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Original article

Estimation of arterial oxygen saturation in relation to altitude☆

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A B S T R A C T

Background and objectives: Arterial oxygen saturation (AOS) predicts altitude sickness. Objectives: To estimate the AOS values with relation to altitude. Furthermore, make a graph to use during activity which assesses the AOS for each altitude and the normal range.
Patients and method: Values of AOS were assessed during eight high mountain activities in the Alps, Himalaya, Caucasus and Andes; 53 mountaineers participated, 17 of them in more than one activity; 761 measurements of AOS were registered.
Results: A Logistic Regression Model was made to estimate the AOS values dependent on altitude, adjusted to possible related factors. A strong lineal relationship exists between altitude and AOS ($R^2 = 0.83$, $p < 0.001$); 0.7 points more in women. The AOS in a particular altitude is not related to age, weight, height, smoking, heart rate, or even with previous experiences in mountains.
The calculation of the AOS responds to the follow equation: Blood Oxygen Saturation = 103.3 − (altitude × 0.0047) + (Z), being $Z = 0.7$ in men and 1.4 in women.
A scatter plot was made to relate the estimated altitude with the AOS, with their normal limits values: percentiles 2.5 and 97.5.
Conclusions: The simple calculation of the AOS estimated for a particular altitude with the proposed graphic can help in the early decision-making onsite.

Estimación de la saturación arterial de oxígeno en función de la altitud

Palabras clave:
Mal de altura
Montañismo
Pulsioximetría
Saturación arterial de oxígeno

R E S U M E N

Fundamento y objetivos: La saturación arterial de oxígeno (SAO) es capaz de predecir el desarrollo de mal de altura. Objetivos: estimar los valores de SAO en función de la altitud y, adicionalmente, diseñar un gráfico para usar sobre el terreno que muestre la saturación esperada para cada altitud y sus límites de normalidad.
Pacientes y método: Se registraron valores de SAO a los participantes de 8 actividades de alta montaña en los Alpes, el Himalaya, el Cáucaso y los Andes. Participaron 53 montañeros; 17 de ellos repitieron en más de una actividad. Se registraron 761 mediciones de SAO.
Resultados: Se diseñó un modelo de regresión lineal múltiple para estimar los valores de SAO en función de la altitud, ajustados por distintos posibles factores relacionados. Existe una fuerte relación lineal entre altitud y SAO ($R^2 = 0{,}83$, $p < 0{,}001$), dando valores 0,7 puntos mayores en mujeres. La SAO a una determinada altitud no se relaciona con la edad, el peso, la talla, el tabaquismo, la frecuencia cardíaca ni con la experiencia previa en montaña.

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El cálculo de la estimación de la SAO responde a la siguiente ecuación: SAO = 103,3 − (altitud × 0,0047) + (Z), siendo Z = 0,7 en hombres y 1,4 en mujeres.

Se ha diseñado una gráfica de coordenadas que relaciona la altitud con los valores estimados de SAO con sus límites de normalidad: percentiles 2,5 y 97,5.

Conclusiones: La sencillez en el cálculo de la SAO estimada para una determinada altitud mediante la gráfica propuesta ayudará en la toma de decisiones precoces sobre el terreno.

Introduction

Different recreational, sporting or professional activities bring many people to the mountains. It happens that at a certain altitude, usually above 2500 m, there is the risk of medical problems related to altitude, encompassed in a general term: *altitude sickness* (AS). This usually happens when ascending to high altitude very quickly, without taking measures to ensure adequate and progressive acclimatization.[1,2]

Typically, altitude-related diseases are unpleasant but benign and self-limiting conditions, consisting primarily of headache, nausea and anorexia; it is called acute mountain sickness (AMS). But there are serious forms of AS, such as the high altitude cerebral oedema (HACE) and the high altitude pulmonary oedema (HAPE). The latter syndromes can be even fatal if they are not recognized and treated early.[3,4]

The Lake Louise Consensus Group defined AMS as the presence of a headache in an unacclimated person who has recently ascended to an altitude higher than 2500 m, plus the presence of one or more of the following events: gastrointestinal symptoms (anorexia, nausea or vomiting), insomnia, dizziness or asthenia.[5] The same group agreed on an Adult AMS Score Scale (range 0–15), according to which 3 or more points on the auto-filled scale implies a mild condition, while 5 or more points implies a moderate-severe condition.

It is estimated that whenever there is a quick ascent, above 2500 m, 9–25% of people suffer from AMS, reaching 13–42% above 3000 m and more than 50% above 4500 m. The most severe HACE and HAPE cases are rare: about 0.01% at 2500 m, 1% at 4000–5000 m, and 2.5–15.5% above 5500 m.[6–8]

Symptoms typically occur at 6–12 h after the ascent, though sometimes they occur as early as within 1 h or as late as 3 days later. AS is seen more often in those who have their residence at sea level, younger than 50–60 years and those who have previously suffered AS. Its occurrence is associated with performing physical efforts, and, surprisingly, physical fitness is not a protective factor.[2–4,6,8]

The basic pathophysiological problem is hypobaric hypoxia, which occurs as partial oxygen pressure and SaO_2 decrease with altitude. Hyperventilation initially compensates hypoxaemia, but desaturation is inevitable above 3000 m.[1,4]

Abnormally low SaO_2 pulse-oximetric values seem to be related to a poor altitude adaptation and are common in cases of severe AMS. Their potential predictive ability for altitude acclimatization problems and the further development of AS would be even more significant. It has even been suggested that AS severity would be proportional to the decrease of SaO_2. Although there is no consensus about these facts,[9,10] the latest publications seem to support this predictive capacity.[11–20]

Sport activities in the mountains are related to the occurrence of AS, and its incidence is higher during exercise than at rest. Additionally, the studies that have assessed the SaO_2 after exercise also seem to find predictive capability for the development of AS; and this is true both in measurements after the usual altitude mountaineering activity,[15] as well as after standardized exercise.[17]

Currently we can perform non-invasive field estimates of SaO_2 through pocket digital pulse oximeters; it is affordable, lightweight and reasonably valid instruments compared with values obtained by arterial blood gas analysis (2–3% maximum error in the range of 70–100% saturation). There is general agreement in the literature that the use of pulse oximetry is highly recommended in high-altitudes. Hikers, mountain climbers, high-altitude workers or residents benefit from its use. It has proven useful in assessing the sick or symptomatic patient and in follow-up and monitoring of patients with cardiovascular disease.[21]

SaO_2 clearly decreases with altitude, but the key issue and, as we shall see, the basic approach of this study is to know what are the normal SaO_2 values for each altitude. Numerous studies have made SaO_2 measurements at different altitudes with varying objectives, sometimes, in vitro, with simulated altitudes in hypobaric chambers.[12,14] With few exceptions,[22] they are samples with just a few individuals, not many measurements, limited range of altitudes or too much variability, not enough to define normal SaO_2 ranges according to altitude and extrapolate the results to the general population.[21,23–28]

The estimated SaO_2 values for a given altitude can be calculated by nomograms or equations obtained by regression models.[17,22,25,28] These estimates, more or less accurate depending on the size of the sample used for the calculations, are certainly useful, but they may prove difficult to use on the field, which is usually high up in the mountains.

Therefore, a more precise definition of what SaO_2 values are expected at different altitudes might be appropriate, so that this information can provide support in decision making and discrimination between different pathological conditions. It would be of great interest to have a simple tool, such as a table or graph that could give us the values of SaO_2 for each altitude, indicating normal limits. This tool could help assessing “there and then”, whether a certain person has abnormally low values, and assist in the control of a cardiopulmonary disease or warn of a possible development of AS.

As objectives, we propose to estimate which should be the normal SaO_2 values based on different altitudes, and set a range of normal limits for the said values. Further objectives would include finding out what factors are related to SaO_2 and designing a tool to use in the field, in the form of a table or graph that shows clearly and quickly the expected saturation for each altitude and its normal limits.

Patients and method

Mountaineers participating in 8 different high mountain activities carried out between 2010 and 2015 were included in the study. In the Nepalese Himalayas: Everest Base Camp-Gokyo trek (peak: 5357 m), Manaslu (peak: 5100 m), and the ascent to Island Peak (6190 m). In the Alps: ascents to Mönch (4107 m) and Gran Paradiso (4091 m). In the Indian Kashmir: Ladakh trek (peak 5015 m). In the Caucasus: the ascent of Elbrus (5642 m). And in the Andes: the ascent to Chacaltaya, Small Alpamayo and Huayna Potosi (6088 m). The activities were selected for the study because some of the authors had participated in them.