

*Original Research Article***Growth Among Tibetans at High and Low Altitudes in India**

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ABSTRACT In India, Tibetans have been living at different altitudes for more than 40 years. This study describes physical growth in terms of height, weight, sitting height, skinfold thickness at triceps and upper arm circumference of Tibetans born and raised at three Tibetan refugee settlements (3,521; 970; and 800 m) from the view point of the hypothesis that growth is retarded at high altitude. Samples consist of individuals between the ages of 2 and 40 years. Tibetans at high altitude in India show a growth pattern similar to that previously observed among Tibetans in Tibet. Tibetans at high altitude are taller and heavier compared to Andean highlanders. The general trends show that Tibetan children and adults of both sexes at low altitude in India are advanced in terms of height, weight, skinfold thickness at triceps and upper arm circumference compared to Tibetans at high altitude. Trunk length (sitting height) is similar at the two altitudes but relative sitting height is greater at high altitude. Greater relative sitting height and lesser leg length at high altitude than at low altitudes is discussed in terms of effect of altitude, temperature, and nutritional status. *Am. J. Hum. Biol.* 19:789–800, 2007.

Growth at high altitude is generally characterized by smaller body size than at low altitude. (Beall et al., 1977; Greksa et al., 1984, 1985; Hoff, 1974; Mueller et al., 1978; Stinson, 1980; Weitz and Garruto, 2004). Growth and development of populations of low altitude ancestry, like the Europeans at high altitude, show retarded growth in size compared to Europeans at low altitude. (Frisancho, 1970; Frisancho and Baker, 1970; Hoff, 1974; Mueller et al., 1978; Stinson, 1982). Andean high altitude populations like Aymara and Quechua clearly exhibit smaller body size at high altitude compared to low altitude populations measured at low altitude (Baker, 1969; Beall et al., 1977; Frisancho, 1969, 1976; Frisancho and Baker, 1970; Greksa et al., 1985; Haas, 1976).

Migration of Han, an Asian low altitude population to high altitude resulted in slower growth at high altitude among children and adolescents (Weitz and Garruto, 2004). Comparison of Han migrants at high altitude in Qinghai with the native Tibetans at high altitude showed no difference in body size for any measurement for any age group or for either gender. Both the groups at high altitude were retarded compared to Han urban children at low altitude (Weitz et al., 2004).

A few exceptions, such as greater size at high altitude for the Andean population as reported by Frisancho et al. (1975) are attrib-

uted to lower socio-economic and nutritional status of the low altitude sample. Migration of Ethiopian highlanders to low altitude resulted in smaller size compared to high altitude (Clegg et al., 1972). A high prevalence of malaria reported at low altitude was postulated as a likely reason for the smaller size at low altitude. Malik and Singh (1978) also found that high altitude Bods, a population of Tibetan ancestry (Kaul and Kaul, 1992; Smriti, 1998) were taller and showed faster growth than low altitude Indians. Not much can be inferred from this study as the two populations compared were of distinctly different genetic background.

There are not many studies reported in literature comparing Tibetans, a high altitude native Asian population believed to be the best adapted at high altitude (Aldenderfer, 2003; Beall, 2000a,b, 2001; Moore, 2001; Moore et al., 2000), to people of similar ethnic-

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ity at lower altitudes. In one study, Pawson (1976) compared Sherpas at high altitude (3,475–4,050 m) with Tibetans at medium altitude (1,000 m) in Nepal. Since Sherpa ancestry is traced from Tibetans (Furer-Haimendorf, 1975), the two populations were considered to share similar genetic backgrounds. Even though Tibetans were slightly advanced in most growth indicators than the Sherpas, the difference was probably not as great as that existing between high and low altitude populations in Peru. Since Sherpa's ancestry is traced from Tibetans, the two samples were considered as belonging to similar genetic background.

Gupta and Basu (1981) compared Sherpa adults at two altitudes (3,500–4,500 m and 1,000–1,500 m) and showed that the high altitude Sherpas exhibited higher values than low altitude Sherpas for most of the length, breadth, girth, and weight measurements. Comparison of Sherpa children and adolescents at two altitudes for stature and weight (Gupta and Basu, 1991) showed that high altitude Sherpas grew slower and longer than the low altitude Sherpas. Weitz et al. (2000) have compared the Tibetan populations at three different altitudes, where all the three were above 3,000 m, none being at low altitude. They reported no differences in morphological measurements between Tibetans born and raised at 3,200 and 3,800 m.

Comparing similar populations under different stresses is an acknowledged method of identifying adaptation (Harrison, 1966). But this has been difficult insofar as Tibetans are concerned, because studies conducted hitherto have not included Tibetans living near sea level. Tibetans born and raised at low altitude do not experience the multitude of stresses that exist at high altitude, hypoxia being the most important. Thus, the study of growth and development of Tibetans in the absence of hypoxia at low altitudes will provide an insight into the unique and possibly adaptive pattern of growth and development of Tibetans at high altitude. This research is possible because Tibetan populations have been living in India since the Dalai Lama was given asylum in 1959. At that time, some 80,000 Tibetans fled Tibet. Those refugees and their descendants have been living in different parts of India at different altitudes for more than four decades. In view of the above, this article reports and compares for the first time the variation in growth in terms of height, weight, sitting height, skinfold thickness at triceps,

and upper arm circumference among Tibetans born and raised at high and low altitudes in India.

MATERIALS AND METHODS

Three Tibetan settlements in India with different ecological settings have been selected for this study. Settlements at Bylakuppe (District: Mysore; State: Karnataka and Chandragiri (District: Gajapati; State: Orissa) have been selected at low altitude. These two locations differ in their ecological and cultural settings. Chandragiri (970 m) is on the Eastern Ghats, nearer to the coast, and away from urban centers. It is also infested with malaria. In contrast, Bylakuppe (800 m) is on the Indian peninsular plateau, away from the sea-coast and nearer to urban centers. The settlement at Choglamsar (District: Leh; State: Jammu and Kashmir) is at a high altitude (3,521 m). Details about the physical features of the three settlements have been described elsewhere (Tripathy and Gupta, 2005). The settlements are divided into smaller camps (villages). The economy of most of the households in the three settlements is based on agriculture. One crop per year is cultivated generally, except at Bylakuppe where some households cultivate two crops per year. Apart from farming, most households are engaged in retail activities involving consumer and traditional products like winter wear, shoes, carpets, etc. The income generated from informal business is generally much higher than farming. A few are engaged in small scale industry like carpet weaving, handicraft etc and few others are in service sector. The flourishing and emergent tourism industry at Ladakh and to some extent at Bylakuppe provides occupational opportunities for many.

This study is based on cross sectional data collected between February 2003 and September 2004. Anthropometric data on children and adolescents were collected from Central schools for Tibetans at Bylakuppe and Chandragiri and SOS-Kinderdorf International Tibetan Children's Village (SOS-TCV) at Choglamsar. Anthropometric data on adults and preschool children were collected at the individual's home or at community centers. Only those children, adolescents, and young adults who were born and raised at the altitude studied have been included in this study. At low altitudes, individuals born at the settlements or in the nearby town or city at similar altitude have been included in the present study.

At high altitude, most of the individuals included in the present study were born in the towns of Choglamsar or Leh in the Leh District. Rest few were born in the nearby Changthang area.

Ages of the children and adolescents were collected from the school records and were cross-checked with the individuals. Six months were deducted from the reported age (based on Tibetan calendar) for those adults who did not remember their date of birth according to the Gregorian calendar (English calendar). Age reported according to Tibetan calendar can be 0–1 year ahead of English calendar. Individuals older than 2 years and younger than 18 years are grouped into 2-year age groups. Adults 18 years and above and less than 40 years of age have been grouped into a single age group 18–40. Age group 2–4 means age greater than and equal to 2 years and less than 4 years.

Anthropometric measurements were taken following Weiner and Louric (1981). The following anthropometric measurements were taken on both the sexes: height, weight, sitting height, skinfold thickness at triceps, and upper arm circumference. Except for sitting height, all the measurements were taken on individuals above two years of age. Sitting height was taken on individual above six years of age. Height was measured by Harpenden anthropometer rod and weight with a weighing scale. Skinfold thickness was taken with the Harpenden skinfold caliper. Upper arm circumference was taken with a non-stretchable measuring tape. Height was recorded to the nearest millimeter, weight to nearest the 0.5 kg, upper arm circumference to the nearest millimeter, and skinfold thickness to the nearest 0.1 mm. Upper arm circumference and skinfold thickness at triceps were used to estimate muscle and fat mass based on the formula for cross sectional upper arm muscle area and fat area described by Frisancho (1981). All the measurements were taken by single investigator (VT). Statistical analysis was done with the help of MS Excel 2000 and SPSS 10.0.

RESULTS

Tables 1 and 2 present the sample sizes, means, and standard deviations for height, weight, and sitting height respectively for males and females at the three study locations and two altitudes. ANOVA was used to compare differences in location for each age group.

T-tests are used to compare altitude differences; the high altitude group is compared to the pooled mean of the two low altitude samples.

For height, significant difference between the places of residence is observed only for age groups 4–6, 16–18, and 18–40 years for males and 2–4, 16–18, and 18–40 years for females. For weight significant difference between the places of residence is observed for age groups 4–6, 6–8, 10–12, 12–14, 14–16, and 16–18 years for males and 2–4, 4–6, 6–8, and 10–12 years for females. Mean height and weight values are lower at high altitude than at low altitude except for the two age groups 2–4 and 8–10 among males. Few of the differences between altitudes are significant. Height values show significant difference between altitudes for age groups 4–6, 12–14, 16–18, and 18–40 years for males and 2–4, 4–6, 14–16, and 18–40 year for females. Weight values show significant difference between altitudes for age groups 4–6, 6–8, 10–12, 12–14, and 14–16 years for males, and 2–4, 4–6, 6–8, 8–10, 10–12, and 18–40 years for females.

To determine whether differences in weight were simply a consequence of differences in height, ANCOVA was used to compare height-controlled differences in weight between Tibetans at high and low altitude. Figure 1 shows that when height is controlled for each age group, many of the significant differences observed earlier for weight were diminished, particularly for the adult age group. Nevertheless, differences were still observed for most of the age groups younger than 14 years among males and younger than 12 years among females. Above these age groups the general pattern as observed for weight is no more observed.

Table 1 shows that sitting height differs significantly for place of residence and for altitude only for the 8- to 10-year-old age group and the 16- to 18-year-old age group among males. Table 2 indicates that sitting height differs significantly for place of residence and for altitude only for 16- to 18-year-old age group among females. However, Figure 2 shows that relative sitting height is greater at high altitude than at low altitude for all age groups among males, and for ages younger than 16 years among females.

Tables 3 and 4 present the sample sizes, means, and standard deviations for skinfold thickness at triceps and mid upper arm circumference, respectively. The high altitude sample shows lower values for skinfold thickness at triceps and for upper arm circumfer-

TABLE 1. Height, weight, and sitting height among Tibetan males at the three places of residence

Age groups	Low altitude						High altitude			F ^a	t ^b
	Bylakuppe			Chandragiri			Leh				
	N	M	SD	N	M	SD	N	M	SD		
Height											
2-4	14	93.4	3.77				5	93.9	6.95	0.042	-0.205
4-6	28	104.2	5.59	8	110.3	4.71	24	102.1	5.16	7.218*	2.387*
6-8	21	115.3	6.41	19	116.0	6.20	35	118.2	6.71	1.371	1.829
8-10	21	123.5	7.20	9	123.4	4.24	20	124.5	7.33	0.115	-0.479
10-12	28	134.1	6.95	9	132.7	4.24	16	131.8	7.17	0.625	0.976
12-14	31	143.5	7.88	9	146.5	8.04	23	139.5	8.79	2.862	2.197*
14-16	29	157.3	8.45	17	154.2	9.21	33	153.6	10.20	1.279	1.185
16-18	20	169.2	6.27	13	164.7	5.37	20	160.0	6.16	11.65*	4.212*
18-40	29	169.2	5.38	42	168.1	5.08	14	164.6	8.52	3.177*	2.394*
Total	221			126			190				
Weight											
2-4	14	14.6	1.41				5	14.0	2.62	0.408	0.635
4-6	28	17.7	1.87	9	19.5	1.96	24	18.1	2.22	9.898*	3.651*
6-8	21	21.5	3.53	19	21.4	2.85	35	18.3	2.14	8.698*	4.197*
8-10	21	24.4	3.25	9	24.5	2.36	20	23.6	3.65	0.41	0.911
10-12	28	31.0	5.17	10	29.1	4.67	16	28.2	3.82	5.992*	3.077*
12-14	31	38.5	6.28	9	38.0	6.21	33	32.4	4.38	4.827*	3.035*
14-16	29	49.0	11.69	17	42.3	7.19	33	41.9	8.84	4.846*	2.083*
16-18	20	58.5	6.85	13	53.7	13.32	20	51.2	7.09	2.971*	1.981
18-40	28	67.7	14.70	42	63.9	13.03	14	63.9	15.13	0.709	0.384
Total	230			128			150				
Sitting height (cm)											
6-8	19	65.2	3.64	11	66.0	2.31	28	64.8	2.85	0.637	0.907
8-10	21	68.0	2.85	9	67.4	1.95	16	70.2	3.74	3.365*	-2.574*
10-12	28	72.4	3.56	8	71.3	1.89	14	71.6	3.49	0.518	0.503
12-14	31	76.3	3.98	9	78.7	2.93	22	75.2	4.36	2.467	1.550
14-16	29	84.2	5.49	17	80.2	6.35	33	83.0	5.71	2.554	-0.154
16-18	20	90.1	4.06	13	88.4	3.22	17	86.2	4.52	4.329*	2.672*
18-40	29	91.5	3.03	40	90.2	3.04	9	89.4	3.94	1.177	0.845
Total	177			108			135				

*F comparing the three places of residence (ANOVA).

^bt-Test comparing the high and low altitudes; the two low altitude samples pooled together.

ence among males and females of all ages. However, differences between places of residence or between altitudes are not statistically significant for many of the age groups. Figures 3 and 4 show that upper arm fat area and upper arm muscle area, based on skinfold thickness at triceps and mid upper arm circumference, also show lower values at high altitude than at low altitude.

DISCUSSION

In this study, height and weight values tend to be higher at low altitudes than at high altitude for most of the age groups for both males and females, though the differences are not significant for all the age groups. The difference in height and weight between the two altitudes may be a result of hypoxia at high altitude or it may be due to the difference in nutritional status between the two altitudes.

The two low altitude samples show similar values for height. One of the low altitude samples is from Chandragiri which is a malaria endemic area. It is surprising that no difference is found between a low altitude area with malaria and one without malaria. It may be because malaria is not accompanied by poor socio-economic conditions. It may be also because of the availability of medical facilities in the settlement and awareness about the disease among the individuals in the settlement.

Figure 5 compares data on height from the present study with data from previous studies on Tibetans (Weitz et al., 2000; Pawson, 1976), a population of Tibetan origin (Sherpa: Pawson, 1976), Andean populations (Quechua: Frisancho et al., 1975, Aymara: Stinson, 1980), and a sample of European origin (Greksa et al., 1985) at high altitude. Weighted means for 2-year age groups were taken for comparison. Ages 18 and above were

TABLE 2. Height, weight, and sitting height among Tibetan females at the three places of residence

Age groups	Low altitude						High altitude			F ^a	t ^b
	Bylakuppe			Chandragiri			Leh				
	N	M	SD	N	M	SD	N	M	SD		
Height											
2-4	14	94.4	4.73				16	90.8	4.02	4.981 ^a	2.232 ^a
4-6	20	104.3	5.64	7	106.6	2.90	24	100.9	7.63	2.722	2.195 ^a
6-8	11	113.8	4.55	15	115.6	4.43	22	111.6	6.77	2.368	2.017
8-10	32	123.1	5.07	16	124.4	5.90	19	122.8	4.85	0.886	0.480
10-12	27	137.6	9.40	13	135.3	8.85	21	133.4	9.46	1.207	1.372
12-14	24	148.0	8.49	31	148.0	7.74	23	144.4	5.74	1.82	1.922
14-16	19	154.6	4.25	21	153.9	5.90	14	151.2	4.02	2.291	2.104 ^a
16-18	10	159.5	5.08	20	158.0	4.63	24	153.1	4.67	6.948 ^a	4.161 ^a
18-40	20	158.0	6.54	56	155.7	5.15	41	154.1	6.10	3.139 ^a	1.953
Total	177			169			204				
Weight											
2-4	14	14.6	1.48				16	12.9	1.51	9.583 ^a	3.096 ^a
4-6	20	17.8	1.91	7	18.6	1.72	24	15.1	2.38	11.872 ^a	4.795 ^a
6-8	11	20.4	1.97	15	20.7	2.46	22	17.7	2.31	9.408 ^a	4.365 ^a
8-10	31	24.3	3.24	16	25.0	4.40	19	22.2	3.12	3.085	2.425 ^a
10-12	27	33.7	7.80	13	30.7	6.88	21	28.4	5.35	3.829 ^a	2.401 ^a
12-14	24	42.6	10.42	21	40.5	7.57	23	38.5	8.29	1.209	1.355
14-16	18	48.2	6.23	21	47.3	8.32	14	45.1	5.93	1.459	1.483
16-18	10	50.9	6.52	20	52.6	8.51	24	50.3	4.09	0.658	0.949
18-40	20	60.2	13.88	56	58.8	10.73	41	53.2	8.54	3.018	2.080 ^a
Total	175			169			204				
Sitting height											
6-8	9	63.0	4.13	10	64.1	2.72	18	63.3	3.19	0.26	0.235
8-10	32	67.8	3.27	14	68.2	2.76	17	68.7	3.36	0.517	-0.926
10-12	27	72.6	7.18	12	72.2	4.50	21	73.6	4.79	0.286	-0.708
12-14	23	78.3	4.19	21	79.1	4.48	21	77.6	4.27	0.696	1.153
14-16	19	82.2	2.01	21	81.6	4.96	13	81.3	1.98	0.267	0.473
16-18	10	84.4	2.15	19	85.4	3.29	19	81.8	4.75	4.055 ^a	2.791 ^a
18-40	14	85.3	1.98	44	84.6	3.46	30	83.7	3.77	1.006	1.254
Total	134			147			128				

^aF comparing the three places of residence (ANOVA).

^bt-Test comparing the high and low altitudes; the two low altitude samples pooled together.

pooled together and are presented in the age group 18-40 years in the graph. Data for Qinghai Tibetans in Tibet from Weitz et al. (2000) are presented as weighted averages for individuals living at 3,200 and 3,800 m.

The comparison of height shows similar patterns for both the sexes. All the samples at high altitude lie below the 5th percentile of US NCHS reference values (Frisancho, 1990), except for European sample which lies between 5th and the 50th percentiles. The European sample (Greksa et al., 1985) is of upper socio-economic status and their retarded growth compared to the NCHS references indicates the effect of hypoxia on them. The Andean high altitude samples, Quechua (Frisancho et al., 1975) and Aymara (Stinson, 1980), show similar patterns and are shorter than the Tibetans at high altitude of the present study.

The growth of Tibetans at 3,200; 3,800; and 4,300 m from Qinghai area of the Tibetan pla-

teau, described by Weitz et al. (2000), does not conform to the hypothesis of slower growth at higher altitudes. The interpretation offered was that of genetic differences between the samples and poorer nutrition and health care of the sample at the lower altitude of 3,200 m. The average heights of the high altitude sample in our study do not differ much from those of Tibetans at 3,200 and 3,800 m reported by Weitz et al. (2000). But, mean height at low altitude in the present study is greater for most ages and for both sexes than the heights reported for Tibetans at 3,200 and 3,800 m in Qinghai. The important difference between the two studies is that our study presents data from a much greater altitude range than was reported by Weitz et al. (2000). Samples described by Weitz et al. (2000) at high altitudes were similar to the Tibetan sample at Lhasa (Ji and Ohsawa, 1993) in terms of height, and taller than Tibetans of Upper Chumik in Nepal (Beall, 1984), Bods of

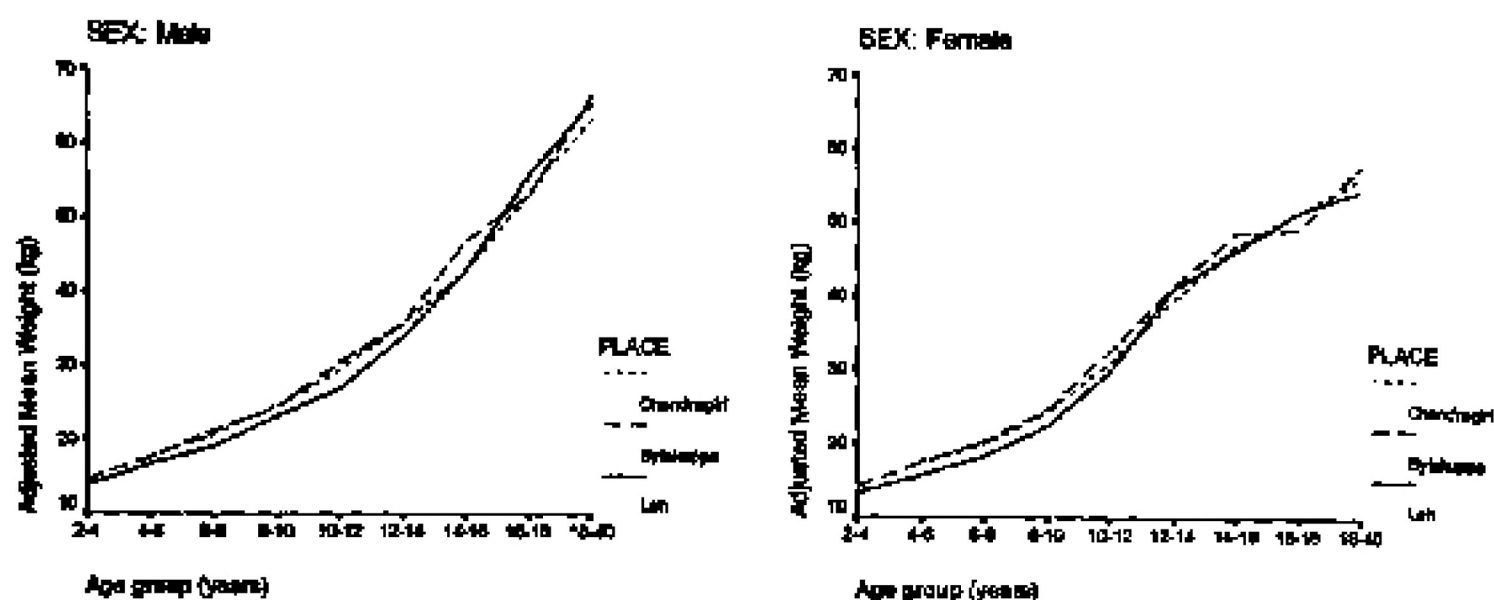


Fig. 1. Weight adjusted for height with age for Tibetan males and females at three places of residence. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

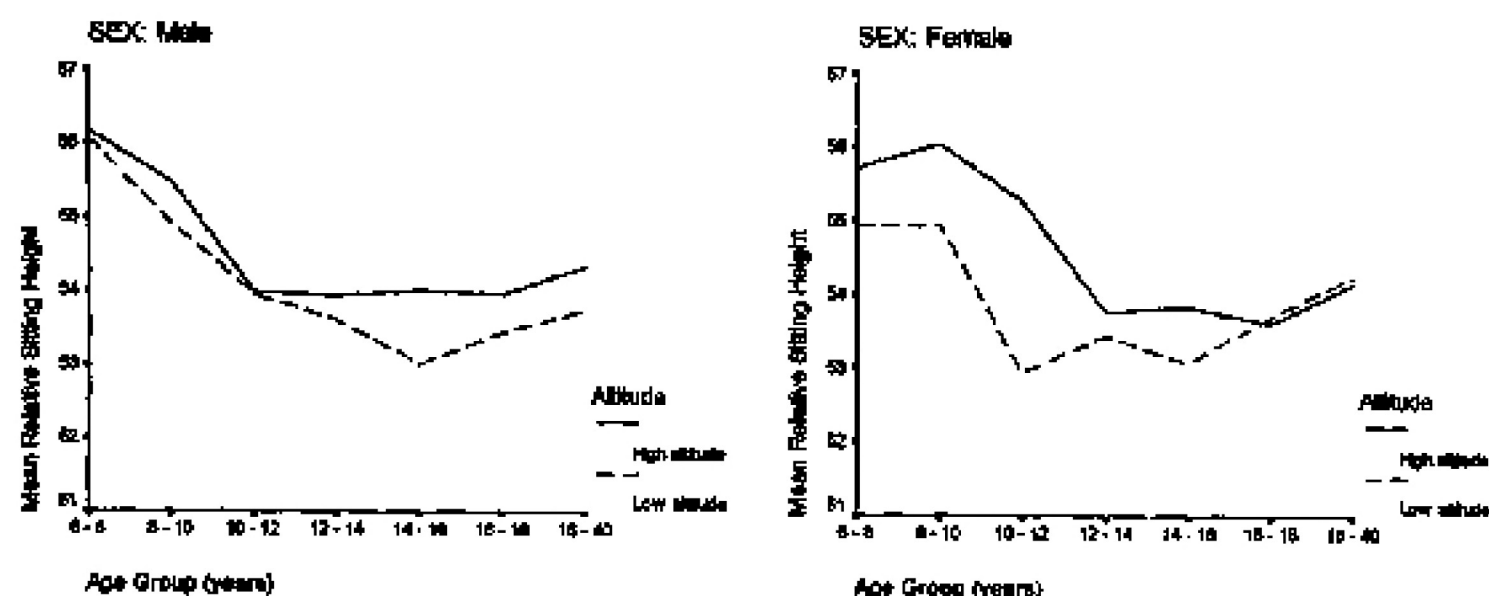


Fig. 2. Relative sitting height with age for Tibetan males and females at high and low altitudes. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Ladakh in India (Malik, 1987; Malik and Pandey, 1999; Malik and Singh, 1978, 1984), Sherpas of Khumbu region in Nepal, and Qinghai Tibetans in Tibet (Kuang, 1980, cited by Weitz et al., 2000). Pawson (1974, 1976) did not find significant differences in height between the sample of Tibetans growing up at medium altitude and Sherpas growing up at high altitude. Since anthropometric measurements indicated that Tibetans at medium altitude were nutritionally better off than the high altitude Sherpas, Pawson (1976) concluded that the growth of Himalayan populations was more likely to be a consequence of genetics than of difference in diet or altitude.

Figure 6 shows that population differences in weight parallel those for height. Europeans are the heaviest and the Pawson's (1976) sam-

ple of Sherpas and Tibetans are the lightest. While the heights of most of the high altitude samples are equal to or below the NCHS 5th percentiles, the weights of some of the high altitude populations are above the NCHS 5th percentiles. In comparison to males, the weights of many of the female samples are above the NCHS 5th percentile. Upper arm muscle area is greater among males than among females, while upper arm fat area is greater among females than among males. Thus, the reason the female samples are above the NCHS 5th percentile for weight may be due to greater fat mass.

Sitting height shows similar values at both high and low altitudes, but consistent differences between the two altitudes are observed for relative sitting height (Fig. 2). Since chest

TABLE 3. Skinfold thickness at triceps among Tibetans at the three places of residence

Age groups	Low altitude						High altitude			F ^a	p ^b
	Bylakuppe			Chandragiri			Leh				
	N	M	SD	N	M	SD	N	M	SD		
Male											
2-4	14	10.3	3.51				4	9.3	1.28	0.528	0.724
4-6	28	8.3	1.68	8	8.3	1.47	22	7.7	1.06	1.09	1.488
6-8	21	7.5	1.44	19	8.6	1.87	35	6.7	1.46	8.402 ^a	3.674 ^a
8-10	21	7.9	2.19	9	9.2	2.46	19	7.6	1.85	1.95	1.074
10-12	28	8.3	2.88	9	7.7	2.26	16	6.7	0.95	2.298	2.061 ^a
12-14	31	8.1	2.48	9	8.2	2.09	23	7.3	1.26	1.387	1.679
14-16	39	8.9	4.32	17	8.4	2.94	33	6.4	1.36	5.407 ^a	3.252 ^a
16-18	20	7.9	2.39	13	8.6	4.81	19	6.2	1.25	2.674	2.230 ^a
18-40	28	9.5	5.19	41	9.2	4.20	12	9.2	5.06	0.049	0.103
Total	220	8.5	3.15	125	8.7	3.30	183	7.1	1.96		
Female											
2-4	14	10.3	2.20				13	9.1	1.58	2.332	1.527
4-6	20	9.5	1.83	7	9.4	0.55	22	8.4	1.43	3.181	2.544 ^a
6-8	11	8.6	1.96	15	9.3	1.26	22	7.1	1.50	11.096 ^a	4.509 ^a
8-10	32	8.9	1.76	14	10.4	1.65	19	8.5	2.30	4.426 ^a	1.654
10-12	27	10.6	3.31	13	9.7	1.72	21	9.0	1.87	2.357	1.912
12-14	23	12.4	4.36	21	11.8	2.66	23	11.3	3.82	0.54	0.881
14-16	19	14.3	4.58	21	14.2	3.64	14	12.7	3.95	0.733	1.221
16-18	10	14.2	2.75	20	14.6	3.64	24	13.8	4.24	0.256	0.677
18-40	13	19.1	7.92	64	17.8	7.20	39	15.6	6.35	2.01	1.678
Total	174	11.7	4.89	165	13.8	5.67	197	11.1	4.57		

^aF comparing the three places of residence (ANOVA).

^bT-test comparing the high and low altitudes; the two low altitude samples pooled together.

length correlates well with sitting height (Stinson and Frisancho, 1978), higher relative sitting height of Tibetans at high altitude indicates that chest/thorax length, relative to height, is greater at high altitude than at low altitude. Low altitude Tibetans are taller, yet have similar sitting heights, compared to high altitude Tibetans. This means that leg length, calculated as sitting height subtracted from height, is greater at low altitude (Fig. 7). Though not all differences are significant, the general trend shows higher values for leg length at low altitude. Higher relative sitting height interpreted as higher relative chest length may indicate an adaptation at high altitude. A review of variation in body size and shape among South American Indians (Stinson, 1990) showed that relative sitting height correlated strongly with temperature; thus groups living in colder areas have shorter legs. This is in conformity with the Allen's rule of shorter appendages in cold climate. The higher relative sitting height and consequently lower leg lengths observed among Tibetans thus may be explained either by altitude or by the cold climate of the place.

Lower leg length relative to stature among high altitude Tibetans also may be an indication of poor nutritional status. Since skinfold

thickness and upper arm circumference can be used as indicators of nutritional status (WHO, 1995), lower values of both measured at high altitude provides additional support for the hypothesis that the diet of high altitude Tibetans is poorer than the diet of low altitude Tibetans. Finally, the high altitude Leh sample shows a higher percentage of children whose height-for-age and weight-for-age Z-scores are more than 2 standard deviations below the NCHS means compared to the low altitude samples. These differences might be due to the direct result of differences in nutritional intake at high altitude or a result of differences in metabolism under the influence of hypoxia.

Other indicators of nutritional status, such as weight-for-height and BMI-for-age, show very little difference between altitudes. Even though 13.3% of the males and 11.9% of the females at high altitude are in the CDC "underweight" category (i.e., BMI-for-age <5th percentile, CDC, 2005) compared to 5.7% of the males and 2.1% of the females at low altitude, the majority of children and adolescents (>82%) at both altitudes are within the CDC "normal" category (i.e., BMI-for-age between the 5th and 85th percentiles, CDC, 2005) (Tripathy and Gupta, unpublished com-

TABLE 4. Mid upper arm circumference among Tibetans at the three places of residence

Age groups	Low altitude						High altitude			F ^a	t ^b
	Bylakuppe			Chandrageri			Leh				
	N	M	SD	N	M	SD	N	M	SD		
Male											
2-4	14	16.1	1.28				4	14.8	0.84	3.339	1.827
4-6	29	16.1	1.07	8	16.9	1.27	22	14.6	1.13	16.98*	5.463*
6-8	21	16.6	1.83	10	17.1	1.18	85	14.9	1.01	27.147*	7.232*
8-10	21	17.3	1.31	9	17.6	1.32	20	16.6	1.49	1.957	1.910
10-12	29	19.2	1.85	9	19.3	1.88	16	16.9	1.06	8.905*	4.002*
12-14	31	20.0	1.96	9	20.1	1.99	23	18.5	1.38	4.96*	3.168*
14-16	29	22.9	3.27	17	20.8	2.03	32	20.3	2.52	7.394*	2.836*
16-18	20	24.1	2.08	13	23.6	3.71	19	22.8	2.90	0.94	1.313
18-40	28	27.3	3.77	41	26.2	3.39	12	24.8	2.91	2.281	1.647
Total	220	20.2	4.38	125	21.6	4.54	183	18.1	3.68		
Female											
2-4	14	16.0	0.93				18	14.0	0.88	30.403*	6.514*
4-6	20	16.6	1.21	7	16.9	1.57	23	14.2	0.92	29.22*	7.665*
6-8	10	16.5	0.75	16	16.7	1.19	22	14.8	0.95	20.359*	6.417*
8-10	32	17.6	1.13	16	17.6	1.61	19	16.1	1.31	8.224*	4.088*
10-12	27	19.6	2.07	18	19.0	1.80	21	16.4	2.79	1.243	1.447
12-14	23	21.1	2.17	21	20.6	2.00	23	19.7	2.53	2.442	2.086*
14-16	19	22.8	1.84	21	21.9	2.23	14	20.7	2.09	4.232*	2.543*
16-18	10	23.1	1.54	20	23.6	2.47	24	22.5	1.98	1.346	1.554
18-40	19	27.0	3.82	51	25.6	3.77	39	24.1	2.60	4.92*	2.724*
Total	173	19.9	3.85	164	21.7	4.21	185	18.9	4.23		

^aF comparing the three places of residence (ANOVA).

^bt-Test comparing the high and low altitudes; the two low altitude samples pooled together.

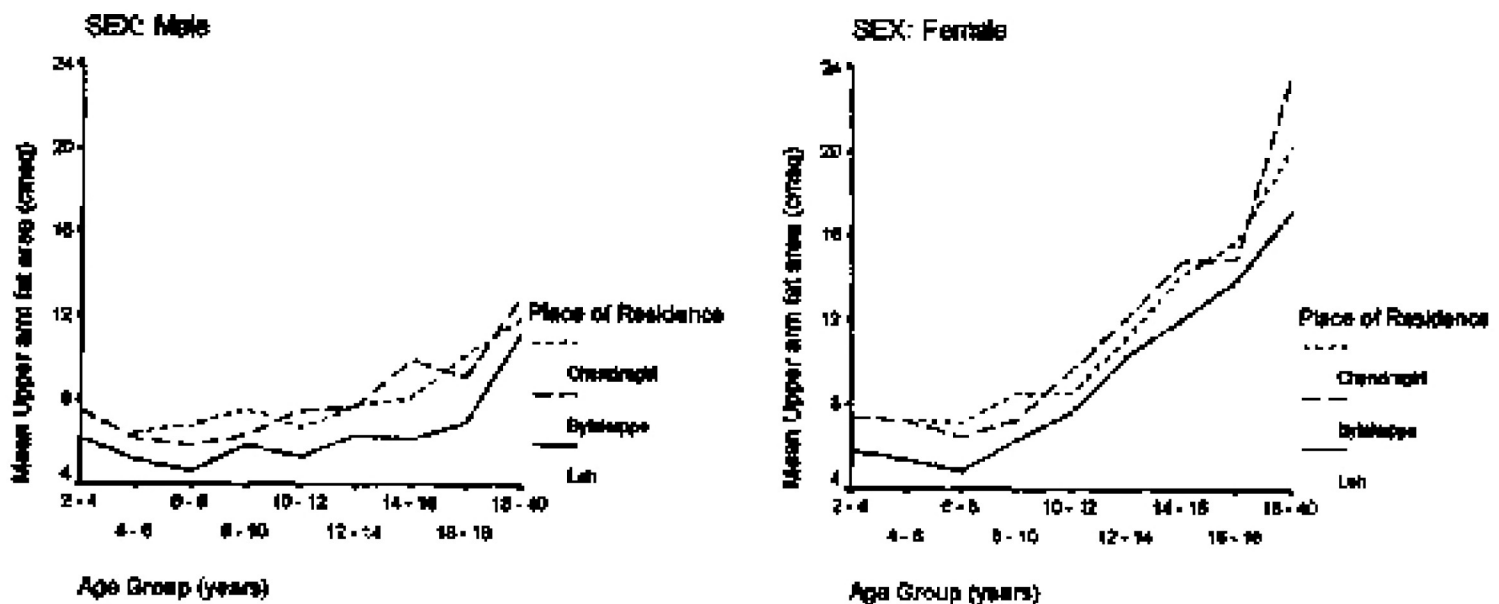


Fig. 3. Upper arm fat area with age for Tibetan males and females at three places of residence. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

munication). The height-adjusted weight data also show similar values at both the altitudes. The low altitude shows higher proportion of individuals in the CDC categories "risk of overweight" and "overweight" (i.e., BMI-for-age greater than 85th percentile; CDC, 2006) compared to high altitude.

Higher level of physical activity at high altitude may be one of the reasons that the pro-

portion of overweight Tibetans is low at high altitude than at low altitude. Upper arm muscle area shows lower values at high altitude than at low altitude which is not as expected if high altitude sample were physically more active. At high altitudes, people depend on walking for traveling the distances within the settlements. Physical activity is higher at high altitude in terms of walking and also

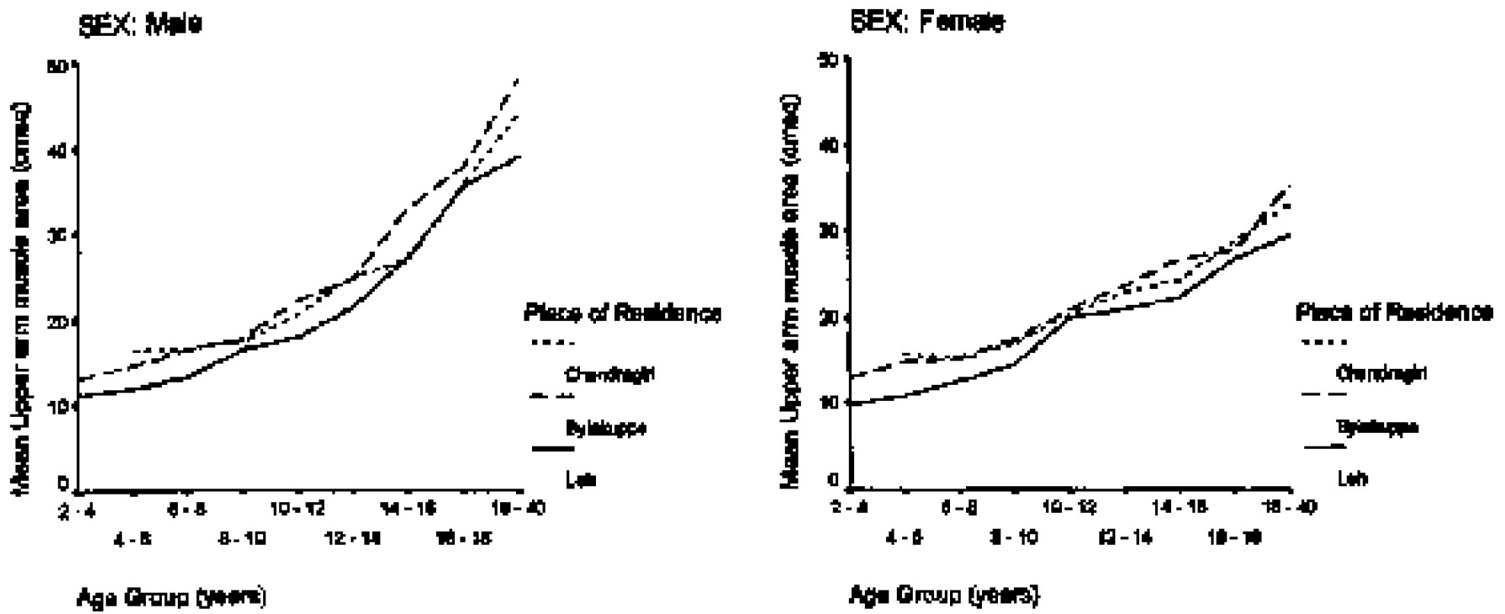


Fig. 4. Upper arm muscle area with age for Tibetan males and females at three places of residence. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

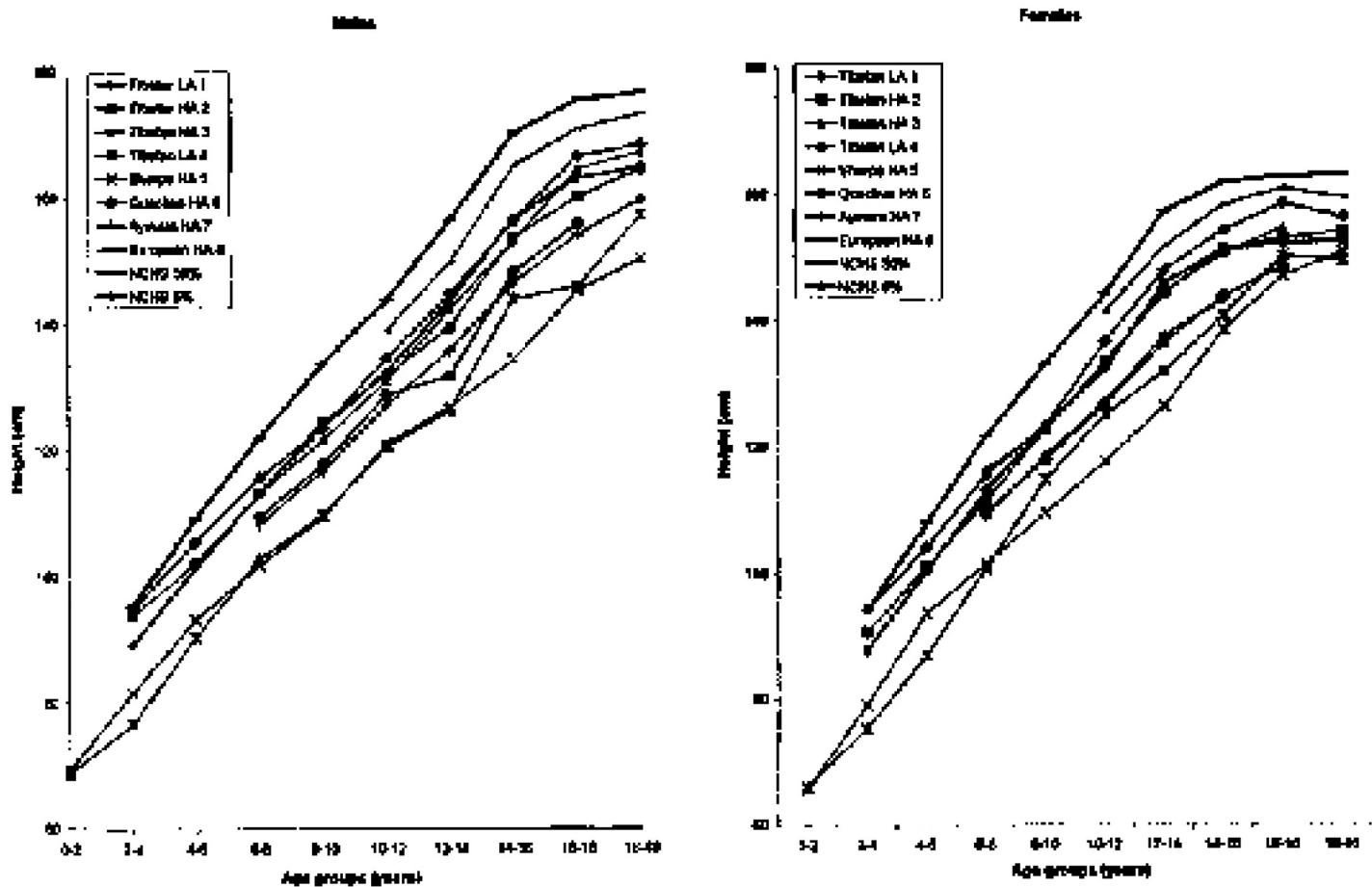


Fig. 5. Height of Tibetan males and females in India at two altitudes compared with Tibetans (Pawson, 1976; Weitz et al., 2000), a population of Tibetan origin (Sherpa: Pawson, 1976), Andean populations (Quechua: Frisancho et al., 1975, Aymara: Stinson, 1980), and a sample of European origin (Greksa et al., 1985) at high altitude. (1 and 2: Present Study; 3: Weitz et al., 2000; 4 and 5: Pawson, 1976; 6: Frisancho et al., 1975; 7: Stinson, 1980; 8: Greksa et al., 1985). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

because of the undulating terrain found at the high altitude as is not the case at low altitudes. This may be a reason why higher physical activity is not reflected in the upper arm muscle area. Nonetheless, difference in weight and muscle mass between the two altitudes may due to altitude difference in nutrition.

A high percentage of adults at both altitudes can be classified as overweight or obese, based on BMI (Tripathy and Gupta, 2006). A community which shows very high percentage of adults within the categories of overweight and obese is not expected to be deficient at least in terms of quantity, if not quality, of

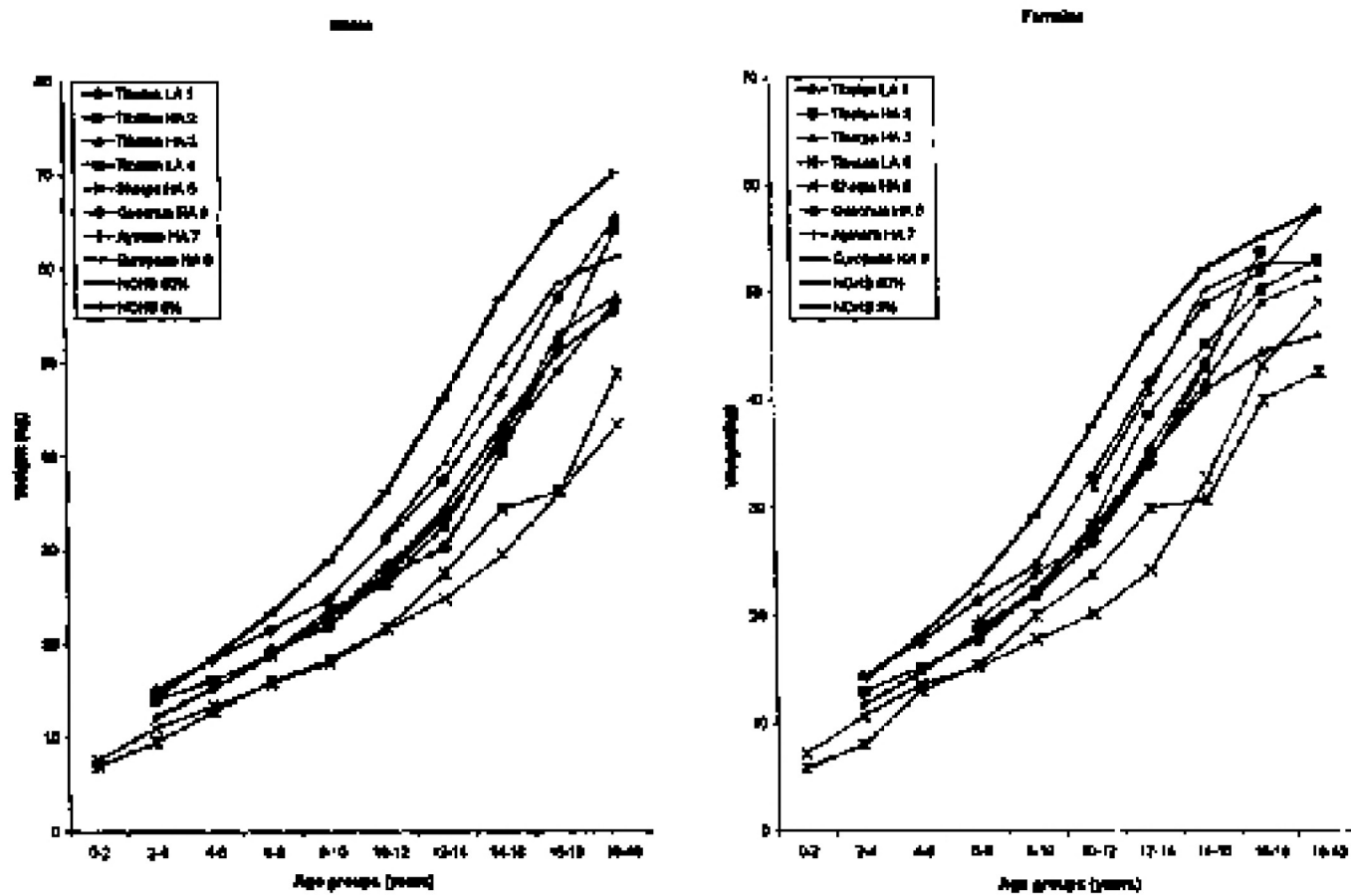


Fig. 6. Weight of Tibetan males and females in India at two altitudes compared with Tibetans (Weitz et al., 2000; Pawson, 1976), a population of Tibetan origin (Sherpa: Pawson, 1976), Andean populations (Quechua: Frisancho et al., 1975, Aymara: Stinson, 1980), and a sample of European origin (Grekso et al., 1985) at high altitude. (1 and 2: Present Study; 3: Weitz et al., 2000; 4 and 5: Pawson, 1976; 6: Frisancho et al., 1975; 7: Stinson, 1980; 8: Grekso et al., 1985). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

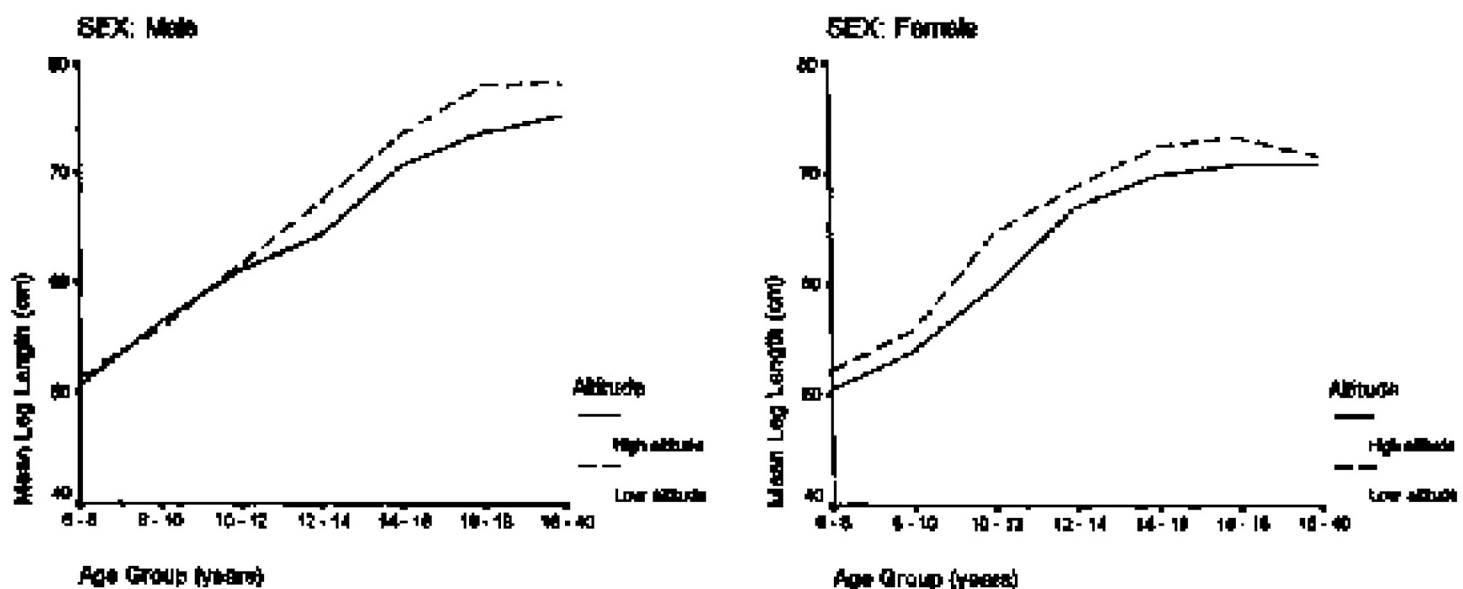


Fig. 7. Leg length with age for Tibetan males and females at high and low altitudes. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

food and nutrition. We observed that the basic food patterns in terms of staple food of Tibetans at different settlements are largely similar. The differences which do exist are due to the differences in availability of vegetables and fruits in winter months. High altitude lacks in variability and availability of vegeta-

bles and fruits, especially in winter months. The proportion of animal protein is thus more in diet at high altitude than at low altitudes.

SUMMARY

The similarity of height of our present sample at high altitude with Tibetans at Qinghai

(Weitz et al., 2000) and at Lhasa (Ji and Ohsawa, 1993) may indicate that in terms of growth the Tibetans at Leh are responding to the stress of hypoxia in the same way as their counterparts in Tibet. In terms of height, Tibetans at low altitude differ significantly from Tibetans at high altitude only for few age groups. The general trend suggests that Tibetans migrated to low altitudes show slightly higher values of height, weight, skinfold thickness at triceps and upper arm circumference. The slight difference observed for height is largely due to higher leg length which may be explained by the difference in food and nutrition. Altitude may or may not be mediating through nutritional status.

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LITERATURE CITED

- Aldenderfer MS. 2003. Moving up in the world. *Am Sci* 91:542-549.
- Baker PT. 1969. Human adaptation to high altitude. *Science* 14:1149-1156.
- Beall CM. 1984. Aging and growth at high altitudes in the Himalayas. In: Lukas J, editor. *The people of South Asia*. New York: Plenum. p 365-385.
- Beall CM. 2000a. Tibetan and Andean patterns of adaptation to high-altitude hypoxia. *Hum Biol* 72:201-228.
- Beall CM. 2000b. Tibetan and Andean contrasts in adaptation to high-altitude hypoxia. *Adv Exp Med Biol* 475: 68-74.
- Beall CM. 2001. Adaptations to altitude: a current assessment. *Annu Rev Anthropol* 30:423-458.
- Beall CM, Baker PT, Baker TS, Haas JD. 1977. The effects of high altitude on adolescent growth in southern Peruvian Amerindians. *Hum Biol* 49:109-124.
- CDC. 2005. BMI—body mass index: About BMI for children and teens. Centers for Disease Control and Prevention (CDC), Department of Health and Human Services. http://www.cdc.gov/nccdphp/dnpa/bmi/childrens_BMI/about_childrens_BMI.htm (accessed 6 January 2005).
- Clegg EJ, Pawaon IG, Ashton ES, Flynn RM. 1872. The growth of children at different altitudes in Ethiopia. *Philos Trans R Soc Lond B* 264:408-437.
- Frisancho AR. 1969. Human growth and pulmonary function of a high altitude Peruvian Quechua population. *Hum Biol* 41:365-379.
- Frisancho AR. 1970. Developmental responses to high altitude hypoxia. *Am J Phys Anthropol* 32:401-407.
- Frisancho AR. 1976. Growth and morphology at high altitude. In: Baker PT, Little MA, editors. *Man in the Andes*. Stroudsburg, PA: Dowden, Hutchinson and Ross. p 180-207.
- Frisancho AR. 1981. New norms of upper limb fat and muscle areas for assessment of nutritional status. *Am J Clin Nutr* 34:2540-2545.
- Frisancho AR. 1990. *Anthropometric standards for the assessment of growth and nutritional status*. Ann Arbor, MI: Michigan University Press.
- Frisancho AR, Baker PT. 1970. Altitude and growth: A study of the patterns of physical growth of a high altitude Peruvian Quechua population. *Am J Phys Anthropol* 32:279-292.
- Frisancho AR, Borkan GA, Klayman JE. 1975. Pattern of growth of lowland and highland Peruvian Quechua of similar genetic composition. *Hum Biol* 47:239-249.
- Furer-Haimendorf CV. 1975. *Himalayan traders. Life in highland Nepal*. Great Britain: John Murray.
- Greksa LP, Haas JD, Leatherman TL, Thomas RB, Spielvogel H. 1984. Work performance of high-altitude Aymara males. *Ann Hum Biol* 11:227-233.
- Greksa LP, Spielvogel H, Caceres E. 1985. Effect of altitude on the physical growth of upper-class children of European ancestry. *Ann Hum Biol* 12:225-232.
- Gupta R, Basu A. 1981. Variations in body dimensions in relation to altitude among the Sherpas of the eastern Himalayas. *Ann Hum Biol* 8:145-152.
- Gupta R, Basu A. 1991. Altitude and growth among the Sherpas of the eastern Himalayas. *Am J Hum Biol* 3:1-9.
- Haas JD. 1976. Prenatal and infant growth and development. In: Baker PT, Little MA, editors. *Man in the Andes*. Stroudsburg, PA: Dowden, Hutchinson and Ross. p 161-179.
- Harrison GA. 1966. Human adaptability with reference to the IPB proposals for high altitude research. In: Baker PT, Weiner JM, editors. *The biology of human adaptability*. Oxford: Clarendon Press. p 509-519.
- Hoff C. 1974. Altitudinal variations in the physical growth and development of Peruvian Quechua. *Homo* 24:87-99.
- Ji CY, Ohsawa S. 1993. Growth changes of Chinese, Mongolian, Uyghur, Korean and Tibetan ethnic groups in the past forty years. *Am J Hum Biol* 6:311-322.
- Kaul S, Kaul FN. 1992. *Ladakh through the ages, towards a new identity*. New Delhi: Indus Publishing Company.
- Malik SL. 1987. Physical growth and altitude: comparison of high- and low-land Bods of western Himalayas. *Indian Anthropol* 17:9-48.
- Malik SL, Pondey AK. 1993. Respiratory adaptation to high altitude in adolescent Bod girls of the western Himalayas. *Ann Hum Biol* 20:575-581.
- Malik SL, Singh IP. 1978. Growth trends among male Bods of Ladakh—a high altitude population. *Am J Phys Anthropol* 48:171-175.

- Malik SI, Singh IP. 1984. Ecology and human physiology in Ladakh. In: Lukacs JR, editor. *The people of South Asia*. New York: Plenum. p 421-439.
- Moore LG. 2001. Human genetic adaptation to high altitude. *High Alt Med Biol* 2:267-279.
- Moore LG, Armaza F, Villena M, Vargas B. 2000. Comparative aspects of high-altitude adaptation in human populations. *Adv Exp Med Biol* 475:46-62.
- Mueller WH, Schull VN, Schull WJ, Soto P, Rothhammer F. 1978. A multinational Andean genetic and health program: growth and development in an hypoxic environment. *Ann Hum Biol* 5:329-362.
- Pawson IG. 1974. The growth and development of high altitude children with special emphasis on population to Tibetan origin in Nepal. Ph.D. dissertation, University Park, Pennsylvania State University, Pennsylvania.
- Pawson IG. 1976. Growth and development in high altitude populations: a review of Ethiopian, Peruvian, and Nepalese studies. *Proc R Soc Lond B* 194:83-88.
- Sariti S. 1988. *Months of people, the voice of God: Buddhist and Muslims in a frontier community of Ladakh*. New Delhi: Sauganya Books.
- Stinson S. 1980. The physical growth of high altitude Bolivian Aymara children. *Am J Phys Anthropol* 52:377-385.
- Stinson S. 1982. The effect of high altitude on the growth of children of high socioeconomic status in Bolivia. *Am J Phys Anthropol* 58:61-71.
- Stinson S. 1990. Variation in body size and shape among South American Indians. *Am J Hum Biol* 2:37-51.
- Stinson S, Frisancho AR. 1978. Body proportions of highland and lowland Peruvian Quechua children. *Hum Biol* 50:57-68.
- Tripathy V, Gupta R. 2005. Birth weight among Tibetans at different altitudes in India: are Tibetans better protected from IUGR? *Am J Hum Biol* 17:442-450.
- Tripathy V, Gupta R. 2008. Nutritional status and hypertension among Tibetan adults in India (special issue). *J Hum Ecol* 14:77-82.
- Weiner JS, Lourie JA, editors. 1981. *Practical human biology*. London: Academic Press.
- Weitz CA, Garruto RM. 2004. Growth of Han migrants at high altitude in central Asia. *Am J Hum Biol* 16:405-418.
- Weitz CA, Garruto RM, Chin CT, Liu JC. 2004. Morphological growth and thorax dimensions among Tibetan compared to Han children, adolescents and young adults born and raised at high altitude. *Ann Hum Biol* 31:282-310.
- Weitz CA, Garruto RM, Chin CT, Liu JC, Liu RL, He X. 2000. Growth of Qinghai Tibetans living at three different high altitudes. *Am J Phys Anthropol* 111:69-88.
- WHO. 1995. *Physical status: the use and interpretation of anthropometry*. Report of a WHO expert committee. Geneva: World Health Organization.