BRIEF REPORT

Effects of Cardiopulmonary Resuscitation at High Altitudes on the Physical Condition of Untrained and Unacclimatized Rescuers

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Objective.—The authors experienced a case of prolonged cardiopulmonary resuscitation (CPR) on Mount Fuji (3776 m) that demanded strenuous work by the rescuers. The objective of this study was to provide information regarding the physiologic effects on the rescuers of performing CPR at moderate altitude.

Methods.—The effects of CPR at 2700 m and 3700 m above sea level on the physical condition of the rescuers were studied in 8 male volunteers.

Results.—Cardiopulmonary resuscitation for 5 minutes at 3700 m significantly reduced arterial blood oxygen saturation and increased rate-pressure products ($P < .05$). Scores on the Borg scale, a subjective score of fatigue, after CPR action at 2700 m ($P < .05$) and 3700 m ($P < .01$) were higher than the scores at sea level.

Conclusions.—Prolonged CPR at high altitude exerts a significant physical effect upon the condition of rescuers. A role for mechanical devices should be considered wherever possible.

Key words: high altitude, alpine accidents, mountain rescue, basic life support

Introduction

A growing number of persons with cardiovascular diseases are ascending to high altitude. Immediate cardiopulmonary resuscitation (CPR) is required for patients with cardiac arrest. Although performing CPR is effort intensive at sea level, performing CPR at high altitude is even more exhausting.

We experienced the following case of prolonged CPR at high altitude. A man of approximately 50 years of age, with an estimated body mass index of 30, complained of chest discomfort shortly before losing consciousness while at an altitude of 3500 m on Mount Fuji. His companion realized that he was not breathing. She sought help from passers-by, some of whom started CPR. Two of the authors of this paper also joined the rescue action. They called for emergency medical equipment and transportation from the nearby mountain hut. In

this situation, transportation consisted of a “crawler,” which is a diesel-powered caterpillar tractor adapted for steep slopes. The only available medical equipment, including an automated external defibrillator, was in a mountain hut approximately 1 km away from the accident site. Since the crawler arrived earlier than the medical equipment, they decided to transport the victim by crawler while continuing CPR. The victim was laid supine on the back seat, which was transversely set in the crawler. Inability to revive the patient despite prolonged CPR in the unfavorable environmental conditions made the rescuers almost decide to abandon the procedure, but repeated heartfelt and sorrowful urging by the patient’s companion made it impossible for them to do so. Although the rescuer believed that performing prolonged CPR in an out-of-hospital setting on someone with a suspected cardiac or neurologic event is generally futile, he could not explain that to the crying foreigner who could not understand the local language. Finally, 4 hours after the patient became unconscious, he was declared dead at a local hospital at the mountain base. The rescuer, who continued CPR during the crawler transportation

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even though CPR in the lopsided narrow carriage was very difficult, was exhausted after the work. Fortunately, the rescuer did not suffer any long-term ill effects of the extreme physical activity. Details of the victim's physical and personal characteristics could not be obtained from the police records for political reasons, and hence, the authors could not make contact with the victim's family for additional information after the incident.

After the rescue action, the authors decided to conduct research to identify the physical condition of rescuers after performing CPR at high altitudes.

Methods

The approval of the local Human Ethics Committee (Gunma University Research Ethics Committee for Human Studies No. 20–20) and informed consent of the participants were obtained before this study. Eight male volunteers (mean age 35 ± 9 years; range, 24–48 years; height 171 ± 7 cm; weight 61 ± 6 kg) were included in this study. They had completed a basic life support and CPR training course (adapted according to International Liaison Committee on Resuscitation guidelines) before this study. All of the subjects were office workers with no regular physical exercise regimen, and none of them had been exposed to an altitude above 2000 m during the year before the first experimental action at 2700 m performed in this study. All of the subjects passed pre-study health check-ups, including chest roentgenogram, electrocardiography, laboratory blood tests, and so forth; and none of the subjects had medical ailments such as cardiovascular or pulmonary diseases. The same members were enrolled in all 3 experimental steps, each of which was separated by more than 3 months.

Physiological parameters of all study subjects were measured at sea level and at 2700 m and 3700 m above sea level. Barometric pressures at these altitudes were 760 mm Hg, 540 mm Hg, and 480 mm Hg, respectively, as reported by the local meteorological center. In the experiments at 2700 m and 3700 m, subjects were transported to an altitude of 2400 m by car, and then ascended the remaining 300 m or 1300 m, respectively, on foot, without being encumbered by any baggage weight. Transportation by car from sea level to an altitude of 2400 m took approximately 4 hours. The total duration required for the ascent from sea level to 2700 m or 3700 m was approximately 6 to 8 hours. All of the experiments were performed in wind-sealed constructions, and the temperature was maintained at 18°C. After arrival at the new altitude, the subjects were permitted 30 minutes of rest time before experimental measurements.

Using a portable life monitor (ProPack II, Protocol Systems Inc, Beaverton, OR) and arterial blood oxygen

saturation (SpO₂) probe set on the right index finger, heart rate, noninvasive blood pressure and SpO₂ were monitored before and after the 5-minute CPR action. During the measurements, subjects rested quietly in the supine position. Rate pressure products (RPP) were calculated as the heart rate multiplied by systolic blood pressure. Serum lactate concentrations were measured immediately before and after the CPR action by sampling 0.3 mL venous blood from the subject's antecubital vein. The lactate oxidase method and an automatic analyzer were used for these measurements (Lactate Pro, KDK Inc, Kyoto, Japan). Borg scale scores were collected immediately after the CPR action.¹ Although the applicability of this score at high altitudes has not yet been confirmed, this simple scale of perceived exertion has often been used to regulate exercise intensity. A higher Borg score indicates a subjective feeling of greater physical intensity.

The CPR (single-operator procedures) was performed continuously for 5 minutes according to the 2010 American Heart Association (AHA) guidelines,² using a transportable CPR trainer (MiniAnne, Laerdal Japan Inc, Tokyo, Japan). The rate of chest compressions was kept constant at 100 times/min with a digital quartz metronome (CN89, Yamaha Musical Trading Inc, Tokyo, Japan). The adequacy of chest compressions was monitored by measuring chest balloon pressures, which were measured by a pressure gauge (CE0123, VBM, Sulz, Germany) connected to the balloon inflating valve. The study subjects were advised to attain peak chest balloon pressures of 30 to 50 cmH₂O with each compression. This pressure value was determined by observing that 4 cm to 5 cm chest compression on the simulator produced this pressure on the gauge (the depth in the 2010 AHA guidelines is 5 cm to 6 cm). The adequacy of breathing was monitored by observing full inflation of the simulator lung. A compression to ventilation ratio of 30:2 was maintained throughout the 5-minute trial.

STATISTICS

All data are expressed as mean $\pm$ SD. Statistical comparisons of measured values were assessed by the Kruskal-Wallis test, using statistical software StatMate III (Atoms, Tokyo, Japan). A *P* value $< .05$ was considered statistically significant.

Results

Before CPR, heart rate, systolic blood pressure, and RPP were not significantly different at the 3 altitudes (Table 1). Pre-CPR diastolic blood pressures at 2700 m and 3700 m were significantly higher than their values at sea

Table 1. Effects of cardiopulmonary resuscitation on the rescuers' physical condition at each altitude

Altitude (m)	SBP, mm Hg		DBP, mm Hg		Heart rate, beats/ min		Rate-pressure product		SpO ₂ , %		Serum lactate, mmol/L		Borg score
	Pre-CPR	Post-CPR	Pre-CPR	Post-CPR	Pre-CPR	Post-CPR	Pre-CPR	Post-CPR	Pre-CPR	Post-CPR	Pre-CPR	Post-CPR	
Sea level	121 ± 12 (104–138)	130 ± 9 (116–145)	81 ± 8 (67–91)	81 ± 8 (71–96)	82 ± 10 (67–94)	96 ± 11 ^a (74–111)	9850 ± 1415 (8509–12 972)	12 478 ± 1864 (9546–14 430)	98 ± 1 (96–99)	96 ± 1 (95–98)	1.0 ± 0.5 (0.1–1.7)	1.6 ± 0.4 (1.0–2.3)	13 ± 1 (12–15)
2700 m	138 ± 10 (128–155)	155 ± 24 (104–180)	94 ± 10 (84–111)	90 ± 21 (41–110)	85 ± 10 (73–96)	98 ± 17 (63–118)	11 765 ± 1262 (9472–13 064)	13 699 ± 3694 (9048–21 240)	88 ± 4 ^d (84–94)	89 ± 4 ^d (84–94)	1.7 ± 0.4 ^d (1.0–2.3)	3.6 ± 2.1 ^d (1.4–7.8)	15 ± 3 ^c (12–18)
3700 m	137 ± 27 (89–176)	158 ± 28 ^a (132–208)	92 ± 16 (71–112)	105 ± 21 ^b (81–150)	86 ± 20 (62–111)	106 ± 13 ^{bc} (80–122)	11 487 ± 2753 (7743–15 515)	16 512 ± 2303 ^c (13 332–20 868)	80 ± 7 ^d (71–90)	76 ± 7 ^{ad} (68–85)	2.7 ± 2.3 (0.8–8.2)	7.9 ± 5.3 ^{bc} (1.9–13.5)	15 ± 1 ^d (13–17)

Data presented as mean ± SD; numbers in parentheses show range of values.

SBP, systolic blood pressure; DBP, diastolic blood pressure; CPR, cardiopulmonary resuscitation.

^a Significantly different from the pre-CPR value ($P < .05$).^b Significantly different from the pre-CPR value ($P < .01$).^c Significantly different from the sea level value ($P < .05$).^d Significantly different from the sea level value ($P < .01$).

level ($P < .05$). Resting values of Spo₂ in the study subjects before CPR were 98% ± 1% at sea level, 88% ± 4% at 2700 m, and 80% ± 7% at 3700 m. The values at 2700 m and 3700 m were significantly lower than the value at sea level ($P < .01$). Pre-CPR serum lactate concentration at 2700 m was higher than the value at sea level ($P < .01$), while the value at 3700 m was comparable to that at sea level.

All subjects could complete the 5 minutes CPR tasks as ordered. The action at 2700 m had no significant effect on measured variables. Performance of CPR at sea level increased the rescuers' heart rate ($P < .05$). The action at 3700 m increased systolic blood pressure ($P < .05$), heart rate ($P < .01$), and serum lactate levels ($P < .01$), whereas the rescuers' Spo₂ decreased after performing CPR at 3700 m ($P < .05$).

Post-CPR diastolic blood pressure, heart rate, RPP, and serum lactate at 3700 m were higher than their corresponding values at sea level ($P < .05$). The Spo₂ at 2700 m and 3700 m was lower than the value at sea level ($P < .01$). Borg scale scores after CPR at 2700 and 3700 m were higher than the scores at sea level.

Discussion

We have clearly demonstrated that CPR makes great demands upon the human body at altitude. In the present study, Spo₂ decreased along with the decrease in barometric pressure associated with increasing altitude. Physical exercise—CPR action in this study—at high altitude induces further Spo₂ reduction, and exercise at altitudes augments circulation. The degree of reduction in Spo₂ observed in our study was comparable to the values measured at similar altitudes in our previous study.³ The relatively wide deviation in Spo₂ among subjects was also comparable. It is well known that Spo₂ values among trekkers are variable at any given altitude.⁴ The effects of the hypobaric environment on resting circulatory variables, such as blood pressure and heart rate, were minor in this study. Much higher altitudes may cause more obvious changes in these measurements in subjects who are not acclimatized.⁵

The activity of CPR is considered to be relatively hard physical work. Several previous studies reported the impact of CPR on the physical condition of rescuers, and demonstrated that CPR for approximately 10 minutes induced fatigue in the rescuers.⁶ That is the basis for the recommendation of frequent switches among rescuers doing chest compressions. Although CPR technique, previous training, and the physical fitness of the rescuer obviously affect energy expenditure and competence during the performance of CPR, the environment of the rescue action is another important factor contributing to the rescuers' health condition.

In our previous studies at high altitudes, Master's double-step exercise for 3 minutes at an altitude of 2700 m induced a

more drastic decline in SpO_2 .³ In that study, SpO_2 was $82\% \pm 6\%$ after the exercise. However, in the present study, SpO_2 was not significantly reduced after CPR at 2700 m ($89\% \pm 4\%$). During CPR, the rescuer inhales a larger than usual amount of air before providing a breath to the victim. Also, while blowing into the victim's lungs, the rescuer exhales against the victim's airway and chest resistance. Resistance to exhalation serves as positive expiratory pressure for the rescuer. Positive end-expiratory pressure and relatively large tidal volumes could increase the rescuer's blood oxygenation and improve SpO_2 values.

The Borg score obtained after CPR at sea level in this study was comparable to the value reported by Bridgewater et al.⁶ At 3700 m, where SpO_2 decreased and RPP increased, Borg scale scores increased. Although SpO_2 and RPP were not significantly altered after CPR at 2700 m, Borg scores obtained after CPR at 2700 m were significantly higher than the value at sea level. Although a high SpO_2 value at high altitudes is a sign of a healthy physical condition, a subjective feeling of fitness does not solely depend on blood oxygenation or on circulatory variables such as heart rate and blood pressure.⁵ Because the Borg score is highly subjective, it is reasonable that SpO_2 values and circulatory measurements among subjects did not correlate with Borg scores. It might be impossible to correlate Borg scores with actual energy output. Also, Borg scores are not normally distributed. Although values greater than 12 to 14 are interpreted as meaning that the exercise is greater than moderate in intensity, the clinical significance of minor differences in the value has not yet been established.

This study was inspired by observation of the severe fatigue shown by the rescuer performing prolonged CPR at a high altitude. We conducted this study in an alpine environment after making the rescuers actually trek. Use of an artificially controlled environment, such as a hypobaric chamber, may provide more standardized data and scientifically solid evidence. Also, in this study, although the subjects who performed CPR were healthy young volunteers, they were unacclimatized and relatively unfit participants. Because there are no specially trained high altitude rangers or rescuers in Japan, we enrolled regular office workers who may visit Mount Fuji (a popular tourist area) as sight-seeing tour participants. Another study with acclimatized rescuers might give different results. If more mature or older subjects are involved as the rescuers, the effects of CPR on their own physical condition could be more serious. In reality, more than half of the trekkers in Japan are not young.⁷ Therefore, in the event that CPR is required, it is increasingly likely that the person performing CPR might be elderly. A similar study including older rescuers would provide more accurate and clinically relevant information.

Although the volunteers in this study had a period of rest before performing CPR, their pre-CPR serum lactate levels

were slightly elevated at 2700 m. It is possible that the 30-minute rest period after the trek was insufficient for lactate washout in some subjects. The duration of the rest period could not be extended beyond 30 minutes, however, because of limitation of the study program to 1-day at each altitude. On the other hand, any rest period is inconsistent with the situation where CPR action is required. Further study without any rest period might give a more drastic result.

Conclusions

This is the first study to assess the effects of performing CPR at high altitude. Above 2700 m, the work of CPR has a significant impact upon the physiological condition of those taking part. The use of equipment such as portable automated external defibrillators, chest balloon pressure, and mechanical chest compression devices should be considered to reduce the workload of CPR on rescuers working at high altitudes.⁸

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