Altitude and Growth: A Study of the Patterns of Physical Growth of a High Altitude Peruvian Quechua Population

A. ROBERTO FRISANCHO AND PAUL T. BAKER
Center for Human Growth and Development and Department of Anthropology, University of Michigan, Ann Arbor, Michigan; Department of Anthropology, Pennsylvania State Uinversity, University Park, Pennsylvania

ABSTRACT Data on physical growth were obtained for a sample of 1202 Quechua subjects, aged 2 to 35 years from the district of Nuñoa, Puno, located in the southern highlands (altitude 4000–5500m) of Peru. These data were supplemented by a three-year longitudinal study of 300 subjects, aged 1 to 22 years.

The patterns of physical growth of members of the indigenous population of Nuñoa are characterized by (1) late sexual dimorphism, (2) slow and prolonged growth in body size, (3) late and poorly defined adolescent stature spurt in both males and females, and (4) accelerated development in chest size. The socio-economic factors associated with urban-rural and altitude differences appear to be reflected in greater deposition of subcutaneous fat and increased weight but do not seem to influence the development of stature. We suggest the pattern of growth of this population is related to the hypoxic effects of high altitude, and/or reflects a genetic adaptation to such stress. The anthropometric and physiological studies conducted during this and previous studies and the comparative data from Peruvian populations situated at lower altitudes document the specific adaptive response of the chest wall to the hypoxic effects of high altitude.

Experimental studies on animals have demonstrated that high altitude hypoxia slows growth. The earlier investigations of Gordon and associates (Gordon, Zornetta, D'Angelo and Charipper '43) and Moore and Price ('48) indicate that rats raised under hypoxic conditions on adequate diets show marked retardation in normal body growth. Recent studies by Timeras and co-workers (Timeras, Krum and Pace, '57; Krum, '57) point out that the inhibition in body growth becomes progressively more accentuated in successive generations. Further, the subnormal rate of growth in size in the animals born at high altitude appears to be irreversible even after prolonged soujourn at sea level (Timeras, '64). Despite these indications, there is insufficient information on the effects of high altitude on human growth to reach any definite conclusions. This fact led the authors to conduct an intensive cross-sectional and semi-longitudinal investigation of human growth of a high altitude native Peruvian Quechua population.

The present article is a detailed follow-up of previous preliminary reports (Frisancho, Thomas and Baker, '65; Frisancho, '66; Baker, Frisancho and Thomas, '66). This study presents the completed analysis on the development of body size of the population of Nuñoa, Puno, Peru.

METHODS AND MATERIALS

Subject population

The subject population was drawn from an ecologically stable area located in the district of Nuñoa, one of the nine political districts comprising the province of Melgar in the department of Puno, Peru. The overall ecology of Nuñoa was given in a recent report (Baker, '69), therefore, only a short description will be given here.

The population of the district as indicated by the 1961 Peruvian Census was 7750, of which 2137 live in the central town of Nuñoa and 5613 are distributed on the aggregated native-owned settlements (*ayllus*) and privately-owned farms (*haciendas*). About 95% of the total population is composed of Quechua *indigenes* and the remaining 5% make up the *mestizo* group. The population lives on the plains of the broad, shallow valleys of the area. The basal altitude of the plains is about 4000 m (13,000 feet) and the settlements extend up the slopes about 5500 m (17,500 feet). The economic focus of the region is herding, with sheep, llamas, and alpacas the major animals. However, the subsistence pattern of much of the indigenous population at around 4000 m is based on a mixed economy of herding of sheep and llamas and cultivation of potatoes and varieties of native chenopodium (*quinua* and *canihua*). On the other hand, at elevations above 4500 m, due to severe cold and frost, agriculture is not practiced, and the subsistence pattern is based on a purely pastoral economy.

Sample

The data to be presented here were collected from June, 1964, to August, 1966. The method of data collection included both cross-sectional and semi-longitudinal samplings.

The cross-sectional sample consisted of 1202 subjects, of which 702 were males and 400 females, between the ages of 2 and 22 years. They represented 30% of the total population under 25 years of age. The adult control sample was comprised of 52 males and 50 females between the ages of 25 and 35 years.

The semi-longitudinal sample consisted of 300 subjects, aged 2 to 22 years, 140 of which were remeasured after one year, and 160 remeasured after two years and three months. Table 1 gives the distribution of these samples by age and sex.

The ages of both samples were verified by official birth records provided by the municipal council of Nuñoa district and the town school officials. These records covered 98% of those between 2 and 22 years of age. The ages of the samples were calculated from their birth-days to the examination dates and then classified into age groups.

Measurements

Standard anthropometric measurements included weight, height, sitting height, biacromial diameter, chest width, chest breadth, chest circumference, arm circumference, upper arm, scapula, and waist skinfold thickness according to the "Recommendations concerning body measurements for the characterization of the nutritional status," ('56). Weight was recorded to the nearest quarter-pound and converted into kilograms. Height was recorded to the nearest millimeter. Sitting height was taken with the subject seated on a firm, flat stool with the knees flexed and trunk in contact with the anthropometer at both scapular and sacral regions. Chest circumference at the xyphoid level was measured at maximum inspiration and expiration, from which the mid-chest circumference was calculated. Biacromial diameter, chest width, and chest depth were measured with the anthropometer's sliding calipers. Utilizing a flexible steel tape, upper arm circumference was measured midway between the acromion and olecranon with the arm hanging freely. All measurements were taken in centimeters.

Skinfold thickness measurements were made with a Lange caliper having a pressure of 10 gm per square millimeter of contact surface area. All measurements were taken on the right side: at the upper arm on the same site as that of the circumference; and also at the lower end of the scapula, waist, and calf. All measurements totaled to give the sum of skin-folds. Three readings were taken at each site and the average was used to represent the subcutaneous fat (plus skin) at that site. The units of measurement are millimeters. The corrected upper arm diameter in millimeters was derived from the upper arm circumference and triceps skinfolds by computation (Brozek, '61).

RESULTS

Patterns of growth

As noted in figure 1 and tables 2 and 3, growth in stature, weight, sitting height, chest width, and chest depth appears to continue until the twentieth and twenty-second years in females and males, respectively. Sexual dimorphism in stature is not well defined until about the age of 16 years. Sex differences in chest size appear to occur even later.

The growth rates of stature derived from the semi-longitudinal data are presented in

TABLE 1

Distribution of cross-sectional sample and semi-longitudinal sample of Nuñoa district by age and sex

Cross-sectional sample				Semi-longitudinal sample					
Males		Females		Males			Females		
Age	N	Age	N	N	Age at first measurement	Age at second measurement	N	Age at first measurement	Age at second measurement
2	8	2	7	8	2	4	4	3	5
3	7	3	7	8	3	5	4	4	6
4	13	4	12	4	4	6	5	6	8
5	11	5	13	4	5	7	4	7	8
6	23	6	26	4	6	8	4	7	9
7	36	7	17	15	7	9	4	8	9
8	40	8	41	7	8	10	6	8	10
9	45	9	30	4	9	10	4	9	10
10	49	10	35	6	9	11	6	9	11
11	51	11	33	11	10	12	4	10	11
12	68	12	34	8	11	12	6	11	12
13	59	13	30	8	11	13	6	11	12
14	43	14	25	12	12	13	5	11	13
15	46	15	20	5	12	14	4	12	13
16	46	16	15	6	13	14	4	12	13
17	40	17	10	6	13	15	4	12	15
18	29	18	10	8	14	15	4	13	14
19	21	19	12	4	14	16	4	14	15
20	17	20	12	8	15	17	5	17	19
21	20	21	27	8	16	17			
22	30	22	36	8	16	18			
Adult	50	Adult	50	8	17	18	5	20	22
				8	17	19			
				9	18	19			
				6	18	20			
				6	19	20			
				6	19	21			
				6	20	21			
				4	20	22			
Totals	752		450	210			90		

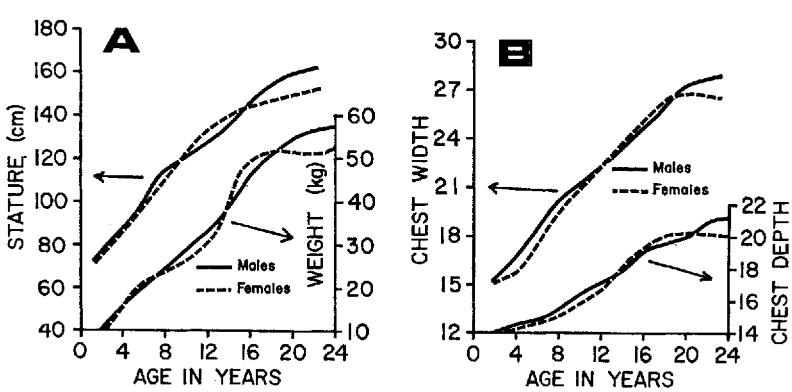

Fig. 1 Development of stature, weight, chest width and chest depth of Nuñoa Indigenes. The pattern of growth in body size is characterized by a late sexual dimorphism.

TABLE 2

Anthropometric measurements of cross sectional sample of Nuñoa district

Age	N	Stature		Weight		Sitting height	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
			Males				
2.11	8	80.4	5.2	10.0	1.9	48.5	3.4
3.37	7	86.3	5.4	11.6	1.6	51.7	3.2
4.19	13	91.4	5.8	13.6	1.5	54.2	2.8
5.27	11	95.6	4.7	14.1	2.0	56.2	3.5
6.19	23	106.2	4.7	20.0	3.8	59.1	8.7
7.11	36	115.6	4.9	21.7	3.1	64.3	4.3
8.30	40	116.4	5.7	22.7	3.4	65.2	3.3
9.25	48	119.6	6.0	24.4	3.6	66.7	3.8
10.27	49	122.7	5.2	26.3	3.5	67.8	4.0
11.29	51	127.7	7.2	28.5	4.6	68.9	3.8
12.23	68	130.3	6.2	30.1	4.1	70.3	3.4
13.28	59	134.8	6.4	32.7	4.0	72.3	3.8
14.22	43	139.5	7.4	35.3	4.7	74.4	3.7
15.31	46	145.6	7.2	39.8	3.5	77.5	5.3
16.30	46	148.2	7.9	42.5	4.0	79.3	4.4
17.24	40	150.3	7.0	45.9	4.5	80.5	5.0
18.24	29	155.3	7.5	49.0	4.9	82.7	5.3
19.35	21	156.7	4.7	50.0	4.8	84.2	2.6
20.15	17	157.1	4.9	50.0	4.9	84.7	2.9
21.31	20	159.9	4.7	52.8	5.6	84.2	4.0
22.35	30	160.3	4.8	53.8	5.9	84.8	4.0
35.00	50	160.0	4.9	55.9	6.5	84.5	6.0
			Females				
2.13	7	79.3	5.8	9.7	2.0	47.8	3.2
3.00	7	85.5	5.5	11.3	2.3	52.2	2.9
4.15	12	90.7	5.2	12.8	1.6	54.2	2.5
5.07	13	96.3	8.2	13.8	1.7	55.3	3.4
6.19	26	105.1	5.4	17.5	1.8	60.4	2.7
7.02	29	110.9	8.5	20.9	6.2	62.7	4.4
8.14	41	114.9	6.3	22.1	4.1	65.0	3.5
9.07	30	119.8	5.1	22.4	2.7	67.2	7.2
10.22	35	124.6	6.8	25.8	3.7	69.9	5.4
11.33	33	129.4	6.4	28.1	5.1	71.5	3.9
12.23	34	132.0	6.1	30.8	5.5	72.7	3.2
13.19	30	136.9	6.0	34.4	5.5	74.3	3.5
14.24	25	140.4	5.3	39.5	6.7	76.4	4.7
15.00	20	141.6	5.1	42.9	5.6	77.8	2.8
16.19	15	143.6	6.0	43.9	7.3	79.0	3.6
17.04	10	148.4	4.3	50.9	8.0	81.9	2.2
18.16	10	147.7	6.5	48.2	5.9	80.6	3.3
19.06	12	149.6	3.7	53.6	3.5	82.6	2.9
20.58	12	148.6	6.7	50.2	7.3	80.2	3.4
21.50	27	148.2	5.2	50.0	1.4	81.0	3.1
22.30	36	148.2	4.8	50.2	6.2	80.0	9.7
35.00	50	148.0	5.2	54.0	6.5	80.0	6.3

table 4. As shown in figure 2, compared to the U. S. Fels standards, it is evident that the Nuñoa males and females have (1) a late and poorly defined adolescent growth spurt, and (2) a very prolonged general body growth period.

Figure 3 and table 5 show that the development of muscle size at the upper arm follows the same pattern in both males and females up to the age of 16 years. In contrast, fat deposition from eight years on is markedly greater in females than males.

Intra-population differences

Rural-urban. For analytic purposes a sample of 388 boys, aged 7 to 22 years, and 216 girls, aged 7 to 16 years, has been divided according to residence into (a) ur-

TABLE 3

Development of chest size in Nuñoa children

Age	N	Chest width Mean	Chest width S.D.	Chest depth Mean	Chest depth S.D.	Mid-chest circumference
			Males			
2.11	8	15.3	1.5	13.7	1.5	51.1
3.38	7	15.8	1.4	13.9	1.8	51.5
4.19	13	16.9	1.1	14.9	2.0	54.2
5.27	11	17.5	3.2	14.9	0.5	55.8
6.19	23	18.2	3.2	15.1	1.3	62.5
7.11	36	20.0	1.7	15.5	1.0	63.7
8.30	40	20.4	1.3	15.8	1.1	64.5
9.25	48	20.9	1.8	15.9	1.0	66.6
10.27	49	21.2	3.1	16.8	1.5	68.9
11.29	51	22.2	1.5	16.8	1.4	70.0
12.23	68	22.6	1.4	16.8	1.0	72.1
13.28	59	22.9	1.2	17.5	1.2	74.2
14.23	43	23.8	1.4	17.8	1.2	77.4
15.31	46	24.4	1.6	18.3	1.5	79.9
16.30	46	24.9	1.7	19.1	1.3	81.5
17.24	40	26.0	2.7	19.3	1.3	85.0
18.24	29	26.8	2.6	19.7	1.0	85.0
19.35	21	27.1	1.3	19.8	1.0	85.9
20.15	17	27.4	1.6	20.5	1.3	86.6
21.31	20	27.4	2.0	20.8	2.3	87.3
22.35	20	28.2	2.0	20.9	1.7	88.5
35.00	52	28.2	4.0	20.5	3.5	90.5
			Females			
2.13	7	15.3	0.7	13.5	0.9	49.6
3.00	7	15.4	1.2	13.7	0.9	52.2
4.15	12	16.1	0.9	14.0	1.1	53.1
5.10	13	16.5	1.5	14.5	2.2	54.4
6.32	24	17.8	2.4	14.9	0.9	58.3
7.18	29	19.4	2.2	14.8	0.9	62.3
8.19	41	19.8	1.4	15.3	1.1	63.0
9.09	30	20.1	1.4	15.4	1.0	64.9
10.27	35	21.4	1.4	15.9	1.4	67.6
11.24	33	21.7	1.5	16.3	1.1	69.2
12.23	34	22.1	1.3	16.5	1.4	72.4
13.19	30	23.2	1.2	17.2	1.1	75.8
14.24	25	23.3	1.7	18.2	1.3	79.1
15.00	20	23.7	1.5	18.3	1.3	79.1
16.19	15	25.3	1.7	19.0	0.9	82.3
17.04	10	26.3	1.9	20.0	1.5	86.9
18.16	10	26.6	1.9	20.0	2.8	86.5
19.06	12	26.7	0.8	20.2	2.1	86.5
20.58	12	26.8	1.9	20.5	2.9	86.1
21.50	27	26.2	2.2	19.7	2.3	84.6
22.30	36	26.4	4.3	19.9	3.3	86.0
35.00	50	26.5	4.3	20.0	3.9	86.0

ban comprising those who reside in the central town and attend the school, and (b) rural, comprising those who live in the aggregate settlements (*ayllus*) and privately owned ranches (*haciendas*) and who do not attend the central school in the central town of Nuñoa.

Table 6 compares the development of sum of skinfolds, and corrected upper arm diameter of the rural and urban samples. Figures 4 and 5 illustrate the data on males. From this information it is clear the urban groups are heavier than the rural samples, but age for age, both groups attain nearly the same stature. The urban groups are also considerably fatter (about 20% more) than the rural samples, while they appear to have nearly the same upper arm diameter.

Altitude. Since the population of Nuñoa lives at altitudes which range from

4000 m to 5500 m, the sample was divided according to the altitude of residence into (a) lower altitude group, comprising those children who reside at around 4000 m (13,000 feet) and (b) higher altitude groups, comprising those who live at altitudes above 4500 m (16,000 feet).

Comparing these two groups on a cross-sectional basis, it was found that those who live above 4500 m were slightly, but not significantly smaller in stature and weight than their counterparts who live at around 4000 m. In contrast, the higher altitude residents had significantly ($p < .05$) greater chest circumference at maximum inspiration than the compared group. These findings were tested using the matched-pair technique whereby 182 male subjects, aged 1 to 35 years, were divided into two altitude groups. These two groups were matched for age to the nearest 0.5 years and then subdivided into three age groups: 1 to 12.9, 13 to 18.9, and 22 to 35.9 years. The comparisons were based upon "t" scores for matched pairs $\left(\frac{t = \text{mean "d"}}{S_e \text{ "d"}} \right)$.

Table 7 presents the selected body measurements of the non-adult Nuñoa sample residing at around 4000 m compared to those who live above 4500 m. From these data it is evident that both lower altitude and higher altitude groups attain nearly the same values of body size and body com-

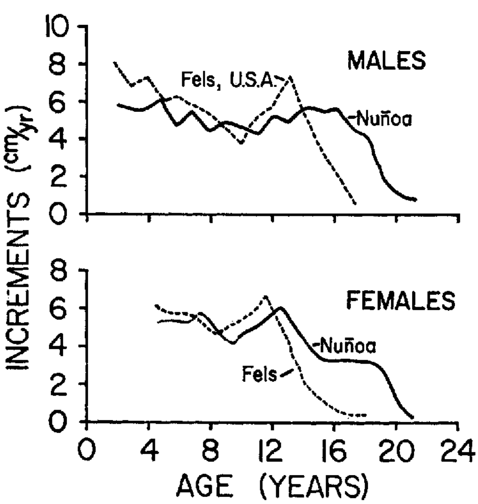

Fig. 2 Stature growth rate of Nuñoa Indigines. Compared to the U.S.A. Fels Standards, the Nuñoa males and females have a late and poorly defined spurt.

TABLE 4

Growth rate of stature, semi-longitudinal Nuñoa sample

Males		Females	
Age span	stature	Age span	stature
	cm		*cm*
2– 4	5.9	3– 5	4.3
4– 5	5.6	5– 6	4.9
5– 6	6.2	6– 8	6.0
6– 7	4.8	8– 9	4.9
7– 8	5.6	9–10	4.3
8– 9	4.4	10–11	5.3
9–10	5.0	11–12	5.6
10–11	4.5	12–13	6.4
11–12	4.1	12–14	4.5
12–13	5.4	14–15	3.9
13–14	4.9	15–16	3.8
14–15	6.0	16–17	3.7
15–16	5.8	17–18	3.6
16–17	5.8	19–20	1.6
17–18	4.5	20–21	0.8
18–19	3.9	21–22	0.0
19–20	1.4		
20–21	0.7		
21–22	0.5		

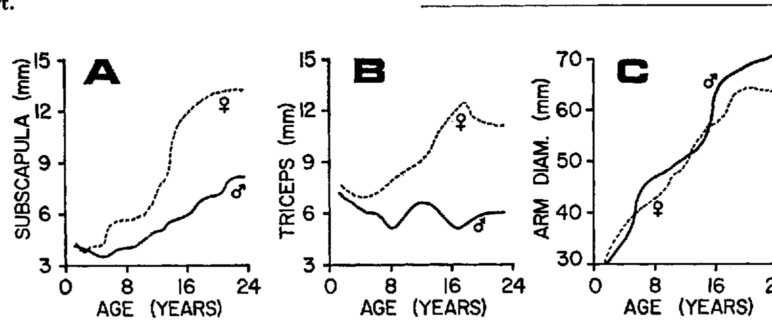

Fig. 3 Skinfold thickness (A and B) and upper arm muscle diameter (C) of Nuñoa Indigenes. Subcutaneous fat deposition from eight years on shows a well defined sex difference, while the development of muscle size follows a similar pattern as that of body size.

TABLE 5

Skinfold thickness and corrected upper arm diameter of Nuñoa cross-sectional sample

Age	N	Triceps md	Scapula md	Waist md	Sum of skin folds md	Upper arm diameter	
						Mean	S.D.
yrs.		*mm*	*mm*	*mm*	*mm*	*mm*	
				Males			
2.11	8	7.2	4.2	4.0	15.4	34.0	3.5
3.37	7	6.9	4.0	4.0	15.0	36.0	3.2
4.19	13	6.7	3.9	3.9	14.5	37.0	5.2
5.27	11	6.0	3.7	3.8	13.5	38.3	5.8
6.19	23	6.0	3.7	3.4	12.9	43.0	4.5
7.11	36	6.0	4.0	3.5	13.5	43.8	5.6
8.30	40	5.0	4.0	3.0	12.0	44.5	7.0
9.25	48	5.0	4.1	3.5	12.6	46.0	2.3
10.27	49	6.0	4.3	4.0	14.3	49.2	9.7
11.29	51	6.0	4.8	4.0	14.8	49.6	5.1
12.23	68	6.0	4.9	4.9	15.8	50.0	8.6
13.38	59	6.1	5.0	5.0	16.1	51.0	3.9
14.92	43	6.5	5.7	5.7	17.4	53.0	3.2
15.30	46	5.4	5.9	6.0	17.3	58.2	4.5
16.29	46	5.0	5.9	6.0	16.9	60.2	6.8
17.23	40	5.0	6.6	6.5	18.1	64.4	7.5
18.22	29	5.7	7.0	6.8	19.5	66.0	6.9
19.35	21	5.8	7.0	7.5	20.5	67.5	4.5
20.15	17	5.9	7.0	7.5	20.5	69.5	4.5
21.31	20	6.0	7.9	7.6	20.1	72.0	3.5
22.35	20	6.3	8.3	7.9	20.8	74.0	3.9
35.00	52	4.0	8.5	8.0	20.5	75.0	4.5
				Females			
2.13	7	7.7	4.3	5.6	17.6	35.0	3.2
3.00	7	7.4	3.8	3.2	14.4	36.5	2.3
4.15	12	7.0	4.2	3.4	14.6	38.0	3.4
5.07	13	7.8	4.2	3.8	15.8	38.8	3.4
6.19	24	7.8	5.0	3.8	16.6	41.2	3.6
7.02	29	8.0	5.5	4.2	17.7	41.9	4.7
8.14	41	8.0	5.5	5.3	18.8	43.8	3.3
9.07	30	8.5	5.5	5.9	19.9	47.4	3.5
10.22	35	8.6	6.0	6.0	20.6	47.3	4.3
11.33	33	9.0	6.4	6.5	21.9	48.3	4.7
12.23	34	9.5	7.5	6.7	23.7	51.7	3.8
13.19	30	9.7	7.9	6.8	24.4	55.3	6.5
14.24	25	11.0	10.9	9.1	31.0	57.1	5.6
15.00	20	11.5	11.5	10.0	33.3	57.5	7.0
16.19	15	12.3	11.8	11.3	35.4	59.4	4.9
17.04	16	12.9	12.5	13.0	38.4	63.2	4.2
18.16	10	12.0	12.9	13.5	38.4	63.5	4.3
19.06	12	12.0	13.7	13.5	39.2	63.5	4.9
20.58	12	10.0	13.5	13.5	37.0	64.0	4.0
21.50	27	10.0	13.8	10.6	34.4	64.0	4.0
22.30	36	10.0	13.8	10.4	33.3	64.0	0.0
35.00	50	9.5	10.7	9.5	29.7	64.0	0.0

position such as stature, weight, sitting height, biacromial diameter, sum of skinfolds, and upper arm diameter. The exception to this pattern appears to be chest circumference at maximum inspiration, which is significantly greater among the samples who live above 4500 m ($p < .05$ for boys 1–12.9 years) and ($p < .01$ for boys 13–18.9 years). As shown in table 8, the adult samples at higher altitudes are slightly heavier and fatter, but are not taller than their counterparts who live at around 4000 m. They also have a significantly greater chest circumference at both maximum inspiration and maximum expiration. The pattern of differences in chest size is illustrated in figure 6 using a cross-sectional sample of 400 subjects, aged 2

TABLE 6

Means and standard deviations of sum of skinfolds (triceps, subscapula, waist) and corrected upper arm diameter (mm) of rural and urban groups of Nuñoa males and females

Age group	Sum of skinfolds (mm)						Level of significance	Corrected upper arm diameter (mm)						Level of significance
	Rural			Urban				Rural			Urban			
	N	Mean	S.D.	N	Mean	S.D.		N	Mean	S.D.	N	Mean	S.D.	
							Males							
7– 8.9	25	11.9	2.3	29	14.4	3.2	$P < 0.05$	25	45.1	3.3	29	42.3	3.7	NS
9–10.9	26	13.0	2.4	21	16.0	3.7	$P < 0.05$	26	49.1	7.5	21	48.3	7.5	NS
11–12.9	28	13.8	3.5	26	16.8	3.9	$P < 0.05$	28	49.4	11.0	26	49.9	5.6	NS
13–14.9	20	14.0	3.9	26	18.4	4.5	$P < 0.05$	20	52.4	4.8	26	53.6	4.4	NS
15–16.9	22	13.8	3.5	29	18.6	5.0	$P < 0.01$	22	58.4	6.5	29	60.7	8.5	NS
17–18.9	25	18.0	4.6	22	20.0	5.0	$P < 0.05$	25	66.7	4.9	22	65.0	4.5	NS
19–20.9	21	19.0	3.8	24	22.9	5.6	$P < 0.05$	21	70.5	4.9	24	67.0	3.5	NS
22–24.9	20	19.0	3.5	24	23.5	5.0	$P < 0.05$	20	75.6	9.2	24	69.8	3.9	NS
							Females							
7– 8.9	21	13.4	3.4	18	21.7	5.2	$P < 0.01$	21	42.1	2.7	18	42.1	3.1	NS
9–10.9	16	14.8	3.8	26	22.0	5.6	$P < 0.01$	16	46.9	2.3	26	43.9	3.7	NS
11–12.9	17	19.3	4.7	22	23.7	6.6	$P < 0.01$	17	48.4	4.7	22	47.6	5.1	NS
13–14.9	23	23.4	5.3	29	31.5	8.5	$P < 0.01$	23	54.9	5.9	29	50.9	3.8	NS
15–16.9	24	27.4	7.8	20	38.4	12.0	$P < 0.01$	24	57.1	5.6	20	57.6	6.0	NS

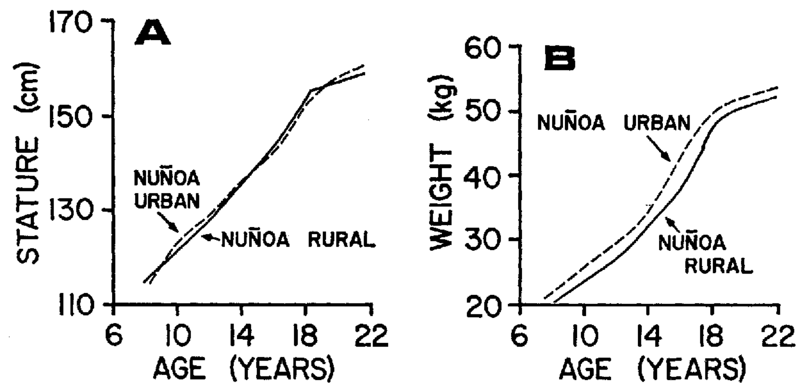

Fig. 4 Comparison of stature (A) and weight (B) of Nuñoa males residing in the urban and rural areas of the district. Age for age, both rural and urban groups attain nearly the same stature, while the urban are slightly heavier than their rural counterparts.

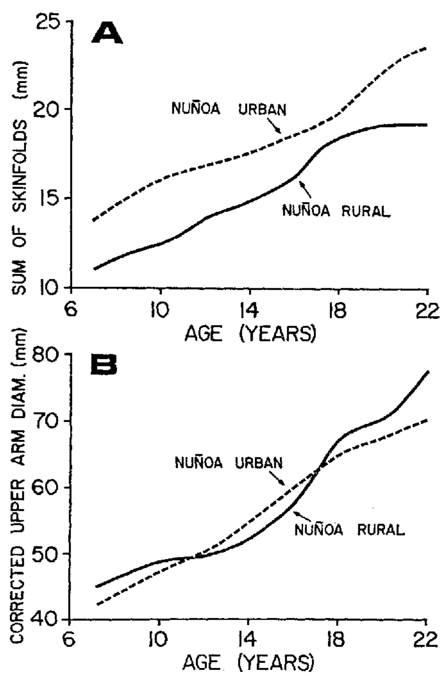

Fig. 5 Comparison of sum of skinfolds (A) and corrected upper arm diameter (B) of Nuñoa males residing in the urban and rural areas of the district. The urban group significantly exceed the rural one, while both groups attain nearly equal values of muscle development.

to 35 years. It is evident that the chest circumference at maximum inspiration relative to the stature is considerably greater among those residing above 4500 m. This difference appears to be more marked between the fourteenth and eighteenth years of age.

Comparison with other studies

The development of stature and chest circumference of the Nuñoa cross-sectional sample is plotted in figure 7, in comparision with data from the United States (Stoudt, Damon and McFarland, '60) and with data on Peruvian samples from sea level and moderate altitudes, respectively (Pretto and Gomez, '47). As shown, the Nuñoa boys are absolutely and relatively smaller than the sea level American boys and Peruvian boys from Ica as well as those from Huanuco, situated at a mean altitude of 2300 m (7,500 feet) (Baker, Frisancho and Thomas, '66). Figure 8 also shows that, despite their smaller statures, the high altitude Nuñoa boys exhibit systematically greater chest circumference averaging about 12 and 15% above the American and other Peruvian samples, respectively. In other words, the chest size of Nuñoa boys shows an accelerated rather than retarded growth.

DISCUSSION

The physical growth of the high altitude Nuñoa Quechua Indian is unquestionably slow. The sexual dimorphism in the development of body size appears to occur after age 16. The growth rates show a late and poorly defined spurt for both males and females. The distance curves, along with the growth rates, indicate a very prolonged

TABLE 7

Comparison of selected body measurements of Nuñoa Quechua boys residing at 4000 m (13,000 feet) and above 4500 m (16,000 feet) matched for age

	Age group: 1 to 12.9 years					
	4000 m N = 45		> 4500 m N = 45		Mean "d"	Level of significance
	Mean	S.D.	Mean	S.D.		
Chronological age	7.38	3.30	7.57	3.21	+0.19	NS
Stature (cm)	109.39	17.26	108.05	18.89	−1.34	NS
Weight (kg)	19.40	6.59	19.20	6.84	−0.20	NS
Sitting height (cm)	60.90	7.60	61.40	8.15	+0.50	NS
Biacromial diameter (cm)	24.24	6.03	24.00	7.15	−0.24	NS
Chest width (cm)	19.39	2.37	19.11	3.02	−0.28	NS
Chest depth (cm)	15.20	1.49	15.45	1.76	+0.25	NS
Chest circumference						
Maximum inspiration	62.98	8.95	65.45	9.24	+2.47 [1]	$p < 0.05$
Maximum expiration	59.15	6.56	58.78	7.61	−0.37	NS
Corrected upper arm diameter (mm)	43.94	9.21	44.12	6.83	+0.18	NS
Sum of pour skinfold sites (mm)	18.65	8.49	19.66	7.12	+1.01	NS

	Age group: 13 to 18.9 years					
	4000 m N = 24		> 4500 m N = 45		Mean "d"	Level of significance
	Mean	S.D.	Mean	S.D.		
Chronological age	15.64	1.65	15.29	2.07	0.15	NS
Stature (cm)	143.31	9.58	141.63	9.05	−1.68	NS
Weight (kg)	39.64	10.82	37.50	8.77	−2.14	NS
Sitting height (cm)	76.19	4.91	76.15	5.57	−0.04	NS
Biacromial diameter (cm)	30.16	2.13	28.58	4.70	−1.58	NS
Chest width (cm)	23.89	1.73	24.11	2.38	+0.22	NS
Chest circumference						
Maximum inspiration	80.09	6.36	84.40	6.61	+4.31 [1]	$p < 0.01$
Maximum expiration	76.24	8.97	74.60	6.49	−0.64	NS
Corrected upper arm diameter (mm)	58.17	8.91	57.44	7.00	−0.73	NS
Sum of four skinfold sites (mm)	23.44	9.51	22.12	8.08	−1.32	NS

[1] $P < 0.05$.

TABLE 8

Comparison of selected body measurements of Nuñoa adult males living at 4000 m (13,000 feet) and above 4500 m (16,000 feet), matched for age

	Age group: 22 to 35.9 years					
	4000 m N = 22		> 4500 m N = 22		Mean "d"	Level of significance
	Mean	S.D.	Mean	S.D.		
Chronological Age	29.73	6.53	30.00	5.86	+0.27	NS
Stature (cm)	158.80	5.90	159.00	4.46	+0.02	NS
Weight (kg)	53.74	3.60	57.51	5.32	+3.77	$p < 0.05$
Sitting height (cm)	84.83	5.92	86.45	2.78	+2.62	NS
Biacromial diameter (cm)	35.20	2.03	35.01	2.88	−0.19	NS
Chest width (cm)	27.46	1.18	28.04	1.61	+0.58	NS
Chest depth (cm)	21.18	2.05	20.94	1.14	−0.24	NS
Chest circumference						
Maximum inspiration (cm)	92.46	2.58	96.42	3.42	+3.96	$p < 0.01$
Maximum expiration (cm)	86.13	2.66	89.03	4.09	+2.90	$p < 0.05$
Corrected upper arm diameter (mm)	72.42	4.91	72.69	5.00	+0.27	NS
Sum of four skinfold sites (mm) [1]	20.72	6.32	25.59	10.43	+4.87	$p < 0.01$

[1] Sum of four skinfold sites: triceps, mid-axillary, subscapular, and waist.

body growth period; termination of growth in stature appears to occur by age 20 in females and 22 in males.

The dietary survey of the rural population of Nuñoa (Mazess and Baker, '64) demonstrated a relatively higher caloric, protein, and iron intake than the recommended daily allowances for Peruvian Andean communities (Collazos Moscoso, Bravo, Castellanos, Caceres, Rosa and Bradfield, '59). This finding has recently been confirmed by Gursky's ('69) dietary survey of individual intakes by age and sex.

The intra-population comparisons indicate that the urbanized groups are slightly heavier and considerably fatter than their rural counterparts. These differences are probably related to differences in activity and dietary intake. In any event, whatever the factors responsible for the greater fat deposition of the urbanized groups, these did not appear to be reflected in taller statures. These findings differ from those reported on American populations. Garn and Haskell ('60) demonstrated that among Ohio White children, increased fatness during childhood and adolescence is positively and systematically associated with taller

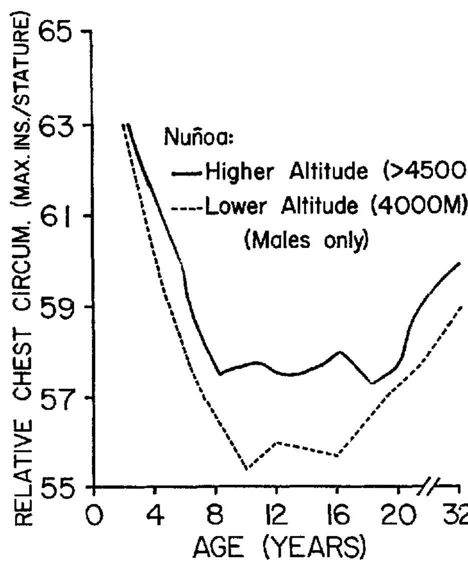

Fig. 6 Comparison of relative chest circumference at maximum inspiration of Nuñoa males residing at around 4000 m and above 4500 m. The higher altitude group attains a significantly greater chest circumference than the group which lives at around 4000 m.

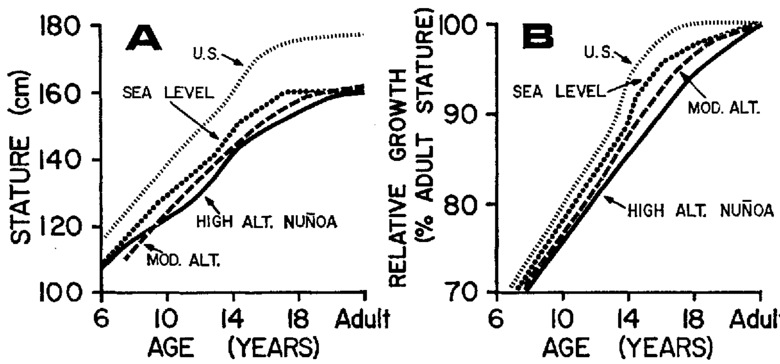

Fig. 7 Comparison of (A) absolute and (B) relative development in stature of Nuñoa males and Peruvian samples from sea level and a modern altitude of 2300 m. The Nuñoa high altitude boys show a slow development in absolute stature, and they also attain a lower percentage of the adulthood values.

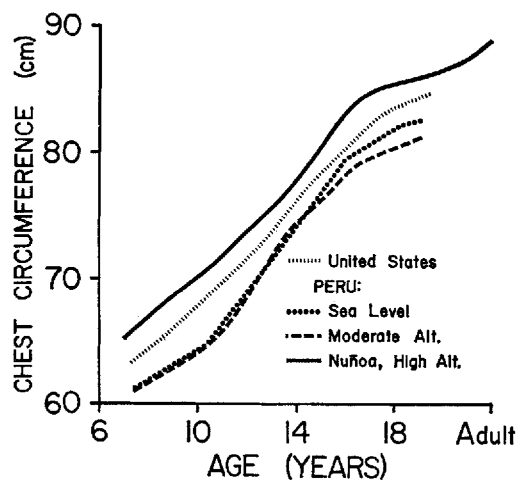

Fig. 8 Comparison of chest circumference of Nuñoa males and Peruvian samples from sea level and moderate altitude of 2300 m. The Nuñoa high altitude boys, despite their slow development in stature, exhibit a rapid growth in chest size.

statures and advanced somatic and sexual development. Nutritional studies on animals also indicate that increased fat deposition speeds maturation and dimensional growth (Hammond, '54). These findings suggest that factors other than malnutrition or caloric deficiency, such as high altitude hypoxia and/or genetics are influential in the slow and prolonged growth of Nuñoa Quechua population. This conclusion by no means implies that all growth variation reflected in slow and prolonged development of high altitude populations is solely related to the effects of hypoxia. Any generalization about growth at high altitude must be done with great caution, and until intensive field studies are done, the role of nutrition cannot be disregarded.

On both a cross-sectional and a matched-pair basis the chest circumference was found to be significantly greater at altitudes above 4500 m than at around 4000 m, while other measurements of body size and composition remain unchanged. This finding suggests that the chest wall is one of the most sensitive morphological characteristics that responds to the stress of high altitude hypoxia. This feature is interpreted as an adaptive response. This conclusion is supported by the following findings. First, as indicated by previous investigations (Hurtado, '32; Monge, '54), the large chest size and lowered diaphragm of the high altitude native is associated with the development of a larger heart, and greater blood and lung volumes. Second, a recent investigation by one of us (Frisancho, '69a) demonstrated that, among a sample of 150 high altitude Quechua boys living above 4200 m (aged 10 to 20 years), chest circumference at maximum inspiration is a better predictor of forced expiratory lung volumes than stature, weight or surface area, contrary to what occurs in sea level populations. Third, comparison of the morphological characteristics of Nuñoa children to those of Peruvian samples at lower altitudes indicates that despite their smaller statures, the high altitude Nuñoa boys exhibit systematically greater chest circumferences.

The implication of the present study is that it attempts to delineate the developmental mechanism whereby the adult characteristics of high altitude populations are attained. Thus, the small stature of Andean man is the result of a slow and prolonged period of growth, while his increased lung volumes and chest size are due to an accelerated development.

ACKNOWLEDGMENTS

This research was part of the investigation of the biological adaptation of man to high altitude hypoxia, a program of the Department of Anthropology of the Pennsylvania State University, supported by the Surgeon General of the U.S. Army (contract DA-49-193-MD-2260). Computer time for analysis of these data was provided by the computer centers of the Pennsylvania State University. The political and educational authorities and citizens of the district of Nuñoa provided substantial aid and facilities. Particular thanks are due to Doctors Michael J. Hanna, Michael A. Little, and R. Brooke Thomas, Mrs. Julio Sotomayor, and Victor Bareda who aided substantially in data collection. Acknowledgment is also given to Shaw Whitney for his assistance in preparing the line drawings.

LITERATURE CITED

Baker, P. T. 1969 Human adaptation to high altitude. Science, *163:* 1149–1156.

Baker, P. T., R. Frisancho and R. B. Thomas 1966 A preliminary analysis of the growth patterns of a high altitude Peruvian Quechua population. New Delhi Defense Department, India.

Brozek, J. 1961 Body measurements including skinfold thickness, as indicator of body composition. In: Techniques for Measuring Body Composition. J. Brozek and A. Henschel, eds. National Academy of Sciences, National Research Council, Washington, D. C.

Collazos, C., I. Moscoso, Y. Bravo, A. Castellanos, C. Caceres, A. Rosa and R. B. Bradfield 1959 La alimentacion y el estado de nutrition en el Peru. Ann. Fac. Med., *1:* 1959.

Frishancho, A. R. 1966 Human Growth in a High Altitude Population. M.A. Thesis, Pennsylvania State University, University Park, Pennsylvania.

——— 1969 Human Growth, Physique, and Pulmonary Function at High Altitude. A Field Study of a Peruvian Quechua Population. Ph.D. Thesis, Pennsylvania State University, University Park, Pennsylvania.

——— 1969a Human growth and pulmonary function of a high altitude Peruvian Quechua population. Human Biol., *41:* 365–379.

Frisancho, A. R., R. B. Thomas and P. T. Baker 1965 Growth patterns of a highland Peruvian population. Proceedings of 34th Annual Meeting of American Association of Physical Anthropologists. Am. J. Phys. Anthrop., *23:* 331.

Garn, S. M., and C. G. Rohmann 1966 Interaction of nutrition and genetics in the timing of growth and development. Pediat. Clin. N. Amer., *13:* 353–379.

Gordon, A. S., F. J. Zornetta, D'Angelo and H. A. Charipper 1943 Effects of low atmospheric pressure on the activity of the thyroid, reproductive system and anterior lobe of the pituitary in the rat. Endocrinology, *33:* 366–383.

Gursky, M. 1969 A Dietary Survey Among Three Highland Communities. M. A. Thesis, Pennsylvania State University, University Park, Pennsylvania.

Hammond, J. 1954 Progress in the physiology of farm animals. Butterworth Scientific Publications, Butterworth and Co.

Hurtado, A. 1932 Respiratory adaptation in the Indian natives of the Peruvian Andes. Studies at high altitude. Am. J. Phys. Anthrop., *17:* 137–165.

Krum, A. A. 1957 Reproduction and Growth of Laboratory Rats and Mice at Altitude. Ph.D. Thesis. University of California, Berkeley.

Mazess, R. B., and P. T. Baker 1964 Diet of Quechua Indians living at high altitude. Am. J. Clin. Nutrit., *15:* 431.

Monge, M. C. 1954 Man, climate and changes of altitude. Meteor. Monog., *2:* 50–60.

Moore, C., and D. Price 1948 A study at high altitude of reproduction, growth, sexual maturity and organ weights. J. Exp. Zool., *108:* 171–216.

Pretto, J. C., and C. M. Gomez 1947 Estudio Bioantropometrics en los escolares peruanos. Boletin de Instituto Psicopedagogico Nacional, *2:* 131, Lima.

Recommendations concerning body measurements for the characterization of nutritional status. 1956 Human Biol., 28: 11–123.

Stoudt, H. W., A. Damon and R. A. McFarland 1960 Heights and weights of White Americans. Human Biol., *32:* 331.

Timeras, P. S., A. A. Krum and N. Pace 1957 Body and organ weights of rats during acclimatization to an altitude of 12,470 feet. Am. J. Physiol., *191:* 598–604.

Timeras, P. S. 1962 Comparison of growth and development of the rat at high altitudes and at sea level. In: The Physiological Effects of High Altitudes. W. Weihe, ed. Pergamon Press, New York.

DISCUSSION

DR. STINI: From your longitudinal data it appeared as if there were little or no growth spurt in males, and in females there was a small one.

DR. FRISANCHO: Yes.

DR. STINI: How much variability did you find in this?

DR. FRISANCHO: Although we were tempted to say there was a lack of stature spurt in males, I do not want to overemphasize it because at that age, the sample size was too reduced for good statistical analysis. Therefore, any definitive conclusion about this point must await further studies.

DR. STINI: Have you analyzed skeletal maturation data?

DR. FRISANCHO: Yes. I had the opportunity to compare the skeletal development of Nuñoa children to those from the village of Vicos (situated at lower altitude than Nuñoa) collected by Dr. Marshall T. Newman. Using the Greulich-Pyle and Tanner-Whitehouse methods of skeletal aging, we found that the skeletal maturation of the Nuñoa children was somewhat more ahead than those of Vicos, who had been nutritionally supplemented for four years. The causes of their differences at present are not clear.