Changes in Spirometric Parameters and Arterial Oxygen Saturation During a Mountain Ascent to Over 3000 Meters

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Objective: To ascertain whether climbing a mountain over 3000 meters high produces any alterations in ventilation, whether such alterations are modified by acclimatization, and whether they correlate with changes in arterial oxygen saturation (SaO_2) or the development of acute mountain sickness (AMS).

Subjects and methods: The following parameters were measured in 8 unacclimatized mountaineers who climbed Aneto (3404 m) and spent 3 days at the summit: forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), airway response to inhaled terbutaline, SaO_2, and the symptoms of AMS.

Results: At the summit, mean (SD) FEV_1 declined by 12.3% (5.7%) and mean FVC by 7.6% (6.7%) while the ratio of FEV_1 to FVC remained normal. The means for both parameters were higher on the following day. No airway response to bronchodilator treatment was observed. The restriction disappeared entirely on descent. At the peak, SaO_2 increased progressively as the climbers became acclimatized. During the ascent, FEV_1 correlated with SaO_2 (r=0.79). One participant who suffered from AMS had a ratio of FEV_1 to FVC less than 70% and the worst SaO_2 during the 3 days on the summit. Obstruction preceded the AMS symptoms, did not respond to bronchodilator treatment, and disappeared when the climber descended.

Conclusions: The mountaineers who climbed over 3000 meters presented restriction that correlated with hypoxemia. This restriction did not respond to bronchodilator treatment, improved with acclimatization, and disappeared on descent. One person with AMS presented obstruction that did not respond to terbutaline and disappeared on descent.

Key words: *Spirometry. Arterial oxygen saturation. Acute mountain sickness. Acclimatization.*

Cambios espirométricos y en la saturación arterial de oxígeno durante la ascensión a una montaña de más de 3.000 metros

Objetivo: Averiguar si en la ascensión a una montaña de más de 3.000 m se produce alguna alteración ventilatoria, si ésta se modifica por la aclimatación y si se relaciona con los cambios en la saturación arterial de oxígeno (SaO_2) o con la aparición de síntomas de mal de montaña agudo (MAM).

Sujetos y métodos: En 8 montañeros no aclimatados que ascendieron a la cumbre del Aneto (3.404 m) y permanecieron 3 días en ella medimos: la capacidad vital forzada (FVC), el volumen espiratorio forzado en el primer segundo (FEV_1), la respuesta a la inhalación de terbutalina, la SaO_2 y los síntomas de MAM.

Resultados: Al llegar a la cumbre disminuyeron el FEV_1 (12,3 ± 5,7%) y la FVC (7,6 ± 6,7%) con la relación FEV_1/FVC% normal. Al día siguiente aumentaron ambos parámetros. No hubo respuesta al tratamiento broncodilatador. La restricción se corrigió totalmente al descender. La SaO_2 en la cumbre aumentó progresivamente con la aclimatación. Durante la ascensión el FEV_1 se correlacionó con la SaO_2 (r = 0,79). Un participante con MAM presentó FEV_1/FVC menor del 70% y la peor SaO_2 durante la estancia en la cima. Esta obstrucción precedió a los síntomas, no cedió con tratamiento broncodilatador y se corrigió con el descenso.

Conclusiones: Los montañeros que ascienden a montañas de más de 3.000 m presentan una restricción que se correlaciona con la hipoxemia, no mejora con el tratamiento broncodilatador, se alivia con la aclimatación y desaparece con el descenso. Un sujeto con MAM sufrió una obstrucción que no respondió a la terbutalina y desapareció con el descenso.

Palabras clave: *Espirometría. Saturación arterial de oxígeno. Mal agudo de montaña. Aclimatación.*

Introduction

Little is known about the changes that occur in pulmonary airflows and volumes when people climb high mountains. Most of the published studies on this intriguing subject report that a restrictive pattern is found at high altitudes, although some authors observed no changes.[1-13] A number of possible explanations for this restrictive defect have been proposed, including an increase in pulmonary vascular flow, interstitial, and/or alveolar edema, muscle fatigue, and changes in pulmonary volumes brought about by air trapping and bronchoconstriction.[14-19]

To date, most studies have been carried out on subjects in hypobaric chambers, on subjects who have traveled up

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Manuscript received September 22, 2004. Accepted for publication March 15, 2005.

a mountain by mechanical means, or else on mountain expeditions of long duration. While hypobaric chambers and mountain locations with access via mechanical transport are ideal for complex studies of hypoxic conditions, such studies do not take into account the effect of the factors that may be inherent in the process of climbing the mountain on foot. Studies carried out on long expeditions do not have this shortcoming, but they involve conditions that make it much more difficult to adhere strictly to a study protocol.

Many field studies have been carried out during approaches to base camps or similar locations during which the climbers acclimatize gradually. However, this type of expedition has little in common with the high mountain activities of the immense majority of European mountaineers, who generally climb mountains of between 2500 meters (the lower limit of high altitude) and 4808 (the height of Mont-Blanc) over a weekend or during a holiday.

The objective of this study was to ascertain whether a typical weekend ascent of a mountain over 3000 meters high produces any alterations in ventilation, whether such alterations are modified by acclimatization, and whether they correlate with changes in arterial oxygen or the appearance of the symptoms of acute mountain sickness.

Subjects and Methods

Eight unacclimatized mountaineers drove from Valencia to Benasque, where they spent the night. The following day they climbed to the summit of Aneto (3404 meters) and they then camped for 2 nights at 3350 meters near the Puente de Mahoma. The group comprised 2 women and 6 men, and the mean (SD) age was 32.5 (6.6) years. Spirometry and pulse oximetry were performed on all 8 mountaineers in Valencia (elevation 20 m), in Benasque (1138 m), at the La Renclusa mountain refuge (2140 m), at the Portillon Superior (pulse oximetry only, 2870 m), at the summit of Aneto (3404 m), on arrival at the high mountain campsite (3350 m), and on the second and third days spent at this camp. In order to provide data for comparison with the results obtained during the ascent, the measurements were repeated in the same places on the way down.

On the second day spent at high altitude, the subjects inhaled 1.5 mg of terbutaline in the form of a dry powder and spirometry was repeated 15 minutes later in order to detect the presence of any bronchostriction that might respond to bronchodilator treatment.

Atmospheric pressure and temperature were measured with a portable Module 950 Alt 6000 combination barometer and thermometer (Casio Computer Company, Tokyo, Japan).

Spirometry was performed with a VM1 Ventilometer (Clement Clarke International, Edinburgh, United Kingdom), a device equipped with a pressure transducer that can measure peak expiratory flow rate and a microprocessor that digitizes the signal. The parameters studied were forced vital capacity (FVC) expressed in liters, forced expiratory volume in 1 second (FEV_1) in liters, peak expiratory flow rate (PEFR) in liters per minute, and the ratio of FEV_1 to FVC. Spirometry was performed with the subjects standing and in accordance with the recommendations of the Spanish Society of Pulmonology and Thoracic Surgery (SEPAR).[20] Results were also then expressed as percentages of the reference values.[21]

The results found in the course of our study led us to suspect that the lower density and viscosity of the air at high altitude had caused the spirometer we used to underestimate the volumes measured.[22] A second ascent was undertaken in order to investigate this effect and obtain the data necessary to correct the results of the first expedition. The destination on this occasion was the summit of Veleta (3396 m) in the Cordillera Penibética. A 3-liter calibration syringe (Sibelmed, Barcelona, Spain) was used to perform 5 measurements of volume on different flows at known altitudes including the summit. We used this data to create a regression equation that would allow us to quantify the percent underestimation of volume depending on elevation. The equation for the percent underestimation of volume (%) was $0.2454 + 0.0044 \times$ meters (elevation in meters). The variability of the measurements increases with decreasing atmospheric pressure (the coefficient of variation at 3396 meters is 1.7%), but this effect is too slight to create problems when the correction formula is applied.[23]

Arterial oxygen saturation (SaO_2) was measured with a CSI 503 SpO2T portable pulse oximeter (Criticare Systems Inc, Waukesha, Wisconsin, USA), a device with a resolution of 1% and an accuracy of 2%. The measurements were performed at rest, with the individual in a sitting or standing position. The SaO_2 value was accepted when the screen showed a reasonably stable result; when the measurement fluctuated, the result was taken to be the mean of several figures.

We tested the accuracy of the pulse oximeter before using it in the mountains by comparing its findings with results of arterial blood gas analysis in our respiratory function research laboratory at Hospital La Fe (intraclass correlation coefficient of 0.86). In addition, to make sure that this device functioned properly at low temperatures we tested it during one afternoon at –24°C in an industrial cold room (Friomerk, Valencia, Spain).

The diagnosis of mountain sickness was confirmed when a subject scored 3 points or higher on the Lake Louise scoring system.[24-27]

Statistical Analysis

The results of our study are expressed as means (SD). The relationships in the values obtained at different elevations and the groups established according to acclimatization were analyzed using repeated measures analysis of variance. The relationship between spirometric data and SaO_2 was analyzed using linear correlation (the Pearson coefficient). Differences were considered significant when the P value was less than .05.

Results

Atmospheric pressure was as follows: in Valencia, 100.9 kPa; in Benasque, 89.5 kPa on the ascent and 88.8 kPa on the descent; in La Renclusa, 78.7 kPa on the ascent and 78.5 kPa on the descent; and at the Portillón Superior it was 71.7 kPa on both occasions. During our stay in the vicinity of the summit of Aneto, atmospheric pressure was 67.6 kPa on the first day, 67.8 kPa on the second, and 67.4 kPa on the third.

Spirometric Parameters

All of the participants had normal spirometry in Valencia. The table and Figure 1 show how the spirometric variables and SaO_2 evolved over the course of the study.