APPROXIMATE SIMULATION OF ACUTE HYPOBARIC HYPOXIA WITH NORMOBARIC HYPOXIA

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INTRODUCTION. Some manufacturers of reduced oxygen (O2) breathing devices claim a comparable hypobaric hypoxia (HH) training experience by providing FIO2 < 0.209 at or near sea level pressure to match the ambient O2 partial pressure (iso-pO2) of the target altitude. METHODS. Literature from investigators and manufacturers indicate that these devices may not properly account for the 47 mmHg of water vapor partial pressure that reduces the inspired partial pressure of O2 (PIO2). Nor do they account for the complex reality of alveolar gas composition as defined by the Alveolar Gas Equation. In essence, by providing iso-pO2 conditions for normobaric hypoxia (NH) as for HH exposures the devices ignore PAO2 and PACO2 as more direct agents to induce signs and symptoms of hypoxia during acute training exposures. RESULTS. There is not a sufficient integrated physiological understanding of the determinants of PAO2 and PACO2 under acute NH and HH given the same hypoxic pO2 to claim a device that provides isoxygen. Isohypoxia is defined as the same distribution of hypoxia signs and symptoms under any circumstances of equivalent hypoxic dose, and hypoxic pO2 is an incomplete hypoxic dose. Some devices that claim an equivalent HH experience under NH conditions significantly overestimate the HH condition, especially when simulating altitudes above 10,000 feet (3,048 m). CONCLUSIONS. At best, the claim should be that the devices provide an approximate HH experience since they only duplicate the ambient pO2 at sea level as at altitude (iso-pO2 machines). An approach to reduce the overestimation is to at least provide machines that create the same PIO2 (iso-PIO2 machines) conditions at sea level as at the target altitude, a simple software upgrade.

Learning Objectives:

1. Applying basic principles of respiratory physiology to the design of reduced oxygen breathing devices.
2. Working toward a better understanding of hypoxia.
INTRODUCTION

Some manufacturers of reduced oxygen (O2) breathing devices claim a comparable hypoxic hypoxia (HH) training experience by providing FIO2 < 0.209 at or near sea level pressure to match the ambient pO2 at the target altitude. METHODS. Literature from investigators and manufacturers indicate that these devices may not properly account for the 47 mmHg of water vapor pressure that reduces the inspired partial pressure of O2 (Pbhypo) at sea level as at altitude (iso-pO2 machines). For example, by providing isobARic conditions for normobaric hypoxia (NH) as for HH exposures the devices ignore Pbhypo and FIO2 < 0.209 as direct agents to reduce signs and symptoms of hypoxia during acute training exposures. RESULTS. There is not a sufficient integrated physiological understanding of the determinants of Pbhypo and PACO2 under acute NH and HH given the same hypoxic pO2 to claim a device that provides isohypoxia. Isohypoxia is defined as the same distribution of hypoxic pO2 and signs and symptoms under any circumstances of equivalent hypoxic and hypoxia, as an isobaric simulation of HH conditions. Some devices that claim an equivalent HH experience under NH conditions significantly overestimate the HH condition, especially when simulating altitudes above 10,000 feet (3,048 m). CONCLUSIONS. At best, the claim should be to the devices provide an approximate HH experience since they only duplicate the ambient pO2 at sea level as at altitude (iso-pO2 machines). An approach to reduce the overestimation is to at least provide machines that create the same PIO2 (iso-PIO2 machines) conditions at sea level as at the target altitude, a simple software upgrade.

METHODS

Reduced O2 breathing devices create a normobaric NH (exposure by providing an FIO2 < 0.209, breathed either through a mask or within a "hyperbaric" tent). Some manufacturers claim an equivalent acute hypoxic hypoxia (HH) experience but under NH conditions. This eliminates the need for an expensive hypobaric chamber and the risk of decompression sickness associated with hypobaric exposure, creating an "equivalent cost-effective hypoxic training device". These devices deliver FIO2 as promised.

The difficulty in using the upper curve in Fig. 3 is that when you provide FIO2 at sea level to match the Pbhypo at the altitude you create a PFO2 that is greater than the target altitude, a consequence of ignoring pO2.

It is best to provide a FIO2 at sea level as defined by the lower curve in Fig. 3. This best approximates the equivalent PIO2 at the altitude, a consequence of ignoring pH2O. Example: 9.0% FIO2 at 1 ATA on the display of an iso-pO2 machine would indicate that you are breathing air at 19,700 feet, so an iso-pO2 machine overestimates the simulated altitude by 1,800 feet. This is a consequence of ignoring the contribution of pH2O.

Even accounting for pH2O is not sufficient to account for PAO2 and PACO2. As direct agents to reduce signs and symptoms of hypoxia during acute training exposure, NH is not adequate. What a normoxic NH environment hides is the complex nature that NH experiences. This eliminates the need for an expensive hypobaric chamber and the risk of decompression sickness associated with hypobaric exposure, creating an "equivalent cost-effective hypoxic training device". These devices deliver FIO2 as promised.

Most manufacturers indicate that these devices may not properly account for the 47 mmHg of water vapor partial pressure that reduces the inspired partial pressure of O2 (Pbhypo) at sea level as at altitude (iso-pO2 machines). For example, by providing isobaric conditions for normobaric hypoxia (NH) as for HH exposures the devices ignore Pbhypo and FIO2 < 0.209 as direct agents to reduce signs and symptoms of hypoxia during acute training exposures. The model to convert field test altitude to ambient pressure was never specified, a necessary detail to understand the operation of these devices. But through analysis, it appears that Eq. 1 is used.

Eq. 1 defines a "Standard Atmosphere - 1976" where distance in kilometers is converted to the equivalent altitude as mmHg.

$PB_{\text{normo}} = 760 \times \left[1 - \frac{1}{298.15 + \frac{T}{273.16}}\right]$  

where PBnormo is most often 760 mmHg, but could be different if the training is done at a location other than sea level. FIO2 is mostly 0.209 but could be different if you are breathing an O2 mixture that is not 20.9%, comes from either Eq. 2 or 3 to convert the ambient pressure at a particular altitude.

$Pbhypo = PB_{\text{normo}} - 47$  

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This simple improvement would provide a device that delivers a HH simulation while under NH conditions accounting for 47 mmHg of water vapor pressure, as seen in Fig. 3.

RESULTS

By providing the correct FIO2 at sea level as defined in Table 1, column 2, the Alveolar Gas Equation will calculate the appropriate PAO2 and PACO2.

APPLICATION OF THE ALVEOLAR GAS EQUATION TO DEMONSTRATE THE INABILITY TO ACCURATELY REPRODUCE HH TRAINING UNDER NH CONDITIONS


