ORIGINAL RESEARCH

The 6-Minute Walk Test as a Predictor of Summit Success on Denali

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Objective.—To test whether the 6-minute walk test (6MWT), including postexercise vital sign measurements and distance walked, predicts summit success on Denali, AK.

Methods.—This was a prospective observational study of healthy volunteers between the ages of 18 and 65 years who had been at 4267 m for less than 24 hours on Denali. Physiologic measurements were made after the 6MWT. Subjects then attempted to summit at their own pace and, at the time of descent, completed a Lake Louise Acute Mountain Sickness Questionnaire and reported maximum elevation reached.

Results.—One hundred twenty-one participants enrolled in the study. Data were collected on 111 subjects (92% response rate), of whom 60% summited. On univariate analysis, there was no association between any postexercise vital sign and summit success. Specifically, there was no significant difference in the mean postexercise peripheral oxygen saturation (SpO_2) between summiters (75%) and nonsummiters (74%; 95% CI, -3 to 1 ; $P = .37$). The distance a subject walked in 6 minutes (6MWTD) was longer in summiters (617 m) compared with nonsummiters (560 m; 95% CI, 7.6 to 106 ; $P = .02$). However, this significance was not maintained on a multivariate analysis performed to control for age, sex, and guide status ($P = .08$), leading to the conclusion that 6MWTD was not a robust predictor of summit success.

Conclusions.—This study did not show a correlation between postexercise oxygen saturation or 6MWTD and summit success on Denali.

Key words: 6-minute walk test, exercise test, altitude sickness, mountaineering, hypoxia

Introduction

Thousands of people travel to elevations higher than 5500 m each year, many of whom attempt to reach the summits of mountains. Many factors contribute to summit success, including physical conditioning, technical skills, weather conditions, avoiding high altitude-related illnesses, and luck. Of persons who travel to these high altitudes, 35% to 90% travel as part of a guided expedition.^{1,2} Mountain guides are often faced with the difficult task of anticipating which members of their group will have difficulty at higher elevations. In recent years, there has been substantial interest in screening climbers before their ascents on the popular mountains of the world. For example, climbers in Argentina on

Aconcagua (6962 m) are required to participate in a health screening examination program before ascent.³ Proper screening has the potential to identify at-risk climbers and thereby decrease the need for high altitude rescues. Rescues conducted at high altitude can be dangerous and expensive, with rescues on Denali averaging \$12,000 per search and rescue response.⁴ At 6190 m, Denali is the tallest mountain in North America. It attracts on average 1200 climbers a year, of whom 52% summit and 30% experience acute mountain sickness (AMS).^{5,6}

Anecdotal evidence suggests that many mountain guides now carry fingertip pulse oximeters to measure their clients' peripheral oxygen saturations (SpO_2) and use these measurements to predict performance at higher elevations. Many guides and climbers apply the reasoning that a “low” SpO_2 predicts poorer acclimatization, functional limitations at higher elevations, and a lower

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chance of summiting. However, there is no consensus on what SpO_2 value correlates with these outcomes. Furthermore, data on pulse oximetry as a predictor of summit success are not conclusive. Some studies have shown significant correlation between a person's resting SpO_2 and his or her subsequent development of AMS,^{3,7-9} whereas others have shown no correlation.^{10,11} Recent studies have shown that postexercise SpO_2 may be a more reliable indicator of functional capacity—a climber's ability to acclimatize and exercise at high altitude—and predicts both development of AMS and summit success.^{8,12-15}

A prospective study examining SpO_2 after a 6-minute walk test (6MWT) and summit success was conducted by Lazio et al¹³ at 4365 m on Aconcagua. Researchers obtained baseline vital signs, had subjects walk as fast as they could without running for 6 minutes, repeated the vital sign measurements after this period of exercise, and recorded the maximum distance walked (6MWTD). The 6MWT is a well-validated assessment of a person's functional capacity. It has been used extensively since the 1970s to evaluate aerobic exercise capacity, treatment outcomes, and mortality in patients with a multitude of ailments including cardiovascular disease, chronic obstructive pulmonary disease, muscular dystrophy, pulmonary hypertension, and cystic fibrosis. An increase in 6MWTD has been shown to be a reliable indicator of a patient's improving lung function after undergoing pulmonary rehabilitation.¹⁶ 6MWTD has also been shown to correlate with peak oxygen uptake, disease severity, and overall mortality in patients with congestive heart failure and chronic obstructive pulmonary disease.¹⁷⁻¹⁹ Before the study by Lazio et al,¹³ the 6MWT had never before been tested as a predictor of functional capacity in high altitude mountaineers.^{16,17,20} Lazio et al¹³ found that in the 64 subjects with complete data, SpO_2 after the 6MWT (postexercise SpO_2) was significantly lower in persons who failed to reach the summit compared with those who summited. Of note, they did not find any significant difference between the 2 groups in the distance a subject walked in 6 minutes. They concluded that postexercise SpO_2 less than 75% had 97.2% sensitivity and 32.1% specificity in predicting failure to reach the summit.¹³

The goal of our study was to evaluate the 6MWT as a predictor of summit success in healthy mountaineers on Denali. We hypothesized that climbers who failed to reach the summit would have a significantly lower postexercise SpO_2 than would those who attained the summit.

Materials and Methods

ETHICAL APPROVAL

The Institutional Review Board of Stanford University School of Medicine (IRB No. 6208, Panel 8) and the

Denali National Park Service (Permit No. 945) granted approval of human subjects research. All subjects signed a document of informed consent before taking part in this study.

STUDY DESIGN

This study was conducted between June 12 and July 5, 2013, in Denali National Park, AK. Data were collected on Denali at the 4267 m camp (14 Camp). This camp is a starting point for many different routes on the mountain, with the great majority of climbers attempting the standard West Buttress route. Inclusion criteria were all willing climbers between the ages of 18 and 65 years who had taken 10 days or less to reach 14 Camp, were not pregnant, and had no significant pre-existing cardiopulmonary disease. Subjects participated on a voluntary basis and received no financial compensation.

A flyer advertising the study was distributed by the National Park Service to all registered climbers before their climb. Researchers then directly informed climbers about the study on their arrival at 14 Camp. Subjects who agreed to volunteer were enrolled within 24 hours of reaching 14 Camp. They were seated in a research tent, informed about the study, signed an informed consent document, and then completed a demographics questionnaire and Lake Louise Questionnaire (pre-LLQ), the latter to determine the presence of AMS.²¹ Demographic data included age, sex, whether the subject was guided, whether the subject was working as a professional guide, prior history of altitude illness, use of acetazolamide, use of ibuprofen, the subject's altitude of residence, the number of days the subject took to reach 14 Camp, and the number of hours the subject had been at 14 Camp at the time of testing.

6-MINUTE WALK TEST

The 6MWT replicated the methodology of Lazio et al.¹³ After completing the demographics questionnaire and pre-LLQ, subjects remained seated for a minimum of 5 minutes, after which heart rate (HR), respiratory rate (RR), and peripheral capillary oxygen saturation (SpO_2) were measured and recorded. HR, RR, and SpO_2 are henceforth referred to as vital signs (VS). Peripheral SpO_2 and HR were obtained from a fingertip pulse oximeter (Onyx 9590, Nonin Medical Inc; Plymouth, MN). Subjects wore warm mittens before pulse oximetry so that digits would be well perfused. One investigator recorded SpO_2 and HR at the end of the 5-minute rest period, with RR counted manually over 30 seconds.

The 6MWT was conducted on a 157 m rectangular outdoor course on packed snow with minimal elevation change. The course was packed daily and probed

regularly to ensure it was flat and free of crevasses and marked with wands placed at 9-m intervals. Subjects were instructed to walk as fast as they could without running for 6 minutes in whatever footwear they preferred. A single investigator observed the participants and recorded their distance (6MWT) to the nearest 9 m. Subjects wore an insulated mitt on the right hand to prevent vasoconstriction and maximize accuracy for the postexercise SpO_2 . Within 1 minute of completing the course, subjects returned to the study tent and removed the mitt, and VS were once again recorded using the aforementioned technique. To ensure subjects reached the study tent within a minute of concluding the 6MWT, researchers would at times instruct subjects to walk out and back on one leg of the course instead of trying to complete a full loop.

After preclimb testing, subjects proceeded to climb toward the summit at their own pace (usually within 3–7 days of testing). The climb from 14 Camp to the summit (6194 m) takes approximately 2 to 3 days in good weather. After their descent, subjects were asked to check in at the research tent, where they completed a postclimb survey detailing maximum elevation reached and, if they failed to summit, the reason for terminating the attempt. Subjects also completed a second LLQ (post-LLQ) that allowed them to declare the worst symptoms experienced during the climb.

Because many studies conducted at high altitude face the problem of poor response rates, researchers collected subjects' e-mail addresses and telephone numbers. Subjects consented to being contacted by telephone or e-mail should they fail to check in at the research tent after their climb.

DATA ANALYSIS

One thousand one hundred fifty-one climbers attempted Denali during the 2013 season. Summitters were defined as subjects who reached the maximum elevation of 6190 m; nonsummitters were individuals who failed to reach

this elevation. Subjects with a headache and pre- or post-LLQ of at least 3 were defined as having AMS. For data with a normal distribution, means and 95% CIs are presented; for other data, medians and interquartile ranges are presented. An independent 2-sample *t* test was used to compare the means. The Mann-Whitney *U* test was used to compare medians. To capture an effect similar to that found by Lazio et al,¹³ we aimed to enroll a minimum of 32 subjects in each arm to reach a power of 0.9. Reported tests of significance are 2-tailed, with type 1 error set at $\alpha = .05$. Variables identified as significant by univariate analysis were entered into a multivariate regression model to predict the outcome variable of successful summing, controlling for age, sex, and whether or not the subject was a guide. All tabulations, statistical tests, and models were calculated using SAS 9.4 (SAS Institute, Cary, NC).

Results

One hundred twenty-one subjects enrolled in the study. Of these, 46 (38%) did not return the postascent survey and were subsequently contacted using survey software (SurveyMonkey, Palo Alto, CA). Thirty-three (72%) of these individuals responded. The remaining 13 subjects were telephoned, of whom 3 (23%) responded. The overall response rate was 111 of 121 (92%). Complete measurements (VS measurements, 6MWT, and pre- and post-LLQ) were collected on 104 subjects. The primary reason a data set was not complete was an incorrectly completed questionnaire. Of the 111 subjects, 67 (60%) summited, thus achieving our goal of at least 32 subjects per group. Twenty subjects were professional mountain guides, of whom 7 did not summit because they escorted clients down instead.

Baseline demographic and medical characteristics of the summitters and nonsummitters are presented in Table 1. There was a significant difference between

Table 1. Demographic and medical characteristics in summitters and nonsummitters (n = 111)^a

Characteristic	Summitters (n = 67)	Nonsummitters (n = 44)	P value ^b
Age (years)	36.4 (33.8–39.1)	39.6 (35.9–43.3)	.15
Sex (% male)	85% (74%–93%)	73% (57%–85%)	.11
Guided (%)	49% (37%–62%)	43% (28%–59%)	.53
Previous altitude illness (%)	12% (5%–22%)	30% (17%–46%)	.02
Acetazolamide use (%)	12% (5%–22%)	16% (7%–30%)	.55
Ibuprofen use (%)	16% (8%–27%)	23% (11%–38%)	.41
Altitude of residence (m)	754 (555–954)	550 (316–783)	.19
Days to reach 14 Camp	6.5 (6.1–6.9)	7.2 (6.8–7.7)	.02
Number of hours at camp	17.1 (15.2–18.9)	15.9 (13.2–18.6)	.46

^a Mean values (95% CIs) are reported.

^b *P* < .05 is significant.

Table 2. Measurements in summiters and nonsummiters (n = 111)^a

Variable	Summiters (n = 67)	Nonsummiters (n = 44)	Difference of means	P value ^b
Resting vital signs				
HR (beats/min)	79 (76–82)	80 (75–85)	1 (–4 to 6)	.75
RR (breaths/min)	16 (15–17)	16 (15–17)	0 (–1 to 2)	.67
Spo ₂ (%)	83 (82–85)	82 (81–83)	1 (–3 to 0)	.16
Postexercise vital signs				
HR (beats/min)	125 (120–130)	120 (115–125)	5 (–12 to 2)	.163
RR (breaths/min)	32 (31–33)	31 (29–34)	1 (–3 to 2)	.66
Spo ₂ (%)	75 (74–76)	74 (72–75)	1 (–3 to 1)	.37
Delta vital signs				
HR (beats/min)	46 (41–51)	37 (28–47)	9 (–18 to 1)	.08
RR (breaths/min)	16 (15–18)	15 (12–17)	2 (–4 to 1)	.27
Spo ₂ (%)	–9 (–10 to –8)	–10 (–13 to –7)	–1 (–4 to 2)	.39
6MWT (m)	617 (591–644)	560 (513–607)	57 (8–106)	.02
AMS (%)	43 (31–56)	34 (20–51)	9 (–10 to 28)	.35

^a Mean values (95% CIs) are reported except for AMS, where medians (interquartile ranges) are reported.

^b $P < .05$ is significant.

AMS, acute mountain sickness; HR, heart rate; RR, respiratory rate; 6MWT, 6-minute walk test distance; Spo₂, peripheral oxygen saturation.

summiters and nonsummiters in history of previous high altitude–related illness, with mean values differing by 18% ($P = .02$). The average number of days it took to reach 14 Camp was significantly higher in nonsummiters ($P = .02$).

Table 2 shows the comparison between summiters and nonsummiters of objective and subjective measurements, including pre-exercise and postexercise VS, difference between pre-exercise and postexercise VS (delta VS), 6MWT, and AMS. There was no significant difference between the summiters and nonsummiters in resting, postexercise, or delta VS. Specifically, postexercise Spo₂ was 1% lower in nonsummiters compared with summiters, which was not statistically significant (95% CI, –3 to 1; $P = .37$). On univariate analysis, the mean 6MWT differed significantly between summiters and nonsummiters, at 617 m and 560 m, respectively, showing a difference of 57 m (95% CI, 7.6–106; $P = .02$). In addition, there was no significant difference in the incidence of AMS between summiters and nonsummiters.

Multivariate logistic regression using the entire study population and controlling for age, sex, and guide status did not identify 6MWT as a significant predictor of summit success ($P = .08$). Of the 2 other variables that were significant in the univariate analysis—the number of days it took to reach 14 Camp and previous history of high altitude illness—only the former achieved statistical significance in the multivariate analysis (odds ratio, 0.73; $P = .04$). The overall model had a moderate fit (c -statistic of 0.73).

A secondary analysis was performed that excluded all 20 mountain guides because it was noted that these

climbers descended because of professional obligation and therefore could have affected the validity of the study. On univariate analysis of the remaining 91 individuals, 6MWT attained statistical significance, with the 54 summiters walking on average 70 m farther than the 37 nonsummiters (95% CI, 17–125; $P = .01$). This effect, however, was not sustained on multivariate analysis (odds ratio, 1.00; $P = .05$).

Discussion

We did not find any significant difference in postexercise vital signs or 6MWT between summiters and nonsummiters on Denali. Although we closely followed the methodology of Lazio et al¹³ and conducted testing at a similar elevation, we did not replicate their finding that nonsummiters had a significantly lower mean postexercise Spo₂ than summiters.

We chose to investigate the 6MWT because it is a well-established test of functional capacity at sea level that correlates with a variety of objective physiologic measurements. In addition, it is relatively easy to perform—requiring only a pulse oximeter and a means of measuring time and distance—and is therefore well suited to remote environments. The study by Lazio et al¹³ introduced the use of 6MWT in healthy subjects at altitude and showed that a low postexercise Spo₂ predicted a lack of summit success with a high degree of accuracy. Our study, however, did not show this to be the case.

We did find an interesting univariate trend toward longer walking distances in summiters than nonsummiters. The trend was further pronounced when mountain

guides were excluded from the analysis. This suggests that perhaps those with a greater capacity for exercise at altitude are more likely to reach the summit, a concept that makes intuitive sense. However, more research on a variety of mountains and elevations is needed to further investigate this trend. Ideally, future investigations would use a more refined end point than simply summiting or not summiting and, instead, identify a group of climbers who fail to summit owing to altitude illness alone. With such an outcome measure, the true value of high altitude exercise testing could be most reliably investigated.

LIMITATIONS

There are several important limitations to our study. First and foremost, summit success is far from an ideal end point. For example, several subjects in our study were forced to descend 61 vertical meters short of the summit because of a rare and unexpected electrical storm. It is unclear how many of these individuals might have summited had it not been for this event. We attempted to account for these external variables by querying the reason for turning around on the postascent survey. However, we did not have sufficient power to provide conclusive results.

Our study was further limited by referral bias innate to the study design, as climbers feeling poorly on arrival at 14 Camp may not have been eager to engage in 6 minutes of further exercise. Indeed, we observed that some climbers who were feeling unwell chose not to enroll in this study. Therefore, we may have captured a particularly healthy cohort of climbers.

Thirty-eight percent of our subjects did not check in at the study tent at the time of descent and were contacted by phone or e-mail in the weeks after the study. This introduces recall bias because subjects may have forgotten how they felt during the climb and why they chose to turn around.

Finally, although used extensively in high altitude research, SpO_2 is known to have decreasing accuracy as oxygen saturation drops below 80%.²² The average SpO_2 values we recorded were consistently lower than those reported by Lazio et al,¹³ presumably because of Denali's higher latitude as compared with Aconcagua, and resultant lower ambient partial pressures of oxygen. Because the postexercise SpO_2 values in this study were consistently below the 80% threshold, it is possible they were less accurate. Consideration of mountain peak latitude might be important in future studies of SpO_2 .

Conclusions

This study did not show a correlation between either postexercise oxygen saturation or the 6-minute walk test distance and summit success on Denali.

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