THEORIES AND PRACTICES OF ALTITUDE TRAINING

—Mechanisms Study on the Effects of SD Rats' Cardiac Function by Simulative Altitude Training with Different Duration and Height

by Zhang Bing

中国体育
博士
双语文丛

高原训练的理论与实践

——模拟不同时程高原训练对大鼠心肌影响的机制研究

张 冰 著

北京体育大学出版社

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Resume

CURRICULUM VITAE OF ZHANG BING

Feb. 29, 1960	born in Beijing, People's Republic of China

EDUCATION BACKGROUD

Sep. 1978	entered the Department of Physical Education at Northwest Normal University
Jul. 1982	received a Bachelor degree of Education
Sep. 1992	entered the Graduate School of Beijing Sport University for a Master degree, major in Sports Physiology
Jul. 1994	received a Master degree of Education
Sep. 1994	entered the Graduate School of Beijing Sport University for a Doctor degree, major in Sports Physiology
Jul. 1997	received a Doctor degree of Education

PROFESSIONAL EXPERIENCE

Sep. 1982 ~ Jul. 1992	stayed on teaching at Northwest Normal University

Aug. 1997	began to work in the Department of Physical Education at Tsinghua University
Nov. 1998	assumed the vice director of the Department of Physical Education
Oct. 1999	became associate professor and tutor of Master student in the Department of Physical Education
Sep. 2002 ~ Oct. 2003	studied in the School of Health, Physical Education, and Recreation at Indiana University as a visiting scholar
Nowadays	the director of the Sports and Health Research Center at Tsinghua University

GRANTS

The Preparation for Beijing 2008 Olympic Games Program, 1.8 million yuan.
The National Fitness Program, 1 million yuan per year, for 3 years.

PUBLICATIONS

Books

Instructions of Sports Nutrition: chief editor.

Physical Education Management in School; The Development of Sports Physiology – Questions and Reflections; The Medical Care of Physical Education; The Choiceness of Teaching Methods in Physical Education Textbooks; Practical Sports Physiology: edited several chapters.

Essentials of Respiratory Physiology: translated and edited.

Articles

Establishment of Animal Model of Simulative Altitude Training. Zhang Bing, Zhou Yun – he, Zhao Ran. Chinese Journal of Sports Medicine, Vol. 10, No. 44, 2006, 215 – 218.

Advancement of Morphology Research about Exercise Effect on Essential Hy-

pertension Target Organ Injury. Zhang Bing, Zhang Shu. Journal of Wuhan Institute of Physical Education, Vol. 39, No. 5, 2005, 32 –35.
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Construction of Research Theory on Cultivating Elite College Student Athletes in Tsinghua University. Zhang Bing, Shi Chun – jian. Journal of Beijing Sport University, Vol. 28, No. 5, 2005, 577 –580.
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The Development of Researches about the Exercise Prescription for Essential Hypertension. Liu Jun – ling, Zhang Bing. Chinese Journal of Sports Medicine, Vol. 24, No. 3, 2005, 357 –361.
The Effect of Liuwei Dihuang Decoction on Exercise – Induced Fatigue in Rats. Wang Yun – jiang, Zhang Bing. Chinese Journal of Sports Medicine, Vol. 26, No. 1, 2007, 56 –59.
Effect of Sprint Exercise on PHGpx Gene Expression in Skeletal Muscle of Rats. Lei Ming – guang, Zhang Shu, Zhang Bing. Chinese Journal of Sports Medicine, Vol. 23, No. 6, 2004, 620 –623.
Standard Storage of Sports Data Based on XML. Li Tian – qing, Zhang Yi, Zhang Bing, Hu Dong – cheng. Computer Engineering and Application, Vol. 37, No. 22, 6 –10.

HONORS

The article "The Gene Expression of Rat Cardiac Muscle β – MHC Influenced by Simulative Altitude Training at Different Durations" has won the first prize of the 6th Scientific Congress of National Undergraduate Games.

The article "Facing the 21st Century: Investigations about the Construction and Development of the Physical Education Faculty at Tsinghua University" has won the first prize of the 1st Conference of China School Physical Education Science.

Participated in the project "Experiments and Investigations about Ordinary Universities Training Elite National Student Athletes". The project has won the first prize of the Soft Science Research at Tsinghua University.

The article "The Investigation and Analysis about the Nutrition of Diet and the Body Compositions of Female Teenager Athletes in Dive Team of Tsinghua University" has won the second prize of the 2005 Best Paper Award of Chinese Association of Higher Education.

The English article "Establishment of Animal Model of Simulative Altitude Training" has won the first prize of the 2006 Best Paper Award of Chinese Journal of Sports Medicine.

Mechanisms Study on the Effects of SD Rats' Cardiac Function by Simulative Altitude Training with Different Duration and Height

Abstract

The effects of altitude training on cardiac function have been an important issue in the field of sports science. Up to now, the effects of altitude training have been reported by many researchers. However, there are few studies on the mechanisms of altered cardiac function induced by altitude training.

In our research, we tested the effects of hypoxia on changes of cardiac index, variation in Ca^{2+}, Mg^{2+} – ATPase activity of ventricular myofibril, the changes of mitochondrion, cardiac troponin T and β – MHC gene expression of myocardium contractile protein.

Male adult SD rats were randomly divided into two stimulating 4000m hypoxia training groups in a hypobaric chamber for 1 – 4 weeks, and then returned to sea level and restoration for 2 weeks' training. The third group increased gradually acclimatized to the altitude step by step and restoration groups. Sea – level groups.

Results:

1. The cardiac index, cholesterol, HDL – cholesterol and triglycerides increased more obviously with the hypoxia degree and time increasing.

2. The results indicated that the ventricular compensatory mechanisms may be with low ATPase activities to decrease oxygen and energy consumption at both cellular and subcellular level. The increase of β – MHC gene expression and results of the redistribution of myosin isozyme may be the biological foundation of altered cardiac function. Although the Ca^{2+}, Mg^{2+} – ATPase activity of ventricular myocardium were decreased significantly in hypoxic acclimatization group, they were significant higher than that of 4000m hypoxia. These results indicated that changes at cellular level are the same as changes at organic level, which may be the biochemical foundation of the protective effect to cardiac function by hypoxic acclimatization. The decreased Ca^{2+}, Mg^{2+} – ATPase activity was a compensatory mechanism to hypoxic environment of cardiac muscles.

3. Hypoxic acclimatization had obviously protected the hypoxia effect to the cardiac function deficiency. The results also indicated that the cardiac performance deficiency induced by hypoxia could be recovered after animals were separated from the hypoxic environment.

Abbreviations

β - MHC	β - myosin heavy chain
cTn - T	Cardiac troponin T
DNA	Deoxyribonucleic acid
cDNA	Complementary DNA
FFA	Free fatty acid
HDL - C	HDL - cholesterol
LDL	Low density lipoprotein
LPL	Lipoprotein lipase
mRNA	Messenger ribonucleic acid
RNA	Ribonucleic acid
SR	Sarcoplasmic reticulum
SDS	Sodium dodecyl sulfate
TC	Total cholesterol
TG	Triglycerides
UAP	Unstable angina pectoris
VLDL	Very low density lipoprotein
EPO	Erythropoietin
RBC	Red blood cell
Hb	Hemoglobin
HCT	Hematocrit
RCV	Red cell volume
2,3 - DPG	2,3 - Diphosphoglycerate

Contents

Part I Literature Summarize

1 Physiological Adaptations to Altitude

The human body requires a continual and adequate supply of oxygen. The ability to transport oxygen from the lungs to the cells depends upon a sequence of events that includes (a) the movement of oxygen from the atmosphere into the lungs, (b) the uptake of oxygen by the blood and subsequent transport via the circulation, (c) the unloading of oxygen at the tissues, and (d) the utilization of oxygen by mitochondrial enzymes for the production of ATP (adenosine trisphosphate).

In moving up from sea level to moderate altitude the body is exposed to a progressive reduction in barometric pressure (P_B). This reduction in barometric pressure leads to a decrease in the partial pressure of oxygen in the inspired air (P_iO_2). A decrease in the partial pressure of inspired oxygen is referred to as hypoxia. Hypoxia results in reduced oxygen uptake by the lungs (P_iO_2) that ultimately leads to decrements in the partial pressure of oxygen within the blood (P_AO_2) and oxyhemoglobin saturation (S_BO_2). Fig 1 – 1 shows the relationship between altitude and the partial pressure of oxygen in inspired air, alveolar air (air in the lungs), arterial and venous blood.[9-13]

In an effort to minimize the effects of hypoxia, the body undergoes several physiological changes. These changes are summarized in Fig 1 – 2 and can be classified into four major groups: (a) Pulmonary, (b) Cardiovascular, (c) Blood chemistry, and (d) Skeletal muscle. Several of these physiological adaptations may have the capacity to enhance sea level endurance performance.

Air(P_iO_2), alveolar air (P_aO_2), arterial blood(P_aO_2) and venous blood(P_pO_2). (Adapted from Haymes and Wells Environment and Human performance, 1986.)

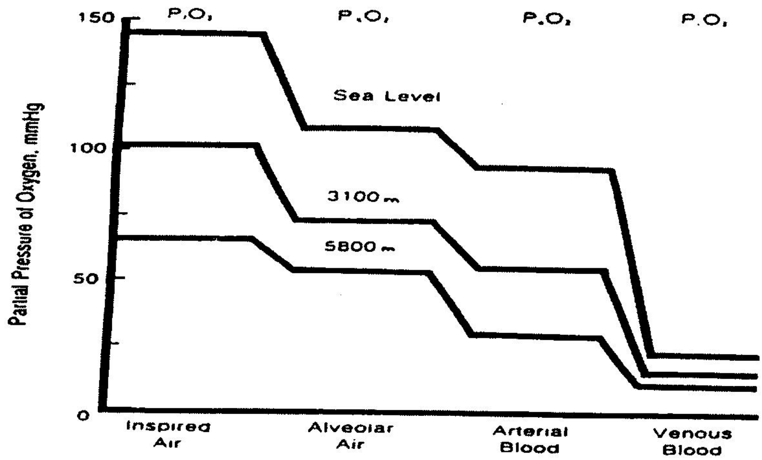

Fig 1 – 1 Relationship between altitude and the partial pressure of oxygen in inspired

1.1 Pulmonary Adaptations

1.1.1 Ventilation

One of the first adjustments that occur upon exposure to altitude is an increase in ventilation (L/min). Also referred to as hyperventilation, this increase in breathing rate and volume occurs in response to the decrease in oxygen availability. Hyperventilation results in an increase in oxygen pressure in the lungs thereby allowing for adequate oxygen supply to the body. Increased ventilation is most pronounced in the first 3 days of altitude exposure but beg ns to stabilize after about one week at altitude. At the same time, however, the hyperventilation tends to reduce blood CO_2 levels and bicarbonate reserves. This reduction results in a decrease in the ability to buffer lactate.

1.1.2 Maximal Oxygen Uptake (VO_2 max)

Upon arrival at moderate altitude, VO_2 max (L/min, ml/kg/min) appears to be reduced by 5% – 10%. This reduction occurs with every new exposure to altitude, even when altitude training has previously been performed. The reduction in maximal aerobic capacity appears to be related to decrements in oxygen saturation of arterial blood and

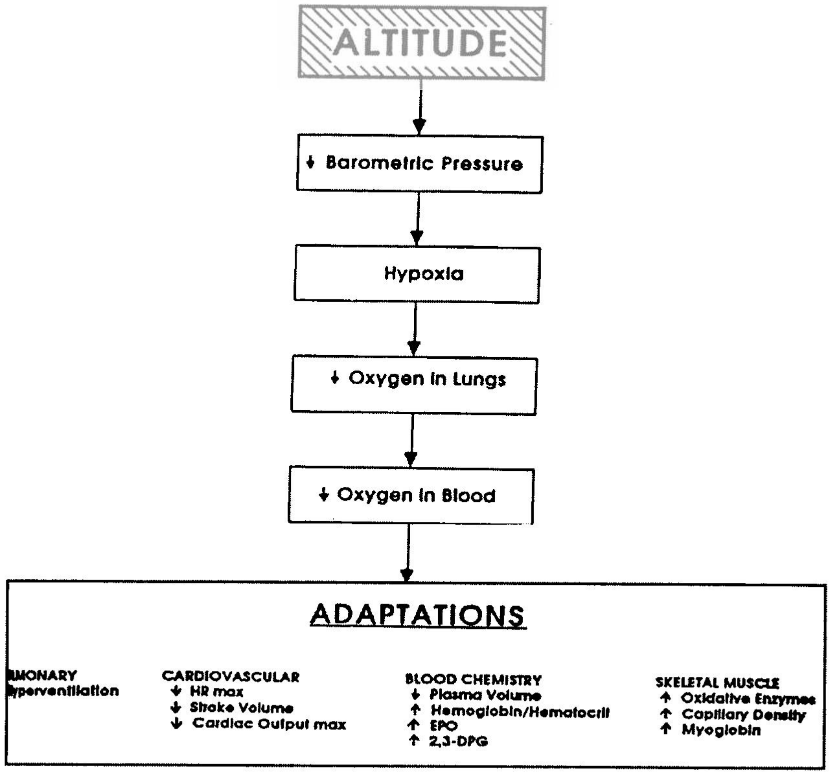

Fig 1 – 2 Physiological adaptations to altitude

maximal cardiac output.

1.2 Cardiovascular Adaptations

1.2.1 Heart Rate

At rest and during submaximal exercise at altitude, the decrease in oxygen content of the blood is compensated for by an increase in heart rate (bpm).

Essentially, the heart has to pump at a greater rate in order to supply the muscles with adequate oxygen. During maximal exercise, however, heart rate may be reduced by approximately 5 – 10 bpm over a period of 8 – 21 days following altitude exposure. A reduction in maximal heart rate may be due to a decrease in oxygen delivery to cardiac muscle.

1.2.2 Stroke Volume

Stroke volume (ml) is defined as the amount of blood that is ejected by the left ventricle of the heart in a single heartbeat. Stroke volume is determined by several factors including total blood volume, size of the heart, and contractile force of the cardiac muscle. Upon exposure to moderate altitude, stroke volume is reduced during rest, submaximal and maximal exercise. The decrease in stroke volume most likely reflects a reduction in total blood volume.

1.2.3 Cardiac Output

Cardiac output (L/min) is the product of heart rate × stroke volume, and represents the amount of blood that is pumped by the heart in one minute. At altitude, cardiac output has been found to increase at rest and during submaximal exercise, and is due to an increase in heart rate which compensates for the decrease in stroke volume. Cardiac output is reduced during maximal exercise at altitude, which occurs because of a reduction in stroke volume and maximal heart rate. A reduction in maximal cardiac output is a contributing factor to the decrease in max observed at altitude. Table 1-1 summarizes cardiovascular responses at moderate altitude.

Table 1-1 Cardiovascular responses at moderate altitude.

	HEART RATE	STROKE VOLUME	CARDIAC OUTPUT
REST	↑	↓	↑
SUBMAXIMAL EXERCLSE	↑	↓	↑
MAXIMAL EXERCLSE	↓	↓	↓

1.3 Blood Chemistry

1.3.1 Plasma Volume

Plasma volume (L) is the liquid component of blood and is equivalent to about 55% of an individual's total blood volume. Upon exposure to moderate altitude, plasma volume has been shown to be reduced by 6% – 21% over a 14day period. The degree of plasma volume reduction is dependent upon the intensity and duration of exercise performed, as well as the balance between fluid intake and output. The majority of plasma volume loss occurs through sweating and urinary excretion of fluid. Small amounts of fluid are also lost via the respiratory tract due to hyperventilation. A decrease in plasma volume leads to the reduction in stroke volume observed at altitude.

1.3.2 Hemoglobin and Hematocrit

Hemoglobin (g/dL blood) is the molecule contained within red blood cells that is responsible for the transport of oxygen. There are several thousand hemoglobin molecules present in a single red blood cell and each hemoglobin molecule is capable of carrying four molecules of oxygen. Hematocrit (%) is defined as the ratio of red blood cells to total blood volume. An increase in hemoglobin and hematocrit is referred to as hemoconcentration.

Within 24 – 48 hours of altitude exposure, hemoconcentration occurs primarily because of a decrease in plasma volume. After several days at altitude, however, hemoconcentration is maintained by a substantial increase in erythropoietin in response to decreased oxygen availability. Several studies have shown a 10% – 12% increase in the hemoglobin levels of individuals exposed to moderate altitude (Faulkner et al., 1967; Ferretti et al. 1990; Horstman et al., 1980). It should be noted, however, that Stray – Gundersen et al. (1992) found altitude – induced erythropoietin was not evident among endurance athletes who were diagnosed as iron deficient (serum ferritin <: 30 mg/ml for males; < 20 mg/ml for females), suggesting that sufficient Iron stores are required for increased red blood cell production,

Altitude – induced hemoconcentration results in a physiological "trade off" for the endurance athlete. In a positive light, elevated hemoglobin concentration can increase the blood's oxygen carrying capacity, which ultimately may lead to improvements in endurance performance. The negative aspect of hemoconcentration is that the blood may become more viscous, thereby reducing stroke volume and cardiac output while simultaneously increasing heart rate,

1.3.3 Erythropoietin(EPO)

Elevated red blood cell production is brought about by an increase in erythropoietin (EPO), a substance released by the kidneys that stimulates the production of red blood cells within red bone marrow. A significant increase in EPO concentration has been demonstrated in humans after just two hours of simulative altitude exposure (Eckardt et al., 1989; Milledge & Cotes, 1985). It appears that EPO remains elevated far as long as 10 days after arriving at moderate altitude (Berglund, 1992).

1.3.4 2,3 – DPG

The substance 2,3 – DPG (2,3 – Diphosphoglycerate) is produced within red blood cells. This compound has the capacity to bind with hemoglobin. When 2,3 – DPG is bound to hemoglobin molecules, oxygen is released more rapidly by hemoglobin thereby providing more oxygen to the muscles. An increase in red blood cell 2,3 – DPG is evident upon exposure to moderate altitude, Mairbaurl et al. (1986) found that 2,3 – DPG increased by 20% over 14day period at moderate altitude.

1.4 Skeletal Muscle Adaptations

1.4.1 Oxidative Enzymes

Upon exposure to altitude, a change in skeletal muscle oxidative enzymes leads to increased oxygen use for the production of energy. Analysis and quantification of oxidative enzymes is done using muscle biopsy techniques. Muscle samples can be analyzed for "marker" enzymes which reflect specific energy – producing pathways. Table 1 – 2 of marker enzymes and their corresponding metabolic pathways is provided to assist the reader.