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Original Paper

Changes in the Indices of Respiratory Functions in Japanese Adult Men during an Ascent of Mt. Fuji

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Abstract

The purpose of this study was to investigate changes in respiratory functions during an ascent of Mt. Fuji. Eight healthy Japanese men (age: 23.3 ± 2.3 years) volunteered to climb Mt. Fuji (3,776 m). Participants' expiratory forced vital capacity (FVC), forced expiratory volume per second ($FEV_{1.0}$), percutaneous arterial oxygen saturation (SpO_2) and degree of dyspnea sensation (DDS) were measured at the five points (Pre-Ground; altitude: 10 m, 5th station; altitude: 2,300 m, 7th station; altitude: 2,700 m, summit: 3,710 m and Post-Ground: 84 m). We reached to Summit at night (4:00 a.m.) and we reached other points during the day. The measurement indices were conducted soon after the subjects' arrival at each point. FVC at the 5th station and the summit were significantly lower than that at Pre-Ground and Post-Ground. There were no significant changes in $FEV_{1.0}$. SpO_2 significantly decreased during ascent. DDS at the summit was significantly higher than that at other points. In conclusion, climbers suffered additive stress to the respiratory system caused by hypobaric and hypoxic stresses, exercise stress after brief periods rest and the effects of autonomic nerve system including sleepiness.

1. Introduction

Characteristic physiological responses develop in humans when they are exposed to a high altitude environment. Previous studies [1] clarified that high altitude diseases such as headache, dizziness and

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nausea are more likely to develop at altitudes over 2,400 m. Exercise in a high altitude environment causes increased stress on respiratory system from the effects not only of exercise intensity, but also hypobaric and hypoxic stress [1].

The Japanese Society of Mountain Medicine [1] has announced guidelines for the prevention of respiratory disease initiation such as bronchial asthma, chest pain and spontaneous pneumothorax whilst climbing high altitude mountains. On the other hand, it has been suggested that airway obstruction in normal individuals is led by airway cooling induced by increases in ventilation air volume combined with increased exercise intensity [2]. Thus, during mountaineering in hypobaric and hypoxic environments the stress on respiratory system is increased both with and without the presence of a respiratory disease.

Mt. Fuji (altitude: 3,776 m) is the highest mountain in Japan, and the number of climbers is estimated at approximately 300,000 per year [3]. Many climbers ascend at night because they want to view the sunrise from the summit. Thus, it can be inferred that many climbers depart to climb the summit at night after limited sleeping time and incur exercise stress in a hypobaric and hypoxic environment. This leads to the development of medical diseases including high altitude disease during climbing such a physiologically demanding environment [1].

Individuals are likely to develop respiratory alkalosis due to an increase of ventilatory volume derived from stimulus of peripheral receptors in a hypobaric and hypoxic environment as experienced over 3,000 m altitude [1, 4]. Climbers risk suffering difficulty in breathing, airway obstruction and serious symptoms including hyperventilation syndrome. Medical doctors remain in the mountain lodge of Mt. Fuji in summer, however, medical conditions often develop during climbing. In addition, if climbers ascend at night and suffer medical problems, rescue work at this time is particularly dangerous. Therefore, from the aspect of safety management, it is necessary to prevent respiratory diseases or symptoms developing during night climbs. However, at present there are no comparative studies relating to changes in the indices of respiratory functions during night and daytime ascents of Mt. Fuji.

The purpose of this study was to clarify the changes in the indices of respiratory functions in adult men climbing Mt. Fuji in both the day and night.

2. Methods

2.1. Subjects

Eight Japanese adult males (age: 23.3 ± 2.3 years, height: 172.4 ± 6.8 cm, weight: 67.0 ± 10.3 kg) volunteered to climb Mt. Fuji (altitude: 3,776 m), located in Yamanashi prefecture, in August, 2010. There are many mountain lodges open in August, and climbers can take refuge there in the event of emergency situations. Therefore, in order to ensure participant safety we decided to climb Mt. Fuji in August. All subjects were taking part in a tour of Mt. Fuji hosted by their university. Informed consent was obtained from all participants after explaining the study purpose and potential risks. Thus, each participant voluntarily joined this program based on an understanding of the associated risks.

2.2. Investigation contents and measurement indices

The subjects went to the 5th station (altitude: 2,300 m) by bus from ground level (rest. altitude: 10 m). They started to climb to the 7th station (altitude: 2,700 m) from the 5th station at 1:00 p.m. Arrival time at the 7th station was 5:00 p.m. They rested in the mountain lodge in the 7th station for four times including two brief sleeping times, and they departed for the summit (altitude: 3,710 m) at 9:00 p.m. The subjects arrived at the summit at approximately 4:00 a.m. They descended to the 5th station from the summit after resting for two times. The subjects took acetazolamide (125 mg) for the prevention of altitude sickness under medical supervision before climbing. Temperature and atmospheric pressure decreased with increasing altitude. It rained during the ascent from the 5th to the 7th station. Therefore, relative humidity increased rapidly from the 7th station onwards. Though the rain stopped after arriving at Summit, it rained during the descent to Post-Ground from the 6th station (Table 1).

Participant's forced vital capacity (FVC), forced expiratory volume per second ($FEV_{1.0}$), peak expiratory flow (PEF), percutaneous arterial oxygen saturation (SpO_2), heart rate (HR), rating of perceived exertion (RPE) and degree of dyspnea sensation (DDS) were measured at the 5 stations using a spirometer (micro: Vitalograph), a pulse oximeter (SpO_2: SAT-2100, NIHON KODEN) and the modified Borg's scale [5, 6]. Atmospheric temperature, relative humidity and atmospheric pressure were measured at each point. Other indices were measured after arriving at the five points (Pre-Ground; altitude: 10 m, 5th station; altitude: 2,300 m, 7th station; altitude: 2,700 m, Summit: 3,710 m and Post-Ground: 84 m). The measurements at each station were conducted in the mountain lodge because we gave priority to the safety of the subjects. The measurements were conducted 2-3 minutes after the subjects' arrival at each point. This investigation was accompanied by a medical doctor with a great deal of experience in mountaineering.

2.3. Statistics

The data were analyzed with repeated measure one-way analysis of variance to examine differences between the means of the five points and are presented as mean ± standard deviation. If statistical significance was identified, comparison of the five points was conducted by using the main effects test (Bonferroni). Changes in DDS were compared using the Kruskal-Wallis test. Furthermore, if statistical significance was identified, Wilcoxon's signed rank test was performed to detect changes of DDS within each point. Statistical significance was set at less than 0.05. The data were analyzed using SPSS ver. 12.0 for Windows.

3. Results

Table 1 shows the changes in meteorological conditions, HR, RPE, SpO_2, FVC, $FEV_{1.0}$, PEF and DDS.

3.1. Changes in HR, RPE and SpO_2 during the ascent

HR and RPE at the 7th station and the summit were higher than that at pre-ground ($p<0.05$). There were significant reductions in SpO_2 at the 5th and the 7th station and Summit as compared with measurements at pre-ground and post-ground ($p<0.05$). Significant reductions in SpO_2 were observed at the summit when compared with measurements from the 5th and the 7th station ($p<0.05$).

3.2. Changes in FVC, $FEV_{1.0}$ and PEF during the climbing of Mt. Fuji

FVC at the 5th station and the summit were significantly lower than at pre-ground and post-ground ($p<0.05$). There was no significant changes in $FEV_{1.0}$. Significant increases in PEF were observed at the 5th and the 7th station, the summit and post-ground when compared with those from pre-ground ($p<0.05$).

3.3. Changes in DDS during the climbing of Mt. Fuji

DDS at the 5th station did not significantly change when compared with those from pre-ground. Significant elevated DDS levels were observed at the summit when compared with those from pre-ground, the 5th station, the 7th station and post-ground ($p<0.05$).

4. Discussion

4.1. Meteorological conditions during the climbing of Mt. Fuji in this study

According to the Boyle-Charle's law, temperature and atmospheric pressure decrease with increasing altitude. The meteorological conditions on the ascent changed as predicted by this law of physics.

The atmospheric pressure of saturated vapor decreases according to a decrease in temperature. The air condition is dry at high altitudes, because the atmospheric pressure of saturated vapor decreases. However, rain and snow occur frequently in high attitude mountains. Therefore, relative humidity can be high. During the ascent in this study, temperature and atmospheric pressure decreased with increasing altitude, and relative humidity was high at the 7th station and the summit due to rainfall more than ground conditions.

Table 1 Changes in the indices of meteorological conditions, respiratory functions and exercise intensity during the climbing of Mt. Fuji

Measurement index	Pre-ground (10 m)	5^{th} station (2,305 m)	7^{th} station (2,700 m)	Summit (3,710 m)	Post-ground (84 m)
Temperature (℃)	30.9	26.1	23.7	14.9	21.8
Relative Humidity (%)	51.7	56.5	74.7	67.4	55.0
Pressure (hPa)	1031	776	735	630	1020
FVC (L)	4.60 ± 0.44	4.27 ± 0.55	4.51 ± 0.40	4.27 ± 0.40	4.85 ± 0.39
$FEV_{1.0}$ (L)	3.71 ± 0.45	3.70 ± 0.42	3.77 ± 0.29	3.71 ± 0.39	4.07 ± 0.31
PEF (L/min)	570 ± 106	623 ± 101	633 ± 98	623 ± 82	651 ± 80
SpO_2 (%)	97 ± 0	92 ± 2	88 ± 3	81 ± 7	97 ± 1
DDS	0	0	0.5	1.5	0
HR (bpm)	71 ± 5	75 ± 9	96 ± 10	105 ± 8	84 ± 9
RPE	6 ± 0	7 ± 2	10 ± 2	14 ± 1	8 ± 3

DDS: Median
FVC, $FEV_{1.0}$, PEF, SpO_2, HR, RPE: Mean ± SD

FVC: Forced Vital Capacity
$FEV_{1.0}$: Forced Expiratory Volume in one second
PEF: Peak Expiratory Flow
SpO_2: Arterial Oxygen Saturation
DDS: The Degree of Dyspnea Sensation

※ $p<0.05$

4.2. Exercise intensity during the ascent

There are many mountain lodges available for rest in August, therefore a great number of climbers attempt the ascent at this time. Due to the large number of other climbers, it is difficult for climbers to ascend at their own pace. Therefore, they must wait behind others, "pausing every step or two". The subjects climbed at a very slow pace in this study. This is why HR and RPE were not high.

4.3. Changes in respiratory functions

The altitude at the 5th station is 2,300 m and oxygen concentration is approximate 16%. If people go to the 5th station by bus, they are exposed to a hypobaric and hypoxic environment. When people are exposed to a hypobaric and hypoxic environment, FVC decrease is induced with overflowing pulmonary blood vessels and respiratory muscle weakness through the effects of hypoxic stresses [7]. It was considered that the factor of decrease in FVC over 10% in the 5th station was effects of hypoxic stress. PEF in the 5th station was significantly higher than at ground level. The reason for this change was considered an increase of peak expiratory flow induced by a decrease of airway resistance and the effort of breathing derived from a reduction of molecular density [7]. $FEV_{1.0}$ did not indicate a significant change. It is able to flow with few volume of gas in pleural cavity under relative stability of $FEV_{1.0}$ in increasing PEF. This is result from air compression. On the other hand, SpO_2 significantly decreased with increasing altitude. Considering the stability of $FEV_{1.0}$ changes, significant decrease in SpO_2 could be explained by a decrease of partial pressure of oxygen in alveoli associated with a decrease of atmospheric pressure, not a ventilation-perfusion ratio inequality caused by an increase of exercise-intensity.

Remarkably, measurement of $FEV_{1.0}$ and PEF at the 7th station did not differ significantly from measurements taken at the 5th station. However, FVC at the 7th station increased significantly when compared with measurements from ground level. Airway resistance decreases during ascent due to reduction in molecular density in air. Thus, hyperventilation is remarkably high in comparison with ground level [8]. In this study, climbing intensity were not high level. From the results of RPE and DDS, the subjects indicated they felt "nothing bad" in their subjective sensations during the ascent. Given this, the stress due to moderate exercise-intensity might effect physiological reactions more than the stress due to hypobaric and hypoxic environment. This was the factor related to the finding that FVC of the 7th station was higher than at the 5th station. On the other hand, $FEV_{1.0}$ did not significantly differ between the summit and the 5th and the 7th station. However, FVC at the summit significantly decreased in comparison to level at the 5th station.

Physiological stress might not be high, because there was no significant difference in HR between the 7th station and the summit in this study. However, the summit was a more hypobaric environment (630 hPa) than the 7th station (735 hPa). In addition, the subjects received stress by accumulation of fatigue derived from exercise intensity due to the long climbing time, short sleeping time, stress on respiratory system due to the increase of ventilatory volume and airway contraction due to inhalation of cold air. It is difficult to identify the main causal factors because there are many possible reasons for a decreasein the indices of respiratory functions. For example, acute exposure to a hypobaric and hypoxic environment, cold temperature, decrease of respiratory muscles due to continuation of exercise intensity, airway contraction derived from an increase of vagal nerve due to sleepiness. Therefore, it was considered that decrease in FVC was derived from the additive effects of the environment factors (hypobaric, hypoxic, cold temperature), the intervention factor (exercise-intensity) and the individual factor (sleepiness).

A previous study [9] indicated that HR and RPE while climbing Mt. Daisen (altitude: 1,709 m) changed remarkably with scores higher than this study. $FEV_{1.0}$ significantly decreased at the summit of Mt. Daisen, FVC did not significantly change. In the previous study [9], the subjects went to the starting point of the mountain (altitude: 780 m) by bus, and they ascended to the summit of Mt. Daisen. SpO_2 did not significantly change during the climb. These results indicated a small degree of decrease in arterial blood saturation and partial pressure of oxygen in the alveoli derived from a decrease in atmospheric pressure. Those indications suggest there is not a large effect on stress due to being a hypobaric and hypoxic environments during a climb of Mt. Daisen. Therefore, FVC did not significantly decrease [9]. However, FVC significantly decreased at the 5th station (altitude: 2,305 m) and at the summit (altitude: 3,710 m) of Mt. Fuji in this study. Although we can not declare the threshold of altitude in starting decrease of respiratory functions associated with decrease of atmospheric pressure. It might be possible to exist the threshold of atmospheric pressure change in range from altitude 2,000 to 3,000 m: Although the work of breathing is easy by reduce in airway resistance, at the same time, it is received restricting stress on respiratory system. In order to clarify this physiological response, a future study is necessary to investigate the relationship between exercise-intensity and respiratory functions during a simulation experiment in a hypobaric and hypoxic room. If this response is verified, it may be useful in preventing sudden chest-wall disorders, and airway contraction derived from stress on the respiratory system during climbing high altitude mountains.

It takes one night and two days to climb Mt. Fuji. Many climbers try to climb the summit at night because they want to view the sunrise from the summit. Therefore, duration of sleep is very short (two hours in this study) and atmospheric temperature is very cold. Climbers develop very sleepy, become chilled, and the stress on the respiratory system such as airway contraction could be influenced by sleepy and chill. Moreover, on an ascent and descent of Mt. Fuji severe conditions of low pressure, low oxygen persist over a long distance. Over and above the need to take preventative measures against potential risks, there is a need to take a medical check in advance of commencing a climb under such severe conditions. Takagi et al. [9] suggest that stress on the respiratory system greatly increases in high altitude mountains compared to lower altitude mountains such as Mt. Daisen (altitude: 1,709 m). Alternatively, they points that the respiratory system could be increased more than severe conditions like cold environment [9]. This study supports the suggestion in previous study [9]. As there are many accidents and cases of medical disease during the climbing of Mt. Fuji, climbers should not think “everybody can climb the mountain” or that climbing the mountain is easy. Therefore, it is advisable to have a medical check at the 5th station and the mountain lodge after sleep break and before the final ascent.

5. Conclusion

The indices of respiratory functions changed significantly during the ascent of Mt. Fuji. FVC at the 5th station and at the summit were significantly lower than at resting condition. The main factors resulting in a decrease in FVC at the 5th station was acute hypobaric and hypoxic stress. However, decrease in FVC at the summit was not only that factor. In attempting to reach the summit by sunrise climbers ascend from the 7th station at night. In leaving at this time climbers endure additive stress to the respiratory system due to hypobaric and hypoxic stresses, cold stress, exercise stress after a brief period of rest and the effects of autonomic nerve system including sleepiness. If climbers try to climb the summit of Mt. Fuji at night, they should take preventive measure to reduce stress on the respiratory system based on the aforementioned factors.

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