ORIGINAL RESEARCH

Change in Oxygen Saturation Does Not Predict Acute Mountain Sickness on Jade Mountain

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Objective.—The purpose of this trial was to establish whether changes in resting oxygen saturation (SpO_2) during ascent of Jade Mountain is useful in predicting acute mountain sickness (AMS). AMS–risk factors were also assessed.

Methods.—A prospective trial was conducted on Jade Mountain, Taiwan from October 18 to October 27, 2008. Resting oxygen saturation (SpO_2) and heart rate (HR) were measured in subjects at the trail entrance (2610 m), on arrival at Paiyun Lodge (3402 m) on day 1, and at Paiyun Lodge after reaching the summit (3952 m) the next day (day 2). AMS was diagnosed with Lake Louise criteria (AMS score ≥ 4). A total of 787 subjects were eligible for analysis; 286 (32.2%) met the criteria for AMS.

Results.—Subjects who developed AMS had significantly lower SpO_2 than those who did not at the trail entrance ($93.1\% \pm 2.1\%$ vs $93.5\% \pm 2.3\%$; $P = .023$), on arrival at Paiyun Lodge on day 1 ($86.2\% \pm 4.7\%$ vs $87.6\% \pm 4.3\%$; $P < .001$), and on the return back to the Paiyun Lodge after a summit attempt on day 2 ($85.5\% \pm 3.5\%$ vs $89.6\% \pm 3.2\%$; $P < .001$), respectively. Trekkers with AMS were significantly younger (40.0 vs 43.2 years; $P < .001$), and had less high altitude (>3000 m) travel in the previous 3 months (29.9% vs 37.1% ; $P = .004$).

Conclusions.—Subjects with AMS had a lower SpO_2 than those without AMS; however, the differences between the 2 groups were not clinically significant. The results of this study do not support the use of pulse oximetry in predicting AMS on Jade Mountain.

Key words: acute mountain sickness, oxygen saturation, heart rate, altitude, Jade Mountain

Introduction

Acute mountain sickness (AMS) is a pathophysiological symptom complex that occurs in high altitude. Although it is benign in nature, AMS may be associated with the development of high altitude cerebral edema and high altitude pulmonary edema. The availability of transportation has allowed increasing numbers of travelers to visit high altitude areas.¹ However, the convenience of transportation allows for rapid ascent to altitudes that can

compromise acclimatization and expose inexperienced climbers to the hazards of high altitude. High altitude illnesses have accounted for 33% of mountain rescues in Yu-Shan National Park (YSNP).² Between April 2007 and March 2008, a prospective, observational study was conducted at Paiyun Lodge on Jade Mountain that reported the prevalence of AMS to be 36%.³ Jade Mountain is the highest peak in Taiwan at 3952 m above sea level. Most trekkers arrive at the park entrance (elevation, 2600 m) by car. From sea level this trip takes approximately 4 hours. A typical ascent of Jade Mountain normally involves an overnight stay at Paiyun Lodge (8.5 km from the entrance; elevation, 3402 m) before climbing a further 2.5 km to the summit (11 km from the entrance; elevation, 3952 m).⁴

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An effective means of predicting AMS remains elusive.³ Studies using simple physiological measurements to predict AMS have shown promise in some studies,^{3,5} but others have shown that these measurements have a number of limitations.^{6–8} It has been suggested that oxygen saturation (SpO_2) as determined using pulse oximetry, a noninvasive means to assess oxygen saturation and heart rate (HR), can be used as a predictive measure of an individual's risk of developing high altitude illness.^{5–9} Alternatively, it has also been suggested that pulse oximetry is limited in the diagnosis of AMS.¹⁰ The aim of this study is to determine whether pulse oximetry can provide a safe, simple, and objective means of predicting AMS in those ascending Jade Mountain, Taiwan.

Materials and Methods

STUDY DESIGN AND SETTING

A prospective observational trial was conducted on Jade Mountain, Taiwan, from October 18 to October 27, 2008. A total of 1132 subjects were asked to participate in the study at the trail entrance; a total of 888 agreed to participate. All measurements were taken at rest. Heart rate and SpO_2 were measured in subjects on the morning of their ascent at the Jade Mountain trail entrance (2610 m). Physicians using an Oximax handheld pulse oximeter (Oximax N65, Nellcor Puritan Bennett Ireland, Mervue, Galway, Ireland) recorded all SpO_2 and HR measurements. All subjects rested for 15 minutes before seated HR and SpO_2 measurements. On arrival at Paiyun Lodge (elevation, 3402 m) on the afternoon of day 1, SpO_2 and HR were taken for the second time. The change of SpO_2 (C- SpO_2) was calculated using SpO_2 data taken at the trail entrance and Paiyun Lodge ($[SpO_2 \text{ at entrance} - SpO_2 \text{ at Paiyun Lodge}] / SpO_2 \text{ at entrance}$). Trekkers stayed overnight in the Paiyun Lodge before their summit attempt on day 2. After returning from the Jade Mountain summit (elevation, 3952 m), SpO_2 and HR were measured at 3402 m in the morning for the third time, and the Lake Louise AMS score system was completed by each subject. The contents of the questionnaire included subject height, weight, high altitude mountaineering history, altitude of their primary residence, and past history of high altitude illness. A diagnosis of AMS was based on the following items rated 0 to 3 (0 = none, 1 = mild, 2 = moderate, 3 = severe/incapacitating): headache, dizziness/lightheadedness, gastrointestinal symptoms, difficulty sleeping, and fatigue or weakness. For the current study, a diagnosis of AMS was based on a recent rise in altitude, the presence of headache with at least 1 other symptom, and a total score of at least 4.¹¹

PARTICIPANTS

To be included in the trial, trekkers needed to stay overnight in the Paiyun Lodge on day 1 and reach the summit on day 2. Trekkers were excluded if they used Diamox (acetazolamide), suffered injury during the ascent, or failed to reach either Paiyun Lodge or the summit. Worth noting, trekkers were allowed to use other AMS prophylaxis, and were not restricted by age or medical history. Informed consent was obtained from all subjects, as reviewed and approved by the Institutional Review Board at Chang Gung Memorial Hospital, Chang Gung University College of Medicine, Tao-Yun, Taiwan.

STATISTICAL ANALYSIS

Subjects diagnosed with AMS were compared with those without AMS (non-AMS) using independent 2-sample Student's *t* tests for continuous variables and χ^2 or Fisher's exact test for categorical variables. Continuous variables were represented as mean $\pm$ standard deviation (SD), and number (n) and percentage (%) represented categorical data. To establish a predictive model of AMS development, all patients were randomly classified into a hypothesis-testing group or validation group (7:3 ratio) by using the random number generator provided with SPSS 18.0 statistical software (SPSS Inc, Chicago, IL).¹² Statistical comparisons between the hypothesis-testing group and validation group were performed to confirm that no significant differences existed between the 2 randomly allocated groups. The hypothesis-testing group was used to build models, and the validation group was used for model validation. Multivariate logistic regression analysis using a conditional forward stepwise selection method was performed to analyze the odds ratio (OR) of significant parameters associated with subjects who developed AMS. Furthermore, a receiver operating characteristic curve was used in the hypothesis-testing group to obtain the area under the curve (AUC), sensitivity, and specificity. All statistical assessments were two-sided, and a probability value of less than .05 was considered significant. Statistical analyses were performed using SPSS.

Results

A total of 888 questionnaires were collected, and 787 were considered appropriate for further analysis; 101 questionnaires were excluded because they were incomplete (n = 47) or the study criteria were not met (n = 54). Almost two thirds of the subjects were men (522 men and 265 women), with an average age of 42 ± 11

Table 1. Demographic characteristics, mountaineering experience, and medical history of subjects with and without acute mountain sickness

	Total (N = 787)	Non-AMS (n = 529)	AMS (n = 258)	P value
Age (years) ^a	42 ± 11	43 ± 11	40.0 ± 11	<.001 ^c
BMI (kg/m ²) ^a	23 ± 3	23 ± 3	23 ± 3	.354
Gender, n (%) ^b				.410
Male	522 (66)	356 (68)	166 (32)	
Female	265 (34)	172 (65)	92 (35)	
Residence altitude, n (%) ^b				.960
<500 m	769 (98)	517 (67)	252 (33)	
≥500 m	18 (2)	12 (67)	6 (33)	
Number of high altitude (>3000 m) mountains summited, n (%) ^b				.001 ^c
≤10	692 (88)	451 (65)	241 (35)	
>10	95 (12)	78 (82)	17 (18)	
Number of high altitude (>3000 m) mountaineering climbs, n (%) ^b				<.001 ^c
≤5	630 (80)	404 (64)	226 (36)	
>5	157 (20)	125 (80)	32 (20)	
High altitude (>3000 m) travel in last 3 months, n (%) ^b				.024 ^c
Yes	275 (35)	199 (72)	76 (28)	
No	512 (65)	330 (64)	182 (36)	

All numbers are mean ± standard deviation unless otherwise specified.

AMS, acute mountain sickness; BMI, body mass index.

^a Probability values based on independent 2-sample Student's *t* test.

^b Probability values based on χ^2 test.

^c Significant difference between AMS and non-AMS groups.

years (range, 9 to 80 years). Of those, 258 (33%) subjects were diagnosed with AMS.

Demographic characteristics, past high altitude mountaineering experience, and the medical history for subjects in the AMS and non-AMS groups are presented in Table 1. Overall, subjects with AMS were significantly younger ($P < .001$) and reported less high altitude mountaineering experience than those without AMS; specifically, the number of high altitude (>3000 m) mountains climbed ($P = .001$) and the number of high altitude (>3000 m) mountaineering climbs ($P < .001$), and high altitude (>3000 m) travel in the last 3 months ($P = .024$) were significantly different between groups. Smoking, alcohol use, heart disease, and hypertension were not significantly different between groups.

Spo₂ was significantly different between subjects with AMS and those without AMS at the trail entrance and at Paiyun Lodge on day 1, and after a summit attempt (Figure 1; $P < .05$). Subjects who developed AMS had significantly lower Spo₂ than those who did not at the trail entrance ($93.1\% \pm 2.1\%$ vs $93.5\% \pm 2.3\%$; $P = .023$), on arrival at Paiyun Lodge on day 1 ($86.2\% \pm 4.7\%$ vs $87.6\% \pm 4.3\%$; $P < .001$), and on the return back to the Paiyun Lodge after a summit attempt on day 2 ($85.5\% \pm 3.5\%$ vs $89.6\% \pm 3.2\%$; $P < .001$), respectively.

No significant difference in HR between the 2 groups was observed ($P > .05$, data not shown). The change of Spo₂ ($CR-Spo_2 = ([Spo_2 \text{ at entrance} - Spo_2 \text{ at Paiyun Lodge}] / Spo_2 \text{ at entrance}) \times 100$) is represented in Figure 2. Sub-

Figure 1. Resting oxygen saturation (R-Spo₂) between subjects with and without acute mountain sickness (AMS) measured at the Jade Mountain trail entrance (2610 m), on arrival at Paiyun Lodge (3402 m) on the first day, and on return from the Jade Mountain summit at the trail entrance (2610 m) on the second day. * $P < .05$, significant difference between AMS and non-AMS groups using independent 2-sample Student's *t* test.

Figure 2. Change of resting oxygen saturation (CR-SpO₂) between subjects with and without acute mountain sickness (AMS) calculated using data taken at the trail entrance and Paiyun Lodge. CR-SpO₂ = change of resting oxygen saturation $([\text{SpO}_2 \text{ at entrance} - \text{SpO}_2 \text{ at Paiyun Lodge}] / \text{SpO}_2 \text{ at entrance}) \times 100$. * $P < .05$, significant difference between AMS and non-AMS groups using independent 2-sample Student's t test.

jects who developed AMS had a significantly lower C-SpO₂ than those without AMS ($7.39\% \pm 0.31\%$ vs $6.24\% \pm 0.21\%$; $P = .002$).

When stratified by symptoms associated with AMS, reports of fatigue or weakness, dizziness/lightheadedness, and difficulty sleeping in the AMS group were associated with significantly higher C-SpO₂ compared with the non-AMS group (Table 2; $P < .05$). Headache was more common in subjects who developed AMS (258 of 258; 100%) than in non-AMS subjects (152 of 529; 28.7%), but this was not significantly different between groups. Gastrointestinal symptoms were also more common in the AMS group, but were not different between AMS and non-AMS groups, respectively.

To establish a predictive model of development of AMS, all subjects were randomly assigned into a hypothesis-testing group ($n = 552$) or validation group ($n =$

235). There were no statistically significant differences in subjects' characteristics between the hypothesis-testing group and the validation group (Table 3). High CR-SpO₂ (OR, 1.062; 95% confidence interval (95% CI), 1.023 to 1.102; $P = .001$), and fewer high altitude mountaineering climbs, defined as the total number of climbs ever done by the subject (OR, 0.404; 95% CI, 0.239 to 0.684; $P = .002$), were significantly associated with the development of AMS. This was determined using a multivariate logistic regression model with the risk factors associated with the development of AMS in the hypothesis-testing group. After controlling for the number of high altitude mountaineering climbs, there were greater changes in resting SpO₂ and an increased chance to develop AMS.

The AUC was 0.59 ($P < .001$; 95% CI, 0.54 to 0.65). A C-SpO₂ of 7.29% was designated as the cutoff point in both the hypothesis-testing and the validation groups. When C-SpO₂ was at least 7.29%, the development of AMS was predicted in the hypothesis-testing group and the validation group, with a sensitivity of 56.59% and 39.47%, respectively, and a specificity of 62.97% and 57.86%, respectively. C-SpO₂ has poor sensitivity and specificity for predicting the development of AMS.

Discussion

The current investigation reports that trekkers on Jade Mountain, Taiwan, diagnosed with AMS had a lower SpO₂ than those without AMS; however, the small differences between the 2 groups were not clinically meaningful. The results of this study do not support the use of pulse oximetry in predicting AMS on Jade Mountain.

An observation in this study is that change in resting oxygen saturation (C-SpO₂) between 2 elevations is associated with the development of AMS, as demonstrated by the statistically significant differences between AMS and non-AMS groups; however, the differences were not

Table 2. Change of resting oxygen saturation between subjects with and without acute mountain sickness stratified by symptoms commonly associated with altitude sickness

<i>Headache</i> (<i>n</i> = 410)												<i>Gastrointestinal symptoms</i> (<i>n</i> = 174)				<i>Fatigue or weakness</i> (<i>n</i> = 255)				<i>Dizziness/ lightheadedness</i> (<i>n</i> = 294)				<i>Difficulty sleeping</i> (<i>n</i> = 548)			
<i>AMS</i> (<i>n</i> = 258)		<i>non-AMS</i> (<i>n</i> = 152)		<i>AMS</i> (<i>n</i> = 131)		<i>non-AMS</i> (<i>n</i> = 43)		<i>AMS</i> (<i>n</i> = 168)		<i>non-AMS</i> (<i>n</i> = 87)		<i>AMS</i> (<i>n</i> = 200)		<i>non-AMS</i> (<i>n</i> = 94)		<i>AMS</i> (<i>n</i> = 244)		<i>non-AMS</i> (<i>n</i> = 304)									
CR-Spo ₂ (%)	7.4 ± 0.31	7.3 ± 0.45	7.4 ± 0.46	6.6 ± 0.80	7.2 ± 0.41	6.0 ± 0.48	7.5 ± 0.37	6.2 ± 0.48 ^a	7.5 ± 0.33	6.2 ± 0.26 ^a																	

All numbers are mean $\pm$ standard deviation.

AMS, acute mountain sickness; CR-SpO₂, change of resting oxygen saturation, defined as $(\text{R-SpO}_2 \text{ at entrance} - \text{R-SpO}_2 \text{ at Paiyun Lodge}) / \text{R-SpO}_2 \text{ at entrance}$.

^a $P < .05$, significant difference between AMS and non-AMS groups using independent 2-sample Student's t test.

Table 3. Demographic characteristics, mountaineering experience, and medical history between groups

	Hypothesis-testing group (<i>n</i> = 552)	Validation group (<i>n</i> = 235)	<i>P</i> value
Age (years) ^a	43 ± 11	41 ± 15	.123
BMI (kg/m ²) ^a	23 ± 3	23 ± 3	.408
Gender, <i>n</i> (%) ^b			
Male	369 (67)	153 (65)	.636
Female	183 (33)	82 (35)	
Residence altitude, <i>n</i> (%) ^b			
<500 m	543 (98)	226 (96)	.070
≥500 m	9 (2)	9 (4)	
Number of high altitude (>3000 m) mountains summited, <i>n</i> (%) ^b			
≤10	485 (88)	207 (88)	.930
>10	67 (12)	28 (12)	
Number of high altitude (>3000 m) mountaineering climbs, <i>n</i> (%) ^b			
≤5	443 (80)	187 (80)	.827
>5	109 (20)	48 (20)	
High altitude (>3000 m) travel in last 3 months, <i>n</i> (%) ^b			
Yes	202 (37)	73 (31)	.142
No	350 (63)	162 (69)	
AMS, <i>n</i> (%) ^b	182 (33)	76 (32)	.864

All numbers are mean ± standard deviation unless otherwise specified.

AMS, acute mountain sickness; BMI, body mass index.

^a Probability values based on independent 2-sample Student's *t* test.

^b Probability values based on χ^2 test.

clinically relevant because of the considerable overlap of individual data between groups. Furthermore, no cutoff point for C-Spo₂ predicted AMS—the highest cutoff point identified yielded a sensitivity of only 64%, which means 36% of subjects tested will remain undetected. The reported specificity of 48% means that there will be 52% false-positive results among those predicted not to develop AMS.

Our results are in agreement with the data that have been reported in previous publications, which demonstrate that reliable prediction of who is susceptible to AMS based on measurements of Spo₂ in hypoxia is not possible. Bartscher et al⁷ compared oxygen saturation after 30 minutes of exposure to hypoxia or high altitude in 75 subjects considered to be the “least” mountain sick

with that of 75 subjects considered to be the “most” mountain sick. These subjects were selected from a total sample of 500 individuals exposed to hypoxia or high altitude. Results showed an overlap of oxygen saturation values of 1 standard deviation in these highly selected groups. Bartscher et al⁷ concluded that Spo₂ values after 20 to 30 minutes of exposure to normobaric or hypobaric hypoxia represent a useful tool to detect subjects highly susceptible to AMS. Considering these data, the conclusion of Bartscher et al⁷ with regard to suitability of identifying individuals with susceptibility to AMS is incorrect. Loeppke et al⁶ also demonstrated a large overlap of oxygen saturation values between the AMS-susceptible and AMS-nonsusceptible individuals despite excluding 19 of 51 subjects with uncertain group allocation.⁶ Roach et al⁸ showed saturation values obtained at 4200 m vs AMS scores measured during further ascent to 6194 m. If a cutoff level for Spo₂ is selected that gives a sensitivity of 100%, the specificity is only 33%, and 67% of nonsusceptible individuals were identified as giving a false-positive result. Karinen et al⁵ measured oxygen saturation after exercise at altitude and related it to subsequent development of AMS. A cutoff value with sensitivity close to 100% yielded a specificity of approximately 50%. Thus, all these studies demonstrate that on an individual level, a reliable prediction of who is AMS-susceptible and who is not—based on measurements of Spo₂ in hypoxia at rest or exercise—is not possible.⁵ Overall, the relationship between low arterial oxygen saturation at altitude and the subsequent development of AMS, as has been reported in the literature, remains unresolved. These papers are seemingly in support of a correlation between low Spo₂ and the development of AMS; however, they lack clinical relevance in predicting susceptibility to AMS as assessed by sensitivity and specificity.

Potential predictors of AMS have been reported in the literature, including high altitude trekking experience or preexposure, history of AMS, age, and ascent speed.³ In the current study, trekkers with AMS were younger, had less high altitude mountain summiting, less high altitude mountain experience, and less high altitude preexposure (Table 1); these associations have been reported elsewhere.⁵ Jade Mountain provides a unique opportunity for exposure to high altitude and rapid ascent to 2600 m. Transportation is available to take trekkers directly to the park entrance (2600 m). Because less experienced trekkers are able to reach what could be considered high altitude via car, possibly before acclimatization, safer, quicker, and more objective measurements are needed as a way to screen for susceptibility to AMS.

The Jade Mountain trail commonly attracts inexperienced trekkers compared with other trails in YSNP, and reports the highest rate of high altitude-related mountain illness in the time YSNP has been open.² Because AMS is often characterized by a delayed onset and most Jade Mountain trekkers developed AMS during the night at Paiyun Lodge,³ it would be helpful to more clearly identify trekkers prone to developing AMS.

LIMITATIONS

The elevation of the entrance to the Jade Mountain trails is 2600 m—it is possible that some trekkers in this study had AMS soon after arrival. The data collection was concentrated only in October. There are several items to consider regarding the measurement of Spo_2 . A single point reading may be inaccurate at higher altitudes considering small changes in arterial Po_2 will cause considerable changes in Sao_2 ; therefore, multiple readings should be considered. Furthermore, the accuracy of portable pulse oximeters at low Spo_2 is limited, and considerable differences exist between devices. However, these issues were overcome by resting each subject for 15 minutes, waiting for Spo_2 to plateau. Additionally, the current Spo_2 results were all in the appropriate range, and the same portable pulse oximeter was used throughout the data collection period. Despite all subjects completing the same route, the speed of ascent was not recorded; therefore, the development of AMS may have been influenced by the ascent rate and not the factors described above.

Conclusions

Subjects with AMS had a lower Spo_2 than those without AMS, but the differences were not clinically significant. The results of this study do not support the use of pulse oximetry in predicting AMS on Jade Mountain.

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Disclosure Statement

The authors have no conflicts of interest or financial ties to disclose.

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