

Application of Hyperbaric Oxygen Preconditioning to Improve Pilot's Lower Body Negative Pressure Tolerance

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Abstract

Objective: To investigate whether the preconditioning of hyperbaric oxygen (HBO) can improve the tolerance of lower body negative pressure in pilots .

Methods: Twenty healthy male fighter pilots were selected as subjects .The multiple HBO chamber was used and 3-time HBO exposure scheme was chosen .The chamber pressure was gradually increased to 2.5 atmospheres absolute [ATA] in 10 min and maintained for 65 min [with twice 30-min mask oxygen breathing and 5-min interval .Then the pressure was gradually reduced to 1.3 ATA in 10 min and returned to normal pressure in 5 min after staying for 5 min .Such 95-min test was undertaken once a day [set at 15:30–17:05] and repeated for 3 days .The lower body negative pressure tolerance was measured before and after HBO preconditioned and self-contrasted .

Results: The cumulative stress index was significantly increased from (-1353.50 ± 449.95) to (-1843.50 ± 522.07) by 3 rounds HBO pretreatment [$t = 11.10$, $P < 0.05$] and it indicated that the lower body negative pressure tolerance had been improved .

Conclusions: Hyperbaric oxygen preconditioning can improve the pilot's lower body negative pressure tolerance

Introduction

The maneuvering performance of modern high-performance fighter aircraft is gradually improved. Due to the sudden change of speed and acceleration in flight, the continuous + Gz with a maximum of 9 G or even higher G value can be generated, and the acceleration growth rate can be as high as 3-6 G/s^[1-2]. Previous studies have shown that the basic + Gz endurance of high-performance fighter pilots is about 4.25 G/10 s^[3]. Despite various anti-load measures, the occurrence rate of loss of consciousness caused by + Gz is still significantly increased, which is an important factor threatening flight safety^[4]. Studies have shown that hyperbaric oxygen (HBO) preconditioning can affect autonomic nervous function by changing heart rate variability in human body under stress, thus improving the erect tolerance of subjects^[5]. This study investigated whether HBO preconditioning could improve pilots' lower body negative pressure endurance, so as to explore the possibility of HBO preconditioning improving pilots' stress acceleration endurance.

Subjects And Methods

1. Subjects

From April 2017 to September 2017, a total of 20 fighter pilots were selected, all male, flying time (577.80 ± 272.98) h, age (26.30 ± 2.89) years old, Height (174.65 ± 3.82) cm, weight (72.43 ± 4.40) kg.

2. Methods

The experiment was approved by the hospital ethics committee, and clearly informed all subjects of the specific research content, precautions and possible technical risks, and signed an informed consent form for the experiment. At the same time, confirm that all experiments are carried out in accordance with the relevant guidelines and regulations.

The lower body negative pressure endurance was measured before and after HBO pretreatment.

2.1 Lower body negative pressure endurance test method:

After entering the laboratory, the subjects will sit in the lower body negative pressure chamber (XF-2008, Yantai Bingleun Hyperbaric Oxygen Chamber Co., LTD., Invention Patent Number: ZL200610153535.8), the subject's iliac crest line is placed below the negative pressure cabin, and the inflatable sealing ring is inflated and expanded to seal it with the edge of the inlet and outlet of the cabin body, so as to ensure the sealing performance of the lower body negative pressure cabin. Before the start of the test, the subjects were informed of the purpose, procedure, precautions, accurate determination of endurance end point and stopping point. Eliminate the tension of subjects and get their close cooperation. During the experiment, the subjects were equipped with some cardiovascular first-aid drugs, and the subjects were guaranteed and monitored by the experimenter, a doctor and a nurse together. Mindray monitor (MODEL: PM-8000Express) was used to monitor the subjects' heart rate, blood pressure, ear pulse oxygen saturation, respiration and other changes during the lower body negative pressure endurance test. The study was terminated when subjects showed endurance end points. Endurance end point judgment indicators: the occurrence of any of the following can be stopped: \square blood pressure suddenly decreased to 90/60 mm Hg (1 mm Hg = 0.133 kPa) below; Systolic blood pressure drop ≥ 20 mm Hg; Diastolic blood pressure decreased ≥ 15 mm Hg; \square The heart rate suddenly dropped 15 times, or less than 60 times/min; \square The waver square pulse data wave pattern was observed on the monitor to flatten; \square The subjects complained of palpitation, chest tightness, nausea, dizziness, black eyes, etc., or lips, pale face, cold sweat and other signs.

2.2 HBO pretreatment method

The hyperbaric oxygen department of PLA Sixth Medical Center was pretreated with multi-person oxygen chamber and HBO for 3 times. The safety pressure window of HBO pretreatment is 1.5 ~ 3.0 atmosphaera Absolutus, A T A, while 2.0 A T A and 2.5A T A are more appropriate pressure conditions [6]. The pressure is too low for HBO preconditioning. After the subject enters the cabin and closes the cabin door, the air is gradually pressurized to 2.5ATA within 10min, and the pressure is stabilized for 65min (wearing mask and inhaling pure oxygen for 30 min \times 2, and resting for 5min). Then, the air is gradually pressurized to 1.3TA within 10min, and stays for 5min. Continue decompression for 5 min to atmospheric pressure 1 A T A end of hatch exit. A total of 95 min, once a day (fixed at 15:30 – 17:05 PM in the chamber for oxygen inhalation), for 3 consecutive days. After the last oxygen inhalation, rest for 30 min and perform the lower body negative pressure endurance test again.

2.3 Lower body negative pressure endurance test procedure

Each subject sits naturally in the lower body negative pressure chamber, and the pressure in the lower body negative pressure chamber can be monitored in real time through the pressure gauge. Lightfoot step-up scheme was adopted (FIG. 1). Negative pressure of the lower body was -20 mmHg/ 1 min, -30 mmHg/3 min, -40 mmHg/5 min, -50 mmHg/ 7 min. -60 mm Hg /9 min, successively increased until the end of the test. The cumulative stress index (CSI) was calculated. $CSI = \sigma$ [negative pressure level (mm Hg) \times Negative pressure tolerance time (min)].

2.4 Statistical analysis

SPSS 21.0 statistical software was used for statistical analysis, and all quantitative data were expressed as mean \pm standard deviation ($\bar{X} \pm S$). The data of this experiment accord with normal distribution. Paired T test was used for the comparison of indicators before and after HBO pretreatment, and $P < 0.05$ was considered as statistically significant difference.

Results

3.1 Comparison of CSI before and after HBO pretreatment

After 3 times of HBO pretreatment, the lower body negative pressure endurance of the subjects was significantly improved. The cumulative stress index was (-1353.50 ± 449.95) min \cdot mm Hg before oxygen inhalation and (-1843.50 ± 522.07) min \cdot mm Hg after oxygen inhalation. The difference was statistically significant ($t = 11.10$, $P < 0.05$).

3.2 Comparison of physiological indicators

The heart rate, systolic blood pressure, diastolic blood pressure, blood oxygen saturation, respiratory rate and other indicators of subjects pretreated by HBO for 3 times were different from those before oxygen inhalation, but the differences were not statistically significant ($P > 0.05$, Table 1).

Discussion

The results of this study show that HBO pretreatment can improve the lower body negative pressure endurance of pilots, and thus improve the acceleration endurance of pilots. Its mechanism can be discussed from the following aspects.

4.1 HBO affects the body's energy metabolism

HBO preconditioning can cause blood glucose to rise after physical stress, timely supplement muscle energy supply, significantly reduce lactate dehydrogenase and Na^+K^+ -ATP enzyme activities and accelerate the removal of lactic acid. This lower level of Na^+K^+ -ATP enzyme activities can achieve the same intensity of physical stress. This can help reduce the consumption of glycogen and oxygen and reduce the consumption of ATP, delay the occurrence of fatigue, reduce fatigue degree and improve labor efficiency^[7]. On the other hand, after HBO pretreatment, the oxygen supply of human body increases, the

cardiopulmonary function is enhanced, the blood circulation is improved, and the oxygen consumption is reduced, which are conducive to the oxygen supply of the body under physical load. HBO pretreatment can make the heart show the phenomenon of "functional saving", which is beneficial to prolong the time of physical load, improve the exercise ability and thus improve the lower body negative pressure endurance [8].

4.2 HBO affects the hypothalamic-pituitary-adrenal cortex axis

HBO can effectively regulate the hypothalamic-pituitary-adrenal cortex axis, promote a series of neuroendocrine reactions such as dopamine, adrenaline, norepinephrine and adrenocorticotrophic hormone, and promote the body's adaptation to negative pressure of the lower body [9]. In this study, HBO pretreatment can further improve the stress response of lower body negative pressure, increase the maximum tolerance time of pilots, and improve the cumulative stress index.

4.3 HBO improves autonomic nervous function

The level of lower body negative pressure endurance ultimately depends on whether blood pressure can be controlled and stable when acute stress occurs. Therefore, heart rate, stroke volume and peripheral vascular resistance to maintain stable blood pressure are the three key factors to determine human lower body negative pressure endurance [10]. If acute stress can reduce human heart rate, increase stroke volume and peripheral vascular resistance, it can maintain the stability of blood pressure, improve the body's cardiovascular function, strengthen the reserve function of blood vessels, and improve the lower body negative pressure endurance.

HBO can prolong the heartbeat interval, slow down the heart rate and increase cardiac output, so as to improve the body's hemodynamics, improve the cardiac reserve capacity [11] and improve the lower body negative pressure endurance. The reason is that under HBO environment, the oxygen concentration in the body increases and the generation of acidic metabolites decreases, which reduces the excitability of central and peripheral chemoreceptors and causes vagus nerve excitation and slow heart rate [12]. Studies have confirmed that different degrees of HBO exposure can decrease cardiac function index, increase average pulse pressure and increase peripheral vascular resistance [13]. This may be caused by: ☒ THE direct effect of HBO on blood vessels can cause the contraction of smooth muscle of blood vessel wall and increase vascular tension and resistance; ☒ HBO can reduce the content of CO₂ in blood, thus reducing its vasodilatation effect; ☒ HBO has α-adrenaline-like effects, which can contract blood vessels and increase blood pressure [14]. The increase in blood pressure can further stimulate baroreceptors and reflexively excite the vagus nerve, slowing the heart rate. On the other hand, HBO can reduce hematocrit, blood viscosity and platelet aggregation, thus reducing blood flow resistance, improving hemorheology and dynamics, and facilitating the recovery of cardiac electrical activity, enhancing cardiovascular function and improving blood circulation [15-16]. Therefore, HBO can increase the regulation ability of blood pressure, so that subjects can keep blood pressure stable in acute stress, thus improving their lower body negative pressure endurance.

Studies have shown that HBO exposure can increase the high-frequency power in the frequency domain index of heart rate variability, thus increasing vagus nerve activity, slowing heart rate, relieving cardiac load and reducing cardiac oxygen consumption^[17].

In the face of acute stress, HBO pretreatment can make the sympathetic and parasympathetic nerves coordinate with each other, and the autonomic nervous system tends to be more stable. Finally, the dynamic balance of vagus nerve and sympathetic nerve is better, so as to improve the adaptability and adjustment ability of the body^[18] and improve autonomic nervous function. So as to improve the pilot's lower body negative pressure endurance. The shortcomings of this study are the small sample size and the failure to monitor the changes of heart rate variability. In the future, a large sample size test will be carried out to study related factors.

Table1 The comparison of physiological indexes before and after preconditioning of hyperbaric oxygen

Time	Heart rate (beat/min)	Systolic pressure (mmHg)	Diastolic pressure (mmHg)	Blood oxygen saturation(%)	Respire (beat/min)
Pre- HBO	96.20±14.76	114.22±8.90	74.83±6.41	95.53±3.08	25.06±2.63
Post- HBO	96.63±12.75	111.69±8.19	72.72±6.43	96.35±2.77	24.37±2.21
t value	0.17	1.16	1.14	-0.96	1.25
P value	0.87	0.26	0.27	0.35	0.23

At present, the therapeutic pressure of the new portable HBO cabin can reach 0.15~ 0.18 M Pa, while that of the foreign oxygen cabin can reach 0.20~ 0.24 M Pa. Its convenience, simplicity and effectiveness can promote its application in remote areas and special environments such as troops, so that HBO can be popularized and provide guarantee for military training^[19].

Cui Jianhua et al.^[20] reported that HBO pretreatment has anti-hypoxia and anti-fatigue effects. Five HBO pretreatments improved oxygen free radical metabolism for up to 8 days after exercise, and two HBO pretreatments lasted for up to 5 days. It has been reported that in HBO's study on factors to improve flight stability, the altitude endurance of people with poor altitude endurance increased significantly after HBO test, the maximum altitude increased by 0.8 ~ 1 km on average, and the reserve time increased by 3 ~ 4 min at 5 ~ 7 km altitude. HBO lasted for 2 months in 7 patients and 3 months in 4 patients^[21]. This is an exploratory experiment, and further studies will be conducted on the mechanism of action, HBO maintenance time, and refinement of improving endurance in people with poor acceleration endurance.

In conclusion, HBO pretreatment can affect human energy metabolism, activate the body's neuroendocrine system to secrete more central monoamine transmitters, and improve autonomic nervous

function under stress state, thus improving pilots' lower body negative pressure endurance and effectively improving their anti-load endurance under acute stress. Therefore, HBO preconditioning before air combat may be an effective method to improve pilots' stress acceleration endurance.

Thanks: thanks to the developers of the lower body negative pressure chamber, the helpers of HBO pretreatment and the volunteers who contributed to this experiment.

Abbreviations

HBOP:Hyperbaric oxygen preconditioning; HBO:Hyperbaric oxygen; G-LOC:G-induced loss of consciousness; LBNP:Lower body negative pressure; PLL:Peripheral light loss;CSI:Cumulative stress index;

Declarations

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Author Contributions

All authors contributed to the study. Conception and design were performed by LH. Material preparation, data collection were performed by MM/WJ/ FZ/ WD. Analysis were performed by/FZ/LQ/ZJ/SR. The first draft of the manuscript was written by MM/LY/LH, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Ethics approval and consent to participate

The experiment was approved by the Air Force General Hospital PLA ethics committee, and clearly informed all subjects of the specific research content, precautions and possible technical risks, and signed an informed consent form for the experiment.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable.

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Figures

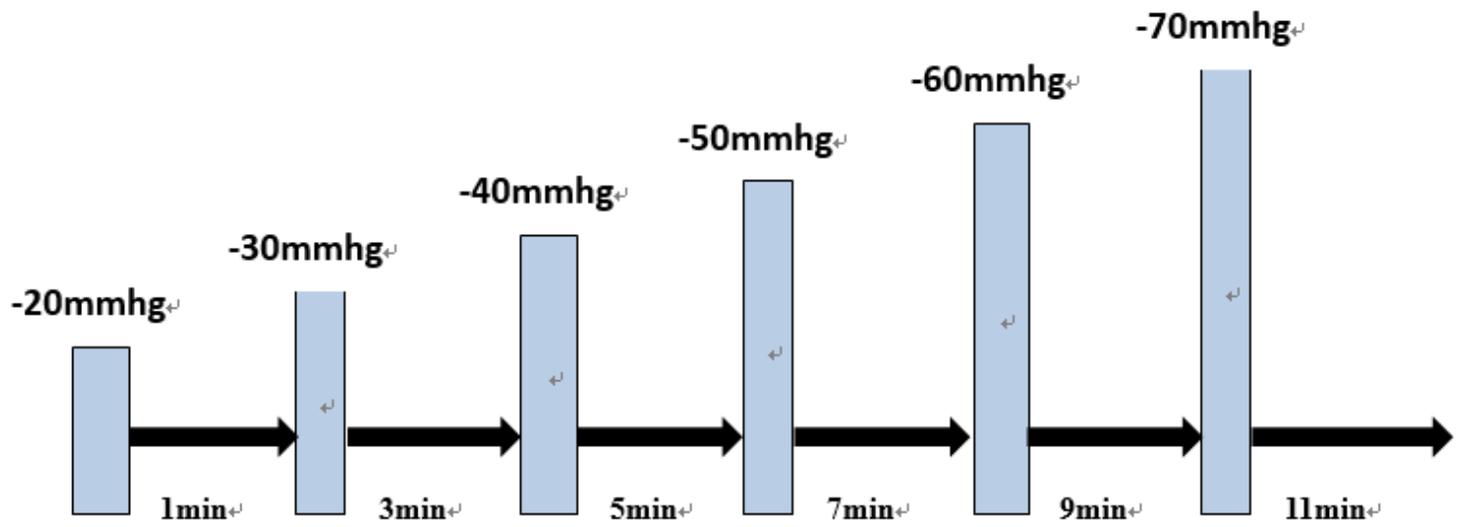


Figure 1

Lightfood pressure diagram of lower body negative pressure tolerance test (1mmHg=0.133kPa)