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ORIGINAL RESEARCH

Long-Term Monitoring of Oxygen Saturation at Altitude Can Be Useful in Predicting the Subsequent Development of Moderate-to-Severe Acute Mountain Sickness

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Objective.—The use of pulse oximetry (Spo_2) to identify subjects susceptible to acute mountain sickness (AMS) is the subject of debate. To obtain more reliable data, we monitored Spo_2 for 24 hours at altitude to investigate the ability to predict impending AMS.

Methods.—The study was conducted during the climb from Alagna (1154 m) to Capanna Regina Margherita (4559 m), with an overnight stay in Capanna Gnifetti (3647 m). Sixty subjects (11 women) were recruited. Each subject was fitted with a 24-hour recording finger pulse oximeter. The subjects rode a cable car to 3275 m and climbed to 3647 m, where they spent the night.

Results.—In the morning, 24 subjects (6 women) had a Lake Louise Questionnaire score (LLS) ≥ 3 (AMS^+), and 15 subjects (4 women) exhibited moderate-to-severe disease (LLS ≥ 5 = AMS^{++}). At Alagna, Spo_2 did not differ between the AMS^- and AMS^+ subjects. At higher stations, all AMS^+ subjects exhibited a significantly lower Spo_2 than did the AMS^- subjects: at 3275 m, 85.4% vs 87.7%; resting at 3647 m, 84.5% vs 86.4%. The receiver operating characteristics curve analysis resulted in a rather poor discrimination between the AMS^- subjects and all of the AMS^+ subjects. With the cutoff LLS ≥ 5, the sensitivity was 86.67%, the specificity was 82.25%, and the area under the curve was 0.88 ($P < .0001$) for $Spo_2 \leq 84\%$ at 3647 m.

Conclusions.—We conclude that AMS^+ subjects exhibit a more severe and prolonged oxygen desaturation than do AMS^- subjects starting from the beginning of altitude exposure, but the predictive power of Spo_2 is accurate only for AMS^{++}.

Key words: hypoxia, pulse oximetry, Lake Louise score

Introduction

Subjects who rapidly ascend to altitudes greater than 2500 m are exposed to progressive hypoxia and can develop acute mountain sickness (AMS), which is a potentially serious condition if symptoms are ignored and ascent is continued.[1,2] It is well-known that AMS depends on the altitude, the rate of ascent, and the individual's susceptibility, independent of sex and physical fitness.[2,3] Given its high prevalence, which is approximately 25% between 2000 and 3000 m[4] and approximately 34% at 3650 m,[5] in recent years many studies have focused on finding a good indicator of impending AMS.

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The predictive role of oxygen desaturation as measured by pulse oximetry (Spo_2) has been studied for a long time. In some studies, both those involving simulated hypoxia and those conducted in the field, the importance of a more severe reduction of Spo_2 as a predictor of AMS development has been reported,[6–8] and values of Spo_2 that are predictive of impending AMS at different altitudes have been proposed.[9–11] In other studies, pulse oximetry failed to predict the development of AMS.[12,13] According to some authors, even if the Spo_2 is on average significantly lower in subjects who are susceptible to AMS, the overlap between individuals without (AMS^-) and with AMS (AMS^+) makes it very difficult to define useful cutoff values.[2]

In the previous studies, Spo_2 was measured only for a few minutes either at rest or immediately after exercise; whether a single resting measurement, even if repeated,

is reliable enough to accurately reflect an individual's Spo_2 is still debatable. In fact, it is well-known that at altitude, a short reading can provide inaccurate and variable results, especially owing to the variation in ventilation.[14] It has also been shown that Spo_2 values obtained at altitude with long-term monitoring are always significantly lower than single measurements at rest.[15] According to Loeppky et al,[8] whether this early desaturation is closely correlated with the subsequent AMS remains to be tested by continuous and prolonged measurements in the same subjects. Portable devices are now available that measure Spo_2 continuously for many hours at a time. Therefore, our aim was to monitor Spo_2 for 24 hours in a large sample of climbers during one of the most popular ascents in the Alps and to relate the severity and length of oxygen desaturation to the subsequent development of AMS to determine the predictive value of this parameter.

Methods

RECRUITMENT

Eighty-six Caucasian climbers (18 women) intending to climb to Capanna Regina Margherita (4559 m), Mount Rosa (Italy), were recruited for the study at the cable car station in Alagna Valsesia (1154 m). The purpose of the study was explained, and the subjects provided their informed consent. All subjects were asked about their medical history, usual physical activity, use of drugs, previous AMS events and anthropometric data. Mountain guides and subjects taking drugs for AMS prophylaxis were excluded from the study. The study complied with the Helsinki principles and was approved by the Ethics and Research Committee of the Medical School of the University of Ferrara, Italy.

STUDY DESIGN

All subjects were equipped with a 24-hour data memory pulse oximeter with a finger sensor (Pulsox-300i, Konica Minolta, Osaka, Japan) to monitor the arterial oxygen saturation and heart rate (HR). The instrument was previously tested at high altitude.[15] A cover was provided to secure the finger probe and to avoid excessive cooling. The pulse oximeter was removed on arrival at Capanna Regina Margherita.

Subjects were also asked to complete the Lake Louise Questionnaire (LLQ; more details in next section) in Alagna before starting, at Capanna Gnifetti (on arrival, in the evening, and in the following morning), and on arrival at Capanna Regina Margherita.

After a 30- to 45-minute cable car ascent to Punta Indren (3275 m) and a 1.5- to 2-hour trek, the subjects arrived at Capanna Gnifetti (3647 m), where they stayed overnight. On the second day, they climbed to Capanna Regina Margherita (4559 m) and descended in the same day after 1 or 2 hours of rest.

LAKE LOUISE QUESTIONNAIRE

The LLQ is designed to identify AMS, and it consists of a symptom assessment section (5 questions with a score from 0 to 3) and a clinical assessment section (3 questions).[16] A total score (LLS) of less than 3 indicates the absence of AMS (AMS^-); a score between 3 and 4 with headache indicates the presence of mild AMS (AMS^+), and a score of 5 or greater indicates the presence of moderate-to-severe AMS (AMS^{++}).

DATA COLLECTION AND ANALYSIS

Data were stored at 1-second intervals and processed by the DS-5 Minolta software.

For analysis, we divided the data into 6 frames: at rest in Alagna (1), on arrival at Punta Indren (2), during the ascent to Capanna Gnifetti (3), during the rest in Capanna Gnifetti (4), during the subsequent night at the same altitude (5), and during the ascent to Capanna Regina Margherita (6). The mean values of HR, Spo_2, and time spent under different Spo_2 values (95%, 90%, 88%, 87%, 85%, 80%, 75%, 70%) were evaluated. Exercise, rest, and sleep were individualized by the time recorded by the subjects in the LLQ and confirmed by the HR. A first analysis was performed between AMS^- and all of AMS^+; a second analysis was performed between AMS^- and the subgroup of moderate-to-severe AMS (AMS^{++}).

STATISTICAL ANALYSIS

Statistical analysis was performed using a statistical software package (GraphPad Prism 5; GraphPad Software, San Diego, CA). Normal distribution was checked with the Kolmogorov-Smirnov test. Comparison among groups at different altitudes was performed by using repeated-measures analysis of variance (mixed model). The Pearson correlation coefficient was used for the single correlation between LLS and Spo_2 at 3647 m (at rest and all through the night) and during the ascent to 4559 m. The receiver operating characteristics curve analysis was performed with the statistical software MedCalc (Ostend, Belgium). The level of significance was set at $P < .05$ for all analyses.

Results

The results are reported as the mean ± SD. Climbers were initially divided into 2 groups according to the LLS recorded in the morning after the first night at 3647 m: