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BREATH: an Innovative Technique to Treat Acute Mountain Sickness

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1. Introduction

Acute mountain sickness (AMS) is a well-known problem for many mountaineers [1] [2] [3]. The phenomena can appear at elevations as low as 2500m, with symptoms such as headaches, sleep problems, and abnormal fatigue. The technique described here permits recovery of sufficient strength and wellbeing to spend a safe and comfortable night at the same altitude, or to allow a safe descent to a lower altitude.

It has been known for many years that mountain sickness is due to the reduced partial pressure of oxygen in air. This paper will not describe all symptoms and physiological consequences, as this has been done extensively in many publications [4]. In the physical approach described here, the problem to solve is “*if the decrease of the partial pressure of oxygen in the lungs is responsible of the AMS, how can this pressure be artificially increased*”.

2. Physical considerations

2.1 Partial pressure of oxygen

The definition of the partial pressure is: [5]

In a mixture of ideal gases, each gas has a partial pressure which is the hypothetical pressure of that gas if it alone occupied the volume of the mixture at the same temperature. The total pressure of a gas mixture is the sum of the partial pressures of each individual gas in the mixture.

and the partial pressure P_x relies on the following isotherm relation

$$\frac{P_x}{V_x} = \frac{P_{tot}}{V_{tot}} \Rightarrow P_x = \frac{P_{tot} \cdot V_x}{V_{tot}} \quad [eq. 1]$$

where:

- P_x is the partial pressure of gas (X)
- P_{tot} is the total pressure of gas mixture
- V_x is the partial volume of any individual gas component (X)
- V_{tot} is the total volume in gas mixture

Air follow this rule approximately since air is not an ideal gas. On earth, in normal conditions - out of pollution or confined space – at any altitude the percentage of oxygen is approximately constant at 20% of air. Therefore we can assume that the partial pressure of oxygen, represented as P_x in our formula, is one fifth the atmospheric pressure P_{tot} ; and is independent of altitude.

2.2 How to increase artificially the partial pressure of oxygen

Considering equation 1, the partial pressure of oxygen P_x can be increased in three ways:

- *increase of the ambient pressure P_{tot}*
- *increase of the concentration of oxygen in air V_x*
- *decrease of the total volume V_{tot}*

Let's discuss these three possibilities. The first two are well-known and commonly used:

- *increase of ambient pressure* is the mechanism used in a hyperbaric chamber. Ambient pressure is increased by artificially blowing air into the chamber.
- *increase of the concentration of oxygen in air* takes place while inhaling pure oxygen.

Both methods have been tested in extreme altitude and are commonly used in expeditions [2][3]. Nevertheless, these methods entail greater inconveniences than advantages, and are often difficult, if not impossible, to implement and operate for a standard mountain practitioner:

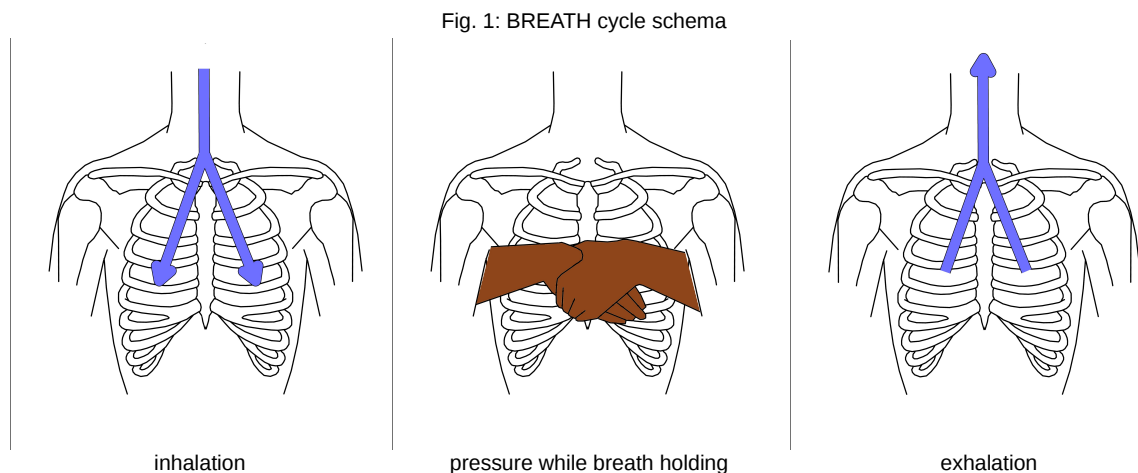
- In case of an underwater accident a hyperbaric chamber is necessary, and is the right therapy to apply. The full body is returned to higher pressure to avoid or minimize barotraumas [6]. These phenomena are well-known in scuba-diving, but in our opinion the use of a hyperbaric chamber is inadequate and impractical in the case of AMS. Nevertheless, if the method is efficient, the disadvantages at high altitude are numerous, such as the weight and volume for transport, the difficulty to operate in extreme conditions, problems with vomiting patients, and the impossibility of assistance in the case of degradation of the health condition of the victim – the chamber being only for one person [7][8].
- Pure oxygen inhalation is very efficient [9]. It increases the partial pressure of oxygen by a factor of 5, as oxygen occupies, in theory the total volume of gas inhaled (e.g. equation 1). But again, this therapy is difficult to apply for common mountain activities.

The third way is our proposed method:

decrease of the total volume V_{tot} of air inside the lungs to increase the partial pressure of oxygen

3. Technique description and protocol

An easy way to artificially increase the pressure inside lungs, is by “thoracic cage embracing”. This technique, easy to implement, requires only one assistant to help the victim suffering from AMS to quickly recover [fig. 1]



- The assistant sits behind the victim. The victim therefore sits comfortably in front of the assistant resting against the assistant's chest
- the assistant intertwines both arms around the victim's chest
- the victim inhales slightly over normal volume of air and holds his breath for about 3 seconds
- the assistant exerts pressure with his arms while the victim holds his breath
- the victim expires and the assistant releases the pressure
- a new cycle starts with the inspiration of the victim

The protocol includes the following properties:

- the victim breathes slowly, without effort
- inhaling, while, slightly exaggerated, should not be too deep; the same for exhaling
- rhythm is about 7 to 10 cycles per minute
- the assistant should apply an "optimum" pressure

The question "what is the optimum pressure" immediately arises.

4. Optimum pressure estimation

Let's try to estimate a reasonable pressure, first using a physical approach, then a physiological one, to finally conclude as Fernand Raynaud in his sketch "Après un coup de feu, combien de temps met le fusil à refroidir".

As a basis for our calculations, take the characteristics of a Gamow bag, a windowed cylindrical portable hyperbaric chamber [10]. Such chambers can augment the ambient pressure by a maximum ratio of 30%. An increase of 10 to 15%, which is approximately equivalent to a change of 1000m in elevation, depending on elevation [table 1], is also often recognized as sufficient for relief of symptoms of high-altitude illness [11].

Physical approach

The local atmospheric pressure depends on several factors, such as the temperature gradient, the water vapor concentration, the wind pattern (weather conditions), the latitude and the altitude. For simplification only the altitude will be considered, pressure being less affected by the other factors. We can therefore consider that the atmospheric pressure decreases exponentially with the altitude, according to the following approximation. This approximation works well within our range of elevation:

$$p = p_0 \cdot \left(1 - \frac{L \cdot h}{T_0}\right)^{\frac{g \cdot M}{R \cdot L}} \approx p_0 \cdot e^{-\frac{g \cdot M \cdot h}{R \cdot T_0}} \approx p_0 \cdot e^{-\frac{h}{h_0}} \quad [eq. 2]$$

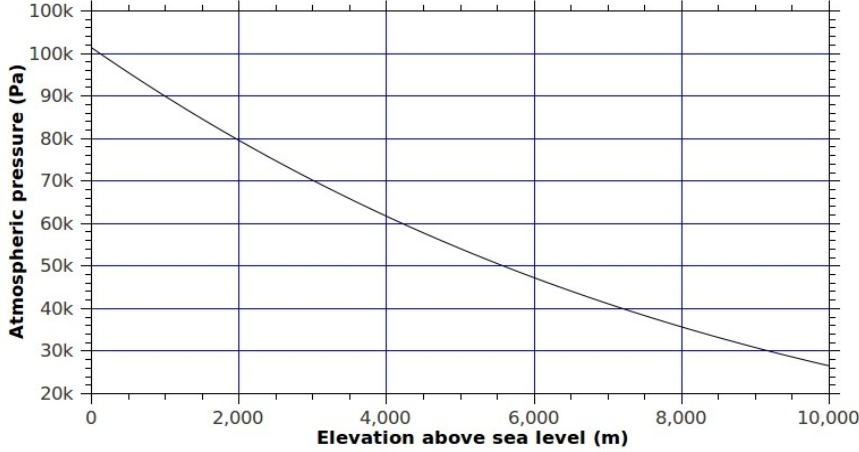
where

- h the elevation (m)
- p pressure (Pa) calculated for a given elevation h (m)
- p_0 sea level standard atmospheric pressure 101325 Pa
- L temperature decrease with altitude 0.0065 K/m
- T_0 sea level standard temperature 288.15 K
- g Earth-surface gravitational acceleration 9.80665 m/s²
- M molar mass of dry air 0.0289644 kg/mol
- R universal gas constant 8.31447 J/(mol•K)
- h_0 height scale 8435 m

giving the approximation for the pressure p in Pa, at the elevation h in m

$$p \approx 101325 (1 - 2.25577 \cdot 10^{-5} \cdot h)^{5.25588} \quad [eq. 3]$$

Fig 2: Elevation and atmospheric pressure



The local atmospheric pressure, compared to sea level pressure, is therefore approximately:

- 30% less at 3000m
- divided by 2 around 5500m
- less than .35 atm. over 8000m

Using the inverse function of equation 3, at a fixed elevation, we can deduce the simulated altitude versus the artificial pressure percentage increase

$$h_{simulated} = h - \partial h \approx 44330.8 (1 - 0.111578 (p_h (1 + x))^{0.190267}) \quad [eq. 4]$$

where

- h is the real altitude
- x the percentage of pressure increase
- p_h the pressure at the fixed altitude h
- ∂h the simulated loss of altitude

Table 1 gives an approximate decrease of altitude versus the pressure percentage increase. On average, an increase of 15% and 30% of the pressure is equivalent to a loss of altitude of 1000m, and 2000m respectively. Simulated loss of altitude is also more efficient at lower elevation – 1860m and 2120m loss at 8000m and 3000m respectively, calculations done at 30% of pressure increase.

Elevation in m.	Simulated altitude in m. versus pressure increase				
	10%	15%	20%	25%	30%
8000	7335	7020	6720	6425	6140
7000	6315	5995	5680	5380	5090
6000	5300	4965	4645	4340	4040
5000	4280	3940	3610	3295	2985
4000	3260	2915	2575	2250	1935
3000	2245	1885	1540	1205	885

Table 1: Simulated altitude in m. versus pressure increase

Finally, considering that for a perfect gas the theory leads to *volume times pressure is constant*, expressed by the formula

$$P \cdot V = Cste \quad [eq.4]$$

for the same quantity of air, an increase of $x\%$ of the gas pressure provides a similar decrease of volume. A diminution of the volume of the thoracic cage will therefore artificially increase the air pressure in the lungs by $x\%$. Applied to the volume of air inside lungs, a decrease of 23% implies an increase of the pressure of 30% and a simulated loss of altitude of 2020m at 5000m of elevation.

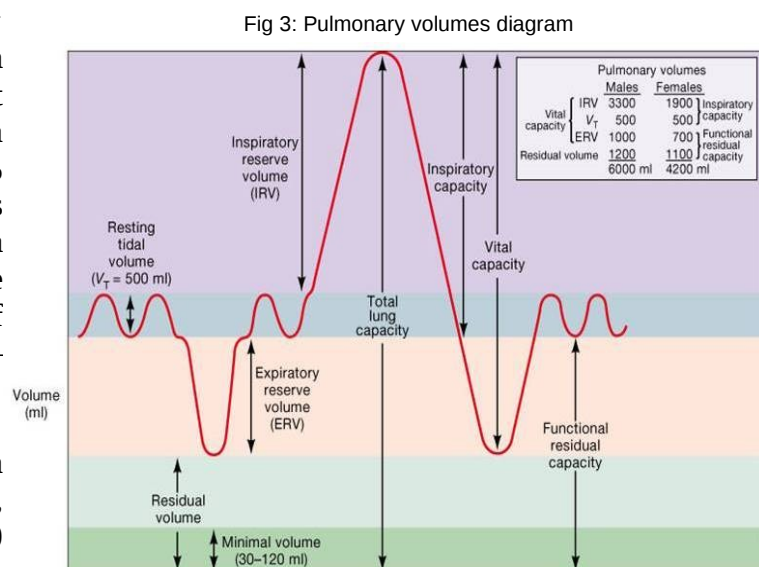
Artificial pressure increase (%)	0	5	10	15	20	25	30	35
Equivalent volume decrease (%)	0	5	9	13	17	20	23	26
Simulated loss of altitude (m) at 5000m	0	370	720	1060	1390	1710	2020	2310

Table 2: Simulated loss of altitude (m) at 5000m versus pressure increase and versus volume decrease

Physiological approach

Take again as reference the Gamow bag which allows a maximum compression of 30% of the ambient atmosphere, keeping in mind also that a loss of 1000m – equivalent to 15% compression – is recognized as sufficient in most cases. Is a compression of 23% of the thoracic cage – corresponding to an augmentation of 30% of the pressure [table 2] – reasonable?

Considering figure 3¹, in average, for an adult human male, by normal breathing, air contained in lungs varies from 2200 to 2700ml - the resting tidal volume (V_T). The total lung capacity (TLC) is about 6000ml and by forced expiration, volume can decrease to 1200ml – the residual volume (RV).



It is therefore reasonable to estimate with a slight forced inspiration:

- first, an initial volume of air in lungs of 3300ml – equivalent to an increase of 600ml of V_T
- second, a decrease of this volume to 2200ml – the functional residual capacity (FRC) – by applying an external compression of the thoracic cage.

Considering this case for an average adult human male, a rough calculation shows that the embracing compression can provide a decrease of air volume inside lungs of about 20 to 25%:

$$\text{Volume decrease} = 1 - (2200 \div 3300) \simeq 23\%$$

1 http://www.as.miami.edu/chemistry/2086/chap23/The%20Respiratory%20System%20Part%20_files/image002.jpg

For an adult human female, the same ratio of 23% is reached with an initial volume of 2600ml - equivalent to an increase of 300ml of V_T , and a decrease of this volume to 2000ml – the functional residual capacity (FRC):

$$\text{Volume decrease} = 1 - (2000 \div 2600) \simeq 23\%$$

Applied to a high altitude, we can conclude that the compression of the thoracic cage can easily simulates a loss of altitude from 1000 up to 2000m – equivalent to a decrease of volume inside the lungs of 13 to 23% (table 2).

Empirical approach

As no scientific measurements have been done to estimate the ratio of compression of the thoracic cage, the above estimates remain hypothetical. In the results presented below, the correct compression ratio is, therefore, based on the victim's perceptions.

While using the embracing method, the communication between the victim and the assistant is essential. The method relies on perception on the part of the victim. Taking the example of physiological re-education or hard training, anyone feels “good pains” under which he can continue training, and “bad pains” where the body itself advises to stop the exercise. In the same way, every time the embracing method has been applied, the victim has always been able to give the right instructions to the assistant.

For experiments done at high altitude, results are purely qualitative with no quantification. Observation and the quick recovery of the victim demonstrate nevertheless that it is easy to apply a *right force* to reduce the thoracic cage volume by a *required ratio*.

5. Experimental results



Cabane du Tracuit, 25 April 2011

This technique has been tested several times, notably during skitouring activities – backcountry skiing in American English – at CAF-RSF [12]. The method was applied while staying overnight at high altitude, when symptoms of AMS were obvious: headache, fatigue, cough or nausea. Once the technique was also used after climbing the Bishorn (4153m), Valais, Switzerland, and a strong effort was required to ski down back to Cabane du Tracuit (3275m).

In each case, 5 to 10 minutes of artificial increasing of air pressure in the lungs were sufficient for the victim to recover, allowing either a comfortable night at the same altitude and fulfilling the programme the next day, or a safe descent, skiing down back to the valley.

The protocol followed was each time approximately the one given in the “technique description” section; the victim instructing the assistant on the right pressure to give.

6. Conclusion

For mountain adepts, we have provided evidence of a new technique for treatment and possible prevention of acute mountain sickness. This technique, Barometric Remedy for Easing Ams Through Hugging (BREATH), is easy to apply and leads to significant improvement of the patient's symptoms within ten minutes.

For a better validation of the technique, further scientific and medical studies are required, as present results are mostly empirical. Trials were limited to only a few cases, without scientific measurements and too few in number to provide meaningful statistics. Risks regarding the compression of the thoracic cage should be addressed, especially concerning barotraumas. Measurements of lung pressure and concentration of gases in blood should be performed during the treatment.

Many questions remain unanswered and should be addressed in clinical trials. A protocol has been proposed for AMS treatment, and it should be possible to develop a similar method for prevention. The possibility to apply the technique over a longer period can be addressed, as well as fabrication of a device such as a jacket or large belt to guide or substitute the actions of the assistant.

Other medical applications may also arise, as this technique could be useful for the treatment of high altitude cerebral edema (HACE) and also for high altitude pulmonary edema (HAPE).

The BREATH technique offers new hope to common mountain adepts suffering from acute mountain sickness. But nobody should ignore health and security; the best recommendation is to decrease altitude as soon as possible whenever severe AMS symptoms appear.

Suffering from mountain sickness? Take a BREATH!

Acknowledgments

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Keywords

AMS; altitude illness; hyperbaric therapy; hypoxia; mountain rescue; HACE; HAPE; BREATH;

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