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Original Article

Exposure to a mild hyperbaric oxygen environment elevates blood pressure

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Abstract. [Purpose] This study aimed to investigate the changes in blood pressure due to mild hyperbaric oxygen at 1.3 atmospheres absolute with approximately 30% oxygen. [Participants and Methods] Ten healthy adults participated in two trials: the control (1 atmosphere absolute with 20.9% oxygen) and the mild hyperbaric oxygen (1.3 atmospheres absolute with approximately 30% oxygen) trials. All participants were exposed to either the control or mild hyperbaric oxygen conditions in a chamber for 45 min on each experiment day. [Results] A lower heart rate and higher peripheral oxygen saturation were observed after exposure in the mild hyperbaric oxygen trial than those in the control trial. After exposure, the change in ratios from the premeasurement of systolic and diastolic blood pressure in the mild hyperbaric oxygen trial was more than that in the control trial, despite no change in the absolute blood pressure values between the two groups during the exposure. [Conclusion] This is the first study to reveal that mild hyperbaric oxygen exposure might be a control method for chronic hypotension. In addition, these results suggest that people with hypertension might require some attention when using mild hyperbaric oxygen.
Key words: Mild hyperbaric oxygen, Blood pressure, Heart rate

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INTRODUCTION

The World Health Organization (WHO) has defined arterial hypotension as low blood pressure (BP) with a systolic BP below 110 and 100 mmHg in male and females, respectively[1)]. Some large population-based studies have shown a relationship between chronic hypotension and minor psychological dysfunction, persistent tiredness, and poor perception of well-being[2–4)]. In addition, other symptoms such as reduced cognitive performance, faintness, dizziness, headaches, palpitations, and increased pain sensitivity are also related to chronic hypotension[5–7)]. Some of these symptoms may be related to diminished cerebral blood flow and cortical activation induced by chronic hypotension[5)]. Some pharmacological methods to improve hypotension have been investigated previously[8–10)], although there are few effective methods without drags or physical activities.

As another way for medical therapy, hyperbaric oxygen (HBO) conditions have been applied to various medical conditions in clinical settings[11, 12)]. HBO refers to breathing of 100% oxygen in a pressurized chamber at 2–3 atmospheres absolute (ATA). In direct correlation with increased atmospheric pressure, oxygen physically dissolves in blood plasma according to Henry's law[12)]. In addition, HBO therapy has been shown to be effective as a medical treatment, with improved healing and reduced edema and infection[13)]. Exposure to mild hyperbaric oxygen (MHO), which is a relatively lower air pressure and oxygen concentration compared to that in the HBO condition, at 1.25–1.3 ATA with 30%–40% oxygen increases blood flow and resting energy expenditure[14)]. MHO enhances oxidative metabolism in tissues owing to increased oxygen content (i.e.,

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dissolved oxygen and hemoglobin-bound oxygen)[15, 16]. MHO also inhibits and/or improves metabolic syndrome[17], type 2 diabetes[18, 19], osteoporosis[20] and hypertension[21] in animals.

Additionally, exposure to MHO has recently attracted public attention globally, because it may be an effective method for recovery after training or conditioning for sports[22], or for anti-aging of skin[23], however, the detailed changes in the cardiovascular system after exposure to MHO are unclear. Exposure to HBO or MHO induces an increased peripheral oxygen saturation (SpO_2) level and a decreased heart rate (HR)[14, 24, 25], although a consistent view of the effects of HBO or MHO on BP has not yet been obtained. In a previous study, within almost an hour after hyperbaric exposure at 4 atm for 30 minutes (min), the mean BP and diastolic BP (DBP) increased[25]. Conversely, 20 sessions of repeated HBO treatment (HBOT) under 2.5 ATA with 100% oxygen for 90 min decreased systolic BP (SBP) in patients with chronic wounds requiring HBOT[26]. Another study showed that HBO under 2.5 ATA with intermittent ventilation of 100% oxygen did not alter blood pressure levels[27].

Excessive production of reactive oxygen species is associated with the pathogenesis of many diseases, including atherosclerosis, myocardial infarction, hypertension, and diabetes, by the generation of free radicals and increased levels of oxidative stress[28]. Exposure to MHO at 1.25–1.3 ATA with 30%–36% oxygen did not result in enhanced levels of oxidative stress in rats and humans, at both sedentary and recovery conditions[14, 15, 22, 24, 29]. Thus, exposure to MHO has a lower risk of complications such as barotrauma because of the relatively lower air pressure and oxygen concentration than the HBO condition[14, 15, 22, 24, 29]. There were some studies of MHO on conditioning or recovery in sports or for anti-aging[22–24], however, they did not include the reports about BP. This study aimed to investigate the effects of MHO on the cardiovascular system, especially BP. The hypothesis of the study was that the blood pressure would be changed by exposure to mild hyperbaric oxygen because our previous research[23] showed changes in the heart rate. This is the first study to show the possibility of an effective method for maintaining BP using MHO. Additionally, this is also the first study to reveal that people with hypertension may need some attention in using MHO.

PARTICIPANTS AND METHODS

This study used a randomized in crossover design following previous study[23]. The participants of this study were healthy adults; six males and four females (mean age, 30.0 ± 2.2 years; height, 168.1 ± 5.8 cm; body mass, 64.8 ± 9.3 kg). They were non-smokers, had taken no medications, and refrained from alcohol intake before and during the experimental period. They ate breakfast before 7:00 a.m. and abstained from caffeine intake on the days of experiment. All participants voluntarily provided a signed informed consent from before participating in the study. The study protocol was approved by the Ethics Committee of the Department of Sport Science (2020-12) at the Japan Institute of Sport Sciences. Moreover, the study complied with the latest version of the Declaration of Helsinki and was conducted according to international standards.

The trials consisted of a control (CON, 1 ATA with 20.9% oxygen) trial and an MHO (1.3 ATA with approximately 30% oxygen) trial. All participants participated in two experimental trials on separate days in a week and arrived at the laboratory at 8:30 a.m. on both days. All participants were exposed to CON or MHO condition in a chamber for 45 min on each experimental day and were asked not to drink water during the experiment. Both SBP and DBP were measured every 10 min throughout the exposure period and immediately after exposure using a BP monitor (Omron Corporation, Kyoto, Japan). The heart rate (HR) and peripheral oxygen saturation (SpO_2) levels were measured every 10 min throughout the exposure period using an HR monitor (Polar V800, Kempele, Finland) and a pulse oximeter (Dretec Co., Ltd., Saitama, Japan), respectively. In the MHO trial, as shown in Fig. 1, participants entered a chamber (Japan Kiatsu Balk Co., Ltd., Shizuoka, Japan) with

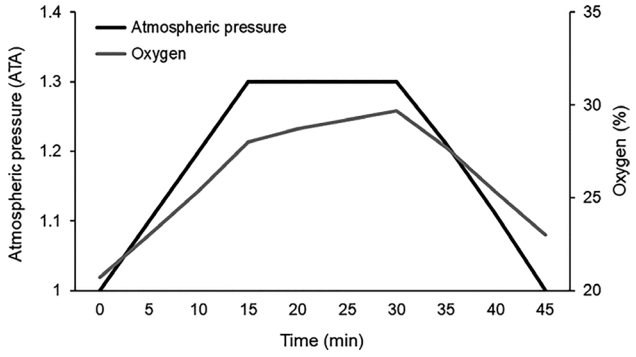

Fig. 1. Oxygen (%) and atmospheric air pressure (ATA) under MHO.
At 30 min after exposure, the oxygen concentration was increased from 20.9% to approximately 30%. Subsequently, the oxygen concentration returned to 20.9% in the next 15 min. Atmospheric air pressure under MHO was increased from 1 ATA to 1.3 ATA in 15 min after the start of exposure and maintained at 1.3 ATA for 15 min. Subsequently, the air pressure returned to 1 ATA in the last 15 min. ATA, atmospheres absolute; MHO, mild hyperbaric oxygen.

approximately 30% oxygen concentration and 1.3 ATA. Oxygen concentration was increased gradually to approximately 30% for 30 min, especially relatively higher increased in first 15 min with increased atmospheric pressure, and subsequently decreased to 20.9% after 15 min in the chamber. The atmospheric pressure was increased gradually from 1 to 1.3 ATA for 15 min and maintained for 15 min, and subsequently decreased gradually to 1 ATA for 15 min. The temperature in the chamber was maintained at 24.4 ± 0.6 °C and 24.6 ± 0.4 °C in CON and MHO trials, respectively.

Data are expressed as mean ± standard deviation (SD) of all ten participants. Differences among repeated measurements of each trial in HR, SpO_2, and BP were evaluated by two-way (time × trial) analysis of variance (ANOVA), followed by the Bonferroni *post hoc* test. The Student's t-test was used to evaluate the differences in change ratios of BP between the CON and MHO trials. Statistical significance was set at $p<0.05$.

RESULTS

There were main effects of MHO exposure on HR and SpO_2 (Table 1, $p<0.05$ and $p<0.01$, respectively). The HR was lower in the MHO trial than in the CON trial at 10, 20, 30 and 40 min after the start of exposure ($p<0.01$ at 10 min, $p<0.05$ at 20, 30 and 40 min). The averaged HR in CON and MHO trial from 10 min to 40 min after the start of exposure was 64.5 ± 1.2 and 60.3 ± 1.0 bpm, respectively. MHO exposure resulted in higher SpO_2 than the CON trial at 10, 20, 30 and 40 min after the start of exposure ($p<0.01$ at 10 and 20 min, $p<0.05$ at 30 and 40 min). The averaged SpO_2 from 10 min to 40 min after start of exposure to CON and MHO was 97.9 ± 0.2 and 98.9 ± 0.2%, respectively. There were no differences in HR and SpO_2 at pre and post exposure between CON and MHO trials.

There were no differences between the two trials in SBP and DBP during the exposure (Table 1, respectively). The main effect of time was observed in DBP ($p<0.05$). The change ratios of SBP and DBP at 45 min after the start of exposure (immediately after exposure) to MHO from pre-exposure were higher than those in the CON trial (Table 2, $p<0.05$). The change ratios of SBP at 45 min after the start of exposure to CON and MHO from pre-exposure was 97.6 ± 5.1 and 102.1 ± 3.1%, respectively. The change ratios of DBP at 45 min after the start of exposure to CON and MHO from pre-exposure was 98.7 ± 3.4 and 101.4 ± 3.5%, respectively.

Table 1. Heart rate, peripheral oxygen saturation levels, and systolic and diastolic blood pressures

	Trial	Pre	10 min	20 min	30 min	40 min	Post	
HR (bpm)	CON	64.7 ± 5.2	63.3 ± 4.7	64.0 ± 3.6	66.2 ± 5.4	64.6 ± 4.2	63.0 ± 4.6	Time: p=0.066
	MHO	62.8 ± 6.6	59.4 ± 6.4**	59.3 ± 4.8*	61.3 ± 5.6*	61.0 ± 5.7*	63.1 ± 5.5	Group: p=0.020
								Time*Group: p=0.062
SpO_2 (%)	CON	97.5 ± 1.3	97.6 ± 1.0	97.9 ± 0.7	98.1 ± 0.7	97.8 ± 0.9	97.2 ± 1.0	Time: p=0.002
	MHO	97.0 ± 1.2	98.7 ± 0.7**	99.0 ± 0.7**	99.0 ± 0.9*	98.7 ± 0.7*	97.3 ± 1.1	Group: p=0.002
								Time*Group: p=0.008
SBP (mmHg)	CON	112.5 ± 10.9	112.8 ± 9.1	112.3 ± 7.6	111.0 ± 7.5	110.5 ± 8.6	109.9 ± 9.7	Time: p=0.882
	MHO	110.6 ± 11.2	110.3 ± 10.8	112.0 ± 8.8	113.4 ± 10.0	112.9 ± 9.8	111.7 ± 11.7	Group: p=0.827
								Time*Group: p=0.060
DBP (mmHg)	CON	77.0 ± 5.1	74.9 ± 6.2	75.4 ± 5.3	75.9 ± 5.6	75.3 ± 5.3	76.9 ± 4.2	Time: p=0.039
	MHO	74.7 ± 5.6	73.9 ± 8.0	74.9 ± 6.3	74.9 ± 6.9	76.9 ± 6.4	78.9 ± 8.6	Group: p=0.878
								Time*Group: p=0.093

HR: Heart rate; SpO_2: peripheral oxygen saturation levels; SBP and DBP, respectively: systolic and diastolic blood pressures at every 10 min during the exposure; CON: control; MHO: mild hyperbaric oxygen. Values are expressed as means ± SD (n=10). *, significant difference from the CON trial, $p<0.05$. **, significant difference from the CON trial, $p<0.01$.

Table 2. The change ratios of systolic and diastolic blood pressures

	CON	MHO
Change ratio of SBP (%)	97.6 ± 5.1	102.1 ± 3.2*
Change ratio of DBP (%)	98.7 ± 3.4	101.4 ± 3.5*

CON: control; MHO: mild hyperbaric oxygen; SBP: systolic blood pressure; DBP: diastolic blood pressure.
The change ratios of systolic and diastolic blood pressures (SBP and DBP) from pre- to immediately post-exposure. Values are expressed as means ± SD (n=10). *, significant difference from the CON trial, $p<0.05$.

DISCUSSION

Although chronic hypotension is usually not considered a severe medical condition, it reduces cognitive performance[6, 7] and induces symptoms such as fatigue, dizziness, headaches, and cold limbs[5, 8]. There are few available data on countermeasures for hypotension without drugs or physical activities. Recently, MHO at 1.3 ATA and approximately 30% oxygen has attracted public attention as a recovery method after sports training[22, 24], or as an anti-aging method for the skin[23]. This study aimed to investigate whether MHO exposure altered BP. We found a decreased HR and increased hemoglobin-bound oxygen content (SpO_2) and BP, change ratio in SBP and DBP from pre-exposure, after MHO exposure compared to normal conditions (Tables 1 and 2).

Some studies have shown that exposure to MHO at 1.25–1.3 ATA with 30%–36% oxygen decreased HR during rest[14] or after exercise[22, 24], consistent with the results of this study. In the present study, exposure to MHO conditions for 45 min including the pressurized and depressurized periods have increased the change ratio of SBP and DBP from pre-exposure, compared with normobaric conditions. An increase in systemic oxygen content induces an increase in vascular resistance by O_2-induced vasoconstriction. HBO at 4 atm for 30 min induced a decreased HR, increased mean BP, DBP, and total peripheral resistance almost 1 h after hyperbaric exposure with 4 ATA. This suggests a rise in heart afterload with decreased heart activity, including HR and contractility[25]. In addition, oxygen exposure at 500 kPa induced increased peripheral vascular resistance in rats[30]. In the present study, the increased heart afterload may have been induced by MHO, despite the relatively lower ATA and oxygen than in the HBO condition. Previous studies have investigated the effects of HBO under 2–4 ATA with or without 100% oxygen on BP[25–27, 30], although there are no available data on the effects of MHO on BP.

In contrast, no change in BP was observed under the HBOT under 2.5 ATA with intermittent ventilation of 100% oxygen for 2 h[27]. In another study, in patients with chronic wounds requiring HBOT, repeated 20 sessions of exposure under 2.5 ATA with 100% oxygen for 90 min induced a decrease in SBP[26]. These studies suggested that frequency and/or period of HBO exposure or participant conditions were the determinant factors for increased BP. Consistent with a previous study[25], the present study used a single time of HBO and MHO for a short usage time (e.g., approximately 30–45 min) and observed decreased HR and increased BP.

Exposure to HBO enhances the parasympathetic tone[31]. After hyperbaric exposure with 4 ATA, the sympathetic low-frequency parameters decreased, and the parasympathetic high-frequency parameters increased[25]. The possibility of activation of the parasympathetic system was demonstrated by exposure to MHO following a decreased HR[24]. Exposure to MHO may increase parasympathetic activity following decreased HR. Altered heart-innervated sympatho-parasympathetic balance with heightened vascular resistance may be related to regulatory changes in the blood-vascular system[25]. In future studies, the details of the relationship between the change in sympatho-parasympathetic balance and BP under MHO conditions are needed to better understanding of this relationship. In future studies, the changes in peripheral resistance under MHO conditions need to be examined.

In this study, it was observed that the HR decreased while SpO_2 and BP increased under MHO at 1.3 ATA with approximately 30% oxygen. The results of this study suggest that the increased BP under MHO may be used as a control method for chronic hypotension. This is the first study to show that people with hypertension may require some attention in using mild hyperbaric environment.

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Conflict of interest

The authors declare no conflict of interest.

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