The body weight loss during acute exposure to high-altitude hypoxia in sea level residents

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Abstract: Weight loss is frequently observed after acute exposure to high altitude. However, the magnitude and rate of weight loss during acute exposure to high altitude has not been clarified in a controlled prospective study. The present study was performed to evaluate weight loss at high altitude. A group of 120 male subjects [aged (32±6) years] who worked on the construction of the Golmud-Lhasa Railway at Kunlun Mountain (altitude of 4 678 m) served as volunteer subjects for this study. Eighty-five workers normally resided at sea level (sea level group) and 35 normally resided at an altitude of 2 200 m (moderate altitude group). Body weight, body mass index (BMI), and waist circumference were measured in all subjects after a 7-day stay at Golmud (altitude of 2 800 m, baseline measurements). Measurements were repeated after 33-day working on Kunlun Mountain. In order to examine the daily rate of weight loss at high altitude, body weight was measured in 20 subjects from the sea level group (sea level subset group) each morning before breakfast for 33 d at Kunlun Mountain. According to guidelines established by the Lake Louise acute mountain sickness (AMS) consensus report, each subject completed an AMS self-report questionnaire two days after arriving at Kunlun Mountain. After 33-day stay at an altitude of 4 678 m, the average weight loss for the sea level group was 10.4% (range 6.5% to 29%), while the average for the moderate altitude group was 2.2% (~2% to 9.1%). The degree of weight loss (Δ weight loss) after a 33-day stay at an altitude of 4 678 m was significantly correlated with baseline body weight in the sea level group (r=0.677, P<0.01), while the correlation was absent in the moderate altitude group (r=0.296, P>0.05). In the sea level subset group, a significant weight loss was observed within 20 d, but the weight remained stable thereafter. AMS-score at high altitude was significantly higher in the sea level group (4.69±2.48) than that in the moderate altitude group (2.97±1.38), and was significantly correlated with baseline body weight. These results indicate that (1) the person with higher body weight during stay at high altitude loses more weight, and this is more pronounced in sea level natives when compared with that in moderate altitude natives; (2) heavier individuals are more likely to develop AMS than leaner individuals during exposure to high-altitude hypoxia.

Key words: body mass index; weight loss; high altitude; Qinghai-Tibetan plateau
受检者乘火车到格尔木地区(海拔2 800 m)，并在此停留7 d，测定体重、体重指数、腰围等指标，之后乘车到昆仑山口(海拔4 678 m)工作33 d后再次测定以上各指标。到达昆仑山口2 d后，采用Lake Louise急性高原病(acute mountain sickness, AMS)评分规则对平原组和高原组进行评分。为了动态观察体重的日变化，对来自平原组的20名施工人员，每天早上施工之前测体重，连续测量33 d。结果显示，平原组在格尔木和昆仑山所测平均体重分别为(67.1±9.5) kg和(60.0±8.1) kg (P＜0.01)，中海拔组体重分别为(63.1±5.5) kg和(61.7±6.4) kg (P＞0.05)。平原组平均体重降低幅度为10.4% (范围6.5%~29%)，而中海拔组为2.2% (范围-2%~9.1%)。平原组体重下降的程度与暴露高原之前的体重(基础值)呈显著正相关(r=0.677, P＜0.01)，而中海拔组体重下降程度与基础体重不相关(r=0.296, P＞0.05)。20名平原人到达高原20 d内体重降低最明显，之后体重基本保持不变。平原组AMS评分(4.69±2.48)显著高于中海拔组(2.97±1.38)，两组AMS评分与基础体重值呈正相关(r=0.643, P＜0.01)。以上结果提示：(1)平原人暴露高原环境之后体重显著减轻，体重越高者体重减轻程度越高；(2)较高体重指数的平原人快速进入高原之后，易出现急性高原反应，甚至发生AMS。

关键词：体重指数；体重减轻；高原；青藏高原
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Previous data demonstrated that the rapid ascent from low to high altitude (above 2 500 m) often causes acute mountain sickness (AMS), a syndrome characterized by headache and other systemic symptoms, such as nausea, lassitude, and difficulty sleeping. The prevalence and severity of AMS depend on the speed of ascent, the altitude attained, preacclimatization, age, sex, exertion levels while at altitude[1,2]. Weight loss is frequently observed during acute exposure to high altitude due to decreased appetite and increased energy expenditure[3-5]. However, for individuals who ascend to high altitude, the amount of weight loss, the rate of weight loss, and the effect on body mass index (BMI) are not known, and whether the subjects who have higher body weight are more susceptible to develop AMS is also unknown. The purpose of the present study is (1) to determine whether exposure to high altitude would induce weight loss in sea level and high altitude natives; (2) to evaluate whether higher body weight individuals are more susceptible to develop AMS when they are exposed to high-altitude hypoxia.

1 MATERIAL AND METHODS

A group of 120 male subjects [aged (32±6) years, and (168.1±5.8) cm in height] who worked on the construction of the Golmud-Lhasa Railway at Kunlun Mountain (altitude of 4 678 m) served as volunteer subjects for this study. Eighty-five workers normally resided at sea level (sea level group) and 35 normally resided at an altitude of 2 200 m; moderate altitude group). Body weight, BMI, and waist circumference were measured in all subjects after a 7-day stay at Golmud (altitude of 2 800 m, baseline measurements). Measurements were repeated after 33-day working on Kunlun Mountain. In order to examine the daily rate of weight loss at high altitude, body weight was measured in 20 subjects from the sea level group (sea level subset group) each morning before breakfast for 33 d at Kunlun Mountain. Body weight of all subjects was measured in underwear without shoes before breakfast. All subjects worked for 5 h per day and participated in similar levels of physical activity.

According to guidelines established by the Lake Louise acute mountain sickness (AMS) consensus report [8], each subject completed an AMS self-report questionnaire two days after arriving at Kunlun Mountain. The questionnaire included items for symptoms of headache, gastrointestinal symptoms, fatigue or weakness, dizziness or light-headedness, and difficulty sleeping. Detail assessment of AMS was described previously [7]. The research protocol was approved by the human subject protection committee at the Medical College of Qinghai University. Informed consent was obtained from each subject.

Data are expressed as means±SD. Measurements of body weight and BMI obtained initially at Golmud (altitude of 2 800 m) and after 33-day living on Kunlun Mountain (altitude of 4 678 m) were compared within groups using a Student’s paired t-test. Student’s unpaired t-test was used for between-group comparisons. Linear regression analysis and correlation coefficients were used to assess the relationships between variables. P value less than 0.05 was considered as statistically significant.

2 RESULTS

The data were collected after 7-day acclimatization at base camp in Golmud, and after 33-day living on Kunlun Mountain. The body weights in baseline (Golmud) and after 33-day at Kunlun Mountain in the sea level group were
(67.1±9.5) kg and (60.0±8.1) kg, respectively (P<0.01); in the moderate altitude group body weights were (63.1±5.5) kg in Golmud and (61.7±6.4) kg in Kunlun Mountain (P>0.05). The average weight loss for the sea level group was 10.4% (range 6.5% to 29%), while the average for the moderate altitude group was 2.2% (-2% to 9.1%). As shown in Fig. 1, the degree of weight loss (Δ weight loss) after a 33-day stay at an altitude of 4 678 m was significantly correlated with baseline body weight in the sea level group (r=0.677; P<0.01), while it was absent in the moderate altitude group (r=0.296, P>0.05). The waist circumference in the sea level group was (88.3±7.6) cm at Golmud and (83.7±7.4) cm at Kunlun Mountain (P<0.01), and it was (85.5±6.8) cm at Golmud and (84.1±7.6) cm at Kunlun Mountain (P>0.05) in the moderate altitude group.

In order to examine the daily rate of weight loss at high altitude, we obtained a measurement of body weight each morning in the sea level subset group. In this group, a significant weight loss was observed within 20 d, but the body weight remained stable thereafter (Fig. 2).

AMS-score after two-day stay at high altitude was significantly higher in sea level group (4.69±2.48) than that in the moderate altitude group (2.97±1.38), and AMS-score was significantly correlated with baseline body weight in both two groups (r=0.643, P<0.001) (Fig. 3).

3 DISCUSSION
Many studies indicated that high-altitude hypoxia induced weight loss is due primarily to decreased appetite and increased energy expenditure [8,9]. Boyer et al. [10] reported that the mean body weight decreased by 1.9 kg during a 7-day exposure to 4 500 m and continued to decrease by 4.0 kg over a 32-day stay. However, these data were collected from field studies on climbers, who may differ from other populations (i.e. non-climbers). No controlled study has previously been completed to evaluate the weight loss that occurs in non-climbers ascending from both sea level and moderate altitudes to high altitude.

In our study, the average weight loss during a 33-day stay at high altitude was more pronounced in the sea level group than that in the moderate altitude group. This may have resulted from the differing responses to high altitude exposure between the two groups. When exposed to an altitude of 4 678 m, the subjects who were normally resident at or near sea level occurred more significant hypoxic response than the subjects who normally reside at moderate altitude, and those subjects had developed severer AMS symptoms and significantly higher AMS-score than those reside at moderate altitude. The frequency and severity of AMS symptoms were significantly different between two

![Fig. 1. The degree of weight loss (Δ weight loss) after a 33-day stay at an altitude of 4 678 m was significantly correlated with baseline body weight in the sea level group (SL-group, r=0.677, P<0.01), while it was absent in moderate altitude group (Alt-group, r=0.296, P>0.05). Closed symbols, SL-group; open symbols, Alt-group.](image)
groups. For example, sea level subjects had very poor appetite (90%) and sleep disorders (80%) during the first week of high altitude exposure, while this finding was minor (poor appetite 35%, sleep disorders 20%) in the moderate altitude group. We assumed that the less developed AMS-score in the moderate altitude group might be attrib-

Fig. 2. Continuous daily measurements of body weight in sea level subset group at Kunlun Mountain (4 678 m) showed that a significant weight loss was observed within 20 days of ascent but then maintained stable thereafter. △, baseline body weight measured at Golmud (2 800 m) after 7-day acclimatization; ▲, body weight measured after 33-day stay at Kunlun Mountain (4 678 m). Data are means±SEM. n=20.

Fig. 3. There was a significant correlation between baseline body weight and acute mountain sickness score (AMS-score) in both sea level (SL) group and moderate altitude (Alt) group (r=0.643, P<0.001). AMS-score was measured at two days after arriving at Kunlun Mountain.
uted to their greater hypoxic tolerance since they have been born and raised at an altitude of 2,200 m.

Most studies have indicated that the decrease in body weight is mainly attributed to a loss of fat during a climb at high altitude. Fusch et al. [14] reported that 70% of the weight loss after 62 d at altitude of 4,900 m was due to loss of fat. Boyer et al. [10] have shown that 33% of the total weight loss at a simulated altitude of 6,000 m for 10 d was due to fat loss. We found that the waist circumference of the sea level group when compared to the moderate altitude group was significantly reduced after a 33-day stay at an altitude of 4,638 m (P<0.05). In addition, the degree of weight loss after 33-day stay at high altitude was positively correlated to the baseline body weight, suggesting that more body weight will be lost during a stay at high altitude if the initial body weight is higher. In a subset of sea level natives, a significant weight loss was observed within 20 d of ascent to high altitude, but the weight remained stable thereafter. It appears that the effects of high altitude on weight loss may be expected to occur within three weeks when people with overweight travel to high altitude.

The mechanisms of decreased food intake and weight loss with high altitude exposure are not fully understood. It is known that peripheral hormones and various cytokines are involved in the regulation of energy balance [15]. Of these, leptin is a key mediator in the regulation of energy homeostasis and food intake. Previous studies have indicated that the mean serum leptin level was significantly increased after a short-term exposure to an altitude of 5,000 m [16-18]. This increase was strongly associated with a loss of appetite, i.e., leptin level was increased by 53% in individuals with decreased appetite, but no significant increase in serum leptin level was found in individuals without loss of appetite.

With the current migration of a great number of sea level residents to the Qinghai-Tibetan plateau, a large number of subjects are at risk for developing AMS at high altitude areas. Contributing factors to the development of AMS have included the speed of ascent, the altitude attained, hypoventilation, sleep disorders and susceptibility of the individual [19,20]. In the present study we found that the heavier individuals have higher AMS scores than leaner individuals during two-day stay at Kunlun Mountain (altitude of 4,678 m). Thus, overweight individual seems to be associated with the development of AMS and that is a fetal risk to get the syndrome worse on mountains. This condition was more pronounced in the sea level group than that in the moderate altitude group. Therefore, we, as health care providers and medical scientists, are confronted with questions of prevention and treatment of AMS while those overweight individuals are traveling to high-altitude areas.

These results indicate that (1) the person with higher body weight during stay at high altitude loses more weight, and this is more pronounced in sea level natives when compared with that in moderate altitude natives; (2) heavier individuals are more likely to develop AMS than leaner individuals during exposure to high-altitude hypoxia.

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