EFFECTS OF OXYGEN ENRICHMENT DEVICE IN LOWLANDERS ASCENDING TO TIBET

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ABSTRACT
When ascending to the high altitude, people living in low altitude areas will suffer from hypoxia and acute mountain sickness. To reduce the risk of acute mountain sickness, based on the technology of oxygen concentration membrane, we developed a new portable oxygen enrichment device for individual. Eight healthy male subjects were screened and flew to Tibet (Lhasa, 3,700 m) to perform the experiment. First, subjects wore the oxygen enrichment device and performed an incremental exercise on cycle ergometer. The test included heart rate (HR), saturation of peripheral oxygen (SpO₂) and physical work capacity (PWC). Then, after a rest period of 4 hours, the experimental protocol was repeated without oxygen enrichment device. The results showed that higher SpO₂, lower HR, and better PWC (measured by the PWC-170) were observed from all the subjects ‘with oxygen enrichment device’ compared with ‘without oxygen enrichment device’ (P<0.01). We suggested that the new portable oxygen enrichment device would be effective in improving exercise performance when ascending to the high altitude.

KEY WORDS
medical devices; hypoxia; oxygen-enrich; high altitude

1. Introduction
Qinghai-Tibet Plateau is the highest plateau of the world with an average altitude of over 4,500 meters, which is called the roof of the world. In recent years, with the opening of Qinghai–Tibet railway in China, more and more people who live in low areas ascend to high altitude for science investigation, tour, commercial, etc. Many of them suffer from hypoxia and acute mountain sickness, due to the low partial pressure of oxygen at high altitudes [1,2]. Moreover, people from low areas may experience a decrease in exercise performance on arriving to high altitude. The higher the altitude is, the more critical the situation becomes [3]. This problem may seriously influence the physical and mental state and work efficacy for the travelers and workers.

By raising the concentration of oxygen in the air, the oxygen partial pressure can be increased and the hypoxia effects of the high altitude can be reduced [1]. It has been shown that increasing the oxygen concentration of the air by 1% (e.g. from 21 to 22%) results in a reduction of equivalent altitude of about 300 m [4]. So, providing lowlanders with oxygen enriched air (the oxygen concentration >21%) would improve their performance [5].

The oxygen enrichment membrane is a kind of gas separation membrane, it can be used to obtain oxygen-enriched air because the oxygen can permeate more than nitrogen, and the oxygen concentration of the air can come up to 40% [6]. It has been widely used in industry, such as steel and chemical, in order to induce the complete combustion and save energy, reduce pollution [7]. However, long-lasting and portable oxygen enrichment device for individual is not yet available. In this paper, portable oxygen enrichment device was developed, and a self-controlled study in Tibet was performed.

2. Materials and Methods

2.1 Subjects

Eight young men (22-24 years old, Han nationality) in Xi’an city were selected. All of them are healthy without the history of pulmonary, cardiovascular, hematological, renal or hepatic disease, because all of the diseases above may affect the body response to the high altitude. After signing informed consent forms, they were taken to the altitude of 3700m by air for the first time.

2.2 Oxygen enrichment device

To reduce the risk of acute mountain sickness, based on the technology of oxygen concentration membrane, the
portable oxygen enrichment device for individual was invented (see Figure 1 and Figure 2). The device is composed of four parts: blast unit (a small DC fan), oxygen enrichment membrane unit, vacuum pump, and buffer unit. The oxygen enrichment membrane is made from polysulphone ultrafiltration membrane. The total weight is 2.7 kg, and the dimensions of machine body are 200 × 180 × 84 mm. As a portable, durable, and convenient device, the oxygen-enrich device can increase oxygen concentration (from 21% to 30%). Its oxygen enriched air flux can reach more than 7 L/min. Conveniently, it can use rechargeable Li-ion batteries (11.1 V, 7800 mAh), which can work continuously for more than 2 hours. In this study, 8 devices were used (one for each).

2.3 Experiment design

When ascending to Lhasa (3,700 m), all the subjects were asked to have a rest for 2 hours and prepare for the experiment. First, sat down in chairs, wore oxygen enrichment devices and switched them on. After 30 minutes, HR and SpO₂ at rest state were recorded by a Multi-parameter patient monitor (IntelliVue MP70, Philips, Eindhoven, Netherlands). Next, to obtain the PWC-170, subjects performed consecutive workloads on a cycle ergometer (839E, Monark Exercise AB, Sweden) with oxygen enrichment devices. Subjects were asked to keep the tachometer at around 60 rpm. Loaded power of the ergometer was initially set to 50 W, and then increased by a step of 50 W per 3 minutes until reaching 200 W [8]. The experimental protocol was repeated without oxygen enrichment devices after a rest of 4 hours. The study was approved by the local institutional ethical review boards of all the participating institutions.

2.4 Statistical analysis

All of the data were shown as means ± SD. SPSS 13.0 software (SPSS Inc., Chicago, IL, USA) was used to perform paired t-test. \( P < 0.01 \) was considered statistically significant.

3. Results

The results showed that the subject with oxygen enrichment device had a higher SpO₂ and lower heart rate at rest than the same subject without device \( (P < 0.01) \). Moreover, based on the consecutive workloads test, the power output of the subject with oxygen enrichment
device was better than that when without device ($P<0.01$, see Table 1).

<table>
<thead>
<tr>
<th>Without oxygen enrichment device</th>
<th>With oxygen enrichment device</th>
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<tbody>
<tr>
<td>HR (beat/min)</td>
<td>83.00±2.07</td>
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<tr>
<td>SpO2 (%)</td>
<td>87.50±1.51</td>
</tr>
<tr>
<td>PWC-170 (W)</td>
<td>201.26±6.46</td>
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4. Discussion

SpO2 is an important indicator of oxygen supply for the body, which is measured by a pulse oximetry at fingertip. At high altitude, the low partial pressure of oxygen stemming from the reduced barometric pressure caused less oxygen diffuse into the capillaries within the lungs, finally caused hypoxia and low SpO2. Heart rate has a close relationship to oxygen consumption, and heart rate increases following ascent to high altitude. The physical capacity for work can be tested by means of the PWC-170 test. The PWC-170 has also been shown to be a valid tool at high altitude [9].

To reduce the risk of acute mountain sickness when ascending to high altitude, many medical devices have been invented, including bottled oxygen, portable hyperbaric chamber and oxygen enrichment room. These devices can raise the oxygen concentration and reduce the equivalent altitude, which can be used to treat mild acute mountain sickness [4,10]. Based on the membrane technology of oxygen enrichment, the polysulphone ultrafiltration membrane was adopted, and a new portable anti-hypoxia device was developed. The concentration of oxygen of device can be increased to 30%, which is examined by oxygen analyzer (Oxymat-61, Siemens, Germany) at 3,700 m. Its oxygen enriched air flux can reach more than 7 L/min, which is examined by float-type flowmeter at the same altitude. The new oxygen enrichment device can provide the oxygen enriched air to respiratory tract by using sample breathing mask. After oxygen enriched air conveyed to the lungs, oxygen partial pressure of inspired air can be increased by this, so more oxygen diffuse into the capillaries within the lungs, and the deleterious effects of the high altitude can be released. Approximately, it can be calculated that increasing the oxygen concentration of the air by 9% (from 21 to 30%) results in a reduction of equivalent altitude of about 2700 m. In this paper, we found that the oxygen enrichment device can increase SpO2 and PWC-170 ($P<0.01$), meanwhile, it can reduce the heart rate ($P<0.01$).

5. Conclusion

The oxygen enrichment device not only increased the level of SpO2 and physical capacity, but also reduced the heart rate, which may have important positive effects on protecting people when ascending to high altitude before acclimatization.

One limitation of the experimental design is that all the subjects performed experiments with oxygen enrichment device first. In future work, more independent experiments should be designed to reveal its effects at different high altitudes.

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References