

## Hyperbaric Air Therapy in Dogs for Clinical Veterinary Medicine: A Basic Study

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**ABSTRACT.** Hyperbaric air therapy (HBA) is a treatment in which an animal is exposed to air pressurized to about 1.3 atmosphere absolute (ATA). Although HBA has already been administered to humans in medical applications, it has not been reported in clinical veterinary medicine. Therefore, we aimed to determine a safe protocol for dogs. To elucidate oxygen dynamics during HBA, we measured partial pressure of arterial oxygen, oxygen saturation of tissue, and partial pressure of transcutaneous oxygen in dogs. HBA could be performed safely with a protocol of pressurizing speed up to 0.1 ATA/min, maximum chamber pressure of up to 1.3 ATA, and pressure duration of around 45 min per treatment. Under these conditions, tissue was adequately oxygenated during and after treatment.

**KEY WORDS:** air, canine, chamber, hyperbaric, pressure.

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Hyperbaric oxygen therapy (HBO) is treatment with 100% oxygen at above 2 atmosphere absolute (ATA) in a chamber. HBO has been used in medicine to treat, for example, skin grafting [15], burn [3], edema [19], cyanide intoxication [21], and skeletal muscle injury [9, 11, 19, 20], and has also been reported in veterinary medicine [5, 6]. However, the highly concentrated oxygen and high pressure in HBO poses a risk of fire and requires a special chamber, which has limited its clinical application.

Hyperbaric air therapy (HBA), on the other hand, is a treatment that does not use 100% oxygen but only air, which is pressurized to around 1.3 ATA. As a result, HBA offers advantages over HBO in safety, cost, and operability. HBA in humans has already been applied in settings related to health, beauty, and sports. In medical settings, it has been used to treat disorders such as autism [2, 16–18], and cerebral palsy [4]. Therefore, we hypothesized that HBA would be more appropriate than HBO for use with small animals, although such application has not been reported to our knowledge.

Here we sought to determine a safe protocol and the oxygenation dynamics of HBA in dogs. The safety of HBA has not been determined in dogs and oxygenation dynamics have been reported only in humans [7]. In determining a safe protocol, we evaluated the optimal pressurizing speed, maximum chamber pressure, and duration of pressure, and to elucidate the effect of pressurization and depressurization on oxygen dynamics, we also measured partial pressure of arterial oxygen (PaO<sub>2</sub>), oxygen saturation of tissue (StO<sub>2</sub>), and partial pressure of transcutaneous oxygen (PtcO<sub>2</sub>) over time in dogs.

**Animals:** Three adult female Beagles (5–9 years old, weighing 8.0–11.0 kg; provided by Narc Inc., Chiba, Japan) were used in the studies to determine a safe protocol and

monitor oxygenation. The dogs were housed in an animal breeding institution approved by Azabu University and in individual cages with tap water. All dogs were found to be clinically healthy on general examination before the experiment.

**HBA Chamber:** Oasis O<sub>2</sub> (Nihon Light Service Inc., Tokyo, Japan) and the Companion Animal Chamber (Technico Inc., Tokyo, Japan) were used. The animal within the chamber could be observed through a window in the wall of the chamber. Air was instilled in the chamber with an air compressor, and the chamber was pressurized and maintained at a set chamber pressure. By regulating the control valve, we could increase the chamber pressure to 1.3 ATA at a pressurizing speed up to 0.1 ATA/min. After pressurization for a set duration, the chamber was depressurized.

**Oxygen monitor:** PaO<sub>2</sub> of arterial blood was measured with a Gastat-3 blood gas analyzer (Techno Medica Inc., Kanagawa, Japan). StO<sub>2</sub> was determined with a BOM-L1<sub>TR</sub>W tissue oximeter (OMEGAWAVE, Tokyo, Japan), which measures oxidization of peripheral tissue by near-infrared spectroscopy [1, 10]. PtcO<sub>2</sub> was monitored with a TCM-400 monitor (RADIOMETER Inc., Tokyo, Japan), which reflects oxidization of peripheral tissue by analyzing the gas diffused on the skin surface [22, 23].

**Safe protocol:** The three dogs were placed in the chambers individually. The following parameters were tested: pressurizing speeds at 0.03, 0.06, and 0.1 ATA/min (under 1.1 ATA maximum chamber pressure), and maximal chamber pressure of 1.1, 1.2, and 1.3 ATA (under 0.03 ATA/min pressurizing speed). For pressurizing speed, the slowest speed (0.03 ATA/min) was tested firstly, and then the speed was increased in the order of 0.06 and 0.1 ATA/min while confirming safety. The fastest speed considered to be safe was assumed to be optimal pressurizing speed. Similarly, the maximal chamber pressures were tested in order of 1.1, 1.2, and 1.3 ATA. Then, the highest pressure considered safe was assumed to be optimal maximal chamber pres-

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tures. The duration of maximum chamber pressure during the test was 90 min. For each experimental condition, four end-points were assessed: behavior and heart rate to determine the effect on psychological aspect, and appearance of the middle ear (as viewed with an otoscope) and lung sounds on auscultation to examine for barotrauma. In addition, a complete blood count (CBC) test was performed before and after pressurization.

**Oxygen dynamics:** In the dogs, arterial blood was tested by drawing it from a catheter placed in the femoral artery under anesthesia with propofol and isoflurane. Probes to measure  $StO_2$  and  $PtcO_2$  were placed on the skin over the femur. One hour from awareness, the dogs were put in the chambers and  $PaO_2$ ,  $StO_2$ , and  $PtcO_2$  were measured before pressurization, at 0, 20, and 45 min of maximum chamber pressure, and then after depressurization. After each animal had undergone HBA according to the protocol and all measurements were taken, the catheter was removed under anesthesia.

For the fastest pressurizing speed (0.1 ATA/min) and the highest maximum chamber pressure (1.3 ATA), the dogs had normal findings for behavior, appearance of the middle ear, lung sounds, and heart rate (Fig. 1). Thus, for the duration of maximum chamber pressure under 0.1 ATA/min pressurizing speed and 1.3 ATA maximum chamber pressure, which produced the highest partial pressure of oxygen, the middle ear and lung sounds were normal in the dogs. Changes in heart rate are shown in Fig. 1. Heart rate and behavior were normal during the first 3 min of pressurization, but after reaching maximum chamber pressure, the heart rate consistently decreased below 78 beats/min and all the dogs became somnolent. One dog's heart rate rapidly returned to normal 75 min after maximum chamber pressure was reached; the heart rate in the other dogs rose 90 min later. All the dogs awoke around 60 min after reaching maximum chamber pressure, and then moved around the chamber. The CBC test under a pressurizing speed up to 0.1 ATA/min, maximum chamber pressure up to 1.3 ATA, and pressure duration of 45 min showed normal findings in all dogs.

$PaO_2$  increased rapidly with pressurization and decreased slowly with depressurization in all dogs, and at 2 hr after the end of depressurization the  $PaO_2$  was slightly higher than it was before pressurization. In all dogs,  $StO_2$  increased slightly during pressurization, and remained above baseline until 30 min after depressurization.  $PtcO_2$  increased rapidly in all dogs during pressurization, and then decreased rapidly in two dogs and slowly in one dog during depressurization (Fig. 2).

Overall, the experimental results indicated that HBA could be safely applied to dogs.

The protocol for treating humans with HBA usually has involved a pressurizing speed of 0.03–0.1 ATA/min, maximum chamber pressure of 1.25–1.3 ATA, and duration of maximum pressure of 30–60 min. However, this protocol has been based on past experience rather than scientific experimentation, because few studies of HBA in humans

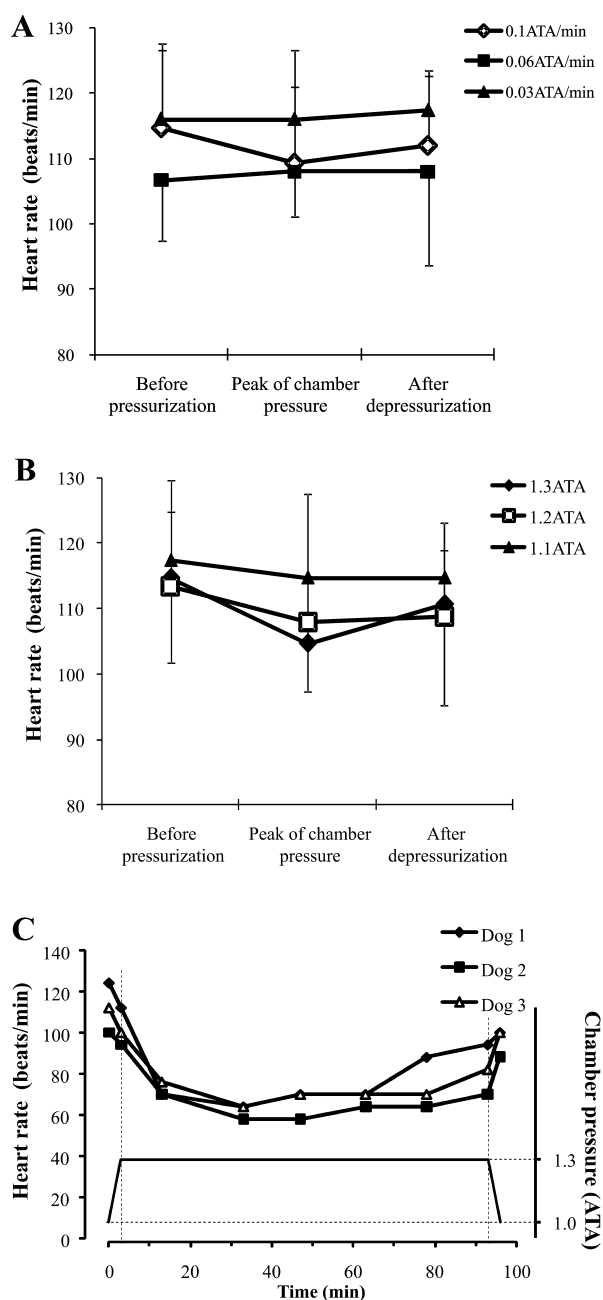


Fig. 1. Changes in heart rate on hyperbaric air therapy. (A) Pressurizing speed (under 1.1 ATA maximum chamber pressure). (B) Maximum chamber pressure (under 0.03 ATA/min pressurizing speed). (C) The duration of maximum chamber pressure was 90 min (under 0.1 ATA/min pressurizing speed and 1.3 ATA maximum chamber pressure).

have been reported [2, 4, 16–18]. Thus, we sought to assess the safety of HBA and determine a protocol for it in dogs. The tests for the fastest pressurizing speed and the highest maximum chamber pressure were safe for all of the dogs tested, based on each of the end-points. Therefore, the pro-

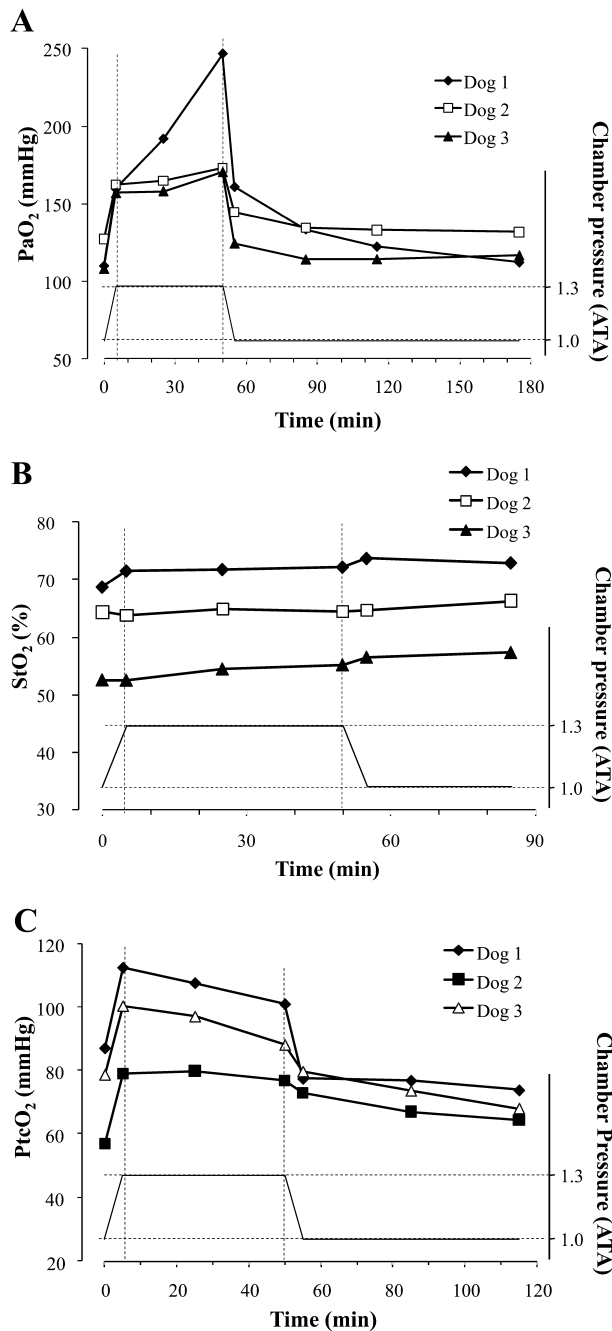


Fig. 2. Oxygen dynamics of dogs treated with hyperbaric air therapy. (A) Partial pressure of arterial oxygen: PaO<sub>2</sub>. (B) Saturation of tissue oxygen: StO<sub>2</sub>. (C) Partial pressure of transcutaneous oxygen: PtcO<sub>2</sub>.

protocol with a pressurizing speed of up to 0.1 ATA/min and maximum chamber pressure of 1.3 ATA, which produces the highest partial pressure of oxygen, is considered safe. Decreased heart rate is ascribed to parasympathetic activity [12] and early sleep accompanies persistent parasympathetic

activity [13]; thus, the somnolence and decreased heart rate observed in the dogs during pressurization may be attributed to parasympathetic activity induced by pressurization. However, the responsible mechanism is unclear and warrants examination. The moving around of the dogs in the chamber later during the pressurization may have been due to boredom and might have led to the subsequent increase in heart rate. This result indicates that one might plan for a pressure duration of 45 min, and adjust this based on the behavioral response of the dog. However, because these results are based on healthy adult Beagles, HBA may not apply to dogs of different ages and weights, or with abnormalities of the respiratory system, ear, or behavior. Thus, dogs should undergo a physical examination before treatment and should be observed carefully during treatment.

Oxygen dynamics under high partial pressures of oxygen has been reported in humans [7], but not in small animals. Thus, PaO<sub>2</sub>, StO<sub>2</sub>, and PtcO<sub>2</sub> in the dogs were measured to elucidate the effect of pressurization and depressurization on oxygen dynamics. In the present study, the increase with pressurization and the decrease with depressurization of PaO<sub>2</sub> and PtcO<sub>2</sub> confirm that HBA increases oxygen partial pressure in not only arterial blood but also peripheral tissue. In other words, HBA increases tissue oxygenation throughout the body. The slight increase in StO<sub>2</sub> with pressurization indicates that the hemoglobin in peripheral vessels is oxygenated by increased partial pressure of oxygen. After depressurization, the faster decrease in PtcO<sub>2</sub> than in PaO<sub>2</sub> and the increased values of StO<sub>2</sub> and PaO<sub>2</sub> above baseline may suggest that oxygen cannot diffuse on the skin surface but remains in the skin tissue and central vessel due to the coarctation of the cutaneous vessels. Since, the cutaneous vessels are innervated by the sympathetic nervous system [8, 14], the coarctation, which produces the oxygen dynamics, might be ascribed to sympathetic activity, and in turn the sympathetic activity might be attributed to the depressurization. In humans undergoing HBO (100% oxygen, 2 ATA), Hanafusa reported that oxidized hemoglobin and PtcO<sub>2</sub> increased during pressurization, and PaO<sub>2</sub> and oxidized hemoglobin remained above baseline after the end of depressurization [7]; our results are in agreement with these findings. As a result, HBA appears to increase tissue oxygenation throughout the body both during treatment and for a long time after depressurization. Moreover, the continuance of oxygenation after treatment can shorten treatment time, and which also then decrease owner's waiting time and the burden on the dog in clinical cases.

In conclusion, HBA can be performed safely in dogs according to a protocol with a pressurizing speed up to 0.1 ATA/min, maximum chamber pressure up to 1.3 ATA, and pressure duration of 45 min or possibly longer. HBA appears to increase tissue oxygenation throughout the body during treatment as well as for several hours afterwards. As all dogs exhibited somnolence and decreasing heart rate under pressurization, and decreasing oxygen diffusion out of the skin under depressurization. HBA might activate parasympathetic and sympathetic activity.

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