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## ***Ventilatory, Circulatory, and Metabolic Mechanisms During Muscular Exercise at High Altitude (La Paz, 3500 m)***

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The scientific study of the natives of the Andes in South America is no longer an isolated or exotic undertaking (9). The Andean peoples are undergoing cultural, social, and economic development unequaled in their histories. The agricultural and mining potential makes the Andean area one of vital importance. However, a whole series of health problems has emerged from the requirements of integration and migration to new economic development centers.

Bolivia extends over approximately 1,000,000 km<sup>2</sup> with permanent settlements between 500 and 5000 m above sea level. The climate ranges from tropical to cold. Its labor force amounts to approximately 2,500,000 people, of which approximately 70% live above altitudes of 2000 m, working in agriculture, metal, mining, smelting, and general services. La Paz, the political and administrative capital, is a city with 800,000 inhabitants and is situated at 3500 m above sea level.

Since all developmental activities are based on physical labor, knowledge of the repercussions of physical exertion on the human organism, the organism's physiologic limits, and the effects of environmental factors is of prime importance. It is useful to know the performance of the re-

spiratory, cardiovascular, and metabolic systems during light, medium, and maximum levels of exertion with respect to the native resident population living at high altitude as well as population groups living at low altitude, since these groups may have to change altitude temporarily or permanently.

It has been shown that in the investigation of sports-related exercise, many useful parameters may be obtained which may then be applied to other fields (3,6,7,11,23).

### **Normal Biologic Parameters (3500 m)**

Studies carried out at the Instituto Boliviano de Biología de Altura (IBBA) show that the most common blood group is O, that men have from 5,200,000 to 5,600,000 and women from 5,100,000 to 5,400,000 red blood cells, with a hematocrit from 49 to 53% in men and from 47 to 50% in women. Men have 15.5 to 17.5 g% hemoglobin and women 15.0 to 16.5 g%. Respiratory values do not show a significant difference in comparison to sea level values (minute ventilation, 7–9 liters/min BTPS; respiratory frequency, 16–18/min), with the

exception of a higher vital capacity and a larger residual volume. Lung compliance is not significantly different from that of natives of Santa Cruz (400 m); neither are inspiratory and expiratory resistances (181 ml/cm H<sub>2</sub>O, 4.2 cm H<sub>2</sub>O/liter/s, and 3.9 cm H<sub>2</sub>O/liter/s; and 175 ml/cm H<sub>2</sub>O, 4.0 cm H<sub>2</sub>O/liter/s, and 3.8 cm H<sub>2</sub>O/liter/s, respectively, in both groups). Lung diffusing capacity for carbon monoxide at steady state is increased: for a person measuring 1.70 m and aged 30, 28.98 ml/min/mmHg were measured.

Gas transport is different at high altitude in comparison to sea level because lower  $PI_{O_2}$  (93 mmHg) secondary to lower  $P_B$  (490 mmHg) causes a  $Pa_{O_2}$  of 66 mmHg and a  $Pa_{CO_2}$  of 30 mmHg.  $Pa_{O_2}$  is 58–60 mmHg;  $Pa_{CO_2}$ , 29–30 mmHg;  $Sa_{O_2}$ , 88–90%; standard bicarbonate, 19 mEq; and pH 7.40, which does not change.

In cardiovascular circulation the systemic pressures are the same as at sea level. Pulmonary artery pressure is higher for individuals of the same age and sex ( $P_s$ , 29 ± 6.6 mmHg;  $P_d$ , 13 ± 3.8 mmHg; and  $\bar{P}$ , 21 ± 4.2 mmHg) without significant differences in pulmonary capillary pressure (mean PCP, 9 ± 2.7 mmHg); cardiac output (6.43 ± 1.69 liter/min); and cardiac index (3.91 ± 1.09 liter/min/m<sup>2</sup>). Total pulmonary vascular resistance and pulmonary arteriolar resistance calculated in La Paz are 265 ± 80 and 148 ± 43 dyn/s/cm<sup>-5</sup>, respectively. Skin blood flow and blood volume are also lowered in sea level natives during acclimatization to high altitude (4,14–17). Finally, cerebral blood flow (2,7,10,20) is decreased (32.6 ml/min/100 g), whereas neither oxygen consumption (3.18 ± 2.8 ml/min/100 kg) nor the respiratory quotient changes.

The VIIIth Bolivarian games took place in La Paz, Bolivia, at an altitude of 3500 m in October of 1977. It was therefore very important to investigate the biological responses to acute high altitude exposure and the physical capacity of as many participants as possible. In La Paz we observed

an increase in the respiratory and metabolic function of the erythrocyte, which contained 3.13 ± 0.5% methemoglobin and 79.85 mg/100 ml red blood cell for reduced glutathione (GSH). ATP is also increased (1968 nmol/ml red blood cell), as well as 2,3-DPG (6193 nmol/ml red blood cell). Total lipids are 772 ± 160 mg%; triglycerides and total cholesterol are 135 ± 9 mg% and 182 ± 32 mg%, respectively (5,13,21).

During maximal muscular exercise, for female sprinters and basketball players maximal heart rate and maximal oxygen consumption are 169.0 ± 12.50 beats/min and 51.59 ± 10.07 ml/min/kg, and 175.0 ± 15.04 beats/min and 48.06 ± 4.14 ml/min/kg, respectively. In men, for long distance running, cycling, boxing, and soccer, the values are 174.0 ± 9.20 beats/min and 68.68 ± 7.71 ml/min/kg, 174.0 ± 12.90 beats/min and 63.73 ± 6.96 ml/min/kg, 170 ± 13.35 beats/min and 49.30 ± 2.41 ml/min/kg, and 175.0 ± 6.0 beats/min and 48.40 ± 11.0 ml/min/kg, respectively (Tables 11-1 and 11-2).

### Maximal Muscular Exercise (3500 m)

Fifteen hundred athletes from Bolivia, Colombia, Ecuador, Panama, Peru, and Venezuela gathered for the VIIIth Bolivarian Games. It was expected that the high altitude of La Paz would be a source of concern, as was the case during the Olympic Games held in Mexico City in 1968. Consequently, the respective competing teams took compensatory action. Some athletes arrived in La Paz 2 weeks before the opening day; others spent some time in high altitude regions in their own countries to achieve some degree of acclimatization. In addition, the First Pre-Bolivarian Symposium of Sports Medicine was organized and held 3 months before opening day. During this symposium various topics were discussed, including age, sex, nutrition, doping, and the relation of high altitude to health. It was concluded that the effects of