International Journal of Osteoarchaeology
Int. J. Osteoarchaeol. **19**: 328–336 (2009)
Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/oa.1040

Diet, Nutrition and Femoral Robusticity of Hunter-Gatherers in Southern Patagonia: Experiences and Perspectives

J. A. SUBY[a*] AND **R. A. GUICHÓN**[b]

[a] *Laboratorio de Ecología Evolutiva Humana, Departamento de Arqueología, Facultad de Ciencias Sociales, Universidad Nacional del Centro de la Provincia de Buenos Aires, 508 Street No. 881, Quequén, Argentina*

[b] *Departamento de Biología, Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Mar del Plata, Argentina*

ABSTRACT Dietary reconstructions through stable isotope studies are one of the most prominent tools for analysing the impact of nutritional and subsistence strategy transitions in the health of past human populations. In the last few years, some palaeopathological studies have been developed related to dietary models proposed for southern Patagonia. In the present work we study the femoral diaphyseal robusticity as an indicator of physical activity and health of a sample of hunter-gatherer individuals from southern Patagonia in relation to their diet, recorded by means of stable isotope values. We discuss the relationship between nutrition and the characteristics of bone structure, as well as the possible impact of pathologies as a source of variability in stable isotope values. Copyright © 2009 John Wiley & Sons, Ltd.

Key words: diet; nutrition; femoral robusticity; southern Patagonia

Introduction

The health of human populations is strongly linked to their biological and ecological pressures, associated with subsistence strategies and dietary patterns. Diet and nutrition are some of the most important factors that affect the development of nutritional and metabolic illnesses, allowing the progress of infectious pathologies through a synergic mechanism (Greenblatt, 2003). The processes by which bone structures respond to nutritional and dietary changes are only partially understood. Three kinds of biological factors are determinant for skeletal structural quality: (a) phylogeny and ontogeny; (b) environmental forces, divided between gravity and muscular force; and (c) those derived from biochemical changes. All these factors include specific cellular activities that are affected by nutrition in variable ways (Frost, 1987, 1990; Rubin *et al.*, 1990; Frost *et al.*, 1998; Martin, 2000; Ferretti *et al.*, 2003). Therefore, analyses of diet and physiological and morphological features of bones can contribute to the understanding of skeletal remodelling.

In this sense, the reconstruction of palaeodietary profiles constitutes a major source of information for the study of human health in the past. Numerous palaeopathological and

* Correspondence to: Laboratorio de Ecologia Evolutiva Humana, Departamento de Arqueología, Facultad de Ciencias Sociales, Universidad Nacional del Centro de la Provincia de Buenos Aires, 508 Street No. 881, Quequén, Buenos Aires, Argentina, 7631.
e-mail: jasuby@hotmail.com

Received 24 September 2008
Accepted 2 October 2008

bioarchaeological works have evaluated the impact of diet and nutrition on past human populations, incorporating information on stable isotope values in the study of stress markers, such as enamel hypoplasia, Harris lines, porotic hyperostosis, and morphological analyses of long bones (Cohen & Armelagos, 1984; Ruff *et al.*, 1984; Buikstra, 1992; Larsen *et al.*, 1992, 2001; Verano & Ubelaker, 1992; Larsen, 1995; Bridges *et al.*, 2000; Ruff & Larsen, 2001). These studies have recognised the impact of diet and lifestyle changes on native human populations in America before and during the European contact, as well as during the transition to agriculture. Despite the vast literature from North America and Europe, in Argentina and particularly in southern Patagonia stable isotope analyses have rarely been employed to study changes in human lifestyles and health (Schinder & Guichón, 2003).

Structural response of bones and nutritional phenomena are both complex and interrelated. Therefore, it is expected that relationships between indicators of both may allow insight into their relationship and help to formulate hypotheses regarding particular situations. Consequently, the objective of this work is to evaluate the relationship between stable isotope values derived from previous studies and data related to mechanical femoral properties of the same samples. It is expected that these analyses will provide information about some of the possible causes of isotopic variability in this sample of human skeletal remains.

Materials and methods

The biomechanical models employed in bioarchaeology usually study the tensile and compressive loads through bone cortical area (CA) and total area (TA) derived from the cross-sectional geometry of long bones. Furthermore, the action of flexion and torsional loads is studied by second moment of area (I) and polar moment (J) (Pearson & Lieberman, 2004). An approximation to these analyses can be obtained from the study of the external morphology of long bones. An example is the femoral robusticity index (FRI), which has a high degree of correspondence with polar moment. Therefore, FRI could inform about the mechanical loading on lower limbs due to mobility, dietary shifts and health, in cases where tomographic and cross-sectional studies are not available (Larsen, 1997; Pearson *et al.*, 2006; Stock & Shaw, 2007).

We estimate the FRI of hunter-gatherer individuals from southern Patagonia, through the formula FRI = [(midshaft breadth$_{ml}$ + midshaft breadth$_{ap}$)/total femoral length] (Boyd & Boyd, 1989; Larsen, 1997). Only those individuals with both geographical provenance and stable isotope values were included. A significant proportion (approximately 40%) of the human bones recovered from southern Patagonia comes from donations and not from systematic excavation. Thus, they do not have assignable spatial information. Only approximately 7% of the total recovered individuals have stable isotope data. These circumstances restrict the available information to bioarchaeological and palaeopathological studies (Guichón *et al.*, 2006; Suby, 2007).

Sex was estimated according to methods suggested by Buikstra & Ubelaker (1994). Only adult individuals were measured to avoid possible inconsistencies due to age variations in external bone geometry. All skeletal elements were complete and well preserved, allowing the measurement of total femoral length on an osteometric table. The individuals included in the analysis and their geographical distributions are shown in Figure 1 and Table 1. The antero-posterior and medio-lateral breadth were measured by calliper on the femoral diaphysis at 50% of total length. Both femora of each individual were measured and their mean value calculated and used in the analysis. Stable isotope values for these individuals were previously reported by Barberena (2002) and Schinder & Guichón (2003, see also Borrero *et al.*, 2009). Barberena (2002) suggested the probable kinds of diet, especially the proportion of maritime and terrestrial resources, that these individuals consumed.

Results

Taking into account the place of origin and the geographical distance between samples, it is

DOI: 10.1002/oa

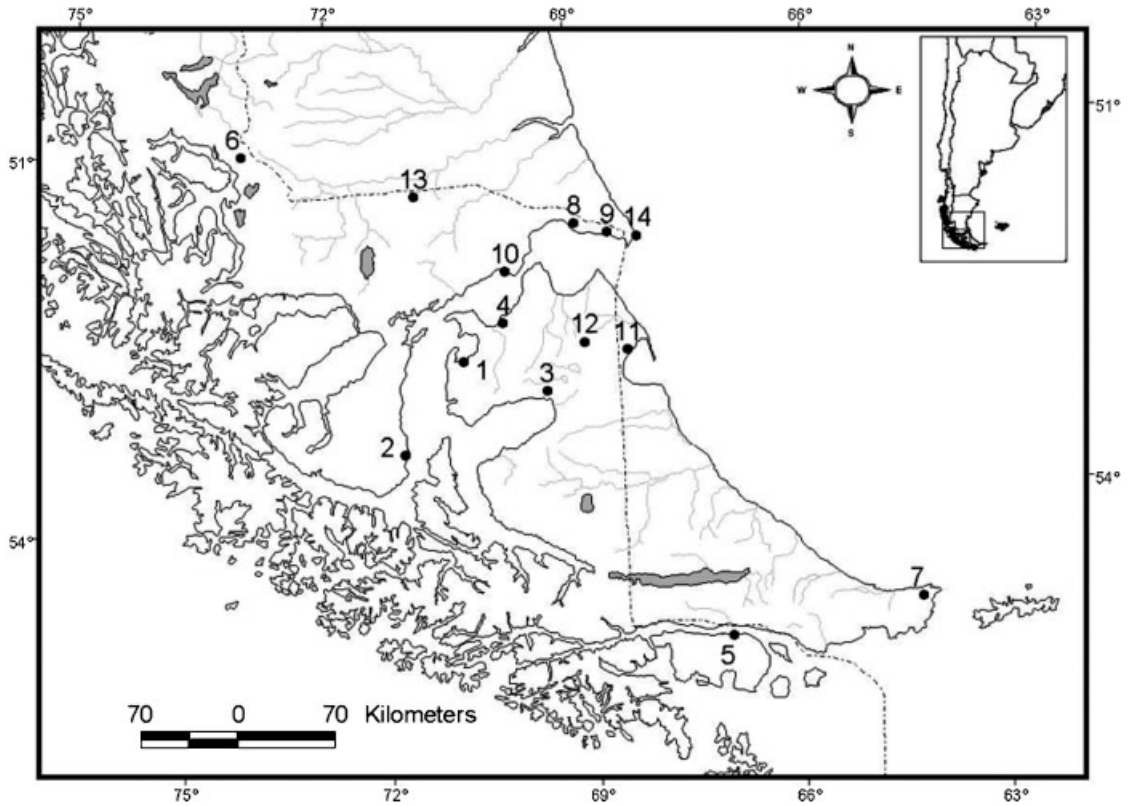

Figure 1. Geographical distribution of included individuals from southern Patagonia: (1) Gente Grande; (2) Punta Santa Ana; (3) Lengua de Vaca; (4) Bah.a Felipe 1 and 2; (5) Lauta 2; (6) Puerto Natales; (7) Caleta Falsa 2; (8) Posesion Olimpia 1 and 2; (9) Punta Daniel 2; (10) Bah.a Santiago; (11) Las Mandibulas; (12) Myren; (13) Juni Aike; (14) Cabo v.rgenes 17.

Table 1. FRI values of human bone rests from southern Patagonia

Site	Sex	Stable isotopes		Diet	FRI
		$\delta^{13}C_{COL}$	$\delta^{15}N$		
Gente Grande	F	−18.36‰	14.66‰	Terrestrial	0.138
Punta Santa Ana	F	−13.24‰	20.02‰	Maritime	0.140
Lengua de Vaca	F	−14.45‰	12.35‰	Mixed	0.124
Bahía Felipe 1	F	−15.58‰	12.71‰	Mixed	0.130
Lauta 2	F	−12.3‰	17.3‰	Maritime	0.143
Puerto Natales	F	−13.93‰	15.75‰	Mixed	0.125
Caleta Falsa 2	M	−11.3‰	15.1‰	Maritime	0.162
Posesión Olimpia 2	M	−19.4‰	13.83‰	Terrestrial	0.141
Bahía Felipe 2	M	−14.92‰	15.81‰	Mixed	0.136
Punta Daniel 2	M	−14.94‰	14.04‰	Mixed	0.140
Posesión Olimpia 1	M	−14.38‰	16.09‰	Mixed	0.121
Bahía Santiago	M	−16.25‰	12.77‰	Mixed	0.133
Las Mandíbulas	M	−18.8‰	11.5‰	Terrestrial	0.128
Myren 1	M	−11.47‰	ND	Mixed	0.108
Juni Aike	M	−15.59‰	12.8‰	Terrestrial	0.138
Cabo Vírgenes 17	M	−16.83‰	13.19‰	Mixed	0.127

Values of stable isotopes and dietary categories from Barberena (2002) and Schinder & Guichón (2003).

DOI: 10.1002/oa

possible to observe different intra-site situations. On the one hand, Posesión Olimpia 1 and 2 sites (site 8 in Figure 1), respectively represented by two male individuals, present fairly different isotopic values and FRI (Figure 2a and b). On the other hand, the sites Bahía Felipe 1 and 2 (sample 4 in Figure 1) are represented by two individuals of different sexes and ages, whose isotopic and FRI values were relatively similar (Figure 2a–b and Figure 3a–b).

Samples recovered from the coast and in comparatively close proximity also showed some degree of variability. In general, aggregate isotope values and FRI were observed, but cases of marked dissimilarity also appeared in the results (for example, Posesión Olimpia described above). The relative distance between sites in relation to the isotopic values and FRI also varied. Punta Santa Ana and Lauta 2 sites (samples 2 and 5 in Figs 1 and 3a–b) have similar isotopic values and FRI results, while Caleta Falsa (site 7 in Figure 2a–b) and Puerto Natales (site 6 in Figure 3a–b) differed. Site Juni Aike, the only case from the continental interior (site 13 in Figure 2a–b) did not show differences in isotopic values or FRI, unlike sites 4, 9 and 10 from the coast of the Strait of Magellan, which are relatively near. Finally, Myren 1 site (site 12 in Figure 2a) had a comparatively low FRI value that differentiated it from all the other individuals.

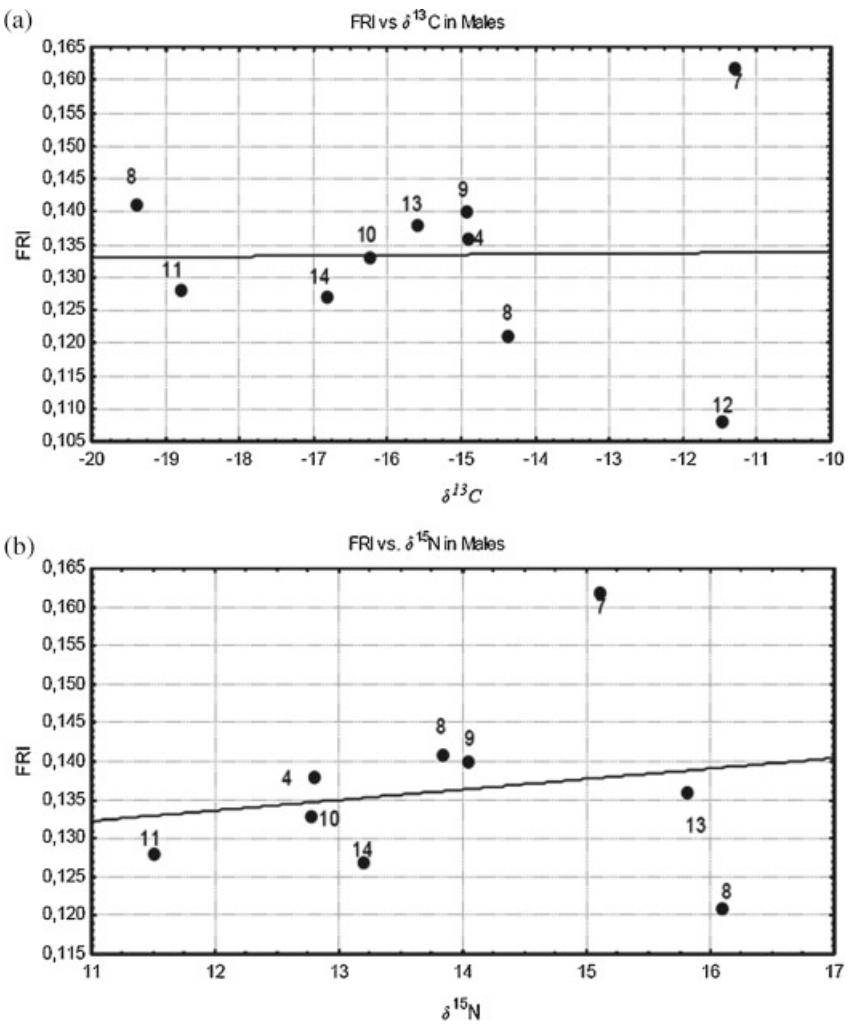

Figure 2. FRI vs. δ^{13}C (a) and δ^{15}N (b) in males from Southern Patagonia ($n = 9$). For references, see Figure 1 caption.

DOI: 10.1002/oa

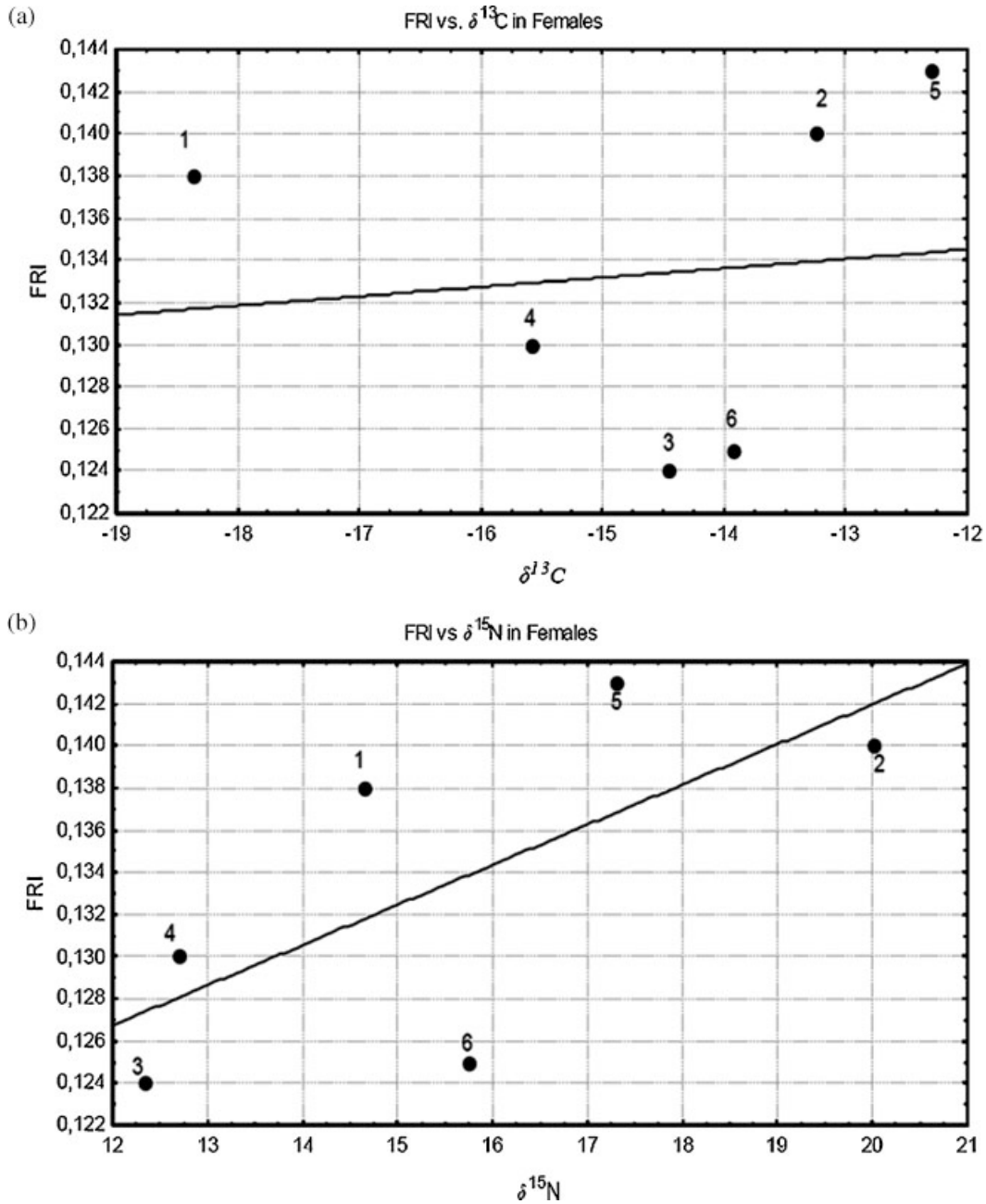

Figure 3. FRI vs. δ^{13}C (a) and δ^{15}N (b) in females from southern Patagonia ($n = 6$). For references, see Figure 1 caption.

However, a diagnosis of osteoporosis for this individual was made previously by Constantinescu (1999) and Rodriguez Martin (personal communication), which could have affected bone development. This fact does not prove that this pathology is the cause of low FRI, but this is a good working hypothesis.

According to Barberena (2002), the clusters of δ^{13}C and δ^{15}N values could represent three categories of diets of hunter-gatherers from southern Patagonia: terrestrial, maritime and mixed. Following this classification, the females showed a tendency for higher FRI in individuals with maritime diets than those with mixed diets

DOI: 10.1002/oa

(Figure 4). The only female individual studied with a terrestrial diet seems to have an intermediate FRI. In males, no differences in FRI were observed between individuals with terrestrial and mixed diets, but a higher FRI value was observed in the only individual with a maritime diet (Figure 4). The FRI values between females and males do not show a substantial difference between individuals with terrestrial and mixed diets (Figure 4). FRI was higher for the single male than for the two females with maritime diets. Finally, the variability between each dietary group including both sexes was similar.

In the subsample of individuals with mixed diet, no differences in FRI were observed between sexes (Kolmogorov-Smirnov $p > 0.10$, $n = 9$). Taking into account all individuals without considering diets, no differences in FRI were observed between sexes either (Kolmogorov-Smirnov $p > 0.10$). Therefore, assuming no differences between sexes, no significant differences in FRI were observed between diets (Figure 5), although individuals with maritime diets presented a tendency towards higher FRI values.

Discussion and conclusions

Despite the increasing attention received in the last few years in Patagonia (Borrero *et al.*, 2001; Guichón *et al.*, 2001; Barberena, 2002; Yesner *et al.*, 2003; Zangrando *et al.*, 2004; Tessone *et al.*, 2005; Borrero & Barberena, 2006; Panarello *et al.*, 2006), palaeodietary information has not been systematically incorporated into studies about health and lifestyles of hunter-gatherer societies. A deeper exploration of the relationships between isotopic values and health interpretation of past populations is necessary, and this research has already begun in Patagonia (Fugassa, 2006; García Guráieb, 2006; Guichón *et al.*, 2006; Suby, 2007).

We presented a study of the relationship between diet and femoral robusticity as indicators of health and physical activity in hunter-gatherers from southern Patagonia. These results suggest higher mechanical demand on the femoral diaphysis of both males and females with a diet that relied upon marine resources than those with terrestrial and mixed diets. No gender differences were observed between individuals with similar isotopic values, suggesting no specific activities by sex and adequate nutritional levels to respond

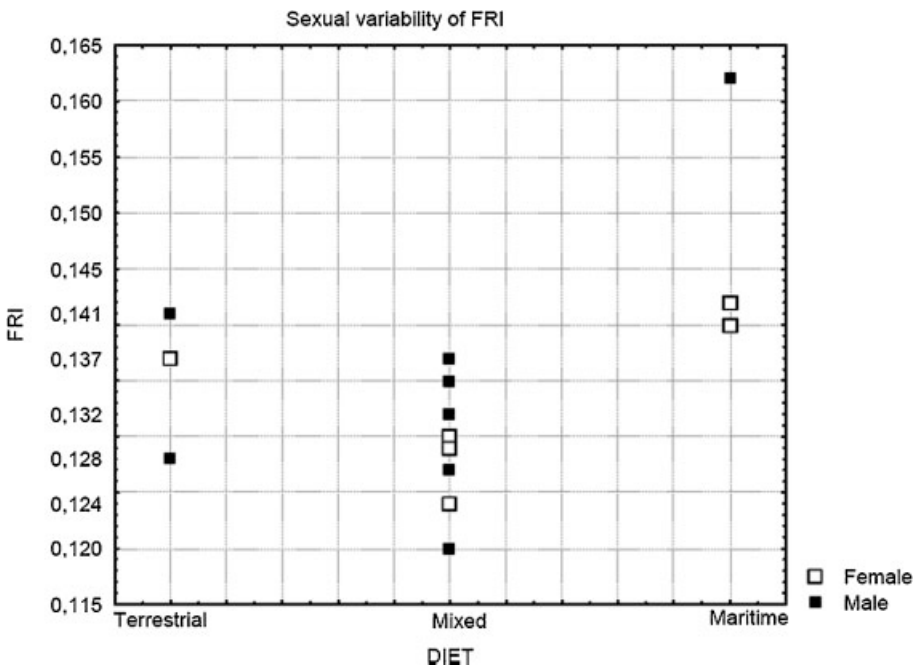

Figure 4. Sexual variability of femoral robusticity index and the diet of hunter-gatherers from southern Patagonia.

DOI: 10.1002/oa

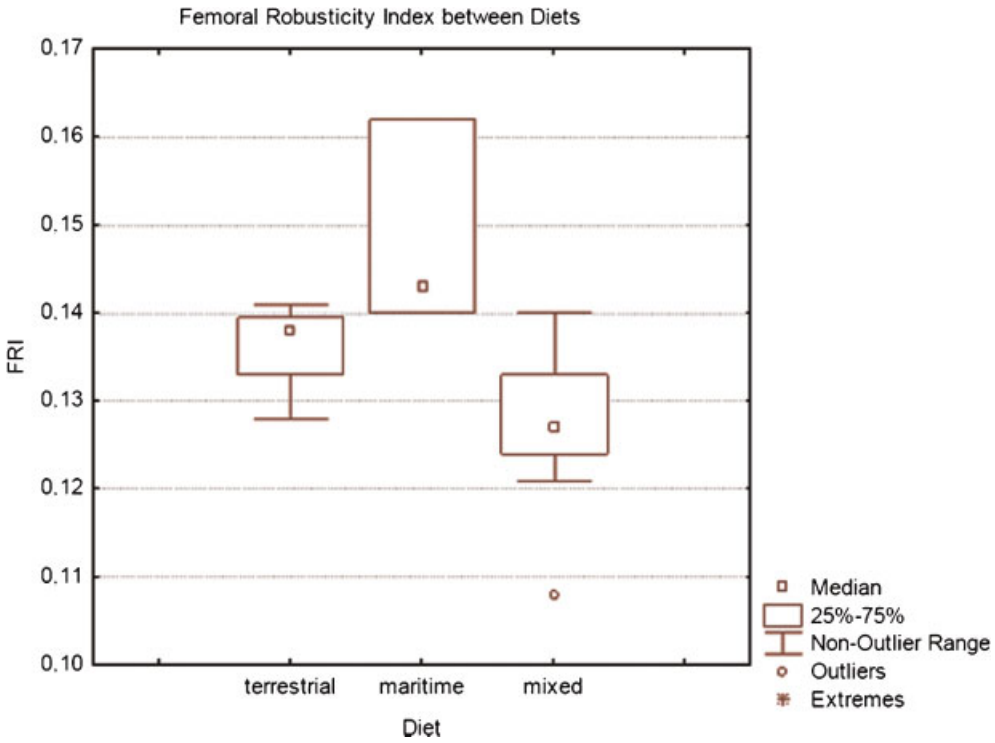

Figure 5. Variability of femoral robusticity index and diet of hunter-gatherers from southern Patagonia. This figure is available in colour online at www.interscience.wiley.com/journal/oa.

to mechanical loads. In addition, femoral robusticity seems not to be related to geographical distribution. However, our inferences could be conditioned by the sample size, which should be increased in future works, as well as by the chronological variability between the sites. Despite these limitations, this work produced preliminary results on the biomechanics and health of hunter-gatherers in relation to palaeodiet in southern Patagonia.

Nutrition is a complex concept that includes the quality and quantity of food, the metabolic responses to specific nutrients, the social and cultural preferences of human populations, and seasonal factors of resources, which depend upon ecological and environmental factors (Kennedy, 1984). It has been proposed that some bias could be introduced in stable isotope values for palaeodietary inferences due to physiological and pathological processes. How do pathologies affect the stable isotope values? Is it possible that some illnesses introduce variability into isotopic information? The study of the relationships between bone microstructure and the physiology of their elements (carbon, nitrogen, calcium and phosphorus principally) is a new area of research that could help to answer these questions. Some of these elements are involved in modelling and remodelling bone through complex mechanisms still under study. The processes of bone change are physiologically related to bone element concentrations, directly or indirectly. Some studies (Hobson *et al.*, 1993; Katzenberg & Lovell, 1999) reported variations, local or systemic, of δ^{15}N due to post-traumatic remodelling, osteomyelitis and bone atrophy. In the same way, it is possible to assume that collagen deficiency, variations in calcium metabolism, changes in acid-base balance (which could produce modifications of carbon concentrations), as well as some renal and digestive pathologies (producing alterations of excretion and absorption of minerals and nutrients), could affect the isotopic concentrations. Consequently, these are situations for which stable isotopes could reflect both diet and health. If variability of stable isotopes is

DOI: 10.1002/oa

affected by local pathological processes, as some research suggests, perhaps bones with lesions must be avoided for these analyses. Currently, the knowledge of the relationship between stable isotope values and human pathologies is unclear and little research has been conducted. The strengthening of palaeopathological analyses by including palaeodietary profiles from stable isotopes could help to improve our inferences about health-related patterns in past human populations.

Acknowledgements

We would like to thank Dr Luis Borrero and the Centro de Estudios del Hombre Austral, Instituto de la Patagonia, Universidad de Magallanes (Punta Arenas, Chile), who provided access to the archaeological material. We also thank the organisers of the Workshop "*Arqueología e Isótopos Estables en el Sur de Sudamérica*", and Drs O. Pearson and L. Luna, whose comments considerably improved this paper. This work was supported by the Research Project "Ecología Evolutiva Humana en Patagonia" (FONCYT-PICT 13889) and Collaboration Research Program between the Instituto Canario de Bioantropología (Santa Cruz de Tenerife, Spain) and the Facultad de Ciencias Sociales, Universidad Nacional del Centro de la Provincia de Buenos Aires, Argentina.

References

Barberena R. 2002. *Los límites del mar. Isótopos estables en Patagonia meridional*. Sociedad Argentina de Antropología: Buenos Aires.

Borrero LA, Guichón RA, Tykot R, Kelly J, Prieto A, Cárdenas P. 2001. Dieta a partir de isótopos estables en restos óseos humanos de Patagonia Austral. Estado actual y perspectivas. *Anales del Instituto de la Patagonia* (Serie Ciencias Humanas) **29**: 119–128.

Borrero LA, Barberena R. 2006. Hunter-gatherer home ranges and marine resources. An archaeological case from southern Patagonia. *Current Anthropology* **47**: 855–867.

Borrero LA, Barberena R, Franco NV, Charlin J, Tykot RH. 2009. Isotopes and rocks: geographical organisation of southern Patagonian hunter-gatherers. *International Journal of Osteoarchaeology* **19**: 309–327. DOI: 10.1002/oa.1036

Boyd DC, Boyd CC. 1989. A comparison of Tennessee Archaic and Mississippian maximum femoral lengths and midshaft diameters: subsistence change and postcranial variability. *Southern Archaeology* **8**: 107–116.

Bridges PS, Blitz JH, Solano MC. 2000. Changes in long bones diaphyseal strength with horticulture intensification in West-Central Illinois. *American Journal of Physical Anthropology* **112**: 217–238. DOI: 10.1002/(SICI)1096–8644 (2000)112:2<217: :AID.-AJPA8>3.0.CO;2-E.

Buikstra JE. 1992. *Diet and disease in late prehistory*, In *Disease and Demography in the Americas: Changing Patterns Before and After 1492*. Verano JW, Ubelaker DH (eds). Smithsonian Institution Press: Washington, DC; 87–101.

Buikstra JE, Ubelaker DH. 1994. *Standards for Data Collection from Human Skeletal Remains*. Arkansas Archaeological Survey Research Series 44: Arkansas.

Cohen MN, Armelagos GJ. 1984. *Paleopathology at the Origins of Agriculture*. Academic Press: New York.

Constantinescu F. 1999. Evidencias bioantropológicas para modos de vida cazador recolector terrestres y marítimo en los restos óseos humanos de Tierra del Fuego. *Anales del Instituto de la Patagonia* (Serie Ciencias Humanas) **26**: 137–174.

Ferretti JL, Capozza RF, Cointry GR. 2003. Interacción entre la nutrición y el control biomecánico de la estructura ósea. *Revista Chilena de Nutrición* **30**: 107–120.

Frost HM. 1987. Bone "mass" and the "mechanostat": a proposal. *Anatomical Record* **219**: 1–9.

Frost HM. 1990. Skeletal structural adaptations to mechanical usage (SATMU): I. Redefining Wolff's Law: The bone remodelling problem. *Anatomical Record* **226**: 414–422.

Frost HM, Ferretti JL, Jee WSS. 1998. Perspectives: Some roles of mechanical usage, muscle strength and the mechanostat in skeletal physiology, disease, and research. *Calcified Tissue International* **62**: 1–7.

Fugassa MH. 2006. *Enteroparasitosis en poblaciones cazadoras-recolectoras de Patagonia Austral*. PhD thesis, Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Mar del Plata.

Garcia Guráieb S. 2006. Salud y enfermedad en cazadores-recolectores del Holoceno tardío en la cuenca del Lago Salitroso (Santa Cruz). *Intersecciones en Antropología* **7**: 37–48.

Greenblatt CL. 2003. An overview: how infection began and became disease. In *Archaeology, Ecology and Evolution of Infectious Disease*, Greenblatt CL,

Spigelman M (eds). Oxford University Press: New York; 3–12.
Guichón RA, Borrero LA, Prieto A, Cárdenas P, Tykot R. 2001. Nuevas determinaciones de isótopos estables para Tierra del Fuego. *Revista Argentina de Antropología Biológica* **3**: 113–126.
Guichón RA, Suby JA, Casali R, Fugassa MH. 2006. Health at the time of native-European contact in Southern Patagonia. *Memorias do Instituto Oswaldo Cruz* **101** (Suppl. II): 97–105.
Hobson KA, Alisauskas RT, Clark RG. 1993. Stable-nitrogen isotope enrichment in avian tissues due to fasting and nutritional stress: implications for isotopic analyses of diet. *The Condor* **95**: 388–394.
Katzenberg M, Lovell NC. 1999. Stable isotope variation in pathological bone. *International Journal of Osteoarchaeology* **9**: 316–324.
Kennedy KAR. 1984. Growth, nutrition and pathology in changing paleodemographic setting in South Asia. In *Paleopathology at the Origins of Agriculture*, Cohen MN, Armelagos GJ (eds). Academic Press: London; 169–192.
Larsen CS. 1995. Biological changes in human populations with agriculture. *Annual Review of Anthropology* **24**: 185–213.
Larsen CS. 1997. *Bioarchaeology: Interpreting Behavior from Human Skeleton*. Cambridge University Press: Cambridge.
Larsen CS, Ruff CB, Schoeninger MJ, Hutchinson DL. 1992. Population decline and extinction in La Florida. In *Disease and Demography in the Americas*, Verano JW, Ubelaker DH (eds). Smithsonian Institution Press: Washington, DC; 25–39.
Larsen CS, Griffin MC, Hutchinson DL, Noble VE, Norr L, Pastor RF, Ruff CB, Russell KF, Schoeninger MJ, Schultz M, Simpson SW, Teaford MF. 2001. Frontiers of contact: bioarchaeology of Spanish Florida. *Journal of World Prehistory* **15**: 69–123.
Martin RB. 2000. Toward a unifying theory of bone remodelling. *Bone* **26**: 1–8.
Panarello H, Zangrando AF, Tessone A, Kozameh L, Testa N. 2006. Análisis comparativo de paleodietas humanas entre la región del canal de Beagle y Península Mitre: Perspectivas desde los isótopos estables. *Magallania* **34**(2): 37–47.
Pearson OM, Lieberman DE. 2004. The aging of Wolffs "Law": ontogeny and responses to mechanical loading in cortical bone. *Yearbook of Physical Anthropology* **47**: 63–99.
Pearson OM, Cordero RM, Busby AM. 2006. How different were Neanderthals' habitual activities? A comparative analysis with diverse groups of recent humans. In *Neandertals Revisited: New Approaches and Perspectives*, Harvati K, Harrison T (eds). Springer: New York; 89–112.
Rubin CT, Mcleod KJ, Bain SD. 1990. Functional strains and cortical bone adaptation. Epigenetic assurance of skeletal integrity. *Journal of Biomechanics* **23**: 43–54.
Ruff CB, Larsen CS, Hayes WC. 1984. Structural changes in the femur with the transition to agriculture on the Georgia Coast. *American Journal of Physical Anthropology* **64**: 125–136.
Ruff CB, Larsen CS. 2001. Reconstructing behavior from Spanish Florida: the biomechanical evidence. In *Bioarchaeology of Spanish Florida: The Impact of Colonialism*, Larsen CS (ed.). University Press of Florida: Gainesville; 113–145.
Schinder G, Guichón RA. 2003. Isótopos estables y estilo de vida en muestras óseas humanas de Tierra del Fuego. *Magallania* **31**: 33–44.
Stock JT, Shaw CN. 2007. Which measures of diaphyseal robusticity are robust? A comparison of external methods of quantifying the strength of long bone diaphyses to cross-sectional geometric properties. *American Journal of Physical Anthropology* **134**: 412–423. DOI: 10.1002/ajpa.20686.
Suby JA. 2007. Metodologías de Análisis de Densidad Mineral Ósea sobre Restos Oseos Humanos de Patagonia Austral. Tafonomía y Paleopatología. In *Arqueología de Fuego-Patagonia. Levantando piedras, desenterrando huesos. . .y develando arcanos*, Morello F, Prieto A, Martinic M, Bahamondes G (eds). CEQUA Editions: Punta Arenas; 381–390.
Tessone A, Zangrando AF, Barrientos G, Valencio S, Panarello H, Goñi R. 2005. Isotopos estables del carbono en Patagonia Meridional: datos de la cuenca del Lago Salitroso (Provincia de Santa Cruz, Republica Argentina). *Magallania* **33**(2): 21–28.
Verano J, Ubelaker DH. 1992. *Disease and Demography in the Americas*. Smithsonian Institution Press: Washington, DC.
Yesner DR, Figuerero Torres MJ, Guichón RA, Borrero LA. 2003. Stable isotope analysis of human bone and ethnohistoric subsistence patterns in Tierra del Fuego. *Journal of Anthropological Archaeology* **22**: 279–291.
Zangrando AF, Tessone A, Valencio S, Panarello H, Mansur M, Salemme M. 2004. Isótopos estables y dietas humanas en ambientes costeros. In *Avances en Arqueometría* 2003. Servicio de Publicaciones de la Universidad de Cádiz: Cádiz; 91–97.