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Original Article

Effect of High Altitude on Cardiovascular Parameters among Permanent Natives of Ladakh

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Abstract

Background: The study undertaken involved finding the effect of high altitude on cardiovascular parameters in a sample of 100 subjects of Ladakh divided into four groups, of age range 1–60 years with normal health, who migrate to lowland area (Jammu) during winter for 1–2 months and the results so obtained were compared with equal number of healthy residents of Jammu (control group).

Materials and Methods: Standard procedures were used. Blood pressure (BP) was recorded using a sphygmomanometer, pulse rate by the palpatory method and respiratory rate by counting the number of breaths for 1 min (observing how many times the chest and abdomen rises).

Results: It was found that the resting mean pulse rate in all the groups of high altitude subjects was higher on day 1 than at 2 months (almost equal to the control group) which was statistically highly significant. The difference in mean pulse rate between high altitude males and females was statistically non-significant. Furthermore, the elderly subjects showed a decreased mean pulse rate compared to the young subjects (mean pulse rate of Groups I, II, III, and IV males was 77 ± 2.6, 73.5 ± 2.6, 69.5 ± 1.8, and 64.1 ± 1.1 and of females was 76.9 ± 2.1, 73 ± 2.0, 69.3 ± 1.8, and 64 ± 1.1, respectively). The high altitude subjects of all groups showed hypoventilation on day 1 of arrival to low altitude which after 2 months became almost equal to that of control group due to adaptation to sea level. There was a steeper increase in the mean BP with age in high altitude people than the lowland people. The increase in mean diastolic BP (DBP) of high altitude people was more which was statistically highly significant. Furthermore, the males had a higher mean DBP than the females. However, the difference in the mean systolic BP was statistically non-significant.

Conclusion: High altitude natives have distinctive biological characteristics that appear to offset the stress of hypoxia. Evolutionary theory reasons that they reflect genetic adaptations resulting from natural selection favoring more effective adaptive responses.

Key words: Acclimatization, Cardiovascular parameters, High altitude

INTRODUCTION

High altitude places are among the most inhospitable on earth. Two main challenges to life at high altitude come from hypobaric hypoxia and the low ambient temperatures. However, many people live and work at high altitude with no apparent adverse effects.[1]

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In the context of human responses to altitude, it is useful to consider three processes that are related but different. The first is high altitude acclimatization which refers to the physiological changes that occur in lowlanders (people who normally live near sea level) when they go to altitudes of up to about 5000 m to work or play. The second process is a true evolutionary adaptation which has occurred in humans who have resided for many generations at high altitude, especially in the South American Andes and the Tibetan plateau. The third process is the physiological changes that take place at extreme altitudes, and these should be distinguished from the first two processes.[2]

Man and some other animals show a remarkable ability to adapt to living at high altitudes, a process known as acclimatization. Various factors participate in this

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acclimatization process including hyperventilation, increase in the red blood cell concentration of the blood, increase in the number of capillaries in peripheral tissues, and changes in the oxidative enzymes within the cells.[3] These integrated responses improve oxygen delivery to the cells through adjustments in the respiratory, cardiovascular and hematological systems and augment the cellular oxygen uptake and utilization mechanisms.[4]

Therefore, the major aim of this study is to assess the effects of high altitude on cardiovascular parameters (blood pressure [BP], pulse rate, and respiratory rate) among permanent natives of Ladakh and how it differs with respect to age and sex in comparison to the lowlanders.

MATERIALS AND METHODS

The present study was undertaken in the Department of Physiology, Government Medical College, Jammu, India. The subjects selected were permanent residents of Ladakh who migrate to Jammu during winter for 1–2 months. A written informed consent was taken from all eligible subjects.

Inclusion Criteria

Healthy permanent residents of high altitude (Ladakh) were included in the study.

Exclusion Criteria

1. History of hypertension
2. Diabetes mellitus
3. Heart diseases
4. Tuberculosis
5. Asthma
6. Occupational lung diseases; and
7. Chronic obstructive pulmonary disease were excluded from the study.

100 subjects who fulfilled the eligibility criteria were selected for the study. They were divided into two groups' males and females. Each group was further subdivided into four different age groups. Group I included subjects of age ≤ 20, Group II included subjects from age 21 to 40, Group III included subjects from age 41 to 60, and Group IV included subjects of age > 60. Their mean height and weight were calculated [Table 1]. They had to undergo two phases of examination, i.e. the first examination on the day of their arrival and the second examination 2 months later. The results so obtained were compared with an equal number of healthy residents of Jammu (control group).

All the eligible subjects were requested to present themselves in the Postgraduate Department of Physiology, Government Medical College, Jammu, at their own convenient time. They were interviewed by the investigator herself, and details of information regarding age, occupation, and any significant recent or past illness were recorded.

BP was recorded using a sphygmomanometer by auscultatory method in sitting position. This method was devised by Korotkoff, in 1905. After a gap of 5 min for mental and physical relaxation, the cuff of the B.P apparatus was placed around the upper arm with center of the bag lying over the brachial artery, keeping its lower edge about 3 cm above the elbow. Chest piece of the stethoscope was placed at the level of the bifurcation of the brachial artery. Cuff was inflated and pressure was raised to about 40–50 mm Hg above the systolic BP ([SBP], found by palpatory method). The pressure was lowered gradually until a clear sharp, tapping sound was heard which was taken as SBP. Continued to lower the pressure and the level at which it became muffled was taken as diastolic BP (DBP). Mean of the three readings of both SBP and DBP was taken as the actual SBP and DBP.[5]

Pulse rate was recorded for 1 min by palpating the radial artery in the wrist with the tips of three fingers, i.e., index, middle, and ring fingers, compressing the vessel against the head of the radius bone after making the subject's forearm slightly pronated and wrist slightly flexed.[5]

Respiratory Rate

The subjects were made to lie comfortably on a bed exposing the chest and abdomen and then counting the number of breaths for 1 min by observing how many times the chest and abdomen rises.[6]

The data were analyzed using computer software Microsoft Excel, SPSS statistics (version 20) for Windows. All parameters were reported as mean and standard deviation. The statistical difference in mean values was tested using Student's *t*-test to evaluate statistical significance. $P < 0.05$ was considered statistically significant and that > 0.05 was considered statistically non-significant.

RESULTS

The resting mean pulse rate of high altitude subjects was higher on day 1 which at 2 months was almost equal to the control group, i.e., on day 1 the mean pulse rate of high altitude subjects of Groups I, II, III, and IV males was 77 ± 2.6, 73.5 ± 2.6, 69.5 ± 2.5, and 64.1 ± 2.3 and of females was 76.9 ± 2.1, 73 ± 2.0, 69.3 ± 1.8, and 64 ± 1.1, respectively [Table 2a]. At 2 months, these values decreased, i.e., mean pulse rate of Groups I, II, III, and IV males was 74.7 ± 2.1, 70.4 ± 2.5, 66.7 ± 2.6, and 62.1 ± 2.2 and of females was 74.5 ± 2, 69.8 ± 2.1, 66.7 ± 2.6, and 61.6 ± 1.6, respectively [Table 2b]. In the control group, the mean pulse rate of Groups I, II, III, and IV males was 74 ± 1.8, 70.2 ± 1.7, 66.2 ± 2.6, and 61.6 ± 2.4 and of females was 74.7 ± 1.2, 70.6 ± 2.8, 65.7 ± 2.2, and 62 ± 2.1, respectively [Table 2b]. The difference in values between males and females was statistically non-significant [Table 2c]. However, the elderly people showed a decreased mean pulse rate compared to the young.

The high altitude subjects showed hypoventilation on day 1 of arrival to low altitude and were statistically highly significant. On day 1, the mean respiratory rate of Groups I, II, III, and IV males was: 11 ± 1, 12.1 ± 1.1, 13 ± 1.2, and 13.5 ± 0.7 and of females: 11 ± 1, 12 ± 1, 12.7 ± 0.7, and 14 ± 0.5, respectively [Table 3a]. This after 2 months became almost equal to that of the control group due to adaptation to sea level, i.e., mean respiratory rate of Groups I, II, III, and IV males was: 14.6 ± 1.5 15.3 ± 2.0, 15.5 ± 1.5, and 15.3 ± 2 and of females: 15.9 ± 2.2, 16 ± 2.2, 16.6 ± 1.6, and 16.1 ± 1.7, respectively [Table 3b]. In the control group, the mean pulse rate of Groups I, II, III, and IV males was 14.5 ± 1.0, 15.8 ± 2.0, 15.7 ± 1.7, and 15.3 ± 1.4 and of females was 15.2 ± 1.7, 15.3 ± 1.3, 14.8 ± 1.7, and 14.8 ± 1.3, respectively [Table 3b]. However, the difference in males and females mean respiratory rate on day 1 was statistically non-significant [Table 3c].

There was a steeper increase in the mean BP with age in high altitude people than the lowland people. The increase in the mean DBP in high altitude people was more and statistically highly significant. On day 1, the mean DBP of Groups I, II, III, and IV males was: 82.7 ± 2.3, 84.1 ± 2.7, 88.1 ± 3.2, and 91.5 ± 2.8 and of females: 79.8 ± 2.4, 82.1 ± 3.5, 86.6 ± 3.6, and 88.2 ± 2.2, respectively [Table 4c] whereas in the control group, the mean DBP of Groups I, II, III, and IV males was: 78.3 ± 2.3, 80.1 ± 2.1, 83.1 ± 2.9, and 85 ± 2.1 and of females: 76.6 ± 2.1, 76.9 ± 3.0, 81.3 ± 3.7, and 81.6 ± 1.7, respectively [Table 4d]. Furthermore, the high altitude males had a higher mean DBP than the females [Table 4e]. However, there was almost no difference in the SBP between the high and the low altitude people and also between males and females which was statistically non-significant [Table 4a, b, e].

DISCUSSION

Pulse Rate

Arterial pulse is the action of the left ventricle felt in a peripheral artery. The normal pulse rate at rest averages about 72 beats/min. The rate is higher in children and slower in old age.[5]

On initial exposure to high altitude hypoxia, the resting pulse rate of lowland natives increases rapidly from an average of 70 beats/min to as much as 105 beats/min. This increase is associated both with generalized increase in sympathetic activity and with abrupt augmentation of resting cardiac output.[7] With acclimatization, the cardiac output declines so that in about a week it equals or is below that attained at sea level. This decline in the cardiac output appears to be associated with a decrease in the heart rate which usually remains above sea level values.[8]

In the present study, the mean values of pulse rate in different age groups of both males and females study groups were higher on day 1 than the mean values of the pulse rate at 2 months of descent to low altitude, and the difference was statistically highly significant. The pulse rate also showed a decrease in elderly people.

Our findings are in agreement with those reported by Hansen and Sander[9] who reported that acclimatization to high altitude hypoxia is accompanied by a striking and long-lasting sympathetic over activity which persisted for 3 days even after return to sea level.

Furthermore, the mean values of the pulse rate of high altitude males on day 1 were higher than the lowland controls. This finding is similar to the study done by Amitabh *et al*.[10]

Respiratory Rate

The normal rate of respiration is 14–20 cycles/min. One inspiration and one expiration making up one cycle. It is faster in children and old age.[5]

Hyperventilation is one of the most important features of acclimatization to high altitude.[3]

Hypoxia directly affects the vascular tone of the pulmonary and systemic resistance vessels and increases ventilation and sympathetic activity through stimulation of the peripheral chemoreceptors.[11]

In the present study, on day 1 the mean values of respiratory rate of both males and females were less than compared with the mean values at 2 months after coming to low altitude. This decrease was statistically highly significant. Furthermore, there was an increase in the respiratory rate in old age with almost no difference between males and females. However, at 2 months, the mean values of respiratory rate were similar to that of the control group.

Table 1: Mean height and weight of study and control groups

Groups	Age	Sex	Study group			Control group		
			Number (*n*)	Mean height (cm)	Mean weight (Kg)	Number (*n*)	Mean height (cm)	Mean weight (Kg)
I	≤20	Male	3	161	43.3	6	160.2	50.2
		Female	13	156.1	43.8	8	150.2	42.5
II	21–40	Male	23	166.7	67.6	18	163	65.3
		Female	22	160.1	53.2	28	161.7	56.8
III	41–60	Male	15	167.3	74.2	20	166	70.4
		Female	7	163.3	61.6	9	161.9	60.6
IV	>60	Male	9	164.7	64.7	6	162.6	53.3
		Female	8	161	58	11	162.4	60.2

Table 2(a): Group-wise comparison between males and females (study) on day 1 and at 2 months according to mean pulse rate (/min)

Groups	Age	Sex	Number (*n*)	Day 1 Mean ±SD	At 2 months Mean ±SD	*t*-test	*P*-value	Statistical inference
I	≤20	Male	3	77±2.6	74.7±2.1	3.50	0.003	HS
		Female	13	76.9±2.1	74.5±2	11.83	0.000	HS
II	21–40	Male	23	73.5±2.6	70.4±2.5	16.44	0.000	HS
		Female	22	73±2.0	69.8±2.1	9.59	0.000	HS
III	41–60	Male	15	69.5±2.5	66.7±2.6	5.25	0.000	HS
		Female	7	69.3±1.8	66.4±2.3	7.07	0.000	HS
IV	>60	Male	9	64.1±2.3	62.1±2.2	3.33	0.000	HS
		Female	8	64±1.1	61.6±1.6	3.66	0.008	HS

SD: Standard deviation

Table 2(b): Group-wise comparison between males and females (study) at 2 months and males and females (control) according to mean pulse rate(/min)

Groups	Age	Sex	Number (*n*)	At 2 months Mean ±SD	Control Mean ±SD	*t*-test	*P*-value	Statistical inference
I	≤20	Male	3	74.7±2.1	74±1.8	1.00	0.423	NS
		Female	13	74.5±2	74.7±1.2	0.00	1.000	NS
II	21–40	Male	23	70.4±2.5	70.2±1.7	-1.22	0.240	NS
		Female	22	69.8±2.1	70.6±2.8	2.15	0.044	NS
III	41–60	Male	15	66.7±2.6	66.2±2.6	0.00	1.000	NS
		Female	7	66.4±2.3	65.7±2.2	0.16	0.881	NS
IV	>60	Male	9	62.1±2.2	61.6±2.4	-4.39	0.070	NS
		Female	8	61.6±1.6	62±2.1	-1.37	0.242	NS

SD: Standard deviation

Table 2(c): Group-wise comparison between males (study) and females (study) on day 1 according to mean pulse rate (/min)

Groups	Age	Males Mean ±SD	Females Mean ±SD	*t*-test	*P*-value	Statistical inference
I	≤20	77±2.6	76.9±2.1	0.76	0.525	NS
II	21–40	73.5±2.6	73±2.0	0.90	0.376	NS
III	41–60	69.5±2.5	69.3±1.8	0.29	0.778	NS
IV	≥60	64.1±2.3	64±1.1	1.14	0.291	NS

SD: Standard deviation

Our findings are in agreement with Zubeta-Calleja[12] who also reported that the resting ventilation decreased on the descent to sea level on the day of arrival.

If high altitude residents go to sea level, there organism is facing relative hyperoxia. The decrease in ventilation is probably defense mechanism for a hyperoxic environment that the body assumes is toxic at the cellular level. The adaptation mechanism acquired over long-term high altitude residence is essentially the high hematocrit which would in the presence of excess oxygen increase the oxygen content of the blood and produce hyperoxemia.[12]

The reasons for re-establishment of respiratory rate to almost sea level values after 2 months of descent could be the following:

Table 3(a): Group-wise comparison between males and females (study) on day 1 and at 2 months according to mean respiratory rate (/min)

Groups	Age	Sex	Number (*n*)	Day 1 Mean±SD	At 2 months Mean±SD	*t*-test	*P*-value	Statistical inference
I	≤20	Male	3	11±1	14.6±1.5	−11.00	0.008	HS
		Female	13	11±1	15.9±2.2	−8.29	0.000	HS
II	21–40	Male	23	12.1±1.1	15.3±2.0	−6.40	0.000	HS
		Female	22	12±1	16±2.2	−8.25	0.000	HS
III	41–60	Male	15	13±1.2	15.5±1.5	−6.51	0.000	HS
		Female	7	12.7±0.7	16.6±1.6	−4.65	0.003	HS
IV	>60	Male	9	13.5±0.7	15.3±2	−2.34	0.047	S
		Female	8	14±0.5	16.1±1.7	−3.60	0.008	HS

SD: Standard deviation

Table 3(b): Group-wise comparison between males and females (study) at 2 months and males and females (control) according to mean respiratory rate (/min)

Groups	Age	Sex	Number (*n*)	At 2 months Mean±SD	Control Mean±SD	*t*-test	*P*-value	Statistical inference
I	≤20	Male	3	14.6±1.5	14.5±1.0	−1.00	0.423	NS
		Female	13	15.9±2.2	15.2±1.7	−0.60	0.567	NS
II	21–40	Male	23	15.3±2.0	15.8±2.0	0.72	0.477	NS
		Female	22	16±2.2	15.3±1.3	−1.58	0.128	NS
III	41–60	Male	15	15.5±1.5	15.7±1.7	0.77	0.450	NS
		Female	7	16.6±1.6	14.8±1.7	−3.74	0.334	NS
IV	>60	Male	9	15.3±2	15.3±1.4	−0.56	0.595	NS
		Female	8	16.1±1.7	14.8±1.3	−1.08	0.338	NS

SD: Standard deviation

Table 3(c): Group-wise comparison between males (study) and females (study) on day 1 according to mean respiratory rate (/min)

Groups	Age	Males Mean±SD	Females Mean±SD	*t*-test	*P*-value	Statistical inference
I	≤20	11±1	11±1	−1.00	0.423	NS
II	21–40	12.1±1.1	12±1	0.00	1.000	NS
III	41–60	13±1.2	12.7±0.7	0.00	1.000	NS
IV	≥60	13.5±0.7	14±0.5	−1.87	0.104	NS

SD: Standard deviation

Table 4(a): Group-wise comparison between males and females (study) on day 1 and at 2 months according to mean systolic blood pressure (mm Hg)

Groups	Age	Sex	Number (*n*)	Day 1 Mean±SD	At 2 months Mean±SD	*t*-test	*P*-value	Statistical inference
I	≤20	Male	3	119.3±1.1	119.3±1.1	0.00	1.000	NS
		Female	13	119.1±1.5	119.2±1.3	−15.50	0.060	NS
II	21–40	Male	23	124.1±5.2	123.2±4.4	2.47	0.074	NS
		Female	22	124±4.0	122.9±3.6	2.04	0.053	NS
III	41–60	Male	15	134±7.1	133.6±7.3	0.67	0.510	NS
		Female	7	134±7.3	132.6±7.4	3.40	0.054	NS
IV	>60	Male	9	137.5±6.2	136.6±5.4	1.83	0.104	NS
		Female	8	137±6.3	135.7±5.4	3.46	0.070	NS

SD: Standard deviation

First, when the subjects from a high altitude are brought to sea level, the disappearance of the polycythemia occurs due to temporary diminution or inhibition of erythropoiesis and greater blood destruction.[13]

Second, there is cessation of the sympathetic overactivity of high altitude people at sea level.

BP

BP is the force exerted by the blood against any unit area of the vessel wall. It is almost always measured in millimeters of mercury (mm Hg) because the mercury manometer has been used as the standard reference measuring pressure since its invention in 1846 by Poiseuille.[14]

Table 4(b): Group-wise comparison between males and females (study) at 2 months and males and females (control) according to mean systolic blood pressure (mm Hg)

Groups	Age	Sex	Number (*n*)	At 2 months Mean±SD	Control Mean±SD	*t*-test	*P*-value	Statistical inference
I	≤20	Male	3	119.3±1.1	120±1.8	1.73	0.225	NS
		Female	13	119.2±1.3	118.7±1.5	−0.28	0.785	NS
II	21–40	Male	23	123.2±4.4	123±2.8	0.94	0.359	NS
		Female	22	122.9±3.6	122±2.9	−1.26	0.220	NS
III	41–60	Male	15	133.6±7.3	133±6.3	0.88	0.389	NS
		Female	7	132.6±7.4	133.3±7.3	2.10	0.069	NS
IV	>60	Male	9	136.6±5.4	137.3±2.4	0.23	0.822	NS
		Female	8	135.7±5.4	135.6±5.2	−0.40	0.704	NS

SD: Standard deviation

Table 4(c): Group-wise comparison between males and females (study) on day 1 and at 2 months according to mean diastolic blood pressure (mmHg)

Groups	Age	Sex	Number (*n*)	Day 1 Mean±SD	At 2 months Mean±SD	*t*-test	*P*-value	Statistical inference
I	≤20	Male	3	82.7±2.3	78.6±1.1	3.46	0.022	S
		Female	13	79.8±2.4	76±2	−7.03	0.000	HS
II	21–40	Male	23	84.1±2.7	80.1±1.3	5.69	0.000	HS
		Female	22	82.1±3.5	77±2.7	7.50	0.000	HS
III	41–60	Male	15	88.1±3.2	83.3±2.9	8.07	0.000	HS
		Female	7	86.6±3.6	81.4±2.2	7.29	0.000	HS
IV	>60	Male	9	91.5±2.8	85.1±2.6	15.01	0.000	HS
		Female	8	88.2±2.2	82.5±2.8	10.48	0.000	HS

SD: Standard deviation

Table 4(d): Group-wise comparison between males and females (study) at 2 months and males and females (control) according to mean diastolic blood pressure (mmHg)

Groups	Age	Sex	Number (*n*)	At 2 months Mean±SD	Control Mean±SD	*t*-test	*P*-value	Statistical inference
I	≤20	Male	3	78.6±1.1	78.3±2.3	1.00	0.423	NS
		Female	13	76±2	76.6±2.1	0.00	1.000	NS
II	21–40	Male	23	80.1±1.3	80.1±2.1	0.00	1.000	NS
		Female	22	77±2.7	76.9±3.0	−0.29	0.773	NS
III	41–60	Male	15	83.3±2.9	83.1±2.9	−0.12	0.906	NS
		Female	7	81.4±2.2	81.3±3.7	0.66	0.524	NS
IV	>60	Male	9	85.1±2.6	85±2.1	2.08	0.071	NS
		Female	8	82.5±2.8	81.6±1.7	−0.78	0.477	NS

SD: Standard deviation

Table 4(e): Group-wise comparison between males (study) and females (study) on day 1 according to mean systolic and diastolic blood pressure (mmHg)

Groups	Age	Blood pressure	Males Mean±SD	Females Mean±SD	*t*-test	*P*-value	Statistical inference
I	≤20	Systolic	119.3±1.1	119.1±1.5	−1.00	0.423	NS
		Diastolic	82.7±2.3	79.8±2.4	−6.87	0.030	S
II	21–40	Systolic	124.1±5.2	124±4	0.00	1.000	NS
		Diastolic	84.1±2.7	82.1±3.5	2.39	0.026	S
III	41–60	Systolic	134±7.1	134±7.3	0.00	1.000	NS
		Diastolic	88.1±3.2	86.6±3.6	0.52	0.017	S
IV	≥60	Systolic	137.5±6.2	137±6.3	−0.22	0.827	NS
		Diastolic	91.5±2.8	88.2±2.2	1.73	0.027	S

SD: Standard deviation

In the present study, the results were that the high altitude people, both males and females, showed a steeper increase in BP with age than the lowland people. The increase in the DBP in high altitude people was more than the lowland people, and the difference was statistically highly significant. Furthermore, males showed a greater increase than the females and the difference was statistically only significant. However, there was almost no difference in the SBP between the high and low altitude people and also between males and females.

These findings are similar to the studies conducted by Wood *et al*.[15] and Otsuka *et al*.[16] Several reasons may account for the increase in BP in high altitude people. First, at higher altitude, atmospheric oxygen is lower; hypoxemia stimulates sympathetic nerve activity, which is associated with an increase in BP.[17]

Second, it has been reported that carotid bodies from the Karakorams (including Ladakh) are heavier and larger, presumably related to the hypobaric hypoxia. Such histological characteristics of the carotid bodies may alter the cardiovascular coordination in Ladakhi people.[18]

Third, Ladakh is a cold desert and its environmental temperature drops as low as − 45°C in winter, whereas in summer, the temperature reaches up to 27°C, a factor that will also stimulate sympathetic activity and increase BP.[16]

CONCLUSION

High altitude natives have distinctive biological characteristics that appear to offset the stress of hypoxia, such as the increased resting pulse rate and ventilation rate, elevated hemoglobin concentration, or the elevated total erythrocyte count. Evolutionary theory reasons that they reflect genetic adaptations resulting from natural selection favoring more effective adaptive responses.

The study of natural selection at high altitude is entering an era of linking genomics, genetics, molecular biology, and physiology to understand what makes an organism better able to function, survive, and reproduce - fit in the Darwinian sense - under the chronic lifelong stress of high-altitude hypoxia.

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