Annals of
Human Biology
Journal of the Society for the Study of Human Biology

http://informahealthcare.com/ahb
ISSN: 0301-4460 (print), 1464-5033 (electronic)

Ann Hum Biol, Early Online: 1–8
 DOI: 10.3109/03014460.2014.959998

informa
healthcare

RESEARCH PAPER

Geographical altitude, size, mass and body surface area in children (1–4 years) in the Province of Jujuy (Argentina)

Estela María Román[1,2], Ignacio Felipe Bejarano[3], Emma Laura Alfaro[1,2,3,4], Guadalupe Abdo[4,5], and José Edgardo Dipierri[1,2,3]

[1]Instituto de Biología de la Altura, Universidad Nacional de Jujuy (UNJu), San Salvador de Jujuy, Jujuy, Argentina, [2]CIT JUJUY – CONICET, San Salvador de Jujuy, Argentina, [3]Unidad de Investigación en Antropología Biológica, Facultad de Humanidades y Ciencias Sociales, San Salvador de Jujuy, Jujuy, Argentina, [4]Facultad de Ciencias Agrarias, UNJu, San Salvador de Jujuy, Jujuy, Argentina, and [5]Programa Pro-Huerta, Jujuy, Argentina

Abstract

Background: Highland child populations show low growth rates.
Aim: To evaluate the variation of size, mass and body surface area of Jujenean infants (1–4 years) as a function of geographic altitude.
Subjects and methods: Nutritional status of 8059 healthy infants was determined based on weight and height data; body mass index, ponderal index, body surface area, body surface area/mass and ectomorphy were calculated. Variables were standardized with a provincial mean and WHO references. Data were grouped by age, sex and geographic altitude: Highlands ($\geq$2500 masl) and Lowlands (<2500 masl). Chi-square, correlation and *t*-tests were applied.
Results: Highlands infants had higher prevalence of stunting, reduced height, weight, body surface area and ectomorphy; also higher body mass index, ponderal index and body surface area/mass. The population average *z*-score for height, weight and body surface area was positive in Lowlands and negative in Highlands. The opposite happened with body mass index, ponderal index and body surface area/mass. In Highlands and Lowlands the average *z*-score reference was negative for weight and height and positive for body mass index. Correlations between indices were high and significant, higher in Highlands.
Conclusion: Jujenean children differ in size, mass and body surface area based on the geographical altitude and adverse nutritional and socioeconomic factors.

Keywords

Body mass, body size, body surface area, geographical altitude, infants, Jujuy

History

Received 20 December 2013
Revised 25 July 2014
Accepted 26 August 2014
Published online 2 December 2014

Introduction

The dynamics of human growth and development reflects a complex multifactorial model in which the individual body components have a certain degree of heritability, while plasticity to environmental (geoclimatic, cultural, economic and social) stimuli in which individuals and populations which they belong to develop (Bogin, 1988; Frisancho, 2013; Mascie-Taylor & Bogin, 1995). The way genetic and environmental factors interact and are inter-related defines the human growth pattern, which undergoes significant adaptive changes during ontogenetic development. Not all populations have the same growth potential and the same responses to certain stimuli. The anthropometric variables exhibit inter-population differences and it is unclear how much of these differences are due to environmental or genetic variance (Bogin, 1988; Eveleth & Tanner, 1990; Tanner, 1978; Ulijaszek & Mascie-Taylor, 1994; Ulijaszek et al., 2000).

Adaptation to high altitude ecosystems is a complex phenomenon in which, besides geographical altitude, various stressors associated with it interact: hypoxia, restricted food resources, large temperature range, high cosmic radiation, etc. (Dipierri et al., 1996; Frisancho & Baker, 1970; Guimarey et al., 1995; Hass et al., 1980; Ulijaszek et al., 2000). This adaptation is basically manifested by a change in shape, proportion and body physiology. Some anthropometric and functional features have been established that characterize the growth and development of high altitude populations over others of relative socioeconomic similarity, location closer to sea level, slow growth over longer periods, increased thoracic volume, elongated trunk relative to overall height, delayed sexual and bone maturation and lower birth weight (Álvarez et al., 2002; Dipierri et al., 1992; Frisancho, 2013; Frisancho & Baker, 1970; Hass et al., 1980, 1982; Leonard et al., 1995; Malhotra, 1986; Yip et al., 1988).

Jujuy province is located in the northwest of Argentina and, due to its location on the Andean foothills, it presents an altitudinal gradient ranging from 500 masl to >4000 masl, configuring three geographical and ecologically well-defined areas in its territory of 53 219 km^2: (1) the tropical valley (between 500–1500 masl), which includes the provincial capital (San Salvador de Jujuy); (2) the Pre Puna (1500–3000 masl), a region that contains the Quebrada de Humahuaca; and (3) Puna (>3000 masl). Differential gene

Correspondence: Estela María Román, Instituto de Biología de la Altura, Universidad Nacional de Jujuy, Av. Bolivia 1661 (CP 4600), San Salvador de Jujuy, Jujuy, Argentina. Tel: 54-0388-4221596. E-mail: eroman@inbial.unju.edu.ar

flow and admixture rates characterize the populations settled in these regions (Gómez-Pérez et al., 2013; Wang et al., 2008). However, different molecular and serological genetic markers show that the Amerindian genetic component is highly predominant in these populations (Dipierri et al., 2000; Gómez-Pérez et al., 2011).

Several anthropometric studies conducted in Jujuy populations at different stages of ontogenesis, especially in newborns, childhood, adolescence and adulthood, have shown a differential regional pattern of growth, conditioned by geographical altitude and socioeconomic factors associated with it (Alfaro et al., 2008; Álvarez et al., 2002; Bejarano et al., 1999, 2009; Dipierri et al., 1996, 1998). This pattern is basically characterized by growth retardation, especially in birth weight and height, at the towns above 2500 masl compared to the same Jujenean populations located closer to sea level. An ontogenetic phase not yet anthropometrically analysed in these populations is childhood (0–4 years).

Studies on growth and development in altitude in this ontogenetic stage are scarce. They come from research works carried out in mountainous environments with different patterns of human adaptation to high-altitude hypoxia and countries with significant socioeconomic disparities: the US (Yip et al., 1988), Ecuador (Leonard et al., 1995), Bolivia (Hass et al., 1982) and Tibet (Dang et al., 2008). The purpose of this paper was to evaluate the variation of size, mass and body surface area depending on the geographical altitude in Jujuy infants with comparable socioeconomic backgrounds.

Materials and methods

This is a convenience sample, i.e. public health posts which provided the data were selected based on the accessibility and especially willingness on the part of managers to allow consultation of anonymous records.

Anthropometric data were taken from healthy children controls conducted between 2005–2007 in Primary Care Centres, under the Primary Health Care Programme of the Ministry of Health in the province of Jujuy. Primary Care Centres are an innovative strategy that involve activities of various health programmes whose fundamental tactic consists of home visits by healthcare workers. It was implemented in the province of Jujuy before the Alma Ata (1978) in what was called the Rural Health Plan. Assessment and monitoring of physical growth of children up to 6 years old has been one of the most significant actions of Primary Care Centres.

The Province of Jujuy presents demographic and socioeconomic differences related to geographical altitude (Table 1). The highest Infant Mortality Rates were present in highlands regions (Quebrada and Puna) where over 80% of the illiterate were women and, of these, 5.6% in Puna and 4.0% in Quebrada were of reproductive age (Eichenberger et al., 2009). This situation, coupled with the adverse environmental conditions typical of highlands, the shortage of medical pre- and peri-natal care, rurality and high percentages of unsatisfied basic needs, could explain these differences (Table 1).

The individuals and families covered by Primary Health Care Programme social benefits provided to the uninsured, come from neighbourhoods and localities that are socially and economically disadvantaged. In addition, these children and their families are beneficiaries of various national and provincial social assistance and food programmes (Maternal and Child Care Programme; Universal Child Allowance Programme), which would ensure a relative cultural and social homogeneity of children examined in this work.

Data used consisted of weight and height of 8059 schoolchildren (3967 males, 4092 females) from 1–4.99 years. Anthropometric measurements were performed according to international (Ulijaszek et al., 2000) and national (SAP, 2013) recommendations by the Primary Care Centres staff, specifically trained for this task. Up to 2 years of age, weight measured in kilograms was taken using lever scales with divisions for up to 50 g readings. When children could stand they were weighed in standing position. Height assessment in children who could not stand was performed in a supine position using a stadiometer, which consists of a hard horizontal surface covered by a scale and a vertical mobile surface, moving at right angles to the horizontal plane. Children who could stand were measured with an altimeter with variations of 0.5 cm.

For analysis purposes, data were grouped by sex, decimal age and geographical location of the Primary Care Centres. Decimal age was calculated taking into account the measurement date and the date of birth, determining four age groups: 1–1.99, 2–2.99, 3–3.99 and 4–4.99 years. According to the geographic location of the Primary Care Centres data were grouped into two altitude levels: (1) Highlands (HL) ($\geq$2500 masl) and (2) Lowlands (LL) (<2500 masl).

The nutritional status of the population was characterized using the WHO reference (De Onis et al., 2004; WHO, 2006) for geographical altitude and independently of sex and age, using the following indicators: stunting (Height/Age <-2 z-score), underweight (Weight/Age <-2 z-score) and emaciated (Weight/Height <-2 z-score).

The following indices were calculated from the height and weight data: (1) Body Mass Index (BMI = Weight (kg)/Height (m)^2) (Keys et al., 1972); (2) Ponderal Index (PI = Weight (kg)/Height (m)^3) (Keys et al., 1972); (3) Body Surface Area according to the Mosteller (1987) equation (BSA = $\sqrt{}$((Height cm $\times$ Weight Kg)/3600)), recommended for use in paediatric individuals (Ahn & Garruto, 2008); (4) BSA/Mass relationship (BSA/M = BSA (cm^2)/Mass (Kg); (5) Ectomorphy (ECT) (Billewicz et al., 1962; Cabañas & Esparza, 2009), which was calculated from Reciprocal Ponderal Index (RPI) = (Height (cm)/3 $\sqrt{}$Weight (kg)). If the RPI was $\leq$38.28, it was assigned an ECT value = 0.1; if it ranged between >38.28 and $\leq$40.75, the formula used was ECT = 0.463 $\times$ RPI $-$ 17.63, and if the RPI was >40.75 we used ECT = 0.732 $\times$ RPI $-$ 28.58.

All variables analysed were standardized with the mean of the sample of this study (POP) by sex and age, while, for weight, height and BMI, WHO references were used (De Onis et al., 2004; WHO, 2006). WHO reference was considered because it is prescriptive; its inclusion criteria involve the absence of health and socioeconomic problems that limit growth and mothers of participating children should be non-smokers and breastfeed new-borns.

Statistical differences by age, sex and geographic altitude were established with t and χ^2 tests. Prior logarithmic

Table 1. Sociodemographic indicators by geographical altitude.

Indicators	LL	HL
Population*	540830	71058
Surface (km^2)*	13065	40154
Density*	41.40	1.80
% Relative intercensal variation*	21.26	7.16
% Illiteracy >10 years of age*	4.24	8.78
% Educated population >3 years of age*	38.15	40.54
% Population with health coverage*	47.64	32.12
% Employed >14 years of age*	43.05	41.98
% Homes with Unsatisfied Basic Needs*	25.17	31.68
% Population with Unsatisfied Basic Needs*	28.08	32.80
Infant Mortality Rate (‰)**	17.40	32.65
Birth Rate (‰)***	24.78	28.88

References: LL, Lowlands; HL, Highlands.
Source: *Instituto Nacional de Estadísticas y Censos (Censo Nacional de Población y Viviendas, 2001); **Alfaro et al. (2005); ***Eichenberger et al. (2007).

Table 2. Nutritional status of the population according to the WHO reference by sex, geographical altitude and the entire province.

Geographic altitude	z-score <−2		z-score −2 to 2		z-score >2	
	n	%	n	%	n	%
	WHO H/A					
LL	159	4.2[a]	3512	91.9[a]	152	4.0[a]
HL	849	20.0[a]	3360	79.3[a]	27	0.6[a]
LL + HL	1008	12.5	6872	85.3	179	2.2
	WHO W/A					
LL	17	0.4[a]	3578	93.6[a]	228	6.0[a]
HL	35	0.8[a]	4134	97.6[a]	67	1.6[a]
LL + HL	52	0.6	7712	95.7	295	3.7
	WHO W/H					
LL	26	0.7	3643	95.3[a]	154	4.0[a]
HL	25	0.6	4083	96.4[a]	128	3.0[a]
LL + HL	51	0.6	7726	95.9	282	3.5

References: LL, Lowlands; HL, Highlands.
[a]χ^2 test between LL and HL, $p < 0.05$.

transformation of the data, to meet normality requirements, variables—regardless of age and sex—were correlated by geographic altitude with Pearson correlation coefficient (SPSS 11.0 software).

Results

Table 2 presents the nutritional status of the population according to the WHO reference, regardless of age and sex, showing that the prevalence of underweight (<−2 *z*-score W/A), although statistically different between LL and HL, was less than 1%. Instead, the stunting prevalence (<−2 *z*-score H/A) was significantly higher in HL (20%) than in LL (4.2%). No statistically significant differences in emaciation percentages due to altitude (<−2 *z*-score W/H) were found, these being less than 1%. In both regions it was further noted that, taking into account such parameters of nutritional status, the highest percentage was within the range considered normal values. Also, percentages of *z*-score >2 H/A, W/A were relatively low and the *z*-score >2 W/H were high (Table 2).

In general in this sample, in all age groups and in both sexes, LL children had higher height, weight, BSA and ECT than children of the HL, the differences being statistically significant (Table 3). Instead BMI, PI and related BSA/M were significantly higher in infants of the HL, except in the age group of 4–4.99 years in both sexes for BMI, where HL values were lower. With respect to the BSA and ECT, which increased significantly with age in both sexes and in HL and LL, the opposite was observed with BMI, PI and the BSA/M ratio.

The average height and weight *z*-score in relation to the population was, in both sexes and in all age groups, negative in HL and positive in LL (Figure 1). In contrast, the mean BMI *z*-score with respect to the population occurred in LL, in both sexes, presenting negative values up to 3.99 years, whereas the opposite was observed in the HL (Figure 1). With regard to the WHO reference, the average height *z*-score was generally negative in HL and LL. The average weight *z*-score of boys and girls of all age groups showed negative values in the HL, while in LL they were positive. The mean BMI *z*-score relative to the WHO reference was positive in all age groups and in both sexes, both in HL and LL, but HL values were slightly higher, except in the 4–4.99 years group. This could be attributed to the combination of two factors, increased duration of breastfeeding and later schooling in HL, while the opposite happens in the LL. In the HL, once the exclusive maternal breastfeeding is disrupted and complementary feeding starts, the latter would be characterized by low caloric density (Naumann & Pinotti, 2012). In terms of schooling, the influence of access to energy-dense foods (snacks, candy, etc.) and school food assistance would explain increased BMI at age 4 in LL.

The average PI *z*-score and BSA/M relationship with respect to the population presented in all age groups and in both sexes showed negative values in the LL and positive ones in the HL, while the average BSA and ECT *z*-score were positive in the LL and negative in the HL for all age groups and in both sexes (Figure 2).

Regardless of geographical altitude, most correlations between variables were high, significant ($p < 0.01$) and tended to be higher in HL (Table 4). Weight presented very low significant correlation to BMI, with negative values in the HL and positive ones in the LL, and the value 0.087 corresponds to correlation coefficient (*r*). However, the negative significant correlation between PI and weight in HL and LL explained 45% and 37%, respectively, of its variation. The correlation between ECT and weight indicated that predominance of linearity against mass increased significantly with the latter, but more so in the HL than LL. BMI and PI presented a significant negative correlation to height, but these values were higher in HL. The positive correlation between ECT and height indicated that the prevalence of linearity with respect to the size reached increased more in LL than in HL. Both in HL and LL, BMI decreased significantly as BSA increased. In the LL BMI variation explained less than 1% of BSA variation and in the HL it explained ~5%. Instead, PI explained 50% and 59% of the BSA variation in LL and HL, respectively. In the HL and LL the BMA/M ratio was negatively associated to BMI and positively with PI, but in the LL this correlation was

Table 3. Number of subjects of this sample, mean and (standard deviation) of the variables analysed by age, sex and geographical altitude.

		LL (<2500 masl)		HL (≥2500 masl)		
Variable	Age (years)	Males	Females	Males	Females	LL + HL
n	1–1.99	604	563	687	742	2596
	2–2.99	520	518	591	622	2251
	3–3.99	431	451	462	482	1826
	4–4.99	364	372	308	342	1386
Height (cm)	1–1.99	78.74 (4.52)[c]	76.67 (4.42)[c]	73.82 (3.24)[c]	71.78 (3.18)[c]	75.00 (4.67)
	2–2.99	88.43 (4.40)[c]	87.50 (4.18)[c]	84.27 (3.66)[c]	82.52 (3.54)[c]	85.49 (4.61)
	3–3.99	96.35 (4.35)[c]	95.03 (4.45)[c]	92.36 (3.96)[c]	90.82 (3.80)[c]	93.55 (4.67)
	4–4.99	103.19 (4.55)[c]	101.72 (4.47)[c]	99.63 (4.20)[c]	97.66 (3.64)[c]	100.64 (4.73)
Weight (kg)	1–1.99	10.79 (1.44)[c]	10.03 (1.41)[c]	9.66 (1.05)[c]	8.99 (1.02)[c]	9.81 (1.39)
	2–2.99	13.10 (1.60)[c]	12.55 (1.54)[c]	11.99 (1.27)[c]	11.39 (1.27)[c]	12.21 (1.55)
	3–3.99	15.01 (1.78)[c]	14.54 (1.75)[c]	13.98 (1.46)[c]	13.32 (1.37)[c]	14.20 (1.72)
	4–4.99	17.15 (2.08)[c]	16.41 (2.11)[c]	15.82 (1.79)[c]	15.03 (1.55)[c]	16.13 (2.06)
BMI (kg/m^2)	1–1.99	17.37 (1.46)[c]	17.02 (1.51)[c]	17.72 (1.45)[c]	17.44 (1.53)[c]	17.41 (1.51)
	2–2.99	16.73 (1.34)	16.36 (1.33)[c]	16.87 (1.30)	16.70 (1.29)[c]	16.67 (1.33)
	3–3.99	16.22 (1.21)	16.08 (1.29)	16.37 (1.22)	16.13 (1.21)	16.20 (1.24)
	4–4.99	16.07 (1.34)	15.82 (1.39)	15.91 (1.19)	15.74 (1.18)	15.89 (1.28)
PI (cm/kg)	1–1.99	22.14 (2.38)[c]	22.28 (2.42)[c]	24.06 (2.34)[c]	24.36 (2.53)[c]	23.31 (2.62)
	2–2.99	18.97 (1.86)[c]	18.74 (1.80)[c]	20.07 (1.88)[c]	20.28 (1.85)[c]	19.57 (1.96)
	3–3.99	16.87 (1.47)[c]	16.96 (1.63)[c]	17.77 (1.61)[c]	17.80 (1.61)[c]	17.36 (1.64)
	4–4.99	15.60 (1.47)[c]	15.58 (1.49)[c]	16.00 (1.37)[c]	16.14 (1.36)[c]	15.82 (1.45)
BSA (cm^2/kg)	1–1.99	48.53 (4.41)[c]	46.16 (4.36)[c]	44.48 (3.16)[c]	42.29 (3.07)[c]	45.16 (4.39)
	2–2.99	56.68 (4.60)[c]	55.17 (4.46)[c]	52.93 (3.69)[c]	51.05 (3.71)[c]	53.79 (4.63)
	3–3.99	63.48 (4.92)[c]	61.90 (4.87)[c]	59.83 (4.11)[c]	57.91 (3.92)[c]	60.70 (4.93)
	4–4.99	70.04 (5.48)[c]	68.01 (5.51)[c]	66.11 (4.83)[c]	63.80 (4.18)[c]	67.08 (5.55)
BSA/M	1–1.99	4.52 (0.22)[c]	4.63 (0.24)[c]	4.62 (0.20)[c]	4.73 (0.21)[c]	4.63 (0.23)
	2–2.99	4.35 (0.19)[c]	4.42 (0.21)[c]	4.43 (0.18)[c]	4.50 (0.19)[c]	4.43 (0.20)
	3–3.99	4.23 (0.18)[c]	4.28 (0.19)[c]	4.30 (0.17)[c]	4.37 (0.17)[c]	4.29 (0.19)
	4–4.99	4.11 (0.19)[c]	4.17 (0.21)[c]	4.20 (0.18)[c]	4.26 (0.17)[c]	4.18 (0.20)
ECT	1–1.99	0.11 (0.05)	0.11 (0.05)[a]	0.10 (0.03)	0.10 (0.03)[a]	0.10 (0.04)
	2–2.99	0.20 (0.26)[c]	0.22 (0.32)[c]	0.13 (0.13)[c]	0.12 (0.10)[c]	0.16 (0.22)
	3–3.99	0.54 (0.45)[c]	0.54 (0.49)[c]	0.35 (0.37)[c]	0.33 (0.36)[c]	0.44 (0.43)
	4–4.99	1.02 (0.65)[c]	1.04 (0.69)[c]	0.83 (0.59)[c]	0.77 (0.58)[c]	0.92 (0.64)

References: LL, Lowlands; HL, Highlands; BMI, Body Mass Index; PI, Ponderal Index; BSA, Body Surface Area; M, Mass; ECT, Ectomorphy.
[a]*t*-test between LL and HL by Sex, $p < 0.05$; [c]*t*-test between LL and HL by Sex, $p < 0.001$.

higher for BMI than for the PI, while the opposite was observed in the HL. The linearity expressed by ECT was negatively correlated to BSA/M in the HL and LL, yet it was higher in the HL.

Discussion

In general, the results of this study are similar to those attained in the US, Bolivia, Ecuador and Tibet (Dang et al., 2008; Hass et al., 1982; Leonard et al., 1995; Yip et al., 1988) in the sense that high altitude infants were significantly lighter and shorter than low altitude ones. However, Leonard et al. (1995) observed that the linear growth and weight were similar in children of altitude farming communities and the coast of Ecuador. Consequently, they concluded that altitude hypoxia played a small role in the growth pattern during the first 5 years of life and that most of the disparity in height between the two samples could be attributed to differences established at 6 months of age. Yip et al. (1988) and Hass et al. (1982) attached great importance to birth weight differences observed in children growing up in the US and Bolivia, but from opposite perspectives. Yip et al. (1988) interpreted the decrease in height and weight could be attributed, in principle, to reduced birth weight, but as these differences persist beyond control of this variable, they did not exclude the presence of a delay effect on extra-uterine growth related to altitude. However, Haas et al. (1982) concluded that the lower weight during the first year of Bolivian altitude children seemed to follow the persistence of low birth weight pattern and not relate to post-natal growth retardation. Finally, Dang et al. (2008) concluded that altitude might slow down the development of height and, to a lesser extent, weight of young age Tibetan children, regardless of socioeconomic factors and other factors that operate through nutrition and disease, which persistently cause adverse effects from birth to 3 years of age.

Conventional malnutrition indicators show different biological growth processes. Stunting (<−2 *z*-score Height/Age) reflects bone growth retardation by chronic malnutrition, underweight (<−2 *z*-score Weight/Age) may be caused by stunting or inadequate weight gain in relation to height or a combination of both processes and emaciation (<−2 *z*-score Weight/Height), which was practically not detected in Jujuy infants, is a measure of acute malnutrition with loss of fat and lean tissue. The prevalence of underweight in HL and LL is low (OMS, 1995), almost negligible, as they are in or near the

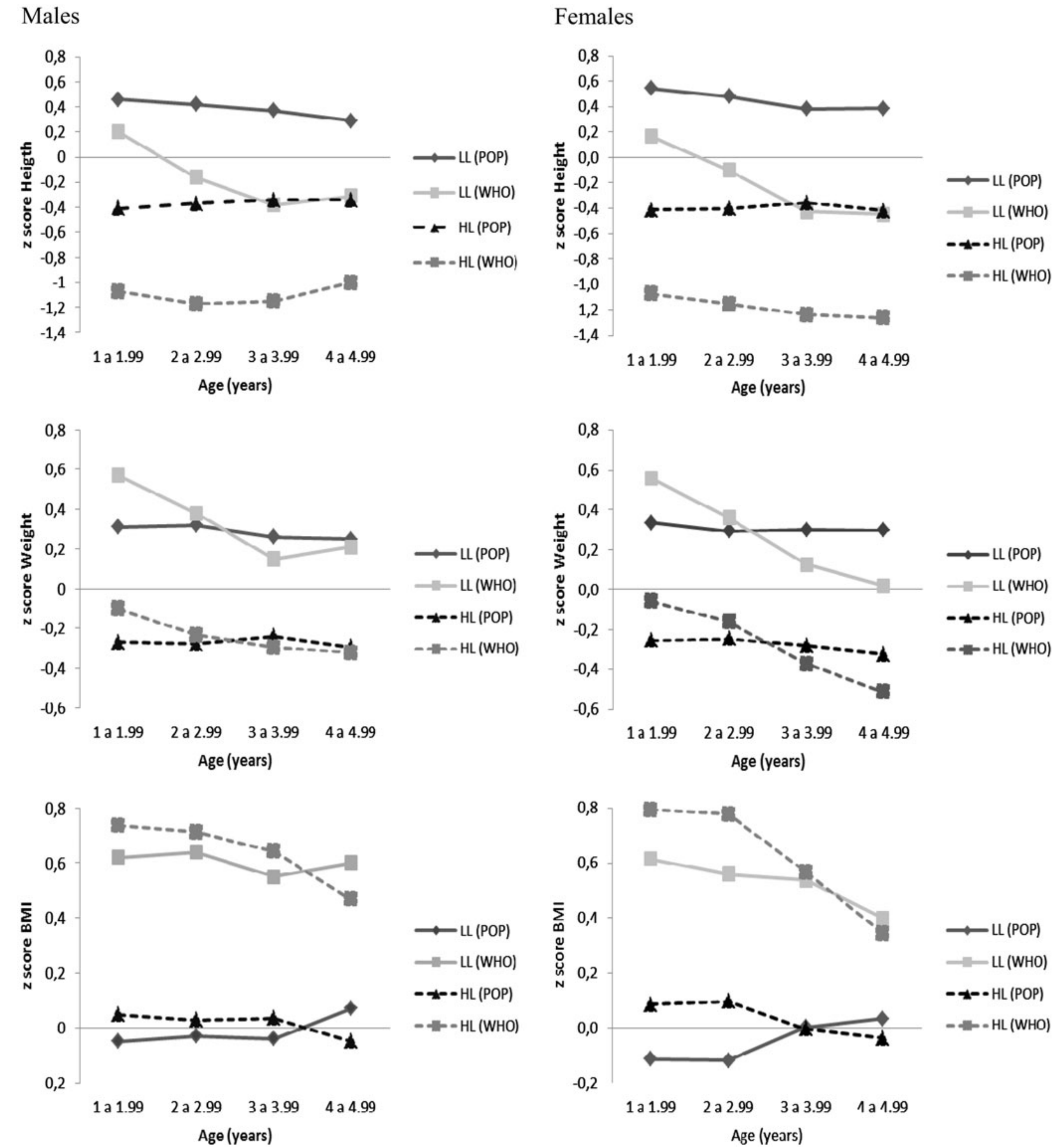

Figure 1. Average z-score for height, weight and BMI standardized with the average of the population of this work (POP) and WHO reference (WHO) by sex, age and geographical altitude.

range expected for normal distribution. The same may hold for emaciation. In contrast, differences in the linear growth of children of HL and LL are significantly different, although the prevalence of stunting in both populations is low according to OMS (1995) criteria (<20%), with HL children having higher growth detection, most probably related to altitude hypoxia and adverse factors associated to it.

What would also contribute to the differential growth pattern expression in relation to height observed in Jujuy children is the fact that previous research indicated that HL infants had delayed pre-natal growth evidenced by significantly lower weight at birth than the same Jujenean populations located closer to sea level (Álvarez et al., 2002; Grandi et al., 2013). Taking these records into account, the results achieved in this work would indicate that pre-natal growth retardation observed in children of Jujuy HL probably persists in early childhood, as height in all age ranges examined had persistently negative and similar z-scores, without oscillating with respect to the WHO reference and the population (Figure 1). The effects of geographical altitude and associated adverse

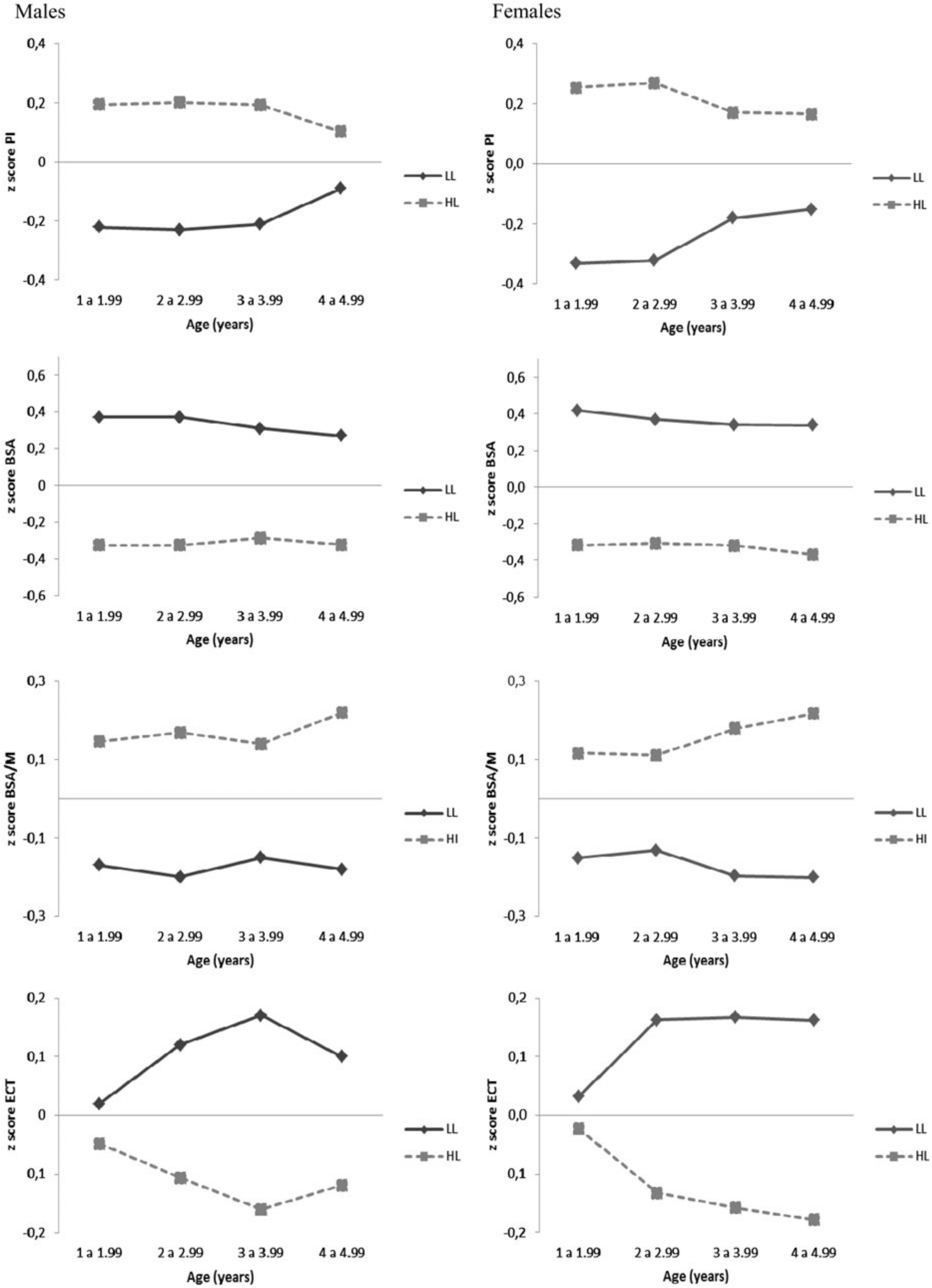

Figure 2. Average *z*-score of PI, BSA, BSA/M and ECT standardized with the average of the population of this work (POP) by sex, age and geographical altitude.

factors were also revealed in body mass, because, although it increased with age, HL *z*-score indicated that weight values moved progressively away from the reference in both sexes.

BMI and PI report on body proportionality based on allometric relationships. As a spherical body such as the human body increases in size or length (diameter), the BSA varies according to the square of the diameter and weight

Table 4. Pearson correlations between variables according to geographic altitude: LL in the upper half, HL in the lower half.

	LL						
HL	Height	Weight	BMI	PI	BSA	BSA/M	ECT
Height	–	0.924[b]	−0.312[b]	−0.863[b]	0.967[b]	−0.723[b]	0.734[b]
Weight	0.932[b]	–	0.074[b]	−0.605[b]	0.991[b]	−0.932[b]	0.515[b]
BMI	−0.443[b]	−0.087[b]	–	0.750[b]	−0.060[b]	−0.430[b]	−0.636[b]
PI	−0.897[b]	−0.674[b]	0.795[b]	–	−0.706[b]	0.275[b]	−0.849[b]
BSA	0.971[b]	0.991[b]	−0.218[b]	−0.766[b]	–	−0.875[b]	0.601[b]
BSA/M	−0.719[b]	−0.922[b]	−0.304[b]	0.337[b]	−0.863[b]	–	−0.235[b]
ECT	0.692[b]	0.524[b]	−0.605[b]	−0.768[b]	0.594[b]	−0.267[b]	–

References: LL, Lowlands; HL, Highlands; BMI, Body Mass Index; PI, Ponderal Index; BSA, Body Surface Area; M, Mass; ECT, Ectomorphy.
[b]$p < 0.01$.

(proportional to volume) to the cube of the diameter. Given the different body proportions between childhood and adulthood, the use of BMI is not recommended in children and, especially in infants, its replacement by the PI is suggested as, due to the dimensions of infants, it would provide a more appropriate adjustment for height (Doak et al., 2013). In Jujenean children of high altitude populations, both indicators were significantly higher and strongly influenced by significantly lower height variations in the HL. Moreover, BMI in particular, presented a negative, significant, but very low correlation to weight in the HL. Khosla & Lowe (1967) established that, for diagnosing obesity, indices based on weight/height relationships should have a high correlation with weight and a distribution independent of height, a situation that could not be verified in this analysis. Nevertheless, previous reports regarding the independence of BMI with respect to height in pre-school children have been contradictory, some in favour (Cole, 1986; Hattori & Hirohara, 2002; Rolland-Cachera et al., 1982) and others against it (Wang et al., 2006).

Additionally, and regardless of geographical altitude, Jujuy children populations with low prevalence of underweight and stunting showed higher BMI values than the WHO standard during most of the period under review. These considerations put forward the complexity of the evaluation of excess adiposity in high altitude populations based on WHO standards. The results obtained suggested that BMI should not be used in altitude populations in the process of growth as one of the variables that influence the BMI is precisely height.

While the concept of BSA has been questioned for its indefinability and the constraints imposed by its measurement (Heaf, 2012), it is a multi-interest anthropometric measure related to studies on body heat transfer, body aerodynamics, hydrodynamics, drug metabolism and chemotherapy and renal and cardiac function (Ahn & Garruto, 2008). In children, BSA is not only important as a measure of body size (Feber & Krásnicanová, 2012), but it is also critically important for drug metabolism, total body water composition, insensible transdermal water loss and thermoregulation (Ahn & Garruto, 2008). According to Feber & Krásnicanová (2012), when BSA is calculated with formulae including weight and height, as the Mosteller (1987) formula used in this analysis, BSA is a function of weight and height and not only allometrically estimated weight. Indeed, BSA has a significantly high correlation to weight and height in the HL and LL (Table 4) and it is significantly lower in infants of both sexes of HL (Table 3). As for many of the indices and ratios calculated and established in this work there are no comparable antecedents on children populations and even less in high altitude children; estimates and their interpretation are preliminary. Likewise, as in infants and children BSA variations cannot be related to the Basal Metabolic Rate (BMR), the observed differences between HL and LL could not be attributed to this linear physiological BSA/BMR relationship observed in adults (Heaf, 2012).

Neither is it clear nor is there sufficient background to understand the interaction between eco-geographical variations produced by high altitude or other climatic factors and allometric changes in body shape during growth in children and adolescents, especially those related to thermoregulatory capacity (Cowgill et al., 2012). HL infants paradoxically showed increased BSA/M compared with LL children, i.e. they would be more exposed to heat loss in cold environments typical of high altitude ecosystems. This condition would be enhanced by the negative effect of height on the BSA/M relationship for, regardless of geographical altitude, it appeared that, the lower the height, the greater the BSA relative to body mass. The prevalence of hypothermia in hospitalized children is not high in non-industrialized countries and even in tropical environments and, while rarely a direct cause of death, it mainly contributes as a comorbidity of other common causes of infant mortality (Cowgill et al., 2012; Khosla & Lowe, 1967; Leonard et al., 1995; Lunze et al., 2013). There is no available information regarding child deaths from hypothermia in the Province of Jujuy; however, the rate of Infant Mortality is higher in high altitude Jujenean ecosystems (Table 1).

A limitation of this study is that the sample consists of children beneficiaries of the Primary Health Care Programme and, therefore, belongs to a low economic status.

Conclusions

The results obtained in this study show variations in the size, body mass and surface of Jujenean children of 1–4.99 years depending on the geographical altitude and age. Without ruling out that this differential growth pattern might be due to the influence of adverse factors (poor nutritional intake, poor economic development, wide thermal amplitude, etc.) associated to geographical altitude, the effect of chronic hypoxia would have probably prevailed as the children examined came from socio-economically comparable settings and showed no increased prevalence of underweight and emaciation.

Acknowledgements

The authors thank authorities and responsible officers of the Primary Care Program of the Ministry of Health of the Province of Jujuy) who provided the data used in this work.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

References

Ahn Y, Garruto R. 2008. Estimations of body surface area in newborns. Acta Paediatr 97:366–3370.

Alfaro E, Grandi C, Dipierri J, Quero L. 2005. Birthweight and child mortality in highlands populations of Jujuy province (Argentina). Pediatr Res 57:923.

Alfaro E, Vázquez M, Bejarano I, Dipierri J. 2008. The LMS method and weight and height centiles in Jujuy (Argentina) children. HOMO 59: 223–234.

Álvarez P, Dipierri J, Bejarano I, Alfaro E. 2002. Variación altitudinal del peso al nacer en la provincia de Jujuy. Arch Arg Pediatr 100:440–447.

Bejarano I, Dipierri JE, Alfaro E, Fiorito A, García T, García N, Kinderman O. 1999. Estudio comparativo de talla en escolares primarios jujeños. Rev Arg Antropol Biol 2:79–90.

Bejarano I, Dipierri J, Andrade A, Alfaro E. 2009. Geographic altitude, surnames, and height variation of Jujuy (Argentina) conscripts. Am J Phys Anthropol 138:158–163.

Billewicz W, Kemsley W, Thomson A. 1962. Indices of adiposity. Br J Prev Soc Med 16:183–188.

Bogin B. 1988. Patterns of human growth. 1st ed. Cambridge: Cambridge University Press.

Cabañas M, Esparza F. 2009. Compendio de cineantropometría. 1st ed. Madrid: CTO.

Cole T. 1986. Weight/height p compared to weight/height^2 for assessing adiposity in childhood: influence of age and bone age on p during puberty. Ann Hum Biol 13:433–451.

Cowgill L, Eleazer CD, Auerbach BM, Temple DH, Okazaki K. 2012. Developmental variation in ecogeographic body proportions. Am J Phys Anthropol 148:557–570.

Dang S, Yan H, Yamamoto S. 2008. High altitude and early childhood growth retardation: new evidence from Tibet. Eur J Clin Nutr 62: 342–348.

De Onis M, Garza C, Victora CG, Bhan MK, Norum K, editors. 2004. The WHO Multicentre Growth Reference Study (MGRS). Edited by WHO. France. Available online at: www.who.int/childgrowth/mgrs (accessed July 25, 2013).

Dipierri J, Alfaro E, Dugoujon J, Constans J. 2000. GM, KM inmunoglobulin allotypes and other serum genetic markers (HP, GC, PI and TF) among South Americans living at different altitudes (Jujuy Province, Argentina): Admixtures estimates. Am J Hum Biol 72: 304–319.

Dipierri J, Bejarano I, Alfaro E, Spione C. 1998. Rural and urban child's height and its relation to geographic altitude in the province of Jujuy (Argentina). Act Med Auxol 30:11–17.

Dipierri J, Bejarano I, Spione C, Etchenique MC, Macias G, Alfaro E. 1996. Variación de la talla en escolares de 6 a 9 años en la provincia de Jujuy. Arch Argen Pediatr 94:369–375.

Dipierri J, Ocampo B, Olguín M, Suárez D. 1992. Peso al nacimiento y altura en la Provincia de Jujuy. In: Cuadernos FHyCS-UNJu. Comp. Ruiz M, Conti V. San Salvador de Jujuy: FHyCS-UNJu. p 156–166.

Doak C, Hoffman DJ, Norris SA, Campos Ponce M, Polman K, Griffiths PL. 2013. Is body mass index an appropriate proxy for body fat in children? Global Food Security 2:65–71.

Eichenberger J, Alfaro EL, Dipierri JE. 2009. Transición demográfica en la provincia de Jujuy: Variación regional. Rev Arg Antropol Biol 11: 15–23.

Eichenberger J, Dipierri JE, Alfaro EL. 2007. Evolución regional del balance migratorio en la provincia de Jujuy (1960–1999). In: Boleda M, Mercado Herrera MC, editors. SEPOSAL 2005 Seminario Internacional de Población y Sociedad en América Latina. Tomo I. Salta, Argentina: GREDES (Grupo de Estudios Socio-demográficos). p 359–370.

Eveleth P, Tanner J. 1990. Worldwide variation in human growth. Segunda ed. Cambridge: Cambridge University Press.

Feber J, Krásnicanová H. 2012. Measures of body surface area in children. In: Preddy VR, editor. Handbook of anthropometry physical measures of human form in health and disease. New York: Springer Science+Business Media. p 1249–1256.

Frisancho A. 2013. Developmental functional adaptation to high altitude: review. Am J Hum Biol 25:151–168.

Frisancho R, Baker P. 1970. Altitude and growth: a study of the patterns of physical growth of a high Peruvian Quechua population. Am J Phys Anthropol 32:279–292.

Gómez-Pérez L, Alfonso-Sánchez MA, Dipierri JE, Alfaro E, García-Obregón S, De Pancorbo MM, Bailliet G, Peña JA. 2011. Microevolutionary processes due to Landscape features in the province of Jujuy (Argentina). Am J Phys Anthropol 23:177–184.

Gómez-Pérez L, Alonso-Sánchez MA, Dipierri JE, Sánchez D, Espinosa I, De Poncorbo MM, Peña JA. 2013. Young Alu insertions within the MHC class I region in native American populations: insights into the origin of the MHC-Alu repeats. Am J Hum Biol 25:359–365.

Grandi C, Dipierri J, Luchtenberg G, Moresco A, Alfaro E. 2013. Efecto de la altitud sobre el peso al nacer y eventos perinatales adversos en dos poblaciones argentinas. Rev Fac Cien Méd 70:55–62.

Guimarey L, Carnese F, Puciarelli H. 1995. La influencia ambiental en el crecimiento humano. Ciencia Hoy 5:41–47.

Hass J, Frongillo EA, Stepick CD, Beard JL, Hurtado L. 1980. Altitude, ethnic and sex differences in birth-weight and length in Bolivia. Hum Biol 52:459–477.

Hass J, Moreno-Black G, Frongillo EA, Pabon AJ, Pareja G, Ybarnegaray J, Hurtado L. 1982. Altitude and infant growth in Bolivia: a longitudinal study. Am J Phys Anthropol 59:251–262.

Hattori J, Hirohara T. 2002. Age change of power in weight/height (p) indices used as indicators of adiposity in Japanese. Am J Hum Biol 14: 275–279.

Heaf J. 2012. The uses and misuses of body surface area in medicine. In: Preedy V, editor. Handbook of anthropometry physical measures of human form in health and disease. New York: Springer Science+Business Media. p 307–320.

Instituto Nacional de Estadísticas y Censos. 2001. Censo 2001. Available online at: http://www.indec.gov.ar/micro_sitios/webcenso/censo2001 s2_2/ampliada_index.asp?mode=38 (accessed September 30, 2013).

Keys A, Fidanza F, Karvonen MJ, Kimura N, Taylor HL. 1972. Indices of relative weight and obesity. J Chronic Dis 25:329–343.

Khosla T, Lowe C. 1967. Indices of obesity derived from body weight and height. Br J Prev Soc Med 21:122–128.

Leonard W, De Walt K, Stansbury J, McCaston M. 1995. Growth differences between children's of highland and coastal Ecuador. Am J Phys Anthropol 98:47–57.

Lunze K, Bloom D, Jamison D. 2013. The global burden of neonatal hypothermia; systematic review of a mayor challenge for newborn survival. BMC Medicine 11:24.

Malhotra R. 1986. Thoracic adaptation to high altitude. Anthrop Anz 44: 355–359.

Mascie-Taylor C, Bogin B. 1995. Human variability and plasticity. Reimpresa ed. Cambridge: Cambridge University Press.

Mosteller RD. 1987. Simplified calculation of body-surface area. N Engl J Med 317:1098.

Naumann S, Pinotti L. 2012. Lactancia materna y alimentación complementaria en la Quebrada de Humahuaca: una aproximación cualitativa. Rev Argent Salud Pública 3:6–14.

OMS, C. d. E. 1995. El estado físico: uso e interpretación de la Antropometría. España: OMS.

Rolland-Cachera M, Sempé M, Guilloud-Bataille M, Péquignot-Guggenbuhi F, Fautrad V. 1982. Adiposity indices in children. Am J Clin Nutr 36:178–184.

SAP. Sociedad Argentina de Pediatría. Comité Nacional de Crecimiento y Desarrollo. 2013. Guía para la Evaluación del Crecimiento Físico. 3rd ed. Buenos Aires, Argentina: SAP.

Tanner J. 1978. Fetus into man. 1st ed. Cambridge: Harvard University Press.

Ulijaszek S, Johnston F, Preece M. 2000. The Cambridge encyclopedia of human growth and development. Reprinted ed. Cambridge: Cambridge University Press.

Ulijaszek S, Mascie-Taylor C. 1994. Anthropometry: the individual and the population. illustrated, reprinted ed. Cambridge: Cambridge University Press.

Wang S, Ray N, Parra MV, Beboya G, Gallo C, Poletti G, Mazzotti G, et al. 2008. Geographic patterns of genome admixture in Latin American mestizos. Plos One 4:1–9.

Wang Y, Moreno L, Caballero B, Cole T. 2006. Limitations of the current World Health Organization growth references for children and adolescents. Food Nutr Bull 27:715–188.

WHO. 2006. Multicentre growth reference study group. Assessment of differences in linear growth among populations in the WHO Multicentre Growth Reference Study. Acta Paediatr Suppl 450:56–65.

Yip R, Binkin N, Trowbridge F. 1988. Altitude and childhood growth. J Pediatr 113:251–262.