as a formal area bundle composed of 10 secondary multiple burials containing 56 individuals of both sexes and various ages (e.g., perinatal, infant, and adult). In this study, 781 teeth and 1036 alveoli from 47 maxillae and 38 mandibles were analysed from 51 adult individuals. The results indicate a moderate rate of dental wear, and dental calculus, and low percentages of caries, abscesses, and antemortem tooth loss. The information obtained suggests a diet based on a combination of proteins, fat and carbohydrates. Results are then compared with those from other lines of analysis for the study area and for the neighboring regions (northeastern Patagonia and southeastern Pampas).

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<sup>☆</sup> This paper was presented at the symposium “The development of dental research in Argentina. Biological Anthropology: current status and perspectives”, during the IX National Meeting of Biological Anthropology from Argentina, Puerto Madryn, 20th–23rd October 2009.

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## R E S U M E N

Las investigaciones arqueológicas en el noreste de Patagonia y sudeste de la región Pampeana han evaluado varios indicadores referidos a la dieta de los grupos cazadores-recolectores que habitaron estas regiones durante el Holoceno tardío, incluyendo el rol de las plantas. Teniendo en cuenta que los análisis dentarios permiten generar información respecto de la subsistencia, el objetivo de este trabajo es documentar e interpretar lesiones dento-alveolares en una muestra osteológica recuperada del sitio arqueológico Paso Alsina 1 (transición pampeano-patagónica oriental, Argentina). Este trabajo explora el estado de salud oral de los individuos y discute información paleodietaria de los grupos cazadores-recolectores que habitaron en el valle inferior del río Colorado durante el Holoceno tardío final (ca. 500 años AP). El sitio es un área formal de inhumación compuesto por 10 entierros secundarios múltiples y representado por 56 individuos de ambos sexos y diferentes edades (e.g., perinato, infante y adulto). Se analizaron 781 dientes y 1036 alvéolos de 47 maxilares y 38 mandíbulas pertenecientes a 51 individuos adultos. Los resultados indican una moderada tasa de desgaste dental y de cálculos dentales, y bajos porcentajes de caries, abscesos y pérdidas antemortem. La información obtenida sugiere una dieta basada en proteínas, grasas y carbohidratos. Los resultados son comparados con otras líneas de análisis del área de estudio como también de regiones vecinas (noreste de Patagonia y sureste de región Pampeana).

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## Introduction

Archaeological research carried out in northeastern Patagonia and southeastern Pampas has revealed that during the final Late Holocene (ca. 1000–250 years BP) major changes in hunter-gatherer organisation occurred. Such changes include: population growth, population expansion and replacement, inter-ethnic contact, interaction of networks of different spatial scales (local, regional and extra-regional), territoriality, spatial circumscription and demographic packing, dietary diversification and intensification in the exploitation of some resources (e.g., plants) (Barrientos and Pérez, 2004; Favier Dubois et al., 2009; Martínez, 2008–2009; Politis, 2008; Prates, 2008, among others). In the context of the above mentioned scenario, analyses of dental lesions in both regions show an increase in the frequency of caries compared with the initial Late Holocene (ca. 3000–1000 years BP). These results support the idea of an increase in the processing and consumption of cariogenic foods (L'Heureux, 2000, 2002; Menéndez, 2010).

In the eastern Pampean–Patagonian transition, an archaeological research project in the lower valley of the Colorado River (Province of Buenos Aires, Argentina) has been systematically carried out over the past 10 years. The main objective is to understand the adaptation and evolution of hunter-gatherer societies that inhabited an ecotonal environment with dry and semi-arid climate during the Late Holocene (3000–250 years BP). There have been many contributions from various lines of research, such as on the organization of lithic technology, mobility patterns, settlement systems, burial practices, palaeopathology, palaeoenvironmental studies (Armentano, 2007; Bayala, 2008; Flensburg, 2010; Martínez, 2004, 2008–2009; Martínez et al., 2007; Stoessel et al., 2008, among others). One of the main subjects of the project was to evaluate, through zooarchaeological evidence and stable isotope analysis, the subsistence and palaeodiet of the hunter-gatherers who inhabited the area (Martínez et al., 2005, 2006a, 2009a; Stoessel, 2007, 2010).

Based on an analysis of the zooarchaeological record, Stoessel (2007) proposed a subsistence model for the area. During the initial Late Holocene (ca. 3000–1000 years BP) the hunter-gatherer

diet was principally composed of “guanaco” (*Lama guanicoe*) and supplemented by deer (*Ozotoceros bezoarticus*), “ñandú” (*Rhea americana*) and, based on indirect evidence coming from ground stone tools (e.g., mortars, “manos”, handstones) included plant resources. However, during the final Late Holocene (ca. 1000–250 years BP), some subsistence changes are observed which include the incorporation of small and medium-sized prey (e.g., armadillos, birds, among others) as well as freshwater and marine fish. Stable isotope studies on human bones also indicate a diet based on meat proteins provided by terrestrial herbivores (e.g., artiodactyls) and supplemented by fish (Martínez et al., 2009a). This new scenario indicates that hunter-gatherers had a diverse diet of resources from different ecological settings (Martínez, 2008–2009; Martínez et al., 2006a; Stoessel, 2007). Furthermore, vegetable consumption would have had an important role in the hunter-gatherer diet during the final Late Holocene. In this sense, the overall changes in subsistence were accompanied by an increase in the frequency of grinding stone production, as well as the design of grinding stones becoming more standardised and formal (Armentano, 2007; Martínez, 2008–2009; Stoessel, 2007).

The evidence mentioned above suggests that in the study area, dietary changes occurred during the final stages of the Late Holocene. The use of plants has been suggested by indirect evidence. The following paper provides new information to expand the discussion concerning the palaeodiet and consumption of plants by hunter-gatherer groups. Dental studies provide important bioarchaeological information regarding the health of individuals, as well as information about diet, functional activities, age of death, population dynamics, among others (Cruwys, 1989; Hillson, 1996; Larsen, 1997; Milner and Larsen, 1991). The objective of this work is to document and interpret dento-alveolar lesions in an osteological sample recovered from the Paso Alsina 1 site. The oral health status of the individuals and palaeodietary information in a sample of hunter-gatherers who inhabited the lower valley of the Colorado River during the final Late Holocene (ca. 500 years BP), are explored. The results of the oral health status of individuals, in comparison with the data generated in adjacent regions of the study area, were discussed (e.g., the middle and lower valley of Negro River and the Humid-Pampa sub-region).

### Study area and the Paso Alsina 1 site

The study area is located within the so-called “Arid Diagonal”, in the southernmost part of South America (Abraham de Vázquez et al., 2000). It is characterised by a warm and dry steppe arid climate, with a mean annual rainfall of 466 mm, and maximum temperatures from 22.2 °C in January to 7.5 °C in July (Sánchez et al., 1998). The dominant vegetation belongs to the “Distrito del Calden”, “Provincia del Espinal” (Cabrera, 1976), although vegetal communities of the “Provincia del Monte” are also recorded in the area (Morello, 1958). Thus, the arid to semi-arid sandy area presents a shrub steppe, an open plant formation composed of xeric short trees mixed with hardy and scarce herbaceous grasses. The area is dominated by C<sub>3</sub> flora (e.g., *Geoffroea decorticans*, *Prosopis* sp. and *Condalia microphylla* sp.), although C<sub>4</sub> species are also present in a subordinated proportion (Martínez et al., 2009a; Villamil and Scofield, 2003). From a zoogeographical perspective, the area is located in the “Subregion Patagonica”, “Distrito Patagonico”, where, among others, species such as *Lama guanicoe* (guanaco or wild camelid), *Chaetophractus villosus* (“peludo”, haired armadillo), *Zaedyus pichi* (“piche”, pichi armadillo), *Rhea Americana* (“ñandú”, greater Rhea), are present (Cabrera and Yepes, 1960). Ichtiogeographical studies from the Colorado and Negro Rivers indicate that there is an overlap in the distribution of fish species from the “Austral” and “Brasílica” subregions (Almirón et al., 1997). The study area is classified as an ecotone located at the eastern Pampean–Patagonian transitional zone (Morello, 1958; Páez et al., 2001; Villamil and Scofield, 2003).

The Paso Alsina 1 site is located in this environmental context. It represents a formal area bundle located on the south bank of the Colorado River and about 100 km from the Atlantic Ocean (Fig. 1).

Ten multiple secondary burials and a minimal number of 56 individuals were recovered from the site, represented by both sexes and several age categories (Bayala, 2008). This site is characterised by a patterned burial orientation with a contiguous and/or overlapped arrangement of the burials, located in a small area (ca. 6 m<sup>2</sup>). An internal repetitive pattern in both the location and the association

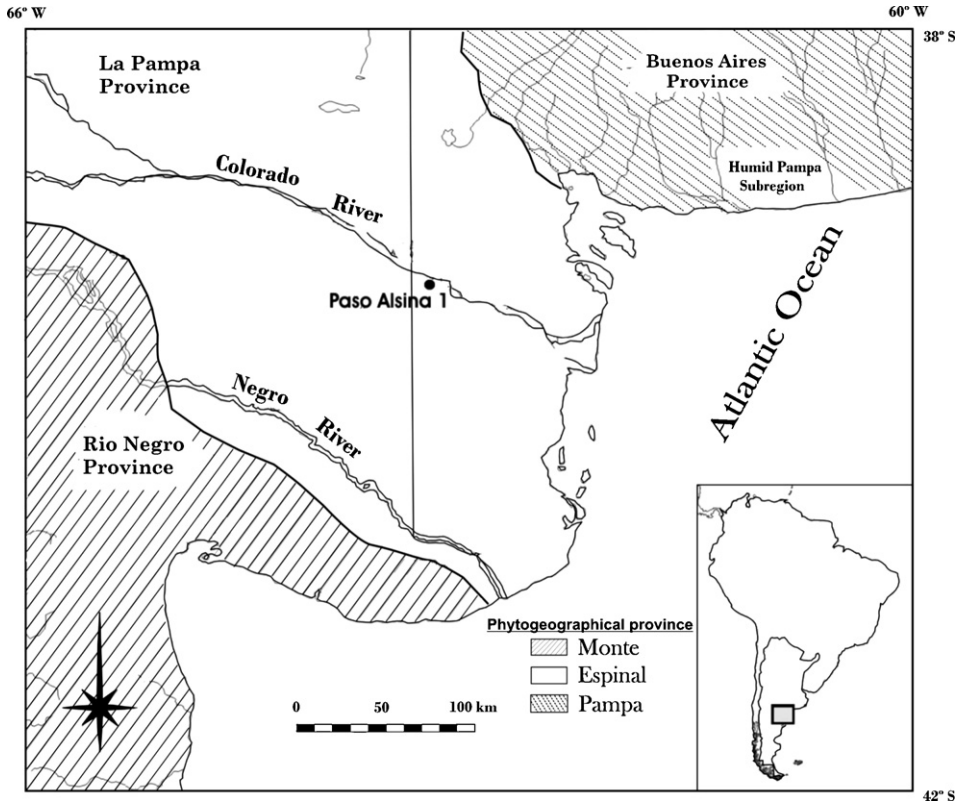


Fig. 1. Lower basin of Colorado River and location of the Paso Alsina 1 site.

of specific bone specimens in each burial was recorded (Fig. 2). Bones were painted in red and the presence of cut-marks indicates that some bodies were disarticulated and defleshed before they were re-buried (Martínez et al., 2007). Thirteen radiocarbon dates placed the site in a chronology from ca. 500 years BP, with a weighted average of  $483 \pm 20$  years BP (see Table 1 in Martínez et al., 2007). The combination of the above mentioned evidence indicates that the inhumations took place during a single event (Martínez, 2008–2009; Martínez et al., 2006b, 2007). This context, which presents a significant number of individuals of different age and sex, arranged in a close spatial and temporal scale, is the first of this kind of site recorded in the study area.

## Materials and methods

The analysed sample consists of 51 individuals represented by both sexes. Due to the underrepresentation and poor preservation of the subadults ( $n = 5$ ), only the adults were analysed. According to the nature of the sample (secondary multiple burials), in the case where bone elements have no anatomical correspondence with each other, the skull and jaws were used for age and sex determination. The morphological characteristics used to determine sex were the nuchal or occipital crest, the supraorbital margin, the arcus superciliaris, the glabella, the mastoid process, and the development and strength of the mental eminence (Bass, 1995; Buikstra and Ubelaker, 1994; Steele and Bramblett, 1988; Walrath et al., 2004; White and Folkens, 2000). The results were grouped into three categories: probable male, probable female, and undetermined (Buikstra and Ubelaker, 1994). As shown in Table 1, both sexes are represented at similar frequencies: 45.1% (23/51) for probable male (PM) and 35.3% (18/51) for probable female (PF). Consequently, there were a moderate percentage of undetermined



**Fig. 2.** Secondary burials at the Paso Alsina 1.

**Table 1**

Number and percentage of individuals by sex and age.

Sex	Age category	<i>n</i>	%
Probable female	Young adult	8	15.7
Probable female	Middle adult	10	19.6
Probable male	Young adult	13	25.5
Probable male	Middle adult	10	19.6
Indeterminate	Young adult	9	17.6
Indeterminate	Middle adult	1	2.0

individuals (19.6%; 10/51). The suture of the cranium was used as the principle characteristic to determine the age of the individuals (Buikstra and Ubelaker, 1994). The results were grouped in three adult age categories, as defined by Buikstra and Ubelaker (1994). As seen in Table 1, the young adults (YA) represent 58.8% (30/51), while middle adults (MA) represent 41.2% (21/51).

In order to perform the analysis, conservation techniques (e.g., reassembling, cleaning and maintenance) were used to improve the anatomical integrity of the sample (Martínez et al., 2009b). All maxillae, mandibles, and loose teeth recovered from various sectors of the burial area were analysed.

All materials were analysed using a macroscopic and binocular magnifier glass (2× and 4×). Of the 51 skulls, 47 maxillae and 38 mandibles were recovered. The total number of quantified teeth was 781, and 1036 alveoli were identified. However, of the total number of teeth, 127 were found loose and could not be assigned to any of the individuals (Table 2). To study the paleopathological lesions, the following indicators were used: caries, abscesses, antemortem tooth loss, and dental calculus.

A carious lesion was recorded only when the demineralisation process had generated cavities in the tooth. To avoid diagnostic differential problems, the tooth surfaces with pulp cavities exposed and without evidence of demineralisation were excluded (Hillson, 2001). Many factors must be considered

**Table 2**

Number of individuals, teeth and alveoli in the sample, discriminated by age within each sex.

Number of	Probable female		Probable male		Indeterminate		Loose teeth	Total
	Young adult	Middle adult	Young adult	Middle adult	Young adult	Middle adult		
Individuals	8	10	13	10	9	1	0	51
Teeth	98	118	175	113	138	12	127	781
Alveoli	128	226	270	224	164	24	0	1036

for this indicator such as diet, age groups, teeth classes, and different preservation of upper and lower teeth (Hillson, 2001; Lanfranco and Eggers, 2010). For the caries analysis, the criterion of Buikstra and Ubelaker (1994, taken and modified from Moore and Corbett, 1971) was used. Here, the locations of the lesions were standardised as occlusal, mesial, distal, lingual, and buccal (Hillson, 2001). In addition, according to the depth of carious lesions, they were classified on the basis of affected tissue as enamel, dentin, and pulp cavity caries (see Lanfranco and Eggers, 2010). Finally, the dimensions of carious lesions were measured in millimeters with a digital caliper, and classified as small ( $\geq 0.5$  mm), medium (0.6–1.5 mm), and large ( $< 1.5$  mm).

Occasionally, severe infection may occur inside the pulp cavity, extending into the alveolus through the root canal, forming a granuloma. This process will eventually give rise to a change in the bone structure, creating a cyst or an abscess. This last is an orifice through which pus drains into the oral cavity (Dias and Tayles, 1997; Ogden, 2008). In order to aid in the diagnosis of abscesses, the methodology proposed by Ogden (2008) was used here. The abscesses were recorded when an affection occurred in one or more tooth roots. The diameter and the texture of the voids and the appearance of the edge feature were observed. For the classification of abscesses, three types of pulp-alveolar defects were recognised, depending on their location and morphology, and according to the classification proposed by Clarke (1990) they were described as periapical, furcal, and complex.

Antemortem tooth loss (ATML) is caused by changes in periodontal bone tissue, affecting the support of the tooth. Several factors may be involved including periodontal disease, pulp-alveolar defects, tooth wear (Clarke and Hirsch, 1991; Hillson, 2000; Ogden, 2008). Antemortem tooth loss was recorded by the presence of alveolar obliteration (Lukacs, 1989). These were classified according to the degree of bone remodeling as: partial, when the alveolus is still observed; moderate, when the alveolus is semi-present; and total, when the alveolus disappears and there is a reduction in the height of the maxillae and/or mandibles.

Dental calculus is a mineralised plaque deposit adhering to the enamel surface. Even though the calculus itself is inactive, a layer of active plaque usually covers it. Plaque is comprised of living bacteria in an extra-cellular matrix. As the active layers of plaque mineralise, new calculus is formed (Greene et al., 2005; Hillson, 2000). This was recorded according to the criteria proposed by Brothwell (1981) as low amount (affects less than one third of the tooth), moderate amount (affects between one and two thirds), and high quantity (up to two thirds).

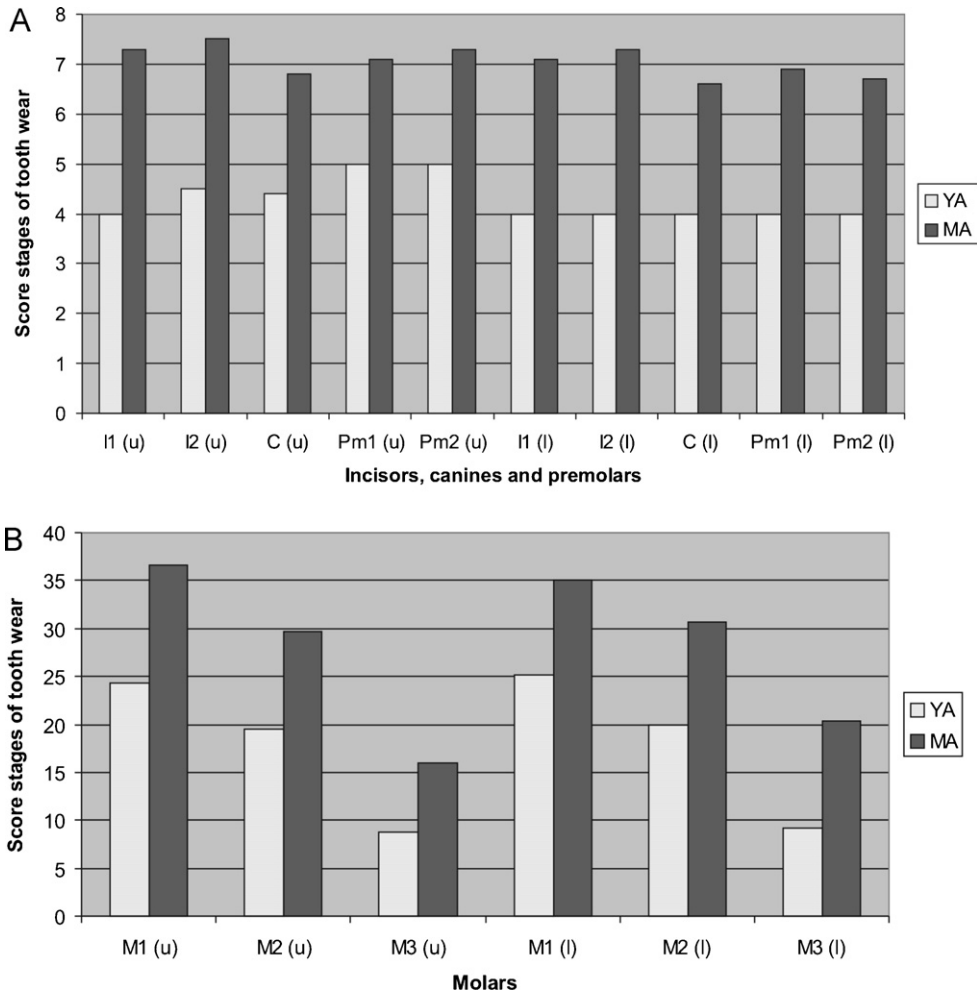
In this study, the frequency of each characteristic was calculated by tooth, alveoli and by individual. This allowed the inclusion of the isolated teeth found in the context of the inhumation (Duyar and Erdal, 2003; Hillson, 2001). Observed differences between the frequencies of lesions by age and sex were tested using Chi-squared tests (differences at or below  $p = 0.05$  were considered significant).

Tooth wear is a complex process involving the gradual and regular loss of enamel and dentin as a result of abrasion, attrition, and erosion (Bell et al., 1998; Grippo et al., 2004). These factors act in combination during the dynamics of mastication. They are difficult to distinguish, and consequently are included within the general category of tooth wear analysis (Larsen, 1997). Dental wear was scored for all teeth using the categorical scale proposed by Smith (1984) and Scott (1979) for anterior and posterior dentition, respectively. Because tooth wear is strongly correlated with an individual's age at death, the rate of tooth wear (Scott and Turner, 1988) was calculated based on the first and second adjacent upper molars, which were largely represented in the sample. The principal axis analysis proposed by Sokal and Rohlf (1979) was used to estimate this characteristic. All statistical tests were performed using R 1.9.1 software (Ihaka and Gentleman, 1996).

## Results

Degrees of wear by tooth type and age category were assessed. As expected, the results indicate that middle adult individuals have teeth that are more worn than young adults (Fig. 3). With respect to sex, the degree of dental wear was greater among probable females than probable males (Fig. 4). The principal axis analysis resulted in a slope of 8.38, indicating a moderate rate of tooth wear in the sample. With respect to sex, a slope of 9.73 was obtained for the probable females and 7.12 for the probable males. However, this difference is not statistically significant ( $\chi^2 = 1.98$ ;  $p = 0.48$ ).





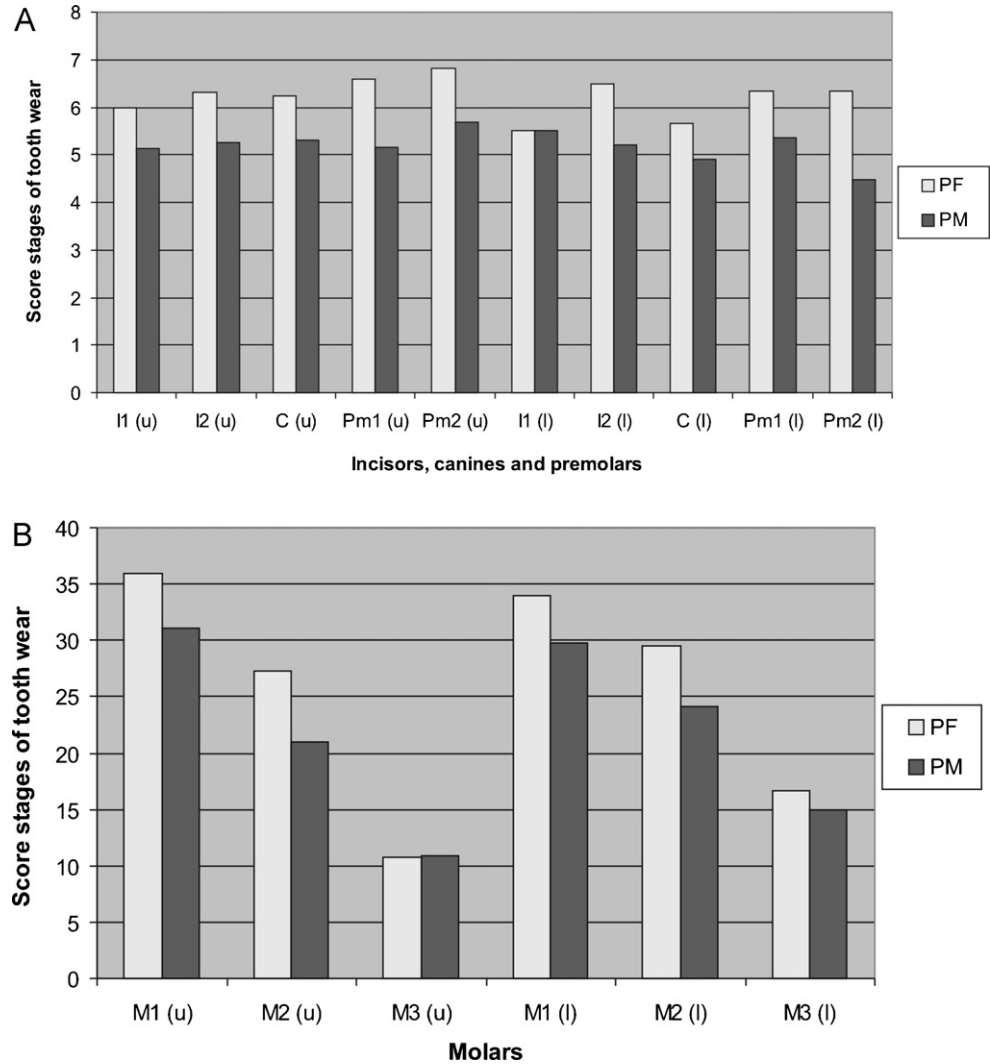
**Fig. 3.** Score stages of tooth wear by age. (A) Incisors, canines and premolars and (B) molars. Note. YA: young adult, MA: middle adult, u: upper, l: lower.

With respect to the caries, of the 781 teeth analysed, 5.7% ( $n = 45$ ) presented lesions in some portion of the tooth. The carious lesions were quite evenly distributed in the maxillae and mandibles. Eighteen individuals (35.3%) suffered from caries in a frequency similar in both sexes ( $\chi^2 = 0.002$ ,  $p = 0.98$ ; Table 3). The majority of these individuals had a single carious lesion (72.2%; 13/18). As shown in Table 4, there was a higher percentage of caries in probable males (7.4%) than in probable females

**Table 3**

Frequency of individuals with oral paleopathological conditions by sex and age.

Paleopathology	Probable Male		Probable Female		Indeterminate		Young Adult		Middle Adult	
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%
Caries	9	39.1	7	38.9	2	20	13	43.3	5	23.8
Abscesses	6	26.1	5	27.7	0	0	3	10.0	8	38.1
ATML	6	26.1	7	38.9	0	0	2	6.7	11	52.4
Dental calculus	13	56.5	11	61.1	5	50	20	66.7	9	42.8



**Fig. 4.** Score stages of tooth wear by sex. (A) Incisors, canines and premolars and (B) molars. Note. PF: probable female, PM: probable male, u: upper, l: lower.

**Table 4**  
Percentage of teeth, alveoli and oral paleopathological conditions by sex.

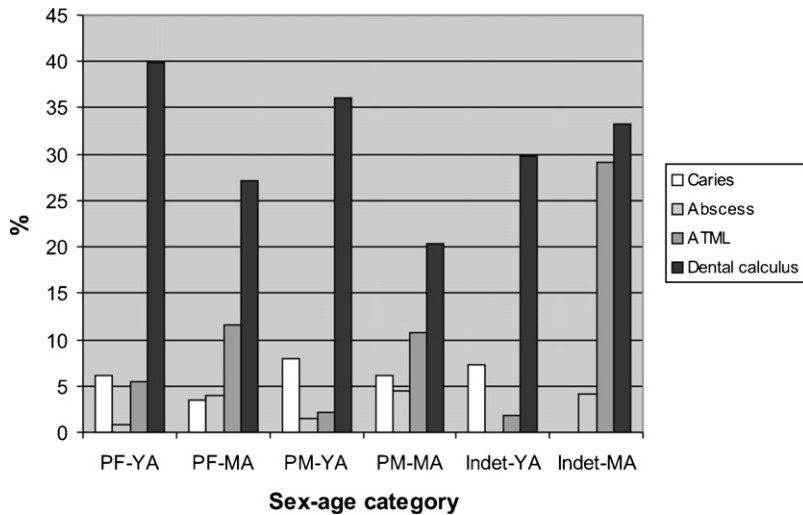
Sex	No. of teeth	No. of alveoli	Caries		Abscesses		ATML		Dental calculus	
			n	%	n	%	n	%	n	%
Probable female	216	354	10	4.6	10	2.8	33	15.3	66	30.5
Probable male	288	494	21	7.3	14	2.8	30	10.4	86	29.9
Indeterminate	277	188	14	5.0	1	0.5	10	3.6	62	22.4



**Table 5**

Percentage of teeth, alveoli and oral paleopathological conditions by age.

Age	No. of teeth	No. of alveoli	Caries		Abscesses		ATML		Dental calculus	
			<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%
Young adult	411	562	30	7.3	5	0.9	16	3.9	143	34.8
Middle adult	243	474	11	4.5	20	4.2	57	23.4	54	22.2
Indeterminate	127	0	4	3.1	0	0	0	0	17	13.4

**Fig. 5.** Percentage of lesions by sex-age groups.

(4.6%). However, this difference is not statistically significant ( $\chi^2 = 1.51$ ,  $p = 0.21$ ). There is also a high frequency of caries in teeth of individuals assigned to indeterminate sex (5%). With respect to age, there was a predominance of caries in the young adults when compared with the middle adults ( $\chi^2 = 2.06$ ,  $p = 0.15$ ; Table 3). The same results were obtained for the registered teeth ( $\chi^2 = 1.99$ ,  $p = 0.15$ ) (Table 5 and Fig. 5).

As showed in Table 6, the highest frequency of caries (10.6%; 36/339) was found in molars, particularly M3 (18.8%; 16/85). Of all lesions, 73.3% were located in the occlusal region (33/45), while to a lesser extent in the labial (13.3%; 6/45), the lingual (8.9%; 4/45) and the mesial and distal regions (2.2%; 1/45 each).

The caries were characterised as small (71.1%; 32/45), medium (20%; 9/45), and large (8.9%; 4/45). The majority of lesions were observed in the dentin (68.8%; 31/45), then the pulp cavity (22.2%; 10/45), and only a few in the enamel (8.9%; 4/45).

**Table 6**

Percentage of oral paleopathologies by tooth type.

Teeth	No. of teeth	No. of alveoli	% Caries	% Abscesses	% ATML	% Dental calculus
I1	57	128	0	3.1	3.9	8.8
I2	72	134	2.8	1.5	3.0	9.7
C	103	139	1.9	2.2	0.7	16.5
Pm1	125	140	2.4	1.4	4.3	18.5
Pm2	85	135	1.2	2.2	10.4	34.1
M1	147	124	4.8	8.1	16.9	32.6
M2	107	125	12.1	0	12.8	43.9
M3	85	111	18.8	0	5.4	25.9

With respect to the abscesses, 25 cases were observed in 1036 alveoli (2.4%). These were evenly distributed between maxillae and mandibles. Abscesses were recorded in 11 individuals (21.6%; Table 3) and their distribution by sex was similar ( $\chi^2 = 0.01$ ,  $p = 0.90$ ). The majority of individuals affected had at least one single abscess (63.6%; 7/11), while the remaining four individuals had between two and six lesions. According to the alveoli, the abscesses were distributed homogeneously in both sexes ( $\chi^2 = 0.31$ ,  $p = 0.57$ ) (Table 4, Fig. 5). The age of affected individuals showed a clear predominance in the middle adult (4.2%) over the young adult (0.9%) category (Table 5, Fig. 5). This difference is statistically significant for individuals ( $\chi^2 = 5.76$ ,  $p = 0.01$ ; Table 3) and for alveoli ( $\chi^2 = 12.10$ ,  $p = 0.0005$ ; Table 5).

The abscesses were recorded mainly in the first molars (8.1%; 10/124; Table 6). They were principally characterised by the complex (62.5%; 15/24) and periapical (37.5%; 9/24) types. These lesions were registered in the buccal (83.3%; 20/24) and lingual (16.7%; 4/24) regions.

Antemortem tooth loss was registered on 73 occasions (7%), equally affecting the alveoli in the maxillae and the mandibles. These lesions occurred in 13 individuals (25.5%), and the distribution by sex was similar ( $\chi^2 = 0.76$ ,  $p = 0.38$ ; Table 3). According to the observed alveoli, affected individuals were mainly the probable females (15.3%), in comparison to the probable males (10.4%), although this difference is not statistically significant ( $\chi^2 = 3.16$ ,  $p = 0.07$ ; Table 4). A low percentage of antemortem tooth loss was found in the indeterminate category (3.6%). With respect to age, it has been shown that the middle adults had a higher quantity of lesions (23.4%) compared with young adults (3.9%) (Table 5, Fig. 5). This difference is statistically significant between individuals ( $\chi^2 = 13.59$ ,  $p = 0.0002$ ) and alveoli ( $\chi^2 = 33.07$ ,  $p = 8.88\text{E} - 09$ ).

The highest percentage of antemortem tooth loss was found in the molars (11.9%; 43/360). There was a relatively homogeneous distribution in the anterior teeth, although a lower frequency was recorded in the canines (0.7%; 1/139, Table 6). The states in which alterations in the lesions were found were described as categories: total (68.5%; 50/73), followed by moderate (19.2%; 14/73) and partial (12.3%; 9/73).

Dental calculus was registered in 214 teeth (27.4%), and was distributed homogeneously between maxillae and mandibles. Of the 29 affected individuals (56.8%), 23 had between 1 and 5 dental plaques (79.3%), while the remaining individuals had between 6 and 19 teeth covered with calculus. The frequencies were similar for both sexes ( $\chi^2 = 0.08$ ,  $p = 0.76$ ) (Tables 3 and 4). The dental calculus was registered at a higher rate in the young adult (34.8%) than in the middle adult age category (22.2%) (Table 5 and Fig. 5). This difference is not statistically significant by individuals ( $\chi^2 = 2.85$ ,  $p = 0.09$ ; Table 3), but is significant by teeth ( $\chi^2 = 12.02$ ,  $p = 0.0005$ ; Table 5).

When considering the teeth affected by calculus, a higher percentage was observed in the second premolars and molars (37.3%; 158/424), with less calculus observed toward the anterior teeth (Table 5). A low amount of calculus was found in 89.7% (192/214) of cases and 10.3% (22/214) of teeth were placed in the moderate category.

## Discussion and final considerations

Caries are linked to the consumption of a diet rich in carbohydrates, sugars, and sticky foods, therefore, the proportion of caries may provide information about carbohydrate and protein intake ratios (Hillson, 1996; Larsen et al., 1991; Lukacs, 1992). Numerous studies of hunter-gatherers describe their diet based in animal protein, producing low percentages of caries in the populations (Hillson, 2000; Larsen, 1997). According to Turner (1979), human groups characterised by a hunter-gatherer way of life show an expected range of caries frequency between 0 and 5.3%. Larsen (1987) has proposed a slightly wider range of caries frequency, between 0.0 and 7.8%. The frequency of caries observed in this analysis (5.7%) is within the range observed for the type of subsistence based on hunting and gathering.

The frequency of caries obtained here is similar to that reported in the lower basin of the Negro River (6.06%; Menéndez, 2010). However, it is higher compared to that in the samples taken from the Northeast Patagonian region (0.5–1.25%, Bernal et al., 2007). When compared with the data from the Humid Pampa sub-region, where an estimated caries frequency of 18.81% in a sample of hunter-gatherers for the Late Holocene (3000–500 years BP) is seen, extending well beyond the expected ranges (L'Heureux,

2000, 2002), the frequency of caries in our sample is lower. The variation in frequency of caries suggests probable differences in the amount of carbohydrates consumed by the hunter-gatherers and their food processing activities. According to L'Heureux (2000), the high percentage of caries could be due to the presence of subadult individuals in the sample, for whom she registered the highest percentage of caries (13.9%). The rate of wear was lower than in adults for this age category, in consequence, the wear process did not affect the expression of caries in the sample she studied (L'Heureux, 2000).

Various researchers present different views on the low frequency of caries found in the hunter-gatherer samples. Some authors suggest a negative relationship between dental wear and caries (Kerr et al., 1990; Maat and van der Velde, 1987) as an explanation, while others are of the opinion that both variables are positively correlated (Miles and Grigson, 1990; Moody, 1960), and some suggest that dental caries and wear should be treated as independent variables (Larsen, 1997; Meiklejohn et al., 1992). According to the results obtained here, a higher frequency of caries was found in young adults, which contradicts the progressive nature of a lesion with age (Hillson, 2000). In this case, the caries tend to inversely alter with tooth wear. Considering that dental wear is greater in middle adult individuals, it is possible that this has allowed the generation of abrasive processes, leading to the removal of the part of the tooth surface and therefore eliminating caries. With respect to sex, in most clinical studies of caries, females show higher rates than males (Thylstrup and Fejerskov, 1994). This trend also seems to be reflected in the bioarchaeological record (Hillson, 2001; Larsen, 1997; Lukacs and Largaespada, 2006). Higher caries prevalence among females is often explained by three main factors, such as earlier eruption of teeth hence longer exposure to the cariogenic oral environment, easier access to food supplies and frequent snacking during food preparation, and pregnancy (Lukacs and Largaespada, 2006). However, in the sample studied here, this trend is reversed, as the probable males are those with the highest percentages of lesions. Still, statistically speaking this difference is not significant, thus the result may be biased and it is possible that both sexes had the same chance of developing caries. Furthermore, considering that the rate of dental wear is higher in probable females compared to probable males (although not statistically supported), it is also possible that this variable has conditioned the results. This difference in tooth wear can be linked to domestic cultural activities (e.g., sediment added to foods during processing with grinding materials). Nevertheless other factors may be involved in the differences of caries frequency, such as sexual division of labor, gender-based dietary preferences, changes in sex hormones, the biochemical composition and flow of saliva (Hillson, 2001; Lukacs, 2008; Lukacs and Largaespada, 2006; Meiklejohn et al., 1992).

According to Park (1991), abscesses may arise as a result of severe wear, a crown fracture, trauma, the extension of periodontal disease below the root, or the formation of caries (Dias and Tayles, 1997). All of these cases can provide direct access of microorganisms to the dental pulp. The higher prevalence of abscesses in middle adults is expected in hunter-gatherer societies. Based on the characteristics of the sample, dental wear may be suggested as a progressive phenomenon and would have been the main cause of abscesses' appearance and low frequency of caries. This is also consistent with the affected alveoli. Teeth that have erupted earlier have greater exposure to wear and, in consequence, have the highest probability to produce infection in the pulp cavity and to produce abscesses, especially in the first molars. These results agree with previous records for the Humid Pampa sub-region (L'Heureux, 2000) and northeastern Patagonia (Bernal et al., 2007; Menéndez, 2010).

Antemortem tooth loss can occur through various events or processes, such as infection of the pulp cavity, tooth fracture, intensive attrition, periodontitis, and cultural avulsion (Littleton and Frohlich, 1993; Lukacs, 1992). According to the results, middle adults suffered higher rates of antemortem tooth loss than young adults. It is possible that dental wear, especially on the occlusal surface, and caries have played an important role in the manifestation of antemortem tooth loss. According to the degree of bone remodeling, the majority of lesions were classified as total. Considering the time it takes to obliterate an alveolus, the characteristics of the lesions suggest that antemortem tooth loss occurred early in the life of the individuals. At a comparative level, the percentages obtained here agree with the results from the northeast of Patagonia (Bernal et al., 2007; Menéndez, 2010) but they contrast with the low frequency reported in the Humid Pampa sub-region (1.1%; L'Heureux, 2000).

The frequency of dental calculus obtained in the sample suggests poor oral hygiene. The presence of calculus indicates that individuals had an alkaline oral environment. This is facilitated by the

precipitation of minerals from the oral fluids (e.g., saliva and gingival fluid) (Hillson, 1996; Lukacs, 1989), which accumulate on tooth surfaces as plaque and then undergo a process of mineralization after the intervention of microorganisms such as bacteria (Hillson, 1996, 2000; Mandel, 1990). While there are many factors involved in the generation of dental calculus (plaque pH, the concentration of calcium phosphate in the oral fluid, among others) (Nancollas and Johnsson, 1994) diet has been of greater interest in research (see references in Lieveise, 1999). The results of this research are contradictory, as some authors argue that dental calculus is linked to protein and fat intake (Greene et al., 2005; y'Edynak, 1978; Pedersen, 1947) while others argue that calculus is based on a carbohydrate diet (Evans, 1973; Kennedy, 1984) and/or a mixed diet (Lukacs, 1989). The presence of calculus in a higher percentage for young adults is expected, given that the rate of dental wear is lower for this age group, which allows the preservation of the crown surface and prevents mineralisation of plaque deposits. In a comparative analysis, the occurrence of dental calculus in the sample is significantly lower than that reported for the Humid Pampa sub-region (73.7%; L'Heureux, 2000). As mentioned above, the sample analysed by the author consists of subadult individuals, and the results did not discriminate between age categories, which could have overestimated the values calculated for adults.

Overall, the results suggest that the individuals represented in this osteological sample had good oral health. The frequencies of each dento-alveolar indicator were within the expected ranges for the profiles of oral pathologies of hunter-gatherer-fishing populations (Bernal et al., 2007; Eshed et al., 2006; Lanfranco and Eggers, 2010; Larsen, 1987; Littleton and Frohlich, 1993; Lukacs, 1989; Menéndez, 2010; Turner, 1979, among others). The main agents which generated the lesions were dental wear and diet. With respect to dental wear, it was sufficient enough, to eliminate caries on the surface of the teeth and stimulate development of other paleopathological lesions. In this sense, several factors may have acted in this process, such as the consumption of fibrous and hard foods (e.g., roots, tubers, pods, Cane, 1989; Fine and Craig, 1981), ingested sediment particles detached from the use of grinding artefacts for food preparation (Martínez, 2004; Powell, 1985; Prates, 2008), abrasive particles (e.g., phytolith calcium oxalate; Lalueza et al., 1996) attached to the food during cooking (e.g., ashes from the hearth), and consumption of dried fish (Littleton and Frohlich, 1993; Pedersen, 1947). Furthermore, considering that the hunter-gatherers lived in a semi-arid environment with high winds that carry sand particles, it is possible that this factor has contributed to tooth wear (Maat et al., 1990). Teeth extramasticatory activities would have played a minor role, since preliminary observations found only isolated cases of this practice on the surface of the teeth (e.g., facets of wear, grooves, among others).

According to several authors, the low rate of caries can be correlated with diets high in protein and fat, factors that inhibit the development of these lesions (Eshed et al., 2006; Littleton and Frohlich, 1993; Maat and van der Velde, 1987; Powell, 1985). The carious process was analysed according to location and depth of caries in the teeth (Lanfranco and Eggers, 2010; Love and Jenkinson, 2002). In this analysis, although tooth wear was a major factor in reducing the manifestation of caries, the lesions occurred mainly in the occlusal surface of the dentin (see Lanfranco and Eggers, 2010). In this sense, caries occurred despite the various abrasive agents affecting the tissues of the teeth. This suggests a recurrent consumption of cariogenic foods and/or changes in food preparation (e.g., use of pottery). Even though the differences in the frequency of caries by sex and age were small, the results indicate that caries were present during the developmental stages of life. According to the results and frequencies of dento-alveolar lesions obtained in the neighboring regions, as a hypothesis to be tested in the future, it can be suggested that there was an increase in carbohydrate intake during the final Late Holocene (ca. 1000–250 years BP) compared to the initial Late Holocene (ca. 3000–1000 years BP) in the study area (see Bernal et al., 2007; Menéndez, 2010).

With respect to potential plant resources ingested, in the phytogeographical "Provincia del Espinal" (Cabrera, 1976) there are several species of plants that provide easily accessible sweet and sticky fruits with a high caloric content of carbohydrates, particularly sugars and starch, including "chañar" (*Geoffroea decorticans*), "algarrobo" (*Prosopis* sp.) and "piquillín" (*Condalia microphylla*). Although the chemical composition of fruits from different species might differ slightly, analysis of *Prosopis alba* and *Prosopis flexuosa* shows that they contain high percentages of carbohydrates (more than 50%) with a variable proportion of fibers and proteins (Roig, 1993). According to the ethnohistorical evidence from northern Patagonia, these sweet fruits were commonly used for direct consumption. This included

their use for the preparation of flour and fermented beverages (see Prates, 2009). The frequency of dental calculus supports other evidence of the use of plant resources (Greene et al., 2005; Lukacs, 1989).

Independent information on the subsistence of hunter-gatherer groups has been provided from different lines of analysis. Based on ethnohistorical information, Prates (2009) observed that post-Hispanic hunter-gatherers who lived in Patagonia mainly exploited wild camelid (“guanaco”), and complemented their diets with rhea, deer, birds, mollusks, rodents, armadillos, among others. With respect to plant resources, accounts suggest the consumption of tubers, roots, fruits of “algarrobo” (*Prosopis* sp.) and specifically carob (*Prosopis campestre* and *Prosopis alpataco*), “piquillín” (*Condalia microphylla*) and “chañar” (*Geoffroea decorticans*). These were either consumed raw, cooked, or toasted (see references in Prates, 2009).

Stable isotope analyses from  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  at the Paso Alsina 1 site were recently published by Martínez et al. (2009a). The results were obtained from 13 adult individuals of different burials. The  $\delta^{13}\text{C}$  values exhibit a narrow range (−20.9‰ to −17.9‰), which indicates a diet based mainly on terrestrial C3 resources. The human  $\delta^{15}\text{N}$  values also show a narrow range (11.5–14.1‰). This general isotopic profile indicates that individuals consumed a diverse selection of animal protein, from terrestrial to aquatic settings. This result is in concordance with the zooarchaeological record in the study area. In this sense, the faunal evidence for the final Late Holocene (ca. 1000–250 years BP) indicates the incorporation of small mammals and fish (marine and freshwater) in the diet (Martínez et al., 2005, 2009a; Stoessel, 2007, 2010). This scenario indicates that hunter-gatherers had a diverse diet using resources from different ecological settings (Martínez, 2008–2009; Martínez et al., 2006a; Stoessel, 2007). With respect to plant consumption an increase in the frequency of grinding stones, as well as more standardised and formal tool designs, suggests that these plant resources played an important role in the hunter-gatherer diet during the final Late Holocene (Armentano, 2007; Martínez, 2008–2009; Stoessel, 2007). However, there are no studies with respect to the functional analysis of these grinding-stone tools. These artefacts may have had multiple purposes and had been used in various ways. Ethnographic evidence indicates that such artefacts were related to the preparation of plants as well as salt, fish and mineral pigments (Bórmida and Casamiquela, 1958–1959). Beyond the functionality of these artefacts, the information obtained in this work supports the idea of a recurrent use of plants in the diet of hunter-gatherers.

In conclusion, the results from the tooth wear analysis, frequency of caries and calculus suggest a mixed diet based on proteins, fat and carbohydrates. This interpretation of the diet of these prehistoric groups is consistent with information provided by other lines of research in the study area. This paper represents the first contribution to dental analysis of the skeletal sample recovered from the lower valley of the Colorado River. The current findings need to be tested in future studies, particularly with the inclusion of new samples from earlier chronological contexts.

## Acknowledgements

This research was supported by CONICET (PIP-CONICET No. 6147/05) and the ANPCyT (PICT N° 264) project. The INCUAPA (Facultad de Ciencias Sociales, UNICEN) provided the facilities and support to carry out this analysis. Dr. Gustavo Martínez, Dr. Valeria Bernal, and Luciana Stoessel provided valuable comments made to the manuscript. Also thanks to Daniel Rafuse and Ana Alcaráz who helped with the English and two reviewers for their constructive comments that helped to improve the quality of the paper.

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