Relationship between arterial oxygen saturation and heart rate variability at high altitudes

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Abstract Autonomic nervous systems have important roles for survival of victims under hypobaric hypoxic condition. In the present study, we assessed the correlation between arterial oxygen saturation (SpO2) and heart rate variability (HRV) to identify the autonomic nervous responsiveness among trekkers at high altitude (n = 21). HRV was analyzed by the maximum entropy method. SpO2 among subjects at 3456 m (495 mm Hg) was 80% ± 5% (mean ± SD; range, 69%–93%). SpO2 and percentile entropy, and SpO2 and low-frequency variability, had positive correlation (r = 0.455 and 0.518, respectively). SpO2 value among subjects with mountain sickness symptoms was not different from that among subjects without the symptoms. In conclusion, autonomic responses among high-altitude trekkers may be blunted under hypobaric hypoxic conditions. Deterioration of autonomic function measured by HRV might be more sensitive to hypoxia than clinical symptoms at high altitudes.

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1. Introduction

Because of the advance of transport technology, many travelers are able to visit highlands or moderate altitudes without having any special training and acclimatization. This trend has had a significant impact on the trends in alpine accidents. Recently, the Japanese National Police Agency announced that alpine accidents induced by bad physical conditions (neither by poor climbing techniques nor by natural disaster) were increasing year by year [1]. This phenomenon may be common in many developed countries, where trekkers include many older people and people with medical problems. Our previous study demonstrated that most trekkers in a nonchallenging middle-altitude mountain were older than 50 years and that almost half of the trekkers had some kind of preexisting medical problems [2].

Rescuing victims from a mountain range is very difficult because of the long distance from towns and extremely hard environmental conditions including hypobaric hypoxia. Autonomic nervous systems have important roles for survival of victims under hypobaric hypoxic condition. Previous studies implied that activities of autonomic nervous systems were blunted and sympathetic activities were relatively dominant during a high-altitude stay [3-6]. Because depressed autonomic nervous responsiveness has a significant prognostic value for cardiac mortality [7,8], the blunted autonomic function under hypobaric conditions may lower the possibility of survival for victims with preexisting medical problems.

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Although several previous studies showed depressed autonomic activities under hypobaric hypoxia [3-6], the correlation between the degree of hypoxia and decrease in autonomic nervous functions has never been studied. Because the degree of hypoxia varies between subjects at an identical altitude [9], the decrease in autonomic activities may also vary according to the degree of hypoxia. In the present study, we assessed the correlation between arterial oxygen saturation (SpO2) and heart rate variability (HRV) to identify the relationship between hypoxia and autonomic dysfunction. The HRV, which is heart-to-beat alteration of the R-R intervals in an electrocardiogram, is a commonly used noninvasive monitoring of autonomic nervous system activities [10-12].

2. Methods

The approval of the local human ethics committee and the informed consent of the experimental subjects were obtained before this study. The total number of subjects in the study was 21 (8 men and 13 women; mean age, 31 ± 10 years; range, 21-55 years). All of the subjects were office workers with no habitual physical exercise regimen and none of the subjects had been exposed to an altitude above 2000 m within a year before the study. None of the subjects had medical complications, such as cardiovascular or pulmonary diseases.

Subjects reached 2100 m by car and ascended another 1356 m on foot, trekking for 4 hours without any weight load. Total duration times required for the ascent from sea level (760 mm Hg) to 3456 m (495 mm Hg) were approximately 6 hours. All of the measurements were performed in wind-sealed constructions, and the temperature was maintained at 18°C. After arrival at the altitude, the subjects were permitted 2 hours of resting time before experimental measurements.

Electrocardiograms were recorded with a standard limb lead II (MWM01; GMS Inc, Tokyo, Japan) and were analyzed by the MemCalc system (MemCalc, TARAWA/WIN, GMS Inc, Tokyo, Japan; GMS) on an on-line computer (FMV-MC302; Fujitsu Inc, Tokyo, Japan). In the program, the time series of R-R interval data was analyzed by the maximum entropy method with high resolution as described previously [13]. The fluctuation of the R-R interval was described as percentile entropy (ENT%) [14]. The index depicted a completely random signal as 100% and a regular one as 0%. The power of HRV was quantified by determining the areas of the spectrum in 2 component widths: low frequency (LF, 0.04-0.15 Hz) and high frequency (HF, 0.15-0.5 Hz) [15]. The ratio of LF power to HF power (LF/HF) was also assessed.

Arterial blood oxygen saturation was monitored using a portable life monitor (ProPack II: Protocol Systems Inc, Beaverton, Ore). An SpO2 probe was set on the right index finger. During the measurement, subjects were resting quietly in a supine position, and were shielded against auditory and visual stimulation. Subjects were advised to breathe regularly without intermittent deep breaths. Data were collected after the stable electrocardiographic baseline was recorded for 10 minutes.

Table 1  Variables at 760 and 495 mm Hg

<table>
<thead>
<tr>
<th>Variable</th>
<th>760 mm Hg</th>
<th>495 mm Hg</th>
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<tbody>
<tr>
<td>SpO2 (%)</td>
<td>98 ± 1</td>
<td>80 ± 5**</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>70 ± 10</td>
<td>107 ± 8*</td>
</tr>
<tr>
<td>Mean blood pressure (mm Hg)</td>
<td>90 ± 12</td>
<td>101 ± 16</td>
</tr>
<tr>
<td>HRV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENT%</td>
<td>55 ± 15</td>
<td>22 ± 17**</td>
</tr>
<tr>
<td>LF (ms²)</td>
<td>1680 ± 482</td>
<td>149 ± 125*</td>
</tr>
<tr>
<td>HF (ms²)</td>
<td>780 ± 211</td>
<td>90 ± 192*</td>
</tr>
<tr>
<td>LF/HF ratio</td>
<td>2.6 ± 0.8</td>
<td>3.5 ± 2.3</td>
</tr>
</tbody>
</table>

* P < .05, significantly higher than the value at 760 mm Hg.
** P < .01, significantly lower than the value at 760 mm Hg.

Fig. 1  Correlation between SpO2 and ENT%. Arterial oxygen saturation and the fluctuation of the R-R interval in electrocardiogram, described as ENT%, had positive correlation (r = 0.455, P < .05).

Fig. 2  Correlation between SpO2 and LF power. Arterial oxygen saturation and the power of HRV in the low-frequency component width (LF, 0.04-0.15 Hz) had positive correlation (r = 0.518, P < .05).
Table 2  Variables at 495 mm Hg and mountain sickness score

<table>
<thead>
<tr>
<th></th>
<th>HAS score = 0</th>
<th>HAS score &gt;0</th>
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</thead>
<tbody>
<tr>
<td>N (male/female)</td>
<td>9 (2/7)</td>
<td>12 (6/6)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>34 ± 10</td>
<td>29 ± 10</td>
</tr>
<tr>
<td>Spo2 (%)</td>
<td>81 ± 7</td>
<td>79 ± 4</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>108 ± 7</td>
<td>107 ± 9</td>
</tr>
<tr>
<td>Mean blood pressure (mm Hg)</td>
<td>95 ± 13</td>
<td>106 ± 17</td>
</tr>
<tr>
<td>HRV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENT%</td>
<td>24 ± 12</td>
<td>21 ± 15</td>
</tr>
<tr>
<td>LF (ms2)</td>
<td>177 ± 82</td>
<td>129 ± 150</td>
</tr>
<tr>
<td>HF (ms2)</td>
<td>61 ± 44</td>
<td>112 ± 128</td>
</tr>
<tr>
<td>LF/HF ratio</td>
<td>4.4 ± 2.8</td>
<td>2.8 ± 1.7</td>
</tr>
</tbody>
</table>

Physical fitness of subjects was evaluated by acute mountain sickness (AMS) score (no symptom, 0; extreme symptom, 23) according to the Lake Louise agreement [16]. All data are expressed as mean ± SD. Statistical comparisons of mean values were assessed using analysis of variance with Scheffe’s modification. To evaluate the correlation between Spo2 and circulatory parameters, simple regression analysis was performed using a computer program (StatView 5.0, SAS Institute Inc, Cary, NC). A P value <.05 was considered statistically significant.

3. Results

Arterial oxygen saturation among subjects was 98% ± 1% at 760 mm Hg and 80% ± 5% at 495 mm Hg (Table 1). The value at 495 mm Hg was significantly lower than the value at 760 mm Hg (P < .01). Heart rate at 495 mm Hg was significantly higher than the value at 760 mm Hg (P < .05). Three indices of HRV, ENT%, LF, and HF, decreased significantly with the reduction in barometric pressure (P < .05). The LF/HF ratio at 495 mm Hg was not significantly different from the value at 760 mm Hg. Spo2 and ENT%, and Spo2 and LF, had positive correlation (r = 0.455 and 0.518, respectively; P < .05) (Figs. 1 and 2). Heart rate and blood pressure did not have correlation with Spo2.

Twelve subjects had minor symptoms of high-altitude sickness, such as headache and nausea, and the average AMS score was 3 ± 1 (Table 2). Arterial oxygen saturation and circulatory values among subjects with mountain sickness symptoms were not different from the corresponding values among subjects without the symptoms.

4. Discussion

4.1. Heart rate variability

In the present study, we measured autonomic nervous activity by assessing HRV. This noninvasive and real-time parameter is the beat-to-beat alteration of the R-R intervals in an electrocardiogram. This method is the most commonly used monitoring of autonomic nervous activities [11]. Power of HRV was quantified by determining the areas of the spectrum in 2 component widths: LF, 0.04 to 0.15 Hz; HF, 0.15 to 0.4 Hz. High-frequency components are considered to be associated solely with cardiac parasympathetic activity, whereas the low-frequency components are associated with both parasympathetic and sympathetic activity [17]. The LF/HF ratio is an index of cardiac sympathetic tone. The ENT% indicates the total fluctuation of heart rate.

The reliability of this method has already been examined in various studies, including large-scale studies regarding ischemic heart disease [7]. A recent multicenter study trial, Autonomic Tone and Reflexes after Myocardial Infarction (TRAMI), revealed that the measurement of heart rate variability is useful in assessing the activity of the autonomic nervous system and in predicting the risk of life-threatening arrhythmias in patients with ischemic heart disease [8]. Rovere et al described the depressed autonomic nervous system responsiveness as having a significant prognostic value for cardiac mortality after myocardial infarction [8]. Several other studies demonstrated a positive correlation between the HRV change and cardiac mortality [18,19]. Therefore, it is possible that an estimation of the autonomic nervous system activity is helpful to understand the risk of circulatory disorders among travelers at a moderate or high altitude.

4.2. Previous reports regarding autonomic activities at low barometric pressure

Until now, a limited number of studies investigated the alteration of autonomic nervous system activity at high altitudes by HRV measurement. Hughson et al [3] demonstrated changes in HRV in the subjects exposed to an altitude higher than 4000 m for more than 10 days. Farinelli et al [4] and Perini et al [5] independently reported changes in autonomic regulation of heart rate among trekkers exposed to 5050 m for almost a month. However, these studies were conducted to study the physiological change during gradual high-altitude acclimatization. In our previous study, to assess the alteration in autonomic nervous control of the heart during high-altitude traveling we investigated how actual acute exposure to altitudes at 2700 m (540 mm Hg) and 3700 m (480 mm Hg) affect the HRV of untrained office workers with no habitual physical exercise regimen [6].

These previous studies conducted in various conditions indicate that autonomic nervous activities are blunted at hypobaric hypoxic conditions, and that the sympathetic nervous system is dominant compared with the parasympathetic nervous system at a high altitude [3-6]. In our previous study at 480 mm Hg (3700 m), HRV was reduced both in high- and low-frequency domains, and LF/HF ratio increased acutely at 480 mm Hg. The results of the present study at 495 mm Hg (3456 m) showed reduction in HF and LF variability; however, increase in LF/HF ratio was minor. In the previous study, the ratio at 540 mm Hg (2700 m) was not significantly different from the value at 760 mm Hg (sea
level) [6]. It is possible that the ratio of sympathetic and parasympathetic nervous activity increase acutely at some point around 500 mm Hg. Although several previous studies implied that the low responsiveness of the autonomic nervous system at a high altitude could be advantageous in protecting organs from excessive and continuous sympathetic stimulation in a long-term stay at high altitude [20], reduction in autonomic nervous system responsiveness indicates the inability to adapt the body to challenging conditions, such as acute exposure to hypobaric hypoxic environment and traumatic accident [7,18,19].

4.3. Variability of Spo2 among subjects

The Spo2 value measured at 495 mm Hg in this study was comparable to the value measured at 480 mm Hg in our previous study [6]. The deviation of Spo2 among subjects was also comparable. It is well known that Spo2 value at altitudes was variable among trekkers [21,22]. Recent publications explain the variability in Spo2 by the difference in respiratory reflex. Under hypobaric hypoxic condition at altitudes, some trekkers acutely increase respiration volume and unconsciously induce respiratory alkalosis. Reduction in partial pressure of CO2 in alveoli increases O2 tension. In addition, alkalosis enhances the affinity of hemoglobin to oxygen. The degree of this reflex is very widely varied among trekkers. West et al [9] demonstrated that climbers with vigorous hypoxic respiratory drive could be adapted to hypobaric hypoxic conditions successfully and could work at altitudes without problems. In contrast, it is highly possible that trekkers or climbers with poor respiratory reflex easily had high-altitude disorders. Reduction in autonomic nervous activity provoked by low Spo2 may be related to the poor performance among people with poor hypoxic respiratory reflex.

4.4. Arterial oxygen saturation reduction and acclimatization to hypobaric hypoxia

Acclimatization to hypobaric hypoxia is attained by several different mechanisms [23]. High Spo2 value is a sign of healthy condition at altitudes; however, a subjective feeling of fitness does not solely depend on blood oxygenation. Because AMS score includes many subjective parameters [16], it is reasonable that Spo2 value and circulatory parameters among subjects with symptoms of mountain sickness were not different from the corresponding values among the subjects without the symptoms. In addition, symptoms among subjects with AMS score were minor in this study. If subjects are exposed to lower barometric conditions and if there are many subjects with severe mountain sickness symptoms, results might be different between groups. Further study with a larger scale will be indispensable to clarify the relation between physiological parameters and symptoms of high-altitude disorders.

Reduction in autonomic nervous activity measured by HRV correlates with the degree of hypoxia measured by Spo2. Autonomic responses among victims of high-altitude accidents may be blunted under hypobaric hypoxic condition. Deterioration of autonomic function measured by HRV might be more sensitive to hypoxia than clinical symptoms at high altitudes. Rescuers should note that autonomic nervous responsiveness of accident victims might be poor at high altitudes.

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References


