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**ORIGINAL ARTICLE**

# Blood pressure variation among Tibetans at different altitudes

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**Abstract**

*Background*: Age-related increase in blood pressure (BP) throughout adulthood have been commonly observed in industrialized and developing populations which is generally not observed in traditional populations. Based on studies in the Andes, Tien Shan, Pamir and US highlands, BP values are generally lower in high- than low-altitude populations. At present, Tibetans are residing at different altitudes in India and little is known about BP variation for this population.

*Aims*: This study reports BP variation among Tibetans in India in view of the hypothesis of age-related increase and of lower BP at high altitude.

*Subjects and methods*: BP, height, weight, triceps skinfold thickness (SFT), mid-upper arm circumference (MUAC), and haemoglobin and haematocrit level were obtained from 1091 individuals (508 males, 583 females) at four different settlements, one being at high altitude (Choglamsar, Leh; altitude: 3521 m) and three at low altitudes (Bylakuppe, Chandragiri and Delhi; altitude: less than 1000 m), which were pooled. Comparison between altitudes was carried out separately for the two sexes and for the two age groups: children and adolescents 10–19 years of age; and adults 20 years and above. Those independent variables that could significantly explain the variance in systolic blood pressure (SBP) and diastolic blood pressure (DBP) in stepwise regression were controlled for while comparing high and low altitudes using analysis of covariance (ANCOVA).

*Results*: The three low-altitude samples showed similar values for adult BP after controlling for age and other BP correlates. Age was highly correlated to adult BP for both males and females after adjusting for anthropometric and haematological variables. A similar analysis for children and adolescents showed lower BP values at high altitude.

*Conclusion*: Lower BP values among Tibetan children and adolescents at high altitude suggest that altitude affects BP as previously hypothesized, but only in youth. Similar BP in adults at low and high altitudes may reflect the effects of other variables on BP. Measures of adiposity (SFT, BMI and MUAC) have a significant effect on BP. Increase in BP with adult age is observed in Tibetans, which is similar to the pattern observed among populations undergoing modernization.

**Keywords:** *Blood pressure, Tibetans, high altitude, India*

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## Introduction

Variation in blood pressure (BP) has been the subject of extensive research because high BP is a common risk factor for cardiovascular and renal disease (Nissinen et al. 1988; Kaplan and Opie 2006). It is generally believed that both systolic blood pressure (SBP) and diastolic blood pressure (DBP) are lower in the high than in the low-altitude populations (Clegg et al. 1976; Frisancho 1979; Hanna 1999). Initial exposure to high altitude leads to increase in BP which is attributed largely to increased autonomic or sympathetic activity (Wolfel et al. 1994; Hanna 1999; Calbet 2003). SBP and DBP gradually decline, after years of residence at high altitude, even falling below those observed at sea level (Marticorena et al. 1969; Ruiz and Penaloza 1977; Mirrakhimov 1978; Hanna 1999). Compared with residents living at sea level, Andean residents at high altitude have lower resting BP, especially SBP (Hurtado 1964; Ruiz and Penaloza 1977). Furthermore, high-altitude residents who migrate to sea level show gradual elevations in BP levels (Hanna 1999). Studies on US Whites born at low altitude living at high altitude showed that the degree of decline in systemic BP is a function of length of time at residence at high altitude (Marticorena et al. 1969). The long-term residents and natives of high altitude Andes show reduced BP, lower rates of hypertension, and lower cardiac anomalies (Hurtado 1964; Ruiz and Penaloza 1977). This observation is also observed in some other high-altitude populations like Sherpas (Basu et al. 1984), natives of Tien Shan and the Pamir (Mirrakhimov 1971, cited by Mirrakhimov 1978) and the people in the Ambars region in Ethiopia (Beall et al. 1997).

The cause of decline in BP at high altitude has been attributed to relaxation of vascular smooth muscle, an increase in collateral circulation, increased vascularization, higher red blood cell level and haemoglobin level, hypocaloric stress and diseases like respiratory tract ailments (Grande 1964; Maddocks and Vines 1966; Tenney and Ou 1970; Penaloza 1971, cited by Clegg et al. 1976; Frisancho 1979, 1993; Heath and Williams 1989; Leon-Velarde et al. 1993).

Some studies like Hoff and Garruto (1977), Rothhammer (1987, cited by Hanna 1999), Olziikhutag and Danilov (1984) and Dasgupta et al. (1982) did not find any effect of altitude on BP on the natives of Andes, native Americans of Chile, natives of Mongolia and an agricultural population of India, respectively. A few studies showed just the opposite relationship, that is, high-altitude residents showing higher BP (Ethiopia: Harrison et al. 1969 and Clegg et al. 1976; Tibetan in comparison to Han: Sun 1986). Another study on Tibetans from a refugee settlement in India at low altitude report lower BP values (Sehgal et al. 1968). Studies on other high-altitude Himalayan populations like Sherpa, who trace their ancestry to Tibet (Oppitz 1974; Furer-Haimendorf 1975, 1984; Gupta 1981), reported lower BP at high altitude and a much smaller age-related increase in BP (Weitz 1982; Basu et al. 1984). But a recent study on Sherpa (Smith 1999) in the modernizing Nepal showed elevated BP for both the altitudes. The variation in BP was explained by body mass index (BMI) and age and not by the altitude of residence.

Tibetans have been living in India at different altitudes since 1959. We report the variation in BP among the Tibetans in India residing at different altitudes, in view of the hypothesis of age-related change and lower BP at high altitude.

## Materials and methods

The migrant Tibetan refugees in India who were given asylum in India following occupation of Tibet by China in 1959 were settled in 35 agriculture-based settlements

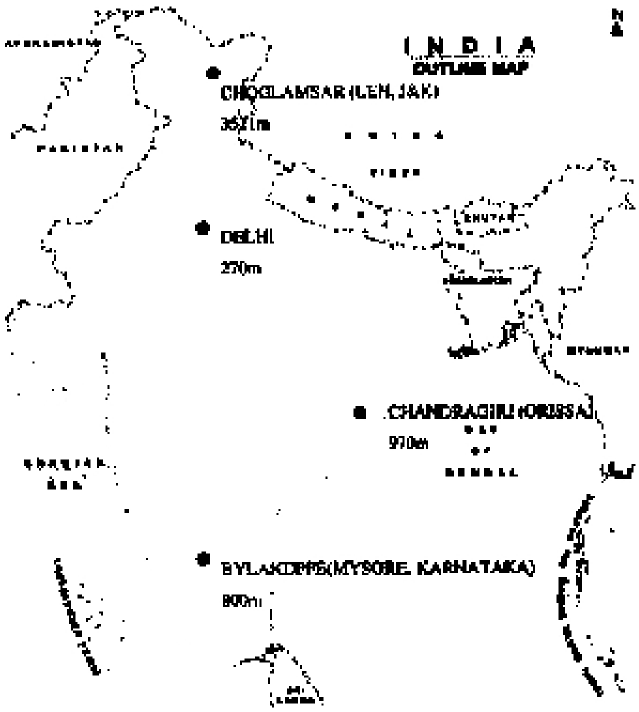


Figure 1. Map of India showing the four places under study – Choglamsar, Chandragiri, Bylakuppe and Delhi.

as well as in colonies in a few cities. Three Tibetan settlements and one colony (Figure 1) in India with different ecological settings have been selected for study.

Settlements at Bylakuppe (district: Mysore; state: Karnataka; altitude: 800 m), Chandragiri (district: Gajapati; state: Orissa; altitude: 970 m) and a colony at Delhi (altitude: 270 m) were selected at low altitude. The Tibetan settlements at Bylakuppe and Chandragiri were among the first to be established in India in the years 1960 and 1963, respectively, and are thus the oldest Tibetan settlement in India. Thus individuals below 40 years of age were born and raised at low altitude. The colony at Delhi was established in two phases, the first phase in 1964 and the second phase in 1980. The low-altitude places differ in their ecological and cultural settings in subtle ways. Chandragiri is on the Eastern Ghats, nearer to coast, and away from urban centres. It is also infested with malaria. In contrast, Bylakuppe is on the Indian peninsular plateau, away from seacoast and is nearer to urban centres. The settlement at Choglamsar (district: Leh; state: Jammu and Kashmir; altitude: 3521 m) is at high altitude. It is the only high altitude Tibetan settlement in India. High altitude is defined as the altitude above which most individuals experience some high-altitude effects (Pawson and Jest 1978). Although no strict delimiter is defined as high altitude, an altitude of 2500 m or 3000 m and above generally considered as high altitude. The settlement at Choglamsar was established in the year 1969. Since this settlement is at high altitude, migration to this settlement is from high altitude to high altitude and length of residence does not matter in this settlement so far as altitude is concerned.

Details about the physical features of the three settlements have been described elsewhere (Tripathy and Gupta 2005). Apart from being at high altitude, the ecology of Choglamsar (high altitude) differs greatly from the three settlements at low altitudes and can be described as arid cold dessert. Three of the settlements are agriculture based. The settlements are divided into smaller camps (villages) and groups. Agriculture is a source of stable income for most of the household. One crop per year is generally cultivated. At Bylakuppe some households cultivate even two crops per year. Apart from farming, most households are engaged in informal business involving retailing to consumers 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 such as carpet weaving, handicraft, etc. and few others are in the 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 from April 2002 to September 2004. Data were collected for individuals 10 years of age or older. BP data on children and adolescents were collected from Central schools for Tibetans at Delhi, Bylakuppe and Chandragiri and SOS Tibetan Children's Village at Choglamsar Leh. For adults, the data were collected at the individual's home or community centres at Bylakuppe, Chandragiri and Choglamsar only. Children and adolescents were selected randomly in the school based on their roll numbers in school attendance registers. For adults, camps were randomly selected in each settlement and an attempt was made to enrol all the available adults in the selected camps. Informed consent was obtained before taking the measurements. BP values for the three low altitudes were pooled together and are referred to as the low-altitude sample.

A mercury sphygmomanometer was used to measure BP. All the measurements were taken on the left arm; subjects being in a seated position, with lower end of the arm resting on the table top. Subjects were asked to relax and rest for 10 min before the pressure measurements were taken. SBP was recorded as the first Korotkov sound (phase I). DBP was taken as the disappearance of the Korotkov sounds (phase V). Hypertension classification among adults was done following JNC 7 (US Department of Health and Human Services 2003). Height, weight, skinfold thickness at triceps (SFT), mid-upper arm circumference (MUAC), haemoglobin level and haematocrit percentage were also measured. SFT and MUAC were taken on the left arm. Anthropometric measurements were taken following Weiner and Lourie (1981). Height was measured with the help of Harpenden anthropometer rod, and weight with a bathroom spring scale. Height was recorded to the nearest millimetre, weight to nearest 0.5 kg, MUAC to nearest millimetre and skinfold thickness to the nearest 0.1 mm. BMI was calculated as weight/(height)$^2$ in kg m$^{-2}$. Sahli's haemometer was used for estimating haemoglobin level expressed as g/100 mL. A LW Scientific ZIPOcrit micro-haematocrit centrifuge was used for estimating haematocrit. Apart from its supposed physiological association with BP, haemoglobin level and haematocrit are measures to assess anaemia, which is one of the important components of nutritional status (Path, US Agency for International Development 1997). Polycythaemia found commonly among Andean highlanders was not found in any of the Tibetan sample. All the measurements were taken by single investigator (V.T.).

The ages of the children and adolescents were collected from the school records and was cross-checked with the individuals. Six months were deducted from the reported age (based on Tibetan animal element calendar) for those adults who did not remember their date of birth according to the Gregorian calendar (English calendar). The individuals are grouped into 2-year age groups until age 20. Adults (20 years and above) were grouped into three age groups 20–39, 40–59 and 60+. Statistical analysis was carried out with MS Excel 2000 and SPSS 10.0. Log-normal variables like BP, skin SFT and MUAC were logarithmically transformed to base e (ln) while performing statistical analysis where normality of data is presumed. Comparison of the three low-altitude places showed no difference for BP values. Therefore, the data of the three low-altitude places were pooled and is referred to as the low-altitude sample. Stepwise regression was performed to assess which variables explained the variation in SBP and DBP most significantly. These variables were then controlled for in ANCOVA for comparing low and high altitudes. Stepwise regression and comparisons between the places of residence and between low and high altitudes were carried out separately for children and adolescents (10–19 years) and adults (20 years and above). Logistic regression was performed to test whether hypertension is significantly associated with age, sex and altitude. The stage 1 and stage 2 hypertension were grouped together as hypertensive, and normal and pre-hypertension were grouped together as normal while performing logistic regression.

## Results

For both SBP and DBP in children and adolescents, and in adults, there was no difference between the three low-altitude places. Similar ANCOVA analysis comparing the four places of residence (three low altitudes and one high altitude) showed significant difference (result not presented) for children and adolescents and not for adults. Table I and Figure 2 compare the mean SBP and DBP at the two altitudes in males and females. A common aspect in the graphs in Figure 2 is that for both males and females, both SBP and DBP show similar values at the two altitudes for ages above 20 years. For children and adolescents, the high-altitude sample shows much lower values for BP. Table II presents the correlation of SBP and DBP with the variables age, height, weight, SFT, MUAC, BMI, haematocrit and haemoglobin level for males and females, stratified by altitude and age group. MUAC shows significant correlation with SBP and DBP for both males and females at both altitudes and both age groups. BMI also shows significant correlation with SBP and DBP except for male children and adolescents at high altitude. Haematocrit and haemoglobin level show non-significant correlation with SBP and DBP for both age groups at high altitude. At low altitude, haematocrit and haemoglobin level show significant correlations for male children and adolescents. For adults at low altitude correlation with both SBP and DBP is significant only for haemoglobin level for males and haematocrit with DBP for females. Significant correlations are observed for more variables at low altitude than at high altitude. In male children and adolescents at high altitude there is a significant correlation with DBP only for MUAC.

Tables III and IV present the result of stepwise regression of SBP and DBP on age, height, weight, SFT, MUAC, BMI, haematocrit and haemoglobin level in children and adolescents (Table III), and adults (Table IV), separately for low and high altitude. MUAC is associated with SBP in children and adolescents at high altitude. There were no significant correlates to DBP in male children and adolescents at high altitude. In low altitude male children and adolescents, MUAC and SFT were related to SBP, and SFT and haemoglobin level were related to DBP. Among female children and adolescents at high altitude BMI and age were related to SBP, and SFT was related to DBP. In low altitude female children and adolescents MUAC and haematocrit were related to SBP, and MUAC to DBP.

BMI, age and haematocrit were associated with SBP and DBP among male adults at low altitude (Table IV). Among male adults at both low and high altitudes the same correlates were related to BP. MUAC was associated with SBP and DBP for males at high altitude. Among female adults at high altitude SFT was associated with SBP, and age with DBP. At low altitude in female adults, age was related to SBP, and age and weight with DBP.

Table V presents the ANCOVA table comparing low and high altitudes for SBP and DBP controlling for other correlates in children and adolescents. In both sexes for children

Table I. Mean and standard deviation for systolic and diastolic blood pressure at high and low altitudes.

| Sex | Age group | High altitude *n* | Mean | SD | Low altitude *n* | Mean | SD | *t* |
|---|---|---|---|---|---|---|---|---|
| *Systolic blood pressure* | | | | | | | | |
| Male | 10–11 | 12 | 98.67 | 11.00 | 31 | 104.03 | 11.81 | 1.378 |
| | 12–13 | 21 | 98.10 | 9.28 | 44 | 103.77 | 8.70 | 2.479* |
| | 14–15 | 33 | 102.30 | 12.66 | 53 | 108.72 | 12.92 | 2.322* |
| | 16–17 | 20 | 105.10 | 11.25 | 41 | 114.63 | 11.24 | 3.279** |
| | 18–19 | 4 | 113.50 | 6.40 | 29 | 115.17 | 13.88 | 0.138 |
| | 20–39 | 10 | 121.20 | 14.09 | 45 | 122.53 | 17.27 | 0.154 |
| | 40 59 | 15 | 132.00 | 19.89 | 37 | 129.76 | 19.23 | −0.387 |
| | 60+ | 24 | 141.00 | 17.52 | 60 | 145.08 | 20.13 | 0.829 |
| Female | 10–11 | 18 | 98.00 | 9.28 | 35 | 105.26 | 10.52 | 2.478* |
| | 12–13 | 22 | 102.73 | 14.43 | 51 | 110.27 | 10.37 | 2.753** |
| | 14–15 | 13 | 98.46 | 10.71 | 41 | 105.39 | 12.18 | 1.761 |
| | 16–17 | 24 | 104.75 | 11.36 | 31 | 109.84 | 10.60 | 1.763 |
| | 18–19 | 4 | 99.00 | 11.02 | 10 | 103.40 | 12.55 | 0.598 |
| | 20–39 | 36 | 117.06 | 18.16 | 67 | 116.03 | 13.22 | 0.162 |
| | 40-59 | 30 | 130.47 | 20.99 | 57 | 131.49 | 21.87 | 0.181 |
| | 60+ | 35 | 148.26 | 30.00 | 77 | 148.69 | 19.63 | 0.431 |
| *Diastolic blood pressure* | | | | | | | | |
| Male | 10–11 | 12 | 52.83 | 11.39 | 31 | 63.19 | 8.38 | 3.403** |
| | 12–13 | 21 | 60.57 | 6.17 | 44 | 63.52 | 8.57 | 1.305 |
| | 14–15 | 33 | 60.55 | 11.03 | 53 | 64.81 | 10.41 | 1.891 |
| | 16–17 | 20 | 58.50 | 8.51 | 41 | 70.12 | 9.34 | 4.630** |
| | 18–19 | 4 | 71.50 | 8.06 | 29 | 70.14 | 12.35 | 0.297 |
| | 20-39 | 10 | 76.60 | 9.94 | 45 | 78.04 | 14.62 | 0.141 |
| | 40-59 | 15 | 82.67 | 14.49 | 37 | 82.97 | 15.18 | 0.080 |
| | 60+ | 24 | 84.67 | 7.91 | 60 | 85.77 | 11.34 | 0.291 |
| Female | 10–11 | 18 | 55.56 | 7.66 | 35 | 64.20 | 8.88 | 3.524** |
| | 12–13 | 22 | 58.55 | 14.57 | 51 | 64.98 | 10.90 | 2.194* |
| | 14–15 | 13 | 58.15 | 11.30 | 41 | 68.07 | 9.54 | 3.359** |
| | 16 17 | 24 | 61.17 | 10.08 | 31 | 70.55 | 6.79 | 4.279** |
| | 18–19 | 4 | 52.50 | 4.43 | 10 | 71.10 | 10.98 | 3.412** |
| | 20–39 | 36 | 72.17 | 11.57 | 67 | 76.51 | 12.49 | 1.695 |
| | 40–59 | 30 | 83.07 | 11.81 | 57 | 85.44 | 14.23 | 0.664 |
| | 60+ | 35 | 88.77 | 17.12 | 77 | 92.82 | 13.39 | 1.610 |

*$p < 0.05$; **$p < 0.01$.

and adolescents the adjusted SBP and DBP values are significantly lower at high altitude than at low altitude.

Table VI presents the above comparison for Tibetan adults. For adults there were no BP differences between altitudes.

The slope of BP curves in Figure 2 shows that adults exhibit a sharp increase in BP with age. BP values among adults show increasing trend with age even when the effects of height, weight, SFT, MUAC, BMI, haematocrit percentage and altitude were controlled for in ANCOVA (For SBP, $F$ value for age, males: 19.217 ($p = 0.000$), females: 17.108 ($p = 0.000$); for DBP, $F$ value for age, males: 9.905 ($p = 0.002$), females: 20.019 ($p = 0.000$).)

The prevalence of hypertension among Tibetan adults at high and low altitude is presented in Table VII. Logistic regression performed by taking sex, altitude and age as independent variable show that only age is significantly related to hypertension.

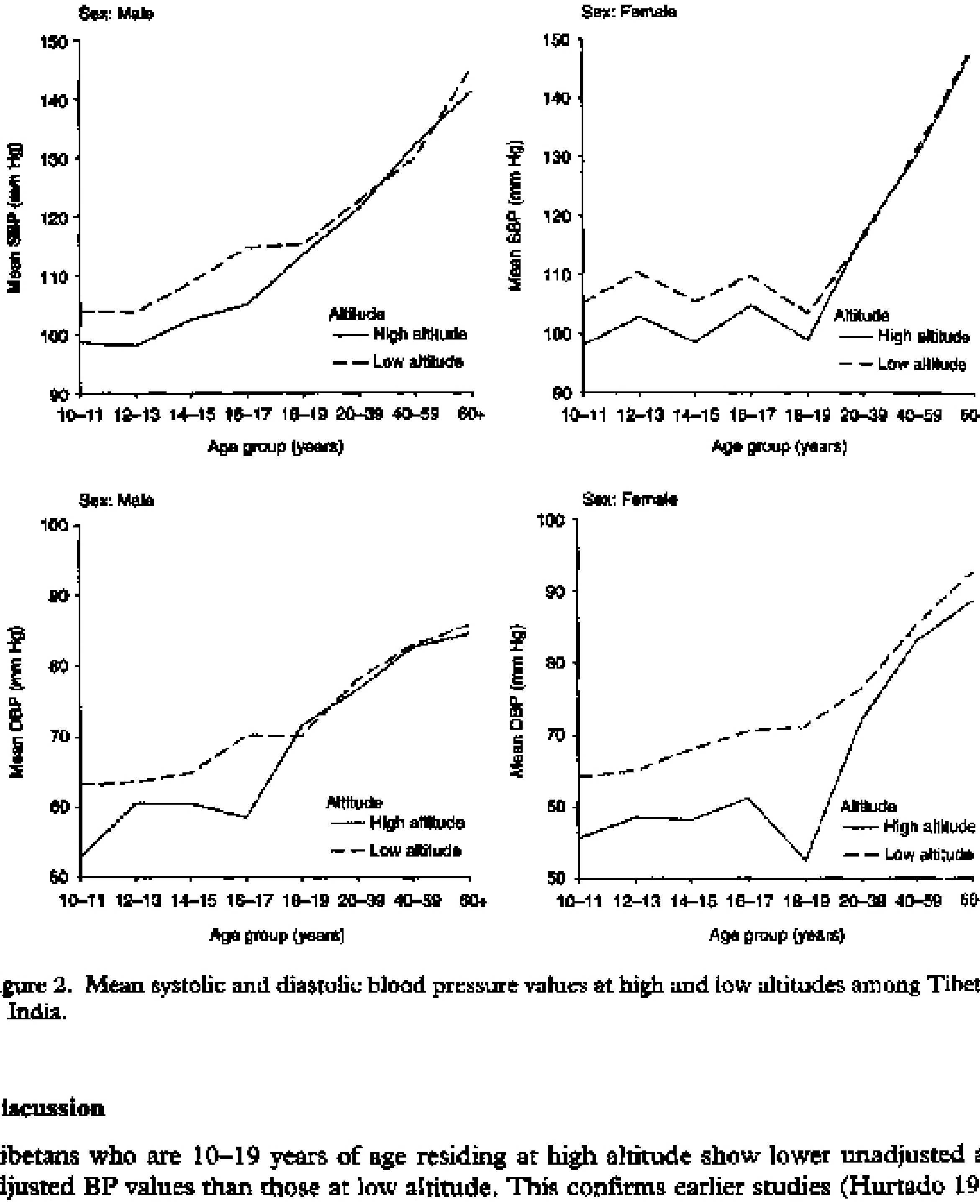


Figure 2. Mean systolic and diastolic blood pressure values at high and low altitudes among Tibetans in India.

## Discussion

Tibetans who are 10–19 years of age residing at high altitude show lower unadjusted and adjusted BP values than those at low altitude. This confirms earlier studies (Hurtado 1964; Ruiz and Penaloza 1977; Mirrakhimov 1971, cited by Mirrakhimov 1978; Basu et al. 1984; Beall et al. 1997). In contrast to the Tibetan children and adolescents, Tibetan adults show similar BP values at both altitudes.

It is not clear why the present results do not find the altitude difference in BP among adults. One factor may be prior exposure to high-altitude life since most adults above the age of 40 years, irrespective of the present place of residence, were born at high altitude. This would produce greater similarity of adult BP adult at both altitudes. BP is, of course, multi-factorial and is influenced by many lifestyle variables such as diet and nutrition, physical activity, smoking, alcohol consumption, and mental stress (Stamler 1991). The present study lacks data on physical activity, dietary intake, smoking, alcohol consumption and mental stress, and future work on altitude and adult BP should include such measures.

Table II. Pearson's correlation coefficient ($r$) between blood pressure and other variables by altitude and age group.

| Age group | Variables | Male | | | Female | | |
|---|---|---|---|---|---|---|---|
| | | $n$ | SBP† | DBP† | $n$ | SBP† | DBP† |
| *High altitude* | | | | | | | |
| Children and adolescents (10–19) | Age | 90 | 0.318** | 0.165 | 81 | 0.130 | 0.097 |
| | Height | 90 | 0.372** | 0.185 | 81 | 0.210 | 0.218 |
| | Weight | 90 | 0.414** | 0.180 | 81 | 0.375** | 0.285* |
| | SFT† | 89 | −0.125 | −0.040 | 81 | 0.189 | 0.305** |
| | MUAC† | 88 | 0.415** | 0.221* | 81 | 0.367** | 0.305** |
| | BMI | 90 | 0.397** | 0.147 | 81 | 0.423** | 0.284* |
| | Haematocrit | 70 | 0.170 | −0.019 | 67 | −0.152 | −0.124 |
| | Hb level | 68 | 0.110 | 0.127 | 57 | −0.145 | −0.084 |
| Adults (20+) | Age | 49 | 0.460** | 0.299* | 101 | 0.549** | 0.501** |
| | Height | 47 | 0.048 | 0.004 | 98 | −0.225* | −0.263** |
| | Weight | 49 | 0.460** | 0.338* | 99 | 0.270** | 0.287** |
| | SFT† | 43 | 0.335* | 0.140 | 86 | 0.231* | 0.264* |
| | MUAC† | 43 | 0.492** | 0.378* | 87 | 0.277** | 0.268* |
| | BMI | 47 | 0.506** | 0.429** | 97 | 0.384** | 0.414** |
| | Haematocrit | 22 | −0.111 | −0.312 | 38 | −0.015 | −0.041 |
| | Hb level | 22 | −0.362 | −0.024 | 30 | 0.153 | 0.273 |
| *Low altitude* | | | | | | | |
| Children and adolescents (10–19) | Age | 198 | 0.360** | 0.222** | 168 | 0.025 | 0.261** |
| | Height | 198 | 0.419** | 0.266** | 168 | 0.197* | 0.276** |
| | Weight | 198 | 0.467** | 0.340** | 167 | 0.290** | 0.317** |
| | SFT† | 198 | 0.272** | 0.242** | 167 | 0.203** | 0.302** |
| | MUAC† | 198 | 0.512** | 0.352** | 167 | 0.305** | 0.348** |
| | BMI | 198 | 0.387** | 0.322** | 167 | 0.308** | 0.291** |
| | Haematocrit | 135 | 0.253** | 0.173* | 133 | 0.118 | 0.040 |
| | Hb level | 143 | 0.264** | 0.198* | 87 | 0.205 | 0.133 |
| Adults (20+) | Age | 142 | 0.508** | 0.284** | 201 | 0.596** | 0.480** |
| | Height | 136 | −0.251** | −0.169 | 191 | −0.183* | −0.122 |
| | Weight | 139 | 0.276** | 0.378** | 197 | 0.245** | 0.294** |
| | SFT† | 83 | 0.482** | 0.488** | 110 | 0.225* | 0.235* |
| | MUAC† | 84 | 0.403** | 0.453** | 107 | 0.334** | 0.377** |
| | BMI | 135 | 0.399** | 0.466** | 190 | 0.317** | 0.360** |
| | Haematocrit | 75 | 0.118 | 0.212 | 104 | 0.192 | 0.239* |
| | Hb level | 63 | 0.283* | 0.356** | 86 | −0.061 | 0.012 |

†ln transformed.
*$p < 0.05$, **$p < 0.01$.

There is a cross-sectional age increase in BP values at both the altitudes, the increase being sharper at high altitude than at low altitude. An age-related increase in adult BP suggests that other lifestyle factors might be playing a major role as well, thus masking the effect of altitude. The effect of lifestyle variables might be less among children and adolescents and thus the effect of altitude is more discernible.

The measures of adiposity like SFT, BMI, MUAC and weight show strong correlation with BP for both children and adolescents, and adults. In fact among children and adolescents one of these variables, and not age, is most significant in stepwise regression at both the altitudes for both the sexes. Among adults, one measure of adiposity was always found to significantly explain the variation in BP, except for females at high altitude where age is the only significant variable. Thus adiposity seems to affect BP significantly among Tibetans.

**Table III.** Result of stepwise regression entering the variables age, height, weight, skinfold thickness at triceps (SFT)†, mid-upper arm circumference (MUAC)†, BMI, haematocrit and haemoglobin level for Tibetan children and adolescents (10–19 years).

| Sex | Altitude | Model | $R^2$ | Variables | $B$ | SE | Beta | $t$ | $p$ |
|---|---|---|---|---|---|---|---|---|---|
| *Dependent variable: SBP†* | | | | | | | | | |
| Male | High altitude | 1 | 0.176 | (Constant) | 3.612 | 0.286 | | 12.611 | 0.000 |
| | | | | MUAC | 0.338 | 0.095 | 0.419 | 3.548 | 0.001 |
| | Low altitude | 2 | 0.259 | (Constant) | 3.596 | 0.207 | | 17.349 | 0.000 |
| | | | | MUAC | 0.321 | 0.074 | 0.396 | 4.34 | 0.000 |
| | | | | SFT | 0.058 | 0.028 | 0.186 | 2.034 | 0.044 |
| Female | High altitude | 3 | 0.317 | (Constant) | 4.799 | 0.192 | | 25.022 | 0.000 |
| | | | | BMI | 0.027 | 0.006 | 0.707 | 4.6 | 0.000 |
| | | | | Age | −0.025 | 0.007 | −0.521 | −3.39 | 0.001 |
| | | | | Haematocrit | −0.009 | 0.004 | −0.251 | −2.11 | 0.040 |
| | Low altitude | 2 | 0.174 | (Constant) | 3.611 | 0.301 | | 11.99 | 0.000 |
| | | | | MUAC | 0.265 | 0.094 | 0.302 | 2.816 | 0.006 |
| | | | | Haematocrit | 0.006 | 0.002 | 0.276 | 2.576 | 0.012 |
| *Dependent variable: DBP†* | | | | | | | | | |
| Male | Low altitude | 2 | 0.122 | (Constant) | 3.636 | 0.151 | | 24.078 | 0.000 |
| | | | | SFT | 0.145 | 0.042 | 0.302 | 3.422 | 0.001 |
| | | | | Hb level | 0.021 | 0.009 | 0.198 | 2.24 | 0.027 |
| Female | High altitude | 1 | 0.133 | (Constant) | 3.241 | 0.272 | | 11.897 | 0.000 |
| | | | | SFT | 0.314 | 0.111 | 0.365 | 2.828 | 0.007 |
| | Low altitude | 1 | 0.193 | (Constant) | 2.644 | 0.371 | | 7.126 | 0.000 |
| | | | | MUAC | 0.505 | 0.121 | 0.44 | 4.182 | 0.000 |

†ln transformed.

**Table IV.** Result of stepwise regression entering the variables age, height, weight, skinfold thickness at triceps (SFT)†, mid-upper arm circumference (MUAC)†, BMI, haematocrit and haemoglobin level for Tibetan adults (20 years and above).

| Sex | Altitude | Model | $R^2$ | Variables | $B$ | SE | Beta | $t$ | $p$ |
|---|---|---|---|---|---|---|---|---|---|
| *Dependent Variable: SBP†* | | | | | | | | | |
| Male | High altitude | 1 | 0.292 | (Constant) | 1.960 | 1.19 | | 1.647 | 0.122 |
| | | | | MUAC | 0.879 | 0.366 | 0.541 | 2.405 | 0.031 |
| | Low altitude | 3 | 0.456 | (Constant) | 3.918 | 0.164 | | 23.859 | 0.000 |
| | | | | BMI | 0.011 | 0.004 | 0.328 | 2.74 | 0.008 |
| | | | | Age | 0.005 | 0.001 | 0.426 | 3.661 | 0.001 |
| | | | | Haematocrit | 0.010 | 0.004 | 0.341 | 2.755 | 0.008 |
| Female | High altitude | 1 | 0.227 | (Constant) | 4.345 | 0.149 | | 29.254 | 0.000 |
| | | | | SFT | 0.148 | 0.055 | 0.476 | 2.708 | 0.012 |
| | Low altitude | 1 | 0.287 | (Constant) | 4.550 | 0.048 | | 95.717 | 0.000 |
| | | | | Age | 0.007 | 0.001 | 0.536 | 5.274 | 0.000 |
| *Dependent variable: DBP†* | | | | | | | | | |
| Male | High altitude | 1 | 0.248 | (Constant) | 1.904 | 1.161 | | 1.64 | 0.123 |
| | | | | MUAC | 0.766 | 0.357 | 0.498 | 2.149 | 0.05 |
| | Low altitude | 3 | 0.460 | (Constant) | 3.103 | 0.214 | | 14.524 | 0.000 |
| | | | | BMI | 0.014 | 0.005 | 0.314 | 2.631 | 0.011 |
| | | | | Haematocrit | 0.016 | 0.005 | 0.422 | 3.425 | 0.001 |
| | | | | Age | 0.006 | 0.002 | 0.363 | 3.135 | 0.003 |
| Female | High altitude | 1 | 0.289 | (Constant) | 4.032 | 0.077 | | 52.195 | 0.000 |
| | | | | Age | 0.006 | 0.002 | 0.538 | 3.188 | 0.004 |
| | Low altitude | 2 | 0.332 | (Constant) | 3.907 | 0.094 | | 41.64 | 0.000 |
| | | | | Age | 0.007 | 0.001 | 0.467 | 4.541 | 0.000 |
| | | | | Weight | 0.003 | 0.001 | 0.234 | 2.269 | 0.026 |

†ln transformed.

Table V. ANCOVA comparing low and high altitudes for SBP and DBP controlling for variables significantly affecting BP (from stepwise regression) among Tibetan children and adolescents (10–19 years).

| Sex | Source | Type III sum of squares | df | Mean square | $F$ | $p$ |
|---|---|---|---|---|---|---|
| *Dependent variable: SBP*† | | | | | | |
| Male | Corrected model | 1.126[a] | 3 | 0.375 | 38.078 | 0.000 |
| | Intercept | 7.551 | 1 | 7.551 | 765.884 | 0.000 |
| | MUAC† | 0.724 | 1 | 0.724 | 73.433 | 0.000 |
| | SFT† | 4.37E–04 | 1 | 4.37E–04 | 0.044 | 0.833 |
| | Altitude | 5.84E–02 | 1 | 5.84E–02 | 5.921 | 0.016 |
| | Error | 2.78 | 282 | 9.86E–03 | | |
| | Total | 6227.032 | 286 | | | |
| | Corrected total | 3.906 | 285 | | | |
| Female | Corrected model | 0.447[b] | 5 | 8.93E–02 | 7.533 | 0.000 |
| | Intercept | 2.119 | 1 | 2.119 | 178.718 | 0.000 |
| | BMI | 5.67E–02 | 1 | 5.67E–02 | 4.785 | 0.030 |
| | Age | 6.46E–02 | 1 | 6.46E–02 | 5.448 | 0.021 |
| | Haematocrit | 1.25E–02 | 1 | 1.25E–02 | 1.051 | 0.307 |
| | MUAC† | 2.85E–02 | 1 | 2.85E–02 | 2.404 | 0.123 |
| | Altitude | 6.19E–02 | 1 | 6.19E–02 | 5.219 | 0.024 |
| | Error | 1.636 | 138 | 1.19E–02 | | |
| | Total | 3099.414 | 144 | | | |
| | Corrected total | 2.083 | 143 | | | |
| *Dependent variable: DBP*† | | | | | | |
| Male | Corrected model | 0.679[c] | 3 | 0.226 | 7.425 | 0.000 |
| | Intercept | 29.934 | 1 | 29.934 | 982.212 | 0.000 |
| | SFT† | 0.152 | 1 | 0.152 | 5.002 | 0.026 |
| | Hb level | 7.22E–02 | 1 | 7.22E–02 | 2.369 | 0.125 |
| | Altitude | 0.366 | 1 | 0.366 | 12.016 | 0.001 |
| | Error | 6.126 | 201 | 3.05E–02 | | |
| | Total | 3548.964 | 205 | | | |
| | Corrected total | 6.805 | 204 | | | |
| Female | Corrected Model | 2.251[d] | 3 | 0.75 | 23.633 | 0.000 |
| | Intercept | 2.762 | 1 | 2.762 | 86.993 | 0.000 |
| | SFT† | 7.71E–02 | 1 | 7.71E–02 | 2.429 | 0.120 |
| | MUAC† | 0.205 | 1 | 0.205 | 6.469 | 0.012 |
| | Altitude | 0.859 | 1 | 0.859 | 27.075 | 0.000 |
| | Error | 7.746 | 244 | 3.18E–02 | | |
| | Total | 4269.408 | 248 | | | |
| | Corrected total | 9.997 | 247 | | | |

[a]$R^2 = 0.288$ (adjusted $R^2 = 0.281$); [b]$R^2 = 0.214$ (adjusted $R^2 = 0.186$); [c]$R^2 = 0.100$ (adjusted $R^2 = 0.086$); [d]$R^2 = 0.225$ (adjusted $R^2 = 0.216$).
†ln transformed.

Very few studies have reported BP values or the prevalence of hypertension among the Tibetans in Tibet and in India. In a study conducted in the year 1979, Sun (1986) reported higher prevalence of hypertension among Tibetans at Lhasa in Tibet compared to Han, a low-altitude native population. The prevalence of hypertension in our sample was much higher than that reported by Sun (1986) for Tibetans in Tibet (Tripathy et al. 2006). The other two studies (Weitz 1982 and Sehgal et al. 1968) on BP of Tibetans were based on study samples of relatively recent migrant refugee populations in Nepal and India. Weitz (1982) reported higher BP values at low altitude than at high altitude. The BP values reported by Sehgal et al. (1968) among Tibetan adult males at Dalhousie (2066 m) in India were lower compared to American and European samples. An unpublished report on

Table VI. ANCOVA comparing low and high altitude places for SBP and DBP controlling for variables significantly affecting BP (from stepwise regression) among Tibetan adults (20 years and above).

| Sex | Source | Type III sum of squares | d.f. | Mean square | $F$ | $p$ |
|---|---|---|---|---|---|---|
| *Dependent variable: SBP*† | | | | | | |
| Male | Corrected model | 0.585[a] | 5 | 0.117 | 8.624 | 0 |
| | Intercept | 0.346 | 1 | 0.346 | 25.501 | 0 |
| | MUAC† | 1.39E–02 | 1 | 1.39E–02 | 1.021 | 0.316 |
| | BMI | 1.47E–02 | 1 | 1.47E–02 | 1.085 | 0.301 |
| | Age | 0.202 | 1 | 0.202 | 14.883 | 0 |
| | Haematocrit | 4.00E–02 | 1 | 4.00E–02 | 2.947 | 0.09 |
| | Altitude | 6.11E–04 | 1 | 6.11E–04 | 0.045 | 0.833 |
| | Error | 0.977 | 72 | 1.36E–02 | | |
| | Total | 1821.76 | 78 | | | |
| | Corrected total | 1.562 | 77 | | | |
| Female | Corrected model | 1.689[b] | 3 | 0.563 | 27.671 | 0 |
| | Intercept | 75.414 | 1 | 75.414 | 3707.069 | 0 |
| | SFT† | 0.186 | 1 | 0.186 | 9.162 | 0.003 |
| | Age | 1.311 | 1 | 1.311 | 64.42 | 0 |
| | Altitude | 2.23E–05 | 1 | 2.23E–05 | 0.001 | 0.974 |
| | Error | 3.906 | 192 | 2.03E–02 | | |
| | Total | 4557.834 | 196 | | | |
| | Corrected total | 5.595 | 195 | | | |
| *Dependent variable: DBP*† | | | | | | |
| Male | Corrected model | 0.797[c] | 5 | 0.159 | 7.93 | 0 |
| | Intercept | 0.168 | 1 | 0.168 | 8.34 | 0.005 |
| | MUAC † | 3.04E–02 | 1 | 3.04E–02 | 1.513 | 0.223 |
| | BMI | 1.07E–02 | 1 | 1.07E–02 | 0.53 | 0.469 |
| | Haematocrit | 0.137 | 1 | 0.137 | 6.819 | 0.011 |
| | Age | 0.187 | 1 | 0.187 | 9.326 | 0.003 |
| | Altitude | 2.94E–04 | 1 | 2.94E–04 | 0.015 | 0.904 |
| | Error | 1.448 | 72 | 2.01E–02 | | |
| | Total | 1498.467 | 78 | | | |
| | Corrected total | 2.245 | 77 | | | |
| Female | Corrected model | 3.343[d] | 3 | 1.114 | 50.098 | 0 |
| | Intercept | 136.227 | 1 | 136.227 | 6125.315 | 0 |
| | Age | 2.362 | 1 | 2.362 | 106.222 | 0 |
| | Weight | 0.902 | 1 | 0.902 | 40.539 | 0 |
| | Altitude | 3.50E–02 | 1 | 3.50E–02 | 1.575 | 0.21 |
| | Error | 6.494 | 292 | 2.22E–02 | | |
| | Total | 5772.188 | 296 | | | |
| | Corrected total | 9.837 | 295 | | | |

[a]$R^2=0.375$ (adjusted $R^2=0.331$); [b]$R^2=0.302$ (adjusted $R^2=0.291$); [c]$R^2=0.355$ (adjusted $R^2=0.310$); [d]$R^2=0.340$ (adjusted $R^2=0.333$).
†ln transformed.

Tibetans at a new settlement at Bylakuppe in South India, reports 80% prevalence of hypertension among those 35 years and above (Tsewang 2005). The only explanation that was given by Sun (1986) for the higher prevalence of hypertension among Tibetans compared to Han at high altitude was a higher intake of salt.

Migrants from Tibet to India now experience a more sedentary and modernized way of life. Similar changes have been observed by Penny-Dimri (1994) in other settlements in North India. The presence of at least one medical clinic in the vicinity of the Tibetan camps in the settlements and the awareness created by the Health programmes run by the

Table VII. Hypertension classification and logistic regression on hypertension taking age, sex and altitude as independent variables among Tibetan adults.

| | | Normal+prehypertension | | | Stage 1 + stage 2 hypertension | | |
|---|---|---|---|---|---|---|---|
| Sex | Altitude | Age group | *n* | % | *n* | % | Total |
| Male | High altitude | 20–39 | 8 | 80.00 | 2 | 20.00 | 10 |
| | | 40–59 | 8 | 53.30 | 7 | 46.70 | 15 |
| | | 60+ | 11 | 47.80 | 12 | 52.20 | 23 |
| | | Total | 27 | 56.30 | 21 | 43.80 | 48 |
| | Low altitude | 20–39 | 34 | 75.60 | 11 | 24.40 | 45 |
| | | 40–59 | 26 | 70.30 | 11 | 29.70 | 37 |
| | | 60+ | 19 | 32.80 | 39 | 67.20 | 58 |
| | | Total | 79 | 56.40 | 61 | 43.60 | 140 |
| Female | High altitude | 20–39 | 29 | 80.60 | 7 | 19.40 | 36 |
| | | 40–59 | 21 | 70.00 | 9 | 30.00 | 30 |
| | | 60+ | 12 | 35.30 | 22 | 64.70 | 34 |
| | | Total | 62 | 62.00 | 38 | 38.00 | 100 |
| | Low altitude | 20–39 | 61 | 91.00 | 6 | 9.00 | 67 |
| | | 40–59 | 35 | 64.80 | 19 | 35.20 | 54 |
| | | 60+ | 19 | 26.40 | 53 | 73.60 | 72 |
| | | Total | 115 | 59.60 | 78 | 40.40 | 193 |
| Variables | | *B* | SE | Wald | d.f. | *p* | Exp(*B*) |
| Constant | | −3.324 | 0.358 | 85.991 | 1 | 0.000 | 0.036 |
| Age | | 0.059 | 0.006 | 89.438 | 1 | 0.000 | 1.061 |
| Sex(1) | | −0.125 | 0.214 | 0.340 | 1 | 0.560 | 0.883 |
| Altitude(1) | | −0.152 | 0.224 | 0.464 | 1 | 0.496 | 0.859 |

Categorical variables coding: altitude: low altitude: 0, high altitude: 1; sex: female: 0, male: 1.

Department of Health, Central Tibetan administration as well as by the Indian Hospitals near the settlements has resulted in better health status so far as nutritional status and infectious diseases are concerned. Populations with adequate nutritional status, and even a tendency towards obesity, show lower incidences of infectious diseases and generally higher BP values (Stamler 1991; Park 2002; Kaplan and Opie 2006).

Lower BP values at high altitude among children and adolescents and similar adult BP at both the altitudes suggest that the increase in BP with age may be greater at high altitude as individuals become adults. The increase in BP with age at both the altitudes is similar to the pattern observed among the populations undergoing modernization. Thus, one factor potentially responsible for the higher BP with age of adult Tibetans at both altitudes could be the stress of cultural and social change due to modernization in India and in Tibet, as observed in other populations (Dressler 1999).


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