Anthropometry and Lung Function of 10- to 12-Year-Old Bolivian Boys

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Abstract

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Anthropometric measurements of 23 HAHSES, 44 HALSES, 43 LAHSES, and 28 LALSES boys (see Introduction to this Supplement) are presented here. They include body height (H), body weight (BW), upper arm circumference (UAC), and skinfold thickness taken at four locations. From these measurements, body fat, lean body mass, and body mass index ($BMI = BW/H^2$) were calculated. The degree of maturation was assessed according to Tanner, orchidometry, and by quantification of testosterone in saliva.

Lung function data include: vital capacity (VC), forced expired volume per 1 s (FEV_1), functional residual capacity (FRC), residual volume (RV), and total lung capacity (TLC).

The results show enhanced lung volumes in both HA groups in comparison to LA groups, with HALSES boys having the greatest increase, even though the LSES boys were significantly smaller compared to the HSES boys at both altitudes and their growth was delayed by approximately 2 years. From the anthropometric data it appears that physical growth of prepubertal boys is dependent on SES but not on high-altitude exposure. We tentatively conclude that chronic hypoxia per se does not affect physical growth in prepubertal boys in an Andean environment and that development of lung function is accelerated in relation to linear growth as has been suggested by other authors (15).

Key words

Prepubertal boys, altitude, lung volumes, socioeconomic status, growth anthropometry

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Introduction

The effect of high-altitude hypoxia on human growth and development has been studied by many authors. Most of them have reported that physical growth of highland children is delayed in comparison to lowland norms (1,9,10,14, 30,34,37) and suggest that the smaller size of highland children could be due to a smaller size at birth, whereas other authors attribute it to a slower growth rate (9,10). Several studies conclude that growth retardation at high altitude is primarily the result of hypoxic stress (9,10,30,37). This conclusion, however, can only be made by comparison with a group of lowlanders of similar ethnic background and by taking into account other factors that might delay growth, such as nutrition, the consequence of low socioeconomic status. In fact, the physical growth pattern usually reported in Andean highland children is similar to that of undernourished lowland children (4,5,27,28, 36).

On the other hand, numerous authors have reported increased lung volumes in adult high-altitude natives as compared to sea-level residents (6,7,10,20,21,40,42). These findings have been attributed to structural changes occurring during developmental adaptation to life at high altitude such as increased chest diameters.

Studies of lung function in high-altitude children and adolescents are less frequent (2,3,13,29,41) and lack comparison with ethnically similar lowland groups.

The purpose of this study was to assess the effect of high-altitude hypoxia and nutritional status on the physical growth and lung function of 10- to 12-year-old boys in Bolivia.

Methods

The past and present nutritional status of 23 HAHSES, 44 HALSES, 43 LAHSES, and 28 LALSES boys was assessed by a series of anthropometric measurements.

They included body height (H), body weight (BW), and upper arm circumference (UAC). A Harpenden skinfold caliper was used to measure the thickness of biceps, triceps, subscapular, and suprailiac skinfolds. Body fat mass (BFM) was calculated by the equation of Durnin and Rahaman

Table 1 Anthropometric characteristics of HAHSES, HALSES, LAHSES, and LALSES boys.

Group n	HAHSES 23	HALSES 44	LAHSES 43	LALSES 28	ANOVA
Height (cm)	140 (7)	131 (5)	141 (5)	132 (6)	A: NS, SES < 0.001 A×SES: NS
Weight (kg)	37 (9)	30 (4)	36 (5)	31 (4)	A: NS, SES < 0.001 A×SES: NS
BFM (%)	21.3 (5.8)	16.5 (3.3)	21.3 (4.5)	17.8 (3.6)	A: NS, SES < 0.001 A×SES: NS
LBM (kg)	29 (5)	25 (2)	28 (3)	25 (3)	A: NS, SES < 0.001 A×SES: NS
UAC (cm)	19.5 (2.2)	17.4 (1.2)	18.7 (1.3)	17.8 (1.3)	A: NS, SES < 0.001 A × SES < 0.05
BMI (kg/cm^2)	18.6 (2.9)	17.2 (1.7)	17.9 (1.8)	17.6 (2.2)	A: NS, SES < 0.05 A × SES: NS

Values are means and standard deviations (SD); n = number of subjects.
BFM = body fat mass; LBM = lean body mass; UAC = upper arm circumference;
BMI = body mass index; ANOVA = analysis of variance; NS = not statistically significant.

(8), and from this variable and body weight we quantified lean body mass (LBM). The body mass index ($BMI = BW/H^2$) was calculated for each boy.

The sexual maturation of the subjects was assessed according to Tanner (38) and only prepubertal boys (Tanner stage I and orchidometry < 6 ml) were included. In addition, obese boys (11 LAHSES) were excluded from the study.

In all boys the following lung volumes were measured: vital capacity (VC), forced expiratory volume in 1 s (FEV_1), functional residual capacity (FRC), from which residual volume (RV) was obtained, and total lung capacity (TLC). Absolute values were corrected for body height and also expressed as percentages of the predicted values obtained from regression equations established by Geubelle for VC, TLC, RV, FRC, according to Thieman for FEV_1. The RV/TLC relationship was corrected after Strang and FEV_1/VC after Solymar (32). Comparisons between groups were made by an analysis of variance (ANOVA) on data expressed as percentages of the predicted values. The criterion for statistical significance was set at $p < 0.05$.

Previously the boys were familiarized with the proceedings and the equipment (9 liter Collins Spirometer, with an incorporated helium analyzer). The subjects were comfortably seated for the measurements. The best of three recordings of each volume was chosen for analysis. Ambient and spirometer temperatures as well as barometric pressure were recorded for calculating the BTPS correction factor.

Five boys from the LA groups were excluded from the statistical analysis of the pulmonary data because they were born at HA and had recently migrated to LA.

Results

The anthropometric characteristics of the four groups of boys are presented in Table 1. At both altitudes HSES boys had significantly more fat and more muscle mass than LSES boys. BFM in percent and LBM in kg were almost identical in children from HSES at both altitudes. These findings show that the effect of the socioeconomic status is highly significant ($p < 0.001$) but that high altitude has no effect on the overall body dimensions of prepubertal boys. Altitude and socioeconomic status have no significant interactions except on UAC.

Table 2 Absolute values of lung function. Data of the four groups corrected for BTPS conditions.

Group n	HAHSES 23	HALSES 44	LAHSES 43	LALSES 28
VC (ml)	2758 ± 450 (2319)	2634 ± 343 (1938)	2403 ± 308 (2319)	2140 ± 295 (1978)
RV (ml)	1103 ± 231 (636)	1160 ± 208 (526)	640 ± 120 (636)	739 ± 194 (573)
FRC (ml)	1920 ± 363 (1277)	2079 ± 383 (1048)	1462 ± 239 (1277)	1510 ± 257 (1072)
TLC (ml)	3861 ± 681 (3001)	3794 ± 551 (2497)	3043 ± 428 (3001)	2879 ± 489 (2550)
RV/TLC (%)	28.5 ± 3.9 (17.1)	30.5 ± 3.0 (17.1)	19 ± 4.5 (17.1)	25.2 ± 4.9 (17.1)
FEV_1 (ml)	2282 ± 371 (1831)	2253 ± 332 (1536)	2072 ± 237 (1831)	1792 ± 279 (1567)
FEV_1/VC (%)	84.5 ± 4.2 (84.6)	85.9 ± 4.2 (84.6)	86.3 ± 4.4 (84.6)	84.7 ± 4.5 (84.6)

Values are means ± SD; n = number of subjects
VC = vital capacity; RV = residual volume; FRC = functional residual capacity; TLC = total lung capacity; FEV_1 = force expiratory volume per 1 s. In parentheses sea-level standards.

Comparison of the results of the spirometry test (Tables 2 and 3) shows the following: Pulmonary function measurements differed significantly between HA and LA groups in absolute values as well as when compared to sea-level standards (Table 2), both HA groups having higher lung volumes and capacities.

Table 3 compares the four groups. The values are corrected for body height and expressed in percentage of sea-level standards.

Table 3 Pulmonary volumes of the four groups.

Group n	HAHSES 23	HALSES 44	LAHSES 43	LALSES 28
VC (ml)	118 ± 10 < 0.001	135 ± 13	103 ± 11 NS	107 ± 10
RV (ml)	175 ± 37 < 0.001	220 ± 37	100 ± 19 < 0.001	138 ± 34
FRC (ml)	151 ± 28 < 0.001	198 ± 37	113 ± 15 < 0.001	140 ± 19
TLC (ml)	129 ± 13 < 0.001	151 ± 15	101 ± 10 < 0.001	113 ± 12
RV/TLC (%)	134 ± 22 NS	145 ± 18	89 ± 26 < 0.01	119 ± 29
FEV_1 (ml)	124 ± 12 < 0.001	146 ± 18	112 ± 9 NS	111 ± 8
FEV_1/VC	104 ± 5 NS	108 ± 5	107 ± 5 NS	107 ± 5

Values are expressed as percentage of sea-level standards
Values are means ± SD, n = number of subjects
VC = vital capacity; RV = residual volume; FRC = functional residual capacity; TLC = total lung capacity; FEV_1 = forced expiratory volume per one second.

When comparing the HA groups, it becomes clear that all lung volumes and capacities are above sea-level standards and that the increase is greater in the LSES group than in the HSES boys.

LAHSES boys are within sea-level standards, as expected. LALSES boys, however, show a significant increase of RV and FRC when compared to LAHSES boys.

Discussion

The statistical analysis of weight and height in this study show that at both altitudes boys with HSES were significantly ($p < 0.001$) taller and heavier and had a greater ($p < 0.05$) body mass index (BMI = weight/height^2) than children with LSES. Comparison of weight and height of HAHSES, HALSES, LAHSES, and LALSES with NHCs standards (18) and Latin American norms (24) shows that HAHSES and LAHSES boys are within the normal range for well-nourished boys of the same age. However, HALSES and LALSES boys were much smaller and lighter than standards. In fact, their physical growth was delayed by approximately 2 years. In spite of the socioeconomic status effect ($p < 0.05$), the BMI of all boys in our study was in the normal range for well-to-do children (33,35). Authors who have found children with low weight and height for age but normal weight for height have concluded that the growth delay was the result of past malnutrition which had occurred during early childhood (4,28,36,39). This could be the case for the HALSES and LALSES boys in our study. Upper arm circumference and skinfold thickness at selected sites (biceps, triceps, subscapular, and suprailiac) reflect protein and energy reserves (12,22,23) and are therefore widely used in nutritional anthropometry. Several studies in children have shown that these reserves are depressed in protein energy restriction (12,16,23). In our study, at both altitudes HSES boys had a significantly ($p < 0.001$) higher upper arm circumference and body fat mass (calculated from four skinfolds) than LSES boys. However, in spite of these differences, both variables were found to be within the normal range for well-nourished boys of the same age in all four groups (11,35). The results, nevertheless, indicate that the diet of HSES and LSES groups differs. In fact, the dietary information obtained by Post et al. (31) in the present study indicates that mean energy and nutrient (protein, fat) intake is marginal in the LSES groups. So it seems that HALSES and LALSES boys can be classified as chronically marginally nourished.

Increased lung volumes in high-altitude natives of Aymara as well as European ancestry have been reported previously (15,17). Our results are in accordance with the observations made by Greksa et al. who described significantly smaller forced vital capacities (FVC) and FEV_1 in HA children of European ancestry and high SES as compared to HA Aymara children of lower SES. Both groups described by Greksa et al. had FVC and FEV_1 well above European standards (13).

The authors attribute the increase of FVC and FEV in the Aymara children to an acceleration in the development of lung function relative to stature (15). This acceleration of lung function was not observed in the European HA children (13). Our results show a significant difference between the lung volumes especially CRF and RV of HA boys compared to both LA groups.

Comparison between the two HA groups shows a significant ($p < 0.001$) increase of CRF and RV related to body height in the HALSES boys.

A surprising finding, however, was that the same difference existed between the two LA groups. This difference could be attributed partly to the greater Aymara or Quechua admixture in the LALSES group. On the other hand, nutritional factors cannot be completely excluded, since numerous studies have reported effects of malnutrition on lung structure and function in animals (19,25,26).

The anthropometric data analysis, however, shows that the LSES children at both altitudes were at the most marginally nourished but clearly not malnourished. It will therefore be necessary to carry out lung function studies and genetic tests in malnourished children at both altitudes in order to clarify the effects of genetic background and nutrition on the lung function in children.

References

1 Beall C. M., Baker P. T., Baker T. S., Haas J. D.: The effects of high altitude on adolescent growth in southern Peruvian Amerindians. *Hum Biol* 49: 109–124, 1977.
2 Beall C. M., Strohl K. P., Gothe B., Brittenham G. M., Barragan M., Vargas E.: Respiratory and hematological adaptation of young and older Aymara men native to 3.600 m. *Am J Hum Biol USA* 1990.
3 Beard J., Hurtado L., Villena M., Vargas E.: Transporte de oxígeno y hematología en niños de altura. *Anuario del IBBA,* La Paz, 1979.

4 Behar M.: What is marginal malnutrition? In: Nutrition in Health and Disease International Development: Symposia from the XII International Congress of Nutrition; A. R. Liss, Inc. 150 Fifth Avenue, New York, NY 10011, 1981, pp 237–246.

5 Buschang P. H., Malina R. M.: Growth in height of mild-to-moderately undernourished Zapotec school children. *Hum Biol* 55: 587–597, 1983.

6 Coudert J., Paz Zamora M., Vargas E.: Volumes pulmonaires, ventilation et pression des gaz du sang chez les résidents de haute altitude transferés a basse altitude. *J Physiol Paris* 67 (3): 336A, 1973.

7 Chiodi H.: Respiratory adaptation to chronic high altitude hypoxia. *J Appl Physiol* 10: 81–87, 1957.

8 Durnin J. V. G. A., Rahaman M. M.: The assessment of the amount of fat in the human body from measurements of skinfold thickness. *Br J Nutr* 21: 681–689, 1969.

9 Frisancho A. R., Baker P. T.: Altitude and growth: a study of the patterns of physical growth of a high-altitude Peruvian Quechua population. *Am J Phys Anthrop* 32: 179–292, 1970.

10 Frisancho A. R.: Human growth and development among high-altitude populations. In: Baker P. T., Little M. A. (eds): The Biology of High Altitude Peoples. International Biological Programme 14, Cambridge University Press, 1978, pp 117–171.

11 Frisancho A. R.: New norms of upper limb fat and muscle areas for assessment of nutritional status. *Am J Clin Nutr* 34: 2540–2545, 1981.

12 Frisancho A. R., Garn S. M.: Skinfold thickness and muscle size. Implications for developmental status and nutritional evaluation of children from Honduras. *Am J Clin Nutr* 24: 541–546, 1971.

13 Greksa L. P., Spielvogel H., Caceres E.: Effect of altitude on the physical growth of upper class children of European ancestry. *Ann Hum Biol* 12: 225–232, 1985.

14 Greksa L. P., Spielvogel H., Paredes-Fernandez I., Paz Zamora M., Caceres E.: The physical growth of urban children at high altitude. *Am J Phys Anthropol* 65: 315–322, 1984.

15 Greksa L. P., Spielvogel H., Caceres E., Paredes-Fernandez I.: Lung function of young Aymara highlanders. *Ann Hum Biol* 14 (6): 533–542, 1987.

16 Gurney J. M., Jelliffe D. B., Neill J.: Anthropometry in the differential diagnosis of protein-calorie malnutrition. *J Trop Pediat Env Child Health* 18: 1–2, 1972.

17 Haas J. D., Moreno-Black G., Frongillo E. A., Pabon J., Pajera G., Ibarnegaray J., Hurtado L.: Altitude and infant growth in Bolivia: a longitudinal study. *Am J Phys Anthropol* 59: 251–262, 1982.

18 Hamill P. V. V., Drizz T. H., Johnson C. L., Reed R. B., Roche A. F., Moore W. M.: Physical growth: National Center for Health Statistics percentiles. *Am J Clin Nutr* 32: 607–629, 1979.

19 Harkema J. R., Mauderly J. L., Gregory R. E., Pickrell, J. A.: A comparison of starvation and elastase models of emphysema in the rat. *Am Rev Respir Dis* 129: 584–589, 1984.

20 Hurtado A., Velasquez G., Reynafarge C., Lozano R., Chavez Aste Salazar: Mechanism of natural acclimatization. Air University School Prepor. 56, 1., U.S.A., 1958.

21 Instituto Boliviano de Biologia de Altura: Parámetros Biológicos del Habitante de la ciudad de La Paz y otras poblaciones del Altiplano Boliviano (Capítulo respiratorio). Publicaciones del IBBA. Edit. Casa Municipal de la Cultura, Biblioteca Paceña, La Paz-Bolivia, 1980.

22 Jellife D. B.: The assessment of the nutritional status of the community. Geneva: World Health Organization, Monograph No. 53, 1966, p 245.

23 Jellife E. F. P., Jellife D. B.: The circumference as a public health index of protein-calorie malnutrition of early childhood. *J Trop Pediat,* Monograph No. 8, vol. 15, 1969.

24 Johnston F. E., Borden M., McVean R. B.: Height, weight and their velocities in Guatemalan private school children of high socioeconomic class. *Hum Biol* 45: 627–641, 1973.

25 Kalenga M., Henquin J. C.: Protein deprivation from the neonatal period impairs – calorie malnutrition in weaned rats. *Respir Physiol* 68: 29–39, 1987.

26 Kerr J. S., Riley D. J., Lanza-Jakoby S., Berg R. A., Spilker Y. U. S. Y., Edelmann N. H.: Nutritional emphysema in the rat. Influence of protein depletion and impaired lung growth. *Am Rev Respir Dis* 131: 644–650, 1985.

27 Manocha S. L.: Malnutrition and retarded human development. C. C. Springfield, Illinois, Thomas, 1972.

28 Martorell R.: Child growth retardation: a discussion of its causes and its relationship to health. In: Blaxter K., Waterlow J. C. (eds): Nutritional Adaptation in Man. London, Libbey, 1985, pp 13–20.

29 Mortola J., Rezzonico R., Fisher J., Villena M., Vargas E., Gonzales R., Peña F.: Compliance of the respiratory system in infants born at high altitude. *Am Rev Respir Dis* 142: 43–48, 1990.

30 Mueller W. H., Schull V. N., Soto P., Rothhammer F. A.: Multinational Andean genetic and health program: growth and development in a hypoxic environment. *Ann Hum Biol* 5: 329–352, 1978.

31 Post G. B., Kemper H. C. G., Lujan C., Parent G., Coudert J.: Comparison of 10–12 years old schoolboys living at high (4100 m) and low (450 m) altitude in Bolivia. *Int J Sports Med* (abstr) 13: 88, 1992.

32 Quanjer P. H., Stocks J., Polgar G., Wise M., Karlberg G. B., Borsboom G.: Compilation of reference values for lung function measurements in children. *Eur Respir J* 2 (suppl 4): 184S–261S, 1989.

33 Rolando-Cachera M. F., Cole T. J., Sempe M., Tichet J., Rossignol C., Charraud A.: Body mass index variations: centiles from birth to 87 year. *Eur J Clin Nutr* 45: 13–21, 1991.

34 Schutte J. E., Lilljeqvist R. E., Johnson: Growth of lowland native children of European ancestry during sojourn at high altitude. *Am J Phys Anthropol* 61: 221–226, 1983.

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