

Hemoglobin levels in Qinghai-Tibet: different effects of gender for Tibetans vs. Han

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Wu, Tianyi, Xiaoqin Wang, Chunyin Wei, Huawei Cheng, Xiaozhen Wang, Yan Li, Ge-Dong, Haining Zhao, Ping Young, Guilan Li, and Zhigang Wang. Hemoglobin levels in Qinghai-Tibet: different effects of gender for Tibetans vs. Han. *J Appl Physiol* 98: 598–604, 2005. First published July 16, 2004; doi:10.1152/jappphysiol.01034.2002.—The Tibetan population, long a resident on the Qinghai-Tibetan Plateau, has lower hemoglobin concentrations than Han Chinese migrants, but it is incompletely known how gender affects the hemoglobin concentrations in the two populations at various altitudes. Measurements of hemoglobin concentration were obtained in 5,887 healthy male and female Tibetan and Han residents aged 5–60 yr, at altitudes of 2,664, 3,813, 4,525, and 5,200 m. Multiple regression equations showed the β -coefficients for altitude and for age were higher ($P < 0.05$) in Han men than in Tibetan men and in Han women than in Tibetan women. Analysis indicated a significant three-way interaction between altitude, gender, and ethnicity ($\chi^2 = 3.72$, $P = 0.05$). With increasing altitude, men progressively had more hemoglobin than women in the Han, but not the Tibetan, population. Above 2,664 m, this gender-related difference in hemoglobin concentration increased from childhood to young adulthood more in Han than in Tibetans. We suggest that the Han-Tibetan ethnic difference in the effect of altitude on hemoglobin concentration depends to a large extent on gender.

Tibetan plateau; hemoglobin; normal values; puberty

HAN SUBJECTS who immigrate to the Qinghai-Tibetan Plateau have hemoglobin concentrations ([Hb]) higher than native Tibetans (1, 4, 5, 8, 13, 23, 36), suggesting an ethnic difference in the erythropoietic response to altitude residence. Also, male subjects, both Han and Tibetan, have higher [Hb] than their female counterparts (5, 13), suggesting gender plays an important role in the chronic erythropoietic response to altitude. Combining these concepts, we considered the hypothesis that much of the ethnic difference in the effect of altitude on [Hb] might relate to gender. Reported [Hb] vary among reports, which often focused on different issues and involved small numbers of subjects from different altitudes and regions in Tibet. Furthermore, few studies have examined [Hb] in women and children (see Ref. 13). A recent study of [Hb] in Han and Tibetan subjects from ages 6 to 30 yr living at altitudes of 3,200 and 3,800 m (13) did not directly evaluate our hypothesis, but their data suggested an ethnic difference in [Hb], which might depend on gender at the higher altitude. Needed to evaluate the hypothesis more fully, were studies involving large numbers of subjects (Han and Tibetan, men and women, adults and children) at several altitudes.

Our approach was to obtain hematological data in persons living on the Plateau at mean altitudes ranging from 2,664 to 5,200 m. We focused our efforts on healthy residents of rural areas, a strategy that minimized the variables of disease and environmental contamination. These were also areas considered to have adequate nutrition regarding iron, protein, and caloric intake, as previously determined (15, 35). Given the previously described differences in hemoglobin levels between Tibetan and Han Chinese residents of the Plateau (26), data collection included both native Tibetans, a population long residing at altitude (23, 26), and, from the same communities, Han Chinese born near sea level but who had migrated to the Plateau. By having large samples from both ethnic populations, we could compare by multiple regression analysis (for varying altitude and age) hemoglobin measurements for Han men versus Tibetan men and Han women versus Tibetan women. Such an extensive examination is novel and is important to better understand the effects of gender on [Hb] at high altitude.

MATERIALS AND METHODS

Geographic areas. Preliminary studies for this project were published in 1987 (15) and 1989 (35), but the data in the present report were collected in the interval between February 1998 and March 2002. Due to the sparse and scattered population in the Qinghai-Tibetan Plateau, this survey was conducted in four geographic areas. All areas are located in the Northeastern and Southwestern part of the Plateau and have a highland continental climate. 1) The Xining-Golmud area (Xining at 2,261 m, Golmud at 2,801 m, and 3 neighboring agricultural villages at 2,560, 2,808, and 2,900 m) had a mean altitude of $2,664 \pm 258$ m. 2) Six pastoral and agricultural villages in the area near Habei (3,719, 3,750, 3,762, 3,790, 3,890, and 3,986 m) averaged $3,813 \pm 96$ m altitude. 3) Seven villages in the mountainous pastures of the Qingnan area in the Kunlun and Bayankala Mountains (4,180, 4,200, 4,300, 4,420, 4,650, 4,700, and 5,226 m) had a mean altitude of $4,525 \pm 370$ m. 4) In addition to the above, populations were sampled at 5,200 m in a Tibetan village known as Snow Mountain, near Mt. Animaqin. It is one of the highest inhabited communities in Tibet. Han Chinese, who had lived in the village for >1 yr, were also studied.

Subjects. Healthy adult high-altitude residents ($n = 5,887$) were studied. To minimize influences from ambient pollution, we favored rural areas devoid of mining and without high population density. A questionnaire for participants indicated age, gender, ethnicity, occupation, place of birth, length of time at lowland, length of residence since migration to high altitude, current and past duration of altitude residence, history of smoking and consumption of alcoholic beverages, current and past medical history, and family history. Whether a subject was Tibetan or Han was determined by the questionnaire.

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genealogical history, and the census registry. No subjects known to be of mixed Han-Tibetan origin were included. Smokers and those who had used drugs in recent weeks were excluded. Menstrual and obstetric history were collected on all women. Pregnant women and those who had delivered within 3 mo were excluded. Medical history, physical examinations, and laboratory tests (resting electrocardiogram, pulmonary function, chest roentgenogram, blood gas analysis, and oxygen saturation) were performed to ensure the subjects' normality. We attempted to exclude patients with chronic mountain sickness by not including persons with hemoglobin values >23 g/100 ml, following the criterion of Carlos Monge C (22). Children (ages 5 up to and including 15 yr) were often reluctant to have blood drawn, so the sample sizes were relatively small for both Tibetan and Han children. The age delineation for childhood followed the report of Leon-Velarde et al. (19) and allows comparison with high-altitude data from the Andes. The protocol was reviewed for the protection of human subjects by the China National Natural Science Foundation and the Qinghai High Altitude Medical Research Institutional Committee on Human Research. Informed consent was obtained verbally for each subject. Children and their parents were given detailed explanation of the purpose of the study and, for the younger children, permission was obtained from both parent and child. Older children gave their own permission.

Subjects meeting the above criteria as Tibetan ($n = 3,000$) had resided since birth at high altitude and had never traveled to the lowlands. By occupation, the 2,668 adults (of whom 1,230 were women) were herders (81.2%), herders/farmers (14.5%), and laborers or office workers (4.3%). The remaining Tibetans were children ($n = 332$). Adult Han Chinese ($n = 2,612$) residing at the same sites as the Tibetan subjects had been born and lived in the lowland below 1,000 m and had migrated to high altitude for at least 1 yr previously, with a range of 1 to 48 years. Residence at altitude exceeded 10 yr in 53% of the total sample of Han subjects, and the mean duration of altitude residence was 16.7 ± 13.5 yr. Han subjects were office workers or laborers (64.1%) or farmers (35.9%). Most descended to the lowlands for 1-mo holidays every 1–3 yr. Han children ($n = 275$) were studied.

Routine hematology. For each subject, two venous blood samples were drawn into vacuum tubes in the morning from resting, seated subjects. One sample in a Wintrobe's tube containing 0.2 mg of sodium heparin was spun for hematocrit at 3,000 rpm for 30 min using a centrifuge (LXY-64 model, Beijing Medical Machine) with an effective radius of 159 mm and a speed of 50 rps. Use of longer centrifugation times did not yield lower hematocrit values. [Hb] were measured by the cyanomethemoglobin technique using a spectrophotometer (SM-571, Shanghai Medical Manufacture, Shanghai, China), which had been previously calibrated. Red blood cell count was carried out by classical microscopy techniques. All blood samples

Table 1. Multiple regression equation for hemoglobin concentration in terms of altitude and age for each of four groups of residents of Tibet

Equation: hemoglobin (in g/100 ml) = $a + b \cdot$ altitude (in m) + $c \cdot$ age (in yr)					
Group	n	a	b	c	P Value
<i>Male subjects</i>					
Han	1,821	9.605	0.001420 ± 0.00028	0.06144 ± 0.013	<0.001
Tibetan	1,626	12.214	$0.000465 \pm 0.00013^*$	$0.02909 \pm 0.006^*$	<0.001
<i>Female subjects</i>					
Han	1,066	10.852	0.000933 ± 0.00012	0.02629 ± 0.004	<0.001
Tibetan	1,374	11.409	$0.000630 \pm 0.00006^*$	$0.00415 \pm 0.005^*$	<0.001

b and c represent β -coefficients (\pm SE) for altitude and age, respectively. All the coefficients shown for altitude and age were significantly different ($P < 0.05$) from zero. * β -Coefficients in Tibetans (male vs. male and female vs. female) are less ($P < 0.05$) than in Han.

Table 2. Hemoglobin values for normal Tibetan male and female and for Han male and female residents of the Tibetan Plateau

Altitude	Males			Females		
	5–15 yr	16–40 yr	41–60 yr	5–15 yr	16–40 yr	41–60 yr
<i>Tibetan</i>						
2,664	13.4 ± 0.9	$14.4 \pm 1.5^*$	14.7 ± 1.6	13.4 ± 1.0	12.8 ± 1.5	13.0 ± 1.6
n	42	215	171	58	150	176
3,813	14.3 ± 1.0	$15.3 \pm 1.7^*$	15.5 ± 1.7	14.0 ± 1.1	14.1 ± 1.4	14.4 ± 1.1
n	66	262	241	44	236	206
4,525	14.6 ± 0.9	$15.6 \pm 1.5^*$	15.7 ± 1.6	14.4 ± 1.0	14.5 ± 1.7	14.7 ± 1.5
n	68	288	231	32	228	204
5,200	14.6 ± 0.8	$15.7 \pm 0.8^*$	15.7 ± 0.8	14.5 ± 0.8	14.6 ± 0.8	14.7 ± 0.8
n	12	15	15	10	15	15
<i>Han</i>						
2,664	13.7 ± 0.9	$15.6 \pm 1.7^*$	15.6 ± 2.0	13.7 ± 0.9	14.0 ± 1.7	$14.5 \pm 1.5^*$
n	72	348	282	54	174	161
3,813	15.3 ± 1.2	$18.1 \pm 1.6^*$	18.4 ± 1.4	14.8 ± 1.1	15.1 ± 1.8	15.5 ± 1.6
n	54	323	283	38	185	174
4,525	16.1 ± 1.2	$18.6 \pm 1.7^*$	$19.0 \pm 1.6^*$	15.4 ± 1.2	16.1 ± 1.6	$16.8 \pm 1.8^*$
n	28	208	187	18	145	82
5,200	17.1 ± 1.2	$19.6 \pm 1.6^*$	19.6 ± 1.5	15.6 ± 1.1	16.3 ± 1.4	16.9 ± 1.4
n	6	15	15	5	15	15

Values are means in g/dl \pm SD. Values are shown for three altitudes (in m) and three age ranges (in yr). Number of subjects are indicated (n). *Within an ethnic, gender, and altitude group, the hemoglobin concentration was higher ($P < 0.05$) in the 16- to 40- than in the 5- to 15-year-old age group or in the 41- to 60- than in the 16- to 40-year-old age group.

were analyzed immediately on site after collection. Hematocrit and red blood cell values (not shown) generally supported the trends in [Hb] shown below in Table 2. Because of the large volume of data, we focused the analysis on the [Hb].

Statistical methods. Data were analyzed using SPSS. For analysis, the entire data set was divided into four groups: Han men, Tibetan men, Han women, and Tibetan women. Multivariate regression analysis for each group assumed the form: [Hb] (g/100 ml) = $a + b \cdot$ altitude (meters) + $c \cdot$ age (years), where b and c were β -coefficients. Analysis of the equations regressed [Hb] on altitude and age for each of four groups: Han men, Tibetan men, Han women, and Tibetan women. Within-gender comparisons were between Han and Tibetans. For men, we determined by Wald χ^2 tests whether the altitude and age coefficients from the multiple regression equations, given their standard errors, were different between Han and Tibetan. We did a similar analysis for females. In addition, for illustration, we presented descriptive statistics including mean and standard deviation for altitude ranges and age classes for the entire cohort by ethnic group and gender. Linear regression analysis and correlation coefficients were used to assess the relationship between variables. Data in Table 1 are reported as means \pm SE, and data in Table 2 are shown as means \pm SD. Differences were accepted as significant when the probability (P) was ≤ 0.05 .

RESULTS

For each of the four groups in Table 1, the number of subjects examined was $>1,000$ and the overall multiple regression in each of the four equations was statistically significant. The individual β -coefficients for altitude and age were statistically significant, indicating that both of these variables affected [Hb] for males and females in both Tibetan and Han subjects. In males, the β -coefficients in Han exceeded ($P < 0.05$) those in Tibetans for both altitude and age, and [Hb] (Table 2) were consistently higher in the Han. Prior reports indicated higher [Hb] in Han than Tibetan men (13). In women,

the β -coefficients in Han exceeded ($P < 0.05$) those in Tibetans, also suggesting higher [Hb] in Han than Tibetan women.

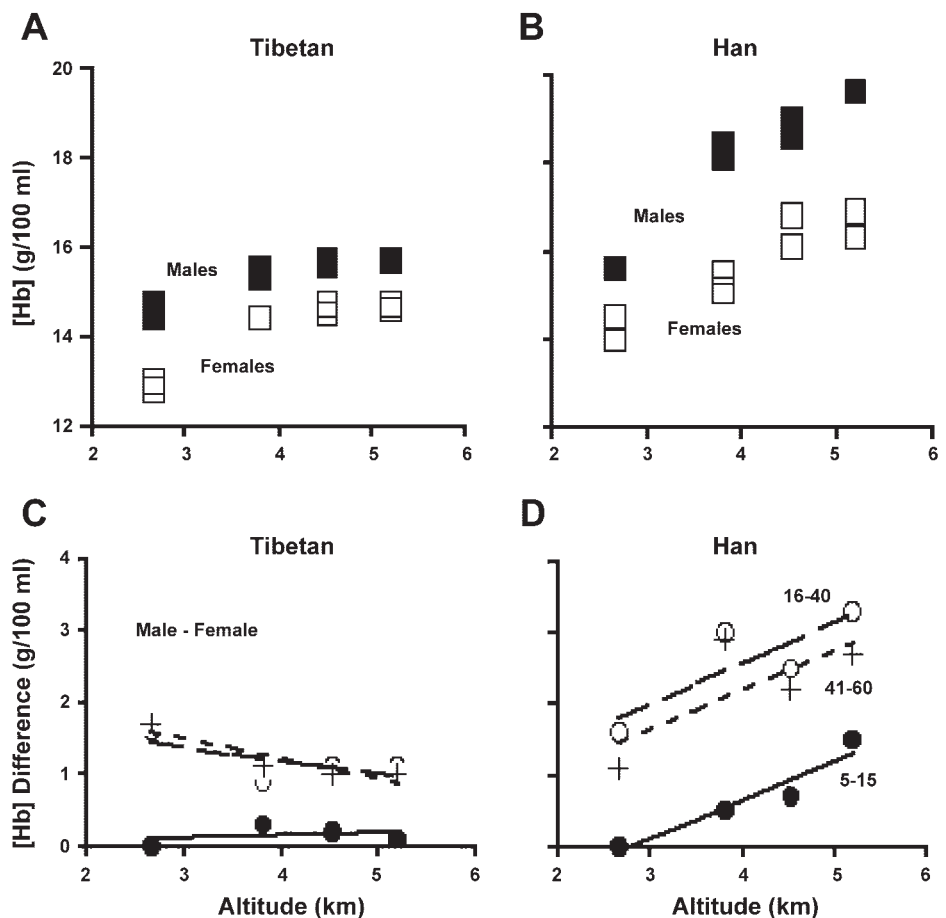
A significant three-way interaction was observed between altitude, gender, and ethnicity ($\chi^2 = 3.72$, $P = 0.05$), indicating that a Han-Tibetan ethnic difference in the effect of altitude on [Hb] depended on gender. This three-way interaction, involving the four variables of ethnicity, altitude, [Hb], and gender, can be illustrated graphically by showing [Hb] for Tibetans vs. Han in classes by gender and altitude range using data in Table 2. For adult Tibetans, the [Hb] were higher in males than females and increased with altitude in both genders (Fig. 1A). The increases were most apparent between 2,664 and 3,813 m, with little more increase above 3,813 m. For adult Han, the [Hb] were higher in males than females and increased with altitude in both genders (Fig. 1B), but further increases were apparent above 3,813 m. Comparison of Fig. 1A with 1B suggested that, for the altitudes of 3,813 m and above, the [Hb] difference between males and females were greater in Han than Tibetan. Figure 1, A and B, supported the concept that, for both adult Han and Tibetan subjects at all altitudes, men had higher [Hb] than did women, and the gender-related difference may be greater in Han.

When the gender-related difference in [Hb] was displayed directly, Tibetan subjects showed no increase with increasing altitude (Fig. 1C). That is, for both adults and children, Tibetan men did not show progressively higher [Hb] than women as altitude increased. By contrast for Han subjects, the gender-related difference in [Hb] increased with increasing altitude

(Fig. 1D). That is, for both children and adults, Han men showed progressively higher [Hb] than women as altitude increased. Thus the illustrations in Fig. 1 supported the concept that there was an ethnic difference in the effect of altitude on [Hb] that was related to gender.

With regard to age, however, a three-way interaction for an ethnic difference in the effect of age on [Hb] did not show a significant dependence on gender [$\chi^2 = 0.42$, $P =$ not significant (NS)]. For example, using data from Table 2, we could illustrate a similar gender-related pattern of [Hb] change with age in the two ethnic groups (Fig. 2). Thus, at all altitudes studied, the male-female [Hb] differences in Tibetan (Fig. 2A) and Han (Fig. 2B) showed a similar pattern with an increase in the [Hb] difference from childhood to young adulthood, but no consistent further increase from younger to older adults. This similar pattern of male-female [Hb] difference in both ethnic groups could be largely attributed to an increase in [Hb] in men who were transitioning from childhood to young adulthood, because there was not a similar and concomitant increase in women (Table 2). The findings were compatible with an increase in [Hb] associated with male sexual maturity in both Han and Tibetan, as has been reported, at least for the former (13). However, as illustrated by comparing Fig. 2A with 2B, Han adults appeared to have greater male-female [Hb] differences than did Tibetan adults for the altitudes 3,813, 4,525, and 5,200 m. Considering the six classes of younger and older adults at altitudes from 3,813 to 5,200 m (Table 2), the male-female [Hb] difference ranged from 1.0 to 1.2 (mean

Fig. 1. Hemoglobin concentrations ([Hb]) in Tibetan and Han subjects at 4 altitudes. A: [Hb] in 2 age classes (16–60 yr) of adult Tibetan males (■) and females (□). B: hemoglobin concentrations in 2 age classes of adult Han males (■) and females (□). (For both panels, note some overlap in symbols.) C and D: differences in hemoglobin concentration between male and female Tibetans (C) and Han (D) for the 3 age ranges (● and unbroken line, 5–15 yr; ○ and broken line, 16–40 yr; + and dashed line, 41–60 yr) as shown D. Data are from Table 2.



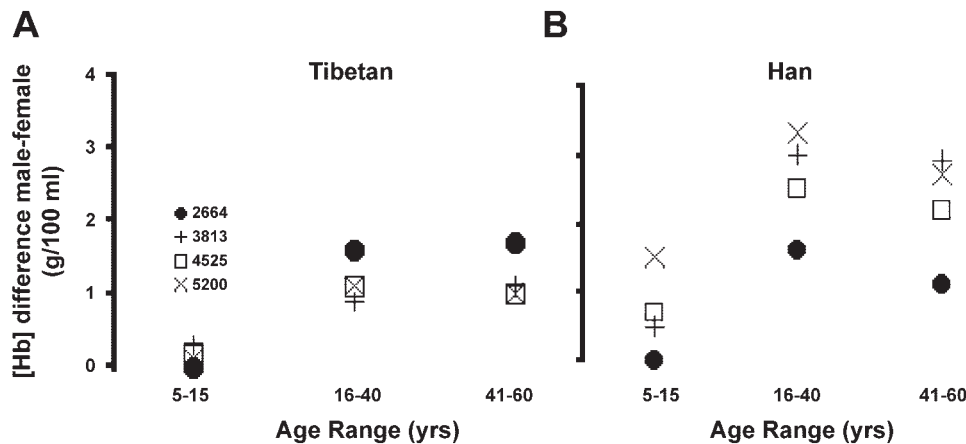


Fig. 2. Difference in [Hb] between males and females for Tibetan (A) and Han (B) subjects at 4 altitudes. Shown are [Hb] differences for 2,664 m (●), 3,813 m (+), 4,525 m (□), and 5,200m (x). Data are from Table 2.

1.1 ± 0.1) g/100 ml in Tibetans compared with higher values 2.2 to 3.3 (mean 2.8 ± 0.4) g/100 ml in Han.

Gender and ethnic differences in [Hb] were seen by histogram data from 4,525 m, the highest altitude for which we had a large number of subjects. We examined the distribution of hemoglobin values within the populations of adults 16–60 yr for Tibetan men, Tibetan women, Han men, and Han women (Fig. 3). In Tibetan men, the [Hb] occurring with the greatest frequency (i.e., the mode) was between 15 and 16 g/100 ml; in Tibetan women, it was between 14 and 15 g/100 ml; in Han men, it was ~ 19 g/100 ml; and in Han women, it was between 16 and 17 g/100 ml. Thus the values for the mode supported the data presented above, showing that Han men and women had higher hemoglobin levels than Tibetan men and women and that the gender-related difference was greater in Han. The histograms also demonstrated non-Gaussian distributions, with skewing of hemoglobin levels toward higher values in the Tibetans and toward lower values in Han (Fig. 3).

DISCUSSION

The main finding of the present investigation, which compared Han and Tibetan residents of the Qinghai-Tibetan Plateau, was that an important ethnic difference in the effect of altitude on [Hb] depended on gender. The present study represents a comparison of native Tibetan residents living on the Plateau with Han migrants from low altitude. We therefore cannot distinguish genetic (26) from developmental (16) dif-

ferences, because Tibetans were born at altitude, whereas Han subjects migrated to high altitude after birth. Han subjects, who were born at high altitude, may have [Hb] closer to those of their Tibetan counterparts (13) than in the Han migrants. However, with nearly 6,000 subjects, the comparison presented represents the largest and most systematic collection and analysis of altitude-related [Hb] performed to date on these high-altitude populations.

Although by history and examination our Tibetan subjects were normal, they had [Hb] in the lower portion of the previously published normal range (Fig. 4). This raised the possibility that iron deficiency or nutritional factors caused them to have smaller [Hb] than did Han. The experimental design aimed to minimize this possibility by examining Han and Tibetan subjects from the same locale, in the same time frame, and using the same methods. In addition, our prior studies in 1998 nomad Tibetan high-altitude families (15, 35) showed normal caloric and nutritional values, iron intake, and serum iron. Total plasma protein and values for vitamin A, B complex vitamins, and vitamin C were normal. Also, diets for both Tibetan and Han populations contain adequate amounts of grains, dairy products, potatoes, and animal protein, including viscera (muscle, heart, liver, kidney) and blood (15, 35). In the present study, had iron deficiency been present, we expected microcytotic and hypochromic red blood cells, but our calculations of mean corpuscular volume and hemoglobin (data not reported) were normal. Furthermore, a recent study in Qing-

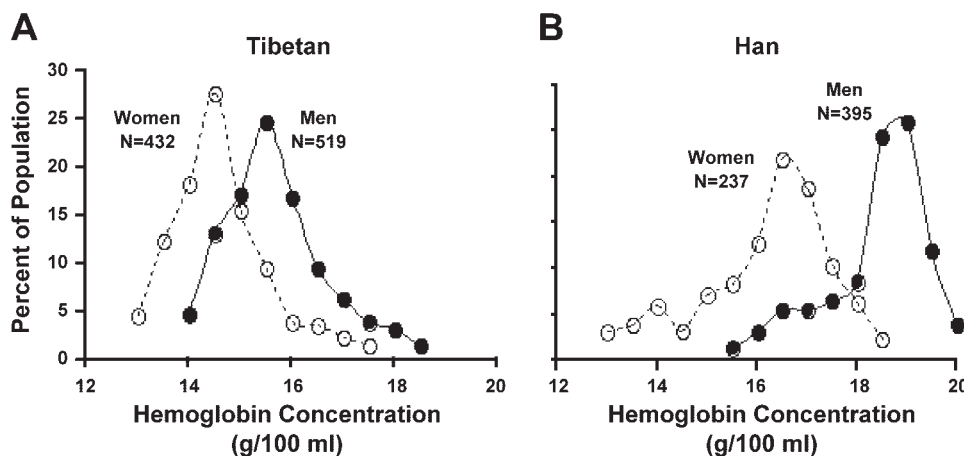


Fig. 3. Frequency distribution of [Hb] among adult (ages 16–60 yr) Tibetan (A) and Han (B) subjects at 4,525 m. ● And solid lines, males; ○ and broken lines, females. Note that the [Hb] are skewed to the right in Tibetans and to the left in Han.

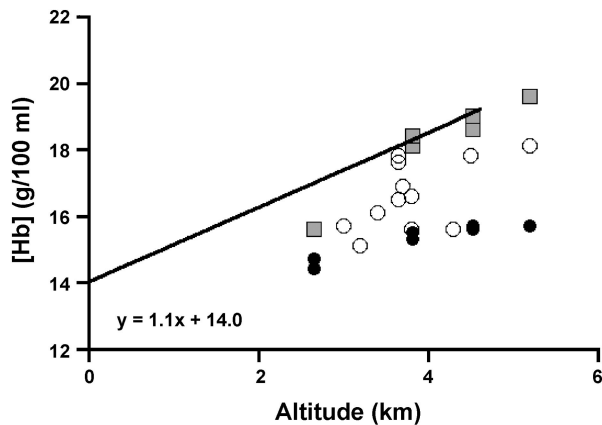


Fig. 4. Hemoglobin values at varying altitudes in normal adult male populations residing at high altitude. Line with its equation represents the line of best fit through mean values reported in the literature from North and South America and for Han subjects in Tibet (3, 6–8, 11–13, 17–19, 22, 23, 25, 27, 28, 30–34). \circ , Hemoglobin values in Tibetan males from prior reports (1–5, 8, 13, 14, 25, 30); \blacksquare , measurements in Han men from this report; \bullet , Tibetan men from this report.

hai, which did take account of iron status, found [Hb] in Tibetans similar to those reported here (Fig. 5). Therefore, we consider the hemoglobin values reported here to be normal for our populations.

Our findings that [Hb] increased with altitude in both Han and Tibetan residents and that hemoglobin levels were higher in Han than in Tibetan residents of the Plateau were consistent with previous reports (1, 4–6, 8, 13, 23, 24). The new findings

in the present study related to the important role of male gender, particularly after sexual maturation, in the different [Hb] between Han and Tibetans at various altitudes. The finding was supported by the multiple regression analysis, which indicated that an important ethnic difference in the effect of altitude on [Hb] depended on gender. The finding was illustrated by showing that at altitudes of 3,813 m and above 1) Han men had higher hemoglobin than did Tibetan men, 2) at a given altitude, hemoglobin levels in young Han and Tibetan women showed little increase from childhood, 3) the male-female [Hb] difference was greater in Han than Tibetan, 4) this gender-related [Hb] difference increased with altitude in Han but not in Tibetan, and 5) the gender-related [Hb] difference associated with the transition from childhood to young adulthood was greater in Han than Tibetan. The finding was also supported by replotting the data from Garruto et al. (13) (Fig. 5), which showed for 3,200 m and 3,800 m, that, before puberty, [Hb] in Tibetan boys and girls were similar to values in Han children and Tibetan women had values similar to Han women. However, at 3,800 m, Han men had higher hemoglobin levels than did Tibetan men (Fig. 5C). Although there were but six measurements in Han men at 4,300 m, their [Hb] were greater than in Tibetan men at this altitude. These findings and those of the present study were consistent with Han men having a greater increase in [Hb] in the time interval associated with puberty than did Tibetan men.

Testosterone stimulates (9, 10), and ovarian hormones blunt, hemoglobin production at altitude (10, 18–21, 29). Although testosterone was not measured in the current study, there are

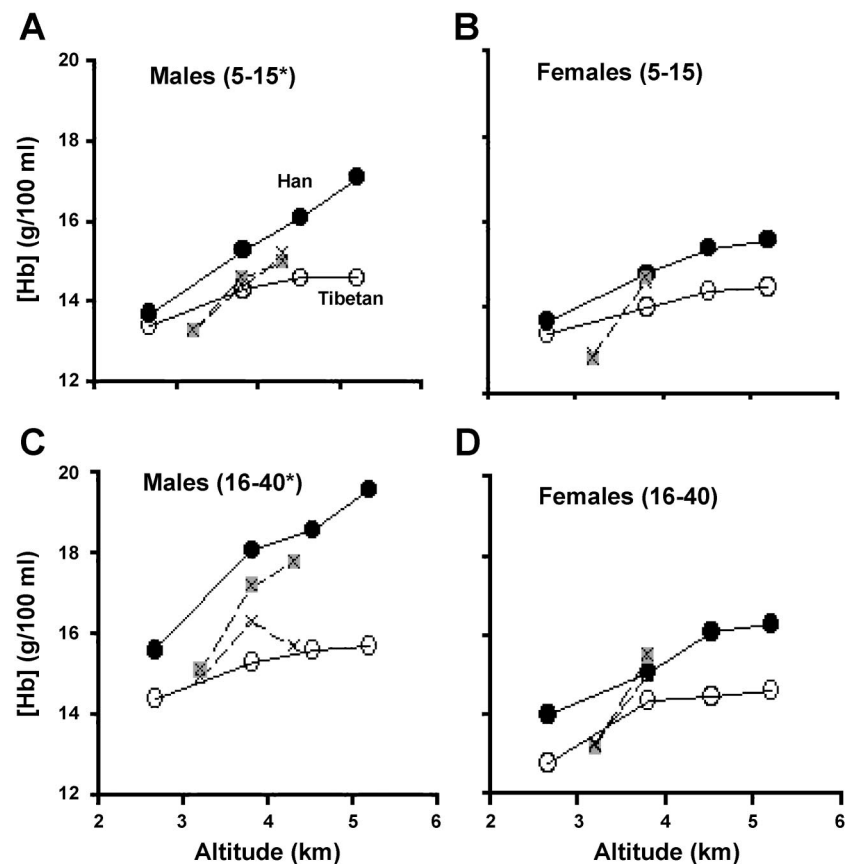


Fig. 5. [Hb] in Han (\bullet) and Tibetan (\circ) residents at 4 altitudes on the Tibetan Plateau from this report. Above are male (A) and female (B) children (5–15 yr of age). Below are male (C) and female (D) adults (16–40 yr of age). Also shown are [Hb] in Han (filled crosses) and Tibetan (open crosses) from the report of Garruto et al. (13). *Somewhat different age ranges in the Garruto report, where children were 6–14 yr of age and adults were 15–30 yr of age.

several possibilities for a gender-related hemoglobin difference, among which are some combination of the following. 1) The [Hb] difference between Han and Tibetans accompanied sexual maturity in men but may not have been due to testosterone. 2) High [Hb] in Han men may have been due to higher testosterone concentrations than in Tibetan men. 3) Han men may have had a greater erythropoietic response to a given testosterone concentration than did Tibetan men. 4) There may be genetic differences between Han and Tibetan populations in ventilatory responsiveness to hypoxia, and testosterone may have had a greater ventilatory depressant effect in Han than in Tibetan men.

Investigators have focused on the latter possibility because prior reports have suggested that, as a result of its long residence on the Tibetan Plateau, the Tibetan population has acquired the genetic adaptation of an improved ventilatory responsiveness and/or blood oxygenation in hypoxia (13, 25, 26). Such traits, which extend over whole populations, could account for our findings of lower [Hb] in the Tibetan men, women, and children than in the Han. Although ventilatory control was not measured in the present study, the possibility existed that ventilatory responsiveness to low ambient oxygen was better maintained in the Tibetan men than Han men, as has been reported by Zhuang et al. (36). Higher ventilatory responsiveness and/or better pulmonary oxygen transport in Tibetan than Han could be genetically related factors, which would improve ventilation and oxygenation in Tibetans and would blunt their hematopoietic responses to high altitude (25, 26). Given the above and our finding that much of the ethnic difference in [Hb] was associated with male sexual maturation, one could speculate that an increase in testosterone levels adversely impacted ventilatory control more in Han than in Tibetan men living at high altitude.

A potentially useful means to examine whether better ventilation and/or oxygenation accounted for the lower [Hb] in Tibetans was suggested by our novel finding in populations at 4,525 m that [Hb] were skewed to higher values in Tibetan but to lower values in Han. If Han subjects from the population skewed to lower hemoglobin values had less hypoxia than other Han, and Tibetan subjects from the population skewed to higher hemoglobin values had greater hypoxia than other Tibetans, this would point to hypoxic stimuli as key contributors to the variable hematopoietic responses. Such findings could provide clues to help investigate how gender, sexual maturity, and genetic factors affected the hemoglobin responses to altitude on the Tibetan Plateau. The present investigation has pointed to the importance of examining how these factors impact the hypoxemic stimulus and the hematopoietic response on a plateau where millions of people live.

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