APPROXIMATE SIMULATION OF ACUTE HYPOBARIC HYPOXIA WITH NORMOBARIC HYPOXIA

J. Conkin¹, J.H. Wessel, III². Universities Space Research Association¹, 3600 Bay Area Boulevard, Houston, TX 77058-3696, Wyle Integrated Science and Engineering Group², 1290 Hercules Drive, Suite 120, Houston, TX 77058-2769.

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 isohypoxia. 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 alveolar gas composition as defined by the Alveolar Gas Equation. In essence, by providing iso-pO2 conditions manufacturers indicate that these devices may not adequately account for the 57 mmHg of water vapor partial pressure that reduces the inspired partial pressure of O2 (PIO2).

We reviewed two equations.

\[
\text{PAO}_2 = \text{PIO}_2 - \text{PACO}_2
\]

Isophyoxia is defined as the same distribution of hypoxia signs and symptoms under the same hypoxic conditions.

\[
\text{P}_2 = \text{P}_{\text{air}} + \text{P}_{\text{H}_2\text{O}}
\]

This eliminates the need for an expensive hypobaric chamber and the risk of decompression sickness associated with hypobaric experiences, creating cost-effective hypoxic training regimens.

METHODS
Reduced O2 breathing devices create a normobaric NH (air) environment by providing an FIO2 < 0.209, breathed either through a mask or within a "hypoxic tent.

We manufactured an equivalent acute hypoxic (HH) environment but under NH conditions. This eliminates the need for an expensive hyperbaric chamber and the risk of decompression sickness associated with hypobaric experiences, creating a cost-effective hypoxic training regimen.

The device is a "Standard Atmosphere - 1976" where distance in kilometers is converted to the equivalent ambient pressure as mmHg.

\[
\text{PB}_{\text{alt}} = 286.95 + (0.112 - 0.0119) \times \text{altitude} (\text{km})
\]

The method to convert test altitude to ambient pressure was never specified, necessary to detail the operation of these devices. But through analysis, it appears that Eq. 1 is used.

\[
\text{PB}_{\text{alt}} = 286.95 + (0.112 - 0.0119) \times \text{altitude} (\text{km})
\]

This is an alternative to Eq. 10.

\[
\text{P}_{\text{H}_2\text{O}} = \text{PB}_{\text{alt}} - 760
\]

Through analysis, it appears that Eq. 1 is used.

\[
\text{P}_{\text{H}_2\text{O}} = \text{PB}_{\text{alt}} - 760
\]

The device seems to duplicate the ambient partial pressure of O2 (iso-PAO2) as sea level at the target altitude.

At best, the claim should be that the devices provide an equivalent NH experience since they only duplicate the ambient pO2 at sea level as at altitude (iso-pO2 machines).

An approach to reduce the overstimulation is to at least provide machines that create the same iso-pO2 (iso-PAO2) conditions at sea level as at the target altitude, a simple software upgrade.

The difficulty in using the upper curve in Fig. 3 is that when you produce a FIO2 at sea level to match the PAO2 at the target altitude you create a PIO2 that is greater than the target O2 pressure, a consequence of ignoring pH2O.

It is best to provide a FIO2 at sea level defined by the lower curve in Fig. 3. At least provide the equivalent PAO2 pressure as at the target altitude, a consequence of ignoring pH2O, which would account for pH2O.

Example: 9.0% FIO2 at 1 ATA on the display of an iso-PAO2 machine would indicate that you are at about 5,000 feet altitude with a pO2 of 68.5 mmHg (Eq. 3). But PB0 at 1 ATA is 64.1 mmHg, equivalent to breathing air at 19,700 feet, so an iso-PAO2 machine overestimates the simulated breathing conditions by 1,800 feet. This is a consequence of ignoring the contribution of pH2O.

Even if the Alveolar Gas Equation was used in reduced O2 breathing devices one must account for the complex time-dependent role that RQ has in modifying PAO2 and PACO2 under a particular hypoxic condition.

An accurate application of the Alveolar Gas Equation requires that the inputs used for the expression Nv; values consistent with the expected Nv; values.

VNL = VNO + VLN = VLN = 0

So is applicable in maneuvers such as breath holding, voluntary hyperventilation, or exercise. But Eq. 6 is invalid to greater or lesser degree when ambient pressure changes or FIO2 is 0.209, or some combination of the two.

This is achieved during a chronic NH or HH exposure.

A first step approach to reduce the overstimulation is to at least provide machines that create the equivalent NH partial pressure conditions at sea level as at altitude, a simple software upgrade from Eq. 3 to Eq. 4.

RESULTS

Table 1. Reasonable Response to Acute HH and NH Exposures

\[
\begin{array}{|c|c|c|c|}
\hline
\text{parameter} & \text{HH Example} & \text{NH Example} & \text{57 mmHg} \\
\hline
\text{PB (mmHg)} & 760 & 760 & 321 \\
\text{FIO2} & 0.031 & 0.036 & 0.036 \\
\text{VA/Q} & 0.031 & 0.031 & 0.036 \\
\text{RQ} & 1.1 & 1.4 & 1.1 \\
\text{VE} & 289 & 389 & 289 \\
\text{VCO2 (mlSTPD/min)} & 251 & 251 & 251 \\
\text{PACO2 (mmHg)} & 24 & 24 & 24 \\
\text{PAO2 (mmHg)} & 35 & 35 & 35 \\
\hline
\end{array}
\]

CONCLUSIONS

We hypothesize that the simulated O2 atmosphere during the course of the present exposure is less than NH in terms of the same iso-pO2.

Some devices that claimed an equivalent NH environment under NH conditions significantly overestimated the NH condition, especially when simulating altitudes above 10,000 feet.

At least, the claim should be that the devices provide an approximate NH environment since they only duplicate the ambient pO2 at sea level as at altitude (iso-pO2 machines).

REFERENCES


