American Journal of Emergency Medicine xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

American Journal of Emergency Medicine

journal homepage: www.elsevier.com/locate/ajem

Using a new plateau hyperbaric chamber to alleviate high altitude hypoxia: Rabbit and human studies

Liang Sun, MD [a,b,*], Meng-jiang Ding, MPH [c], Tian-cai Cai, MPH [d], Hao-jun Fan, MD [e], Hong-mei Gao, MD [f], Jian-peng Zhang, MD, PhD [a,f]

[a] Medical College of Chinese PLA, Chinese PLA General Hospital, 28#, Fu-Xing Road, Haidian District, Beijing 100853, China
[b] Department of Respiratory and Critical Care Medicine of Ping Jin Hospital, Affiliated Hospital of Logistic University of Chinese People's Armed Police Force, China
[c] Tianjin Municipal Corps Hospital of Chinese People's Armed Police Forces, China
[d] Xia men sanatorium of Chinese people's Armed Police Forces, China
[e] Institute of Disaster Medicine and Public Health, Affiliated Hospital of Logistic University of Chinese People's Armed Police Force, China
[f] Department of Respiratory, General Hospital of Chinese People's Armed Police Force, China

ARTICLE INFO

Article history:
Received 10 December 2016
Received in revised form 30 March 2017
Accepted 17 April 2017
Available online xxxx

Keywords:
Acute mountain sickness
Hyperbaric chambers
Hypoxia
Test

ABSTRACT

Objectives: To validate the effects of the new plateau hyperbaric chamber on alleviating high altitude hypoxia on Mount Kun Lun.
Methods: A prospective, controlled study of rabbits and adult volunteers was conducted at altitudes of 355, 2880 and 4532 m. We obtained arterial blood samples from rabbits and volunteers before and after hyperbaric treatment. The respiratory rate, heart rate, and blood pressure (BP) of adult volunteers were monitored during hyperbaric treatment.
Results: The mean PaO_2 levels of experimental group rabbits and volunteers increased significantly after 60 min of hyperbaric treatment at 350, 2880 and 4532 m. The mean $PaCO_2$ and pH levels of rabbits were not significant different before and after hyperbaric treatment at each altitude. The mean $PaCO_2$ and pH levels were not significant different at 355 m in the human study. However, at 2880 and 4532 m, pH fell with increasing $PaCO_2$ levels in humans before and after hyperbaric treatment.
Conclusions: The new multiplace plateau hyperbaric chamber may be used to alleviate plateau hypoxia by increasing patient PaO_2. However, its value in treating AMS must be confirmed in field conditions.

1. Introduction

Although the pathophysiology of acute mountain sickness(AMS) has not been completely clarified, hypobaric hypoxia is thought to play a predominant role [1]. The partial pressure of atmospheric oxygen falls progressively as barometric pressure decreases with increasing altitude. Therefore, descent is lifesaving when severe symptoms suggest the onset of AMS. If descent is not possible, simulated descent through pressurization in a hyperbaric chamber is equally effective in the treatment of AMS.

The Gammow bag is the most important and popular device used in most trekking and high altitude expeditions to treat and prevent AMS [2-4]. The Gammow bag is an inflatable cylindrical tube made of heavy rubber or durable fabric that pressurizes the atmosphere sealed within it to that of a much lower altitude.

However, treatment of sick subjects within the very confined space of the chamber can be difficult, and prolonged treatment makes considerable demands on the individuals required to maintain pressure with the foot pump [5]. Particularly, the Gammow bag is not always an acceptable therapy alternative in a predominantly elderly population. Moreover, most types of portable hyperbaric chambers are monoplace chambers. If many patients suffer from AMS, such as laborers and soldiers, the portable hyperbaric chamber may be ineffective.

The efficacy of hyperbaric oxygen therapy has been validated by extensive clinical experience and scientific studies for decompression sickness and high-altitude illnesses [6-7]. However, the potential risks, shortage of oxygen supply, and complexity of using hyperbaric oxygen have limited its application in the treatment of AMS.

Like other portable hyperbaric chambers, based on the principle of increasing ambient pressure within the chamber, a new multiplace plateau hyperbaric chamber has been designed to satisfy the needed of patients who suffer from AMS (Fig.1). Unlike other portable hyperbaric chamber, atmospheric pressure is increased by adjusting the opening of the expiration valve in proportion to the ambient pressure. Hence, carbon dioxide(CO_2) inside the chamber will not be accumulated during

* Corresponding author at: Medical College of Chinese PLA, Chinese PLA General Hospital, 28#, Fu-Xing Road, Haidian District, Beijing 100853, China.
E-mail address: sunlianghys@163.com (L. Sun).

http://dx.doi.org/10.1016/j.ajem.2017.04.034
0735-6757/

Fig. 1. The new multiplace plateau hyperbaric chamber (1 = Compressor; 2 = Doors; 3 = Control device; 4 = Desk; 5 = Beds; 6 = Gas vent; 7 = Air evacuation valve; 8 = Windows; 9 = Main compartment; 10 = Buffer compartment; 11 = Intake-tube; 12 = Silencer). Minimum pressure of the main compartment can reach up to 0.029 MPa at 355 m, 0.022 MPa at 2880 m and 0.02 MPa at 4532 m.

pressurization. We have demonstrated the safety and convenience of the chamber and have suggested possible applications for the chamber in AMS treatment [8]. During pressurization, the minimum pressure of the main compartment can reach up to 0.029 MPa at 355 m, 0.022 MPa at 2880 m and 0.02 MPa at 4532 m. In the current study, further research on rabbits and adult volunteers will be conducted to validate the effects of the chamber on alleviating high altitude hypoxia on Mount Kun Lun.

2. Ethics statement

Animal and human experiments inside the plateau hyperbaric chamber were performed at altitudes of 355, 2880 and 4532 m (Fig.2). Experiments were approved by the Ethical Review Board of the General Hospital of Chinese People's Armed Police Force. In animal experiments, operative procedures and animal care were performed in compliance with national and international regulations (Italian Regulation D.L.vo 116/1992 and European Union Regulation 86/609/EC). The protocol was examined and approved before the start of the study by the Ethics Committees, Animal Facility of General Hospital of Chinese People's Armed Police Force. The recommendations of the ARRIVE guidelines in animal research were also consulted and considered [9].

In human experiments, volunteers were given written information and a verbal explanation concerning the study before obtaining written informed consent for their participation. Before commencement of the study, all volunteers were fully informed and signed an informed consent document.

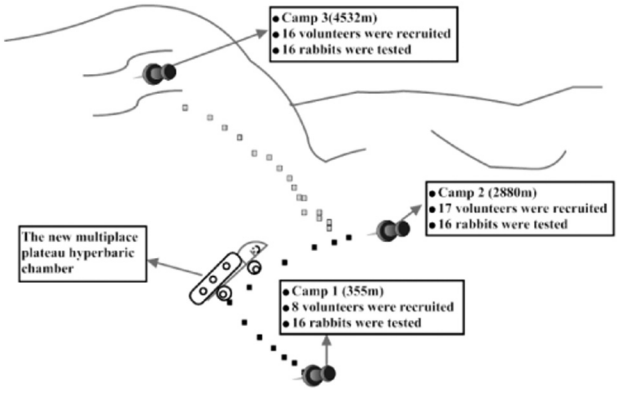

Fig. 2. The location, altitude, and volunteer recruitment at various altitudes between Xi'an City and the Kun Lun Mountains.

3. Methods

3.1. Study design

3.1.1. Animal experiments

Sixteen adult male rabbits were used for the experiment at each altitude. The animals were purchased from a laboratory animal supplier (Animal experiment center of Xi'an Jiaotong University Health Science Center and Ma Wang Zhen rabbit farm of Xi'an City). All animals were anesthetized using 2% pentobarbital sodium (Sigma, USA). Under general anesthesia, a tracheotomy was performed 1-cm dorsal from the cricoid and a tracheal tube with 3.5-mm internal diameter and 14-cm length portex tracheal tubes (SIMS Portex, Portex) was inserted into the trachea. Then, an arterial indwelling catheter was inserted into the right carotid artery. After the operation, the first arterial blood samples were collected from the rabbit carotid arterial indwelling catheters. Then, eight rabbits of the experimental group were placed into the plateau hyperbaric chamber and underwent hyperbaric treatment. Eight rabbits of the control group breathed ambient air. The second arterial blood samples of the experimental group were collected after 60 min of hyperbaric treatment. The second arterial blood samples of the control group were collected after 60 min of exposure to ambient air. These samples were measured immediately, in all cases, the time elapsed between sampling and analysis was <1 h.

Arterial blood samples were analyzed with the use of a portable blood gas analyzer (i-STAT 200, Abbott Point of Care Inc., USA). The PaO_2, $PaCO_2$, and pH levels were measured. The blood gas analyzer was altered from its original specification so that it would function at high altitude. This modification was necessary to circumvent an inbuilt mechanism that prevented the analysis of samples at barometric pressures lower than 400 mmHg (53.3 kPa).

3.1.2. Human experiments

Volunteers were recruited at 355, 2880 and 4532 m for the present study. All participants were medically evaluated to exclude those with acute or chronic conditions that could increase the risk of harm from exposure to the hyperbaric chamber. The selection criteria included the following: 1) ethnic Han; 2) residence in the highlands for at least four weeks preceding the study; and 3) arrival from a low-altitude province (<2500 m). Potential participants were excluded if they had AMS, signs and symptoms of a substantial acute infection, additional physical training or were scheduled to gain or lose weight, or any known cardiac, pulmonary, or other chronic diseases that would render them at increased risk of altitude illness.

Each participant took part in only one test session. After being informed, testers and participants entered the chamber and closed all doors. At the beginning of each session, participants were instructed to breathe regularly and quietly in a sitting position. After 60 min of rest, the first arterial blood samples were collected from the radial artery. Then, the chamber was pressurized with an electrically driven centrifugal compressor. Participants spent most of the time in assigned seats but were encouraged to walk or stand when involved in a test activity. Respiratory rate (RR), heart rate (HR) and blood pressure (BP) of the participants were monitored during hyperbaric treatment. RR, HR and BP were recorded before and after 60 min of hyperbaric treatment. The second arterial blood samples were collected from each participant after 60 min of hyperbaric treatment. The blood samples were analyzed immediately in the hyperbaric chamber, in all cases, the time lapse between sampling and analysis was under 1 h.

Arterial blood samples were analyzed using a portable blood gas analyzer (i-STAT 200, Abbott Point of Care Inc., USA). PaO_2, $PaCO_2$, and pH levels were measured. RR and HR were monitored by fingertip pulse

Please cite this article as: Sun L, et al, Using a new plateau hyperbaric chamber to alleviate high altitude hypoxia: Rabbit and human studies, American Journal of Emergency Medicine (2017), http://dx.doi.org/10.1016/j.ajem.2017.04.034