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Tibet vs the Andes: Adaptations to Chronic Hypoxia

Introduction

High altitude dwellers have existed throughout human history and have adapted in response to the constant hypoxia (lack of oxygen) they face. In "Human Adaptation to High Altitude: Regional and Life-Cycle Perspectives," Moore states: "Nearly 140 million people reside at high altitude, defined here as elevations above 2500 m (8,000 ft.)," (Moore, 1998). While visitors to these areas would experience mountain sickness, local inhabitants do not. These adaptations should not be confused with acclimatization, a series of time-dependent physiological responses that all people experience in response to high altitudes. High altitude adaptations are irreversible physiological changes that are genetic adaptations consisting of changes in the oxygen transport system, which cause higher birth weight, increased lung capacity, and high resting metabolism.

Adaptations in high altitude dwellers are relatively straightforward examples in understanding evolution due partially to the widespread existence of hypoxia as well as because of the generational occupation of high altitude environments (Julian et al. 2008). Through the excavation of highland obsidian deposits and dental morphology of human remains in the Andes Mountains, Burger et al. concluded people migrated from the coast to the mountains some 10,000 years ago. Similar studies in the Tibetan Plateau indicate hominids occupied the area from at least 2 million years ago (Brown, 1999; Dennell et al., Etler, 1996) and lived directly in the mountains from 18,000-20,000 years ago (Aldenderfer and Zhang, 2004; Huang, 1994; Zhang and Li, 2002).

Background

Research on high altitude occupants centers on adaptations of people living in the Andes and Himalayas because of the long history of residence and isolation of the humans residing in these two areas. However, these two areas have also had an influx of lowland populations who migrated to them, so comparative studies have become much easier to conduct. This essay will do a cross-cultural analysis of Tibetans' adaptations to living in the Himalayan mountain range and several Andean people's adaptations.

To further explain Himalayan heritage, modern day Tibetans are theorized as descendant of people who first occupied the Tibetan Plateau since the mid-Holocene (7,000-5,000 years ago) and perhaps since the late Pleistocene (more than 21,000 years ago). "Ethnic Tibetans possess heritable adaptations to their hypoxic environment, as indicated by birth weight, hemoglobin levels, and oxygen saturation of blood in infants and adults after exercise," (Yi, 2010). Conclusively this shows natural selection favored these adaptations. Although similar characteristics of certain adaptations can be found in both Tibetan and Andean descended people, Tibetans were observed to have more substantial levels of difference in the characteristics they possessed.

Data

Infants and Pregnant Women

Under conditions of living at high altitude and experiencing hypoxia, one of the most studied effects is lower birth weight of infants. Results show that birth weight decreases at an average of 100g per 1,000m. However, the studies conducted show women of high altitude ancestry give birth to heavier infants when compared to non-indigenous people. This denotes that people of high altitude ancestry adapted in order for their children to maintain a healthier birth weight.

"In Tibet, babies born to lifelong residents of Tibetan ancestry weighed 294– 650g more than babies born to Han women who had lived there for several years," (Moore, 1998). To understand the reasons for this phenomenon, the terms arterial oxygen saturation and uterine blood flow must be understood. Oxygen saturation refers to the percentage of oxygen saturated hemoglobin in relation to the total hemoglobin. Normal levels are between 95 to 100 percent. Uterine blood flow describes a condition during pregnancy in which blood must flow to the uterus to provide the fetus with oxygen."In Tibetan women, their pregnancies increased maternal ventilation, but arterial oxygen saturation, C_aO_2, was unchanged." This redistribution to the uterine artery accounts for higher birth weights in the Tibetan vs. the Han samples. The data suggested Tibetans adapted in a way to maximize their increase in uterine blood flow instead of CaO2.

Similarly in studies of Andean pregnant women and the birth weight of their babies, it has been found that descendents of Andean natives birthed infants who weighed 143g more than children mothered by women of European or mestizo ancestry. Usually, Tibetans experience higher birth weight than Andeans, even if they live at similar altitudes. This might be due to greater heritability of factors that lead to higher birth weight in Tibetan populations.

Another issue associated with having children at high altitudes in intrauterine growth retardation (IUGR). IUGR is a condition that occurs at high altitudes as a result of lowered oxygen supply levels from the placenta to the fetus. However high altitude residents whose ancestors lived in the same areas seem to display protection from IUGR. This suggests that the protection is a genetic adaptation. In studies of Tibetan and Andean natives, Tibetan women possess greater levels of protection from IUGR than Andean natives. This can be attributed to the existence of different genetic variations creating different adaptation levels.

In populations of Tibetan women, proper delivery of fetal-placental oxygen is managed through an increase in uterine blood flow. The Andean groups studied in Peru however experienced a different adaptation. IUGR was avoided due to a mechanism that increased arterial oxygen content (CaO2). Thus increased levels of CaO2 are found in pregnant women of that population. The difference between the Tibetan and Andean adaptations implies that different methods for maintaining fetal-placental oxygen delivery exists between individuals and populations implies genetic factors are present. Increase in uterine blood flow in Tibetan women leads to infant weights which mimic infants birthed at sea level. These factors evident in both Tibetan and Andean populations imply that over time and generations, these adaptations have been selected for. They are not present in non-Native populations, and differ in method amongst Native populations.

In a comparative study of Andeans and Tibetans with samples from 3,900m, the Andean sample had 21% higher hemoglobin concentration than the Tibetan sample (Beall et al., 1998). Although both respond with increased hemoglobin concentration, Tibetan populations respond to altitudes of above 4,000m while the Andeans respond at 1,600m. In conclusion, Andeans experience the adaptations under conditions that are much less severe than Tibetans, although Tibetans have a smaller response. However, there is no evidence of genetic variation in the Andes in favor of adaptations, but there is evidence in Tibetan populations which are genetically homogenous for these traits.

Childhood Growth and Development

Adaptations are visible in infants and children as well. In an Andean samples which compared high altitude to low altitude infants, there was a consistent reduction in length and weight for children recorded from birth to 2 years of age. However, many argue that socioeconomic and nutritional factors may influence this data. In addition to this, larger than average chest dimensions, especially chest depth and development has been observed in high altitudes of the Andes. According to Moore, the larger chest dimensions have been accredited to natural selection. He states: "Phenotypic plasticity may also be involved since genes coding for accelerated chest development might be preferentially expressed at high altitude," (Moore, 1998).

Although large chest dimensions do not correlate with lung volume, higher lung volumes are associated with high altitudes. This is evident in Tibetan residents who have a distinctly larger lung volume. It results from exposure to high altitude during growth and development and cannot be acquired as an adult, although genetics can influence it. For example a study of Bolivian high and low altitude residents "found that growth and development at high altitude accounted for approximately 25% of the increase in vital capacity and residual volume among males [and] genetic factors accounted for an additional 25% of the variability," (Moore, 1998).

Studies of high altitude dwellers suggest that their body's growth in childhood and adolescence is stunted compared to growth in sea-level residents. However, all high altitude dwellers developed enlarged lung dimensions. Some argue that the impaired growth of children and adolescents is more dependent on the lack of nutrition in their diets, due to limited food resources. But this theory can be challenged by the fact that stunted growth remains an issue even when the nutritional value of their diets is increased.

Adults

In addition to larger lung volume, ventilation control is also a factor measured in ancestral, high altitude dwellers. It has been studied through hypoxic ventilatory response (HVR). This mechanism is a nervous response to hypoxia in which consists of slower heart rate, increased respiratory frequency, and eventually a steady flow of ventilation (Easton et al. 1986). Non-native groups tend to have high HVR when they are first exposed to high altitudes, high levels return to normal within days, and within months or years the levels fall well below normal. Interestingly, Tibetans have a normal HVR compared to sea level inhabitants, but Andeans have lower HVR than their sea level residing counterparts. Tibetans have double the HVR of Andeans. When these differences are analyzed in regards to evolutionary adaptations, it can be assumed Tibetan respiratory physiology adapted from temporary increases in HVR to creating similar physiological responses within normal HVR levels which they maintained indefinitely (Beall, 2006).

In adults, hemoglobin concentration has been shown to increase in high altitude dwellers. This adaptation affects various traits, all centering around oxygen transportation. These adaptations include hemoglobin concentration, percent of oxygen saturation of hemoglobin, resting ventilation, etc. As oxygen levels are lower in high altitude areas, humans adapted in order to be able to breathe sufficiently and survive in their environments. As with other adaptation, the heritability between populations of Tibetans and Andeans varies. Tibetans have noteworthy heritability in hemoglobin concentration, oxygen saturation, resting ventilation, and hypoxic ventilatory response. However, Andeans only show evidence for heritability in hemoglobin concentration and hypoxic ventilatory response (Strohl, 2007).

In low altitude dwelling populations, when they are exposed to hypoxic conditions, oxygen saturation decreases a great deal almost immediately. This is due to the lower partial oxygen pressure at altitudes of above 3,000 meters (Reeves et al., 1993). In both Tibetan and Andean populations, between 97-98% of residents have lower oxygen saturation than those at sea level. In a sample taken to compare Tibetan and Andeans, the Andeans had 2.6% (one standard deviation) higher oxygen saturation. This suggests that Andeans were less stressed by hypoxic conditions at the same altitude. (Beall, 2006).

Additionally, when hemoglobin concentration is compared between Tibetan and Andean samples, the results show that Tibetans need much higher elevations to display higher hemoglobin concentration and even when this response is triggered, it is smaller than that of the Andean counterpart. Tibetans have increased hemoglobin concentration at altitudes of 4,000 meters. However, Andeans have the same response at lower altitudes of 1,600 meters. In samples collected from both the Andes and Tibet at 3,900 meters, the Andean sample had 21% higher hemoglobin concentration than the Tibetan sample (Beall et al., 1998). These studies confirm that high hemoglobin concentration is not necessarily a ubiquitous response to high altitude hypoxia (Garruto et al., 2003).

Together, oxygen saturation and hemoglobin concentration determine arterial oxygen content. adaptation. These traits are known as distinguishing characteristics amongst people of Andean and Tibetan descent. In the Andes, the typical pattern found in residents is that of high hemoglobin concentration, low oxygen saturation, and an arterial oxygen content that is about 16% higher than sea-level reference values. In Tibetan, the pattern is sea-level hemoglobin concentration (until very high altitudes), very low oxygen saturation, and an arterial oxygen content that is approximately 10% lower than those at sea level. (Beall, 2006). This implies human occupation of high altitude locations presented two different biological outcomes.

To determine if these traits were the result of natural selection, quantitative genetic analyses were taken from Tibetan and Andean samples at 3,900 meters. Both showed high heritability (h^2) for high hemoglobin concentration, with h^2 of .89 for the Andean and .64 for the Tibetan samples. These results indicate there is genetic variation in both samples, and there is the possibility for natural selection to select higher hemoglobin concentration in both populations (Beall et al., 1998). In regards to oxygen saturation, the Andean sample had no significant heritability, while the Tibetan sample had a h^2 of .40. There is evidence of a major gene[1] for oxygen saturation within Tibetan populations.

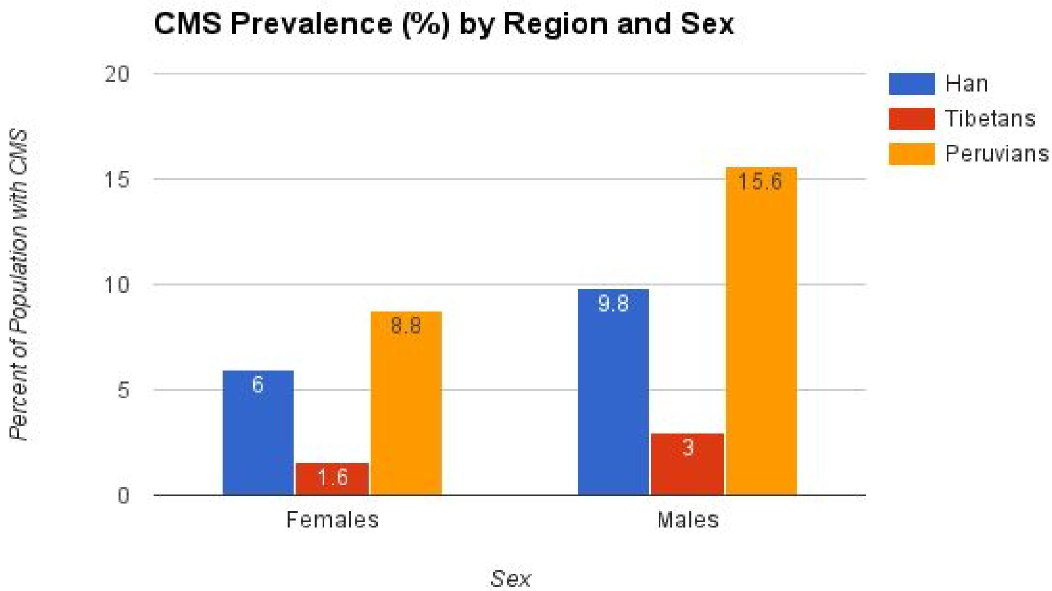
Elderly

Chronic Mountain Sickness (CMS) has a lower prevalence amongst Tibetans than Andeans or sea level residents. This condition is an adaptative failure found in the elderly who have resided in high altitudes for long periods of time. CMS causes dizziness, fatigue, memory loss, and insomnia, but it can be fatal if left untreated. The results of studies of CMS prevalence at altitudes of above 3,800 meters are shown in Table 1 (Leon-Velarde et al., 1997; Monge et al., 1992; Wu et al., 1994; Xie et al., 1981). The comparative studies examined data from male and female Han (Chinese ethnic group residing at sea level), Tibetans, and Peruvians. Conclusively, the data suggest CMS prevalence is greatest in Han migrants, intermediate in lifelong Andean residents, and lowest in Tibetan highlanders. This low prevalence in Tibetans may be due to their higher ventilation levels in addition heredity and other factors .

Discussion

Table 1

[1] A major gene is an inferred allele with a large quantitative effect at a segregating autosomal locus (Weiss, 1993).


CMS Prevalence (%) by Region and Sex
Percent of Population with CMS
20
15
10
5
0
6
1.6
8.8
9.8
3
15.6
Females
Males
Sex
Han
Tibetans
Peruvians

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