High Altitude Dynamics in Cerebral Oxygenation of Mountain Rescue Personnel: A Prospective Alpine Proof-of-Concept Field Study

Sebastian Schnaubelt, MD, PhD, FERC;[1,2] Alexander Egger, MD, MSc;[3,4] Verena Fuhrmann, MD;[1] Katharina Tscherny, MD, BSc;[1,4] Maximilian Niederer, MD;[1,3,4] Thomas Uray, MD, MBA, MPH;[1] Wolfgang Schreiber, MD;[1] Harald Herkner, MD, MSc;[1] Dominik Roth, MD, PhD[1]

1. Department of Emergency Medicine, Medical University of Vienna, Austria
2. Emergency Medical Service Vienna, Vienna, Austria
3. Austrian Mountain Rescue Service, Austria
4. Department of Anesthesiology and Intensive Care Medicine, Hospital Scheibbs, Austria

Correspondence:
Sebastian Schnaubelt, MD, PhD, FERC
Department of Emergency Medicine
Medical University of Vienna, Waehringer Guertel 18-20, 1090 Vienna, Austria
E-mail: sebastian.schnaubelt@meduniwien.ac.at

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Abbreviations:
AMS: acute mountain sickness
HEMS: helicopter Emergency Medical Service
MRS: Mountain Rescue Service(s)
NIRS: near-infrared spectroscopy
rSO2: regional cerebral oxygen saturation
SpO2: peripheral oxygen saturation

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Abstract

Background: Mountain Rescue Services (MRS) are a vital link in the chain of survival when it comes to emergencies at high altitudes. Cognitive impairment in hypobaric hypoxic conditions is known, and previous studies have shown suboptimal performance of MRS members after a steep ascent. These impairments may be linked to regional cerebral oxygenation (rSO2). Therefore, this study aimed to investigate whether there are dynamics in rSO2 between "baseline" and "working" altitudes after climbing up to a potential patient.

Methods: In this alpine proof-of-concept field study, experienced mountaineers of the Austrian MRS had to perform an active rapid ascent of 1,200 meters on foot to 3,454 meters above sea level. Near-infrared spectroscopy (NIRS) was used to measure rSO2 before and after the climb. Continuous data were compared among subgroups using Mann-Whitney-U tests, and categorical data were compared with χ^2-square tests. Statistical significance was defined by two-tailed P values of <.05.

Results: Twenty MRS members were assessed. Their rSO2 values at baseline altitude were significantly higher than at working altitude (70 [SD = 1]% versus 60 [SD = 1]%; absolute difference 10 [95% CI, 6-15]; P <.001). When assessing the single dynamics of each mountain rescuer, there was a wide variability in delta rSO2, ranging from a minimum of 0% to a maximum of 32% (mean 10 [SD = 8]%).

Conclusion: Overall, low rSO2 values were found in mountain rescuers at high altitudes, and there were considerable interpersonal differences of changes in cerebral oxygenation after an ascent. Using rSO2 to assess performance-readiness in mountain rescuers and individual proneness to potential cognitive dysfunction or acute mountain sickness (AMS) could be further research goals.

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Introduction

Hypobaric hypoxia plays a vital role in acute mountain sickness (AMS). However, partial pressure of oxygen (PaO2) values – sometimes estimated through peripheral oxygen saturation (SpO2) measurements – do not necessarily correlate with susceptibility or clinical symptoms, leading to the hypothesis that cerebral hypoxia may be more relevant.[1] Brain oxygenation has been deemed critical in determining performance and illness at high altitude. This is also partly due to the close relation of cerebral oxygenation with cerebral carbon dioxide levels, vasodilation, and constriction, and resulting cerebral hemodynamics.[2] Regional cerebral oxygen saturation (rSO_2) measured non-invasively through near-infrared spectroscopy (NIRS) is an emerging tool in modern clinical medicine. Especially in acute settings, rSO2 can give an insight towards cerebral oxygenation.[3–5] It is important to observe dynamics over a period of time rather than single measurements. Also, a high inter-subject variability makes individual rather than general baselines and normal ranges necessary.[6–8] Near-infrared spectroscopy has been described to be suitable for use in the high-altitude field in both patients and healthy volunteers.[1,2,9]

Due to a constant increase in mountain leisure time activity and a considerable amount of tourists with comorbid conditions, Mountain Rescue Services (MRS) continuously gain in importance.[10–12] Helicopter Emergency Medical Service (HEMS) can improve the speed of response for injured or acutely-ill mountaineers until adverse weather conditions or difficult terrain make a conventional ascent of MRS necessary, inducing considerable physical strain.[13] Either way, rescuers are usually exposed to high altitudes and most often also hypobaric hypoxic environments. Therefore, this study aimed at assessing the influence of an active on-foot ascent of MRS to a high altitude on their cerebral oxygenation.

Methods

Experienced members of the Austrian MRS over 18 years of age were included, who took part in this proof-of-concept study voluntarily. The Austrian MRS is an emergency response force with a nation-wide 24-hour stand-by service. In alpine areas, the MRS is in charge of tending to and rescuing individuals in need. This encompasses tasks like locating missing individuals, performing avalanche rescues, and extracting injured and ill patients in rough terrain.

The study measurements took place both at a low altitude (Lienz, East Tyrol, Austria; 673m above sea level) and after an ascent by foot from a mid-height base camp (at 2,240m; >1,213m difference in altitude for the ascent) to a mountain shelter at 3,454m (Erzherzog Johann Hütte; Großglockner Mountain, Austria). The ascent was carried out with a backpack to mimic standard mountain rescue gear. Study logistics were conducted in cooperation with the Austrian Armed Forces, and this study reproduced a previously-described setup.[13] All data were collected prospectively. In brief, NIRS was measured at the low (673m) and high (3,454m) altitudes using NONIN SenSmart X-100 (Nonin Medical Inc.; Plymouth, Minnesota USA) devices, which are portable, lightweight, and highly-reliable under bright ambient light conditions.[14] One optode was placed on the right and one on the left forehead of each study subject, and measurements of five minutes with data points every four seconds were conducted. The acquisition of subjects' demographic data including smoking status, fitness assessment, and SpO2 has been described in a previous publication.[13]

Continuous data are presented as absolute differences and medians, with the respective 95% confidence intervals (CI) and interquartile ranges (IQR), and were compared among subgroups using Mann-Whitney-U tests. Categorical data are presented as counts and percentages and were compared using χ^2-square tests. Statistical significance was defined by two-tailed P values of <.05. Data analysis was performed using SPSS 22.0 (IBM; Armonk, New York USA).

Ethical approval for this study (N° 1291/2018) was acquired from the Ethical Committee of the Medical University of Vienna, Austria, and all participants provided informed consent. The study protocol complies with the Declaration of Helsinki.

Results

Twenty active members of the Austrian MRS were included. High fitness levels were determined via a standardized fitness questionnaire (FFB mot [Funktionsfragebogen Motorik; motor functions]), as reported previously.[13] The active on-foot ascent was achieved in 178 (SD = 40) minutes, with a median backpack weight of 10 (8-14) kg. The weather conditions were as follows - Lienz: Sunny, 18°C, 11km/h wind from the south direction, 75% humidity; Großglockner: Sunny, 0.4°C, 25km/h wind from the southwest direction, 70% humidity.

Basic demographics of the study subjects as well as respective NIRS values are summarized in Table 1. The rSo2 values were significantly higher when measured at baseline altitude than at high working altitude (69.9 [SD = 0.6] versus 59.5 [SD = 1.0]; absolute difference 10.4 (95% CI, 6.3-14.5); P <.001), and this was also seen in the subgroups of smokers, non-smokers, men, and women (Table 1 and Table 2). When assessing the single dynamics of each mountain rescuer, there was a wide variability in delta rSO2, ranging from a minimum of 0% to a maximum of 32.1% (Table 3; mean 10.4 [SD = 8.4]%). No symptoms of any kind were reported by the participants.

RSO2, % (SD)	Valley N = 20	Mountain N = 20	Absolute differences (95% CI)
Overall	69.9 (SD = 0.6)	59.5 (SD = 1.0)	10.4 (6.3-14.5)
Smokers	75.1 (SD = 2.2)	57.6 (SD = 8.7)	17.5 (6.0-41.1)
Non-Smokers	69.0 (SD = 4.9)	59.8 (SD = 6.3)	9.2 (5.0-13.4)
Male	68.9 (SD = 4.7)	58.6 (SD = 6.3)	10.3 (5.8-14.8)
Female	75.2 (SD = 4.6)	64.3 (SD = 5.9)	10.9 (13.8-35.7)

Table 1. Cerebral Oxygenation (rSO2) Measured via Near-Infrared Spectroscopy (NIRS) in the Valley at 673m Above Sea Level and on the Mountain at 3,454m

Note: Overall study population and subgroups. All of the differences were statistically significant.

Abbreviations: rSO2, regional cerebral oxygen saturation; SD, standard deviation.

RSO2, % (SD)	Male N = 17	Female N = 3	Smokers N = 3	Non-Smokers N = 17
Overall	63.8 (SD = 7.6)	69.8 (SD = 7.6)	66.3 (SD = 11.2)	64.4 (SD = 7.2)
Valley	68.9 (SD = 4.7)	75.2 (SD = 4.6)	75.1 (SD = 2.2)	69.0 (SD = 4.9)
Mountain	58.6 (SD = 6.3)	64.3 (SD = 5.9)	57.6 (SD = 8.7)	59.8 (SD = 6.3)

Table 2. Differences in Cerebral Oxygenation (rSO2) Measured via Near-Infrared Spectroscopy (NIRS) between Men and Women as well as Smokers and Non-Smokers

Note: None of the differences were statistically significant.

Abbreviations: rSO2, regional cerebral oxygen saturation; SD, standard deviation.

Discussion

A depletion of cerebral oxygenation in high altitudes is well-known, with a potential adaptation in long-term residents of high-altitude areas.[15–17] However, to the authors' knowledge, this was the first study assessing cerebral oxygenation (and confirming depleted values) at a high altitude in mountain rescuers after a steep

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Rescuer No.	Age, Years	Female Sex	BMI	Active Smoker	Mean rSO2 Valley, % (SD)	Mean rSO2 Mountain, % (SD)	ΔrSO2 (Mountain – Valley), %
1	26	1	23.5	No	70.2 (SD = 1.8)	68.5 (SD = 1.5)	−1.7
2	26	1	22.0	No	76.3 (SD = 1.1)	66.8 (SD = 1.0)	−9.5
3	30	0	22.9	No	74.7 (SD = 1.9)	42.6 (SD = 4.7)	−32.1
4	30	0	23.8	No	66.9 (SD = 2.1)	66.9 (SD = 1.0)	0.0
5	42	0	21.5	No	69.5 (SD = 1.3)	64.5 (SD = 8.0)	−5.0
6	26	1	22.3	No	79.2 (SD = 0.8)	57.6 (SD = 4.0)	−21.6
7	52	0	22.5	No	64.3 (SD = 2.1)	55.4 (SD = 1.1)	−8.9
8	55	0	24.0	Yes	75.2 (SD = 4.9)	47.7 (SD = 4.6)	−27.5
9	54	0	26.9	No	73.0 (SD = 1.0)	65.4 (SD = 1.0)	−7.6
10	37	0	23.8	No	72.7 (SD = 2.5)	55.6 (SD = 1.8)	−17.1
11	19	0	24.2	No	69.3 (SD = 1.0)	58.8 (SD = 3.7)	−10.5
12	35	0	24.2	Yes	72.8 (SD = 1.9)	64.3 (SD = 1.9)	−8.5
13	39	0	25.9	Yes	77.2 (SD = 4.0)	60.7 (SD = 2.1)	−16.5
14	20	0	23.3	No	64.8 (SD = 3.6)	60.2 (SD = 2.1)	−4.6
15	45	0	24.4	No	66.0 (SD = 2.4)	52.7 (SD = 2.4)	−13.3
16	41	0	21.1	No	67.6 (SD = 2.8)	61.1 (SD = 3.5)	−6.5
17	55	0	23.0	No	61.2 (SD = 2.0)	60.0 (SD = 1.3)	−1.2
18	33	0	21.0	No	62.2 (SD = 2.1)	58.0 (SD = 1.7)	−4.2
19	57	0	22.8	No	67.2 (SD = 2.6)	60.3 (SD = 1.5)	−6.9
20	33	0	22.5	No	67.2 (SD = 0.8)	62.3 (SD = 1.4)	−4.9

Table 3. Single Cerebral Oxygenation (rSO2) Values of the Mountain Rescuers Measured via Near-Infrared Spectroscopy (NIRS), as well as Individual Differences between Values in the Valley at 673m Above Sea Level and on the Mountain at 3,454m
Note: Age 28 (SD = 12) years, BMI 23 (SD = 2).
Abbreviations: rSO2, regional cerebral oxygen saturation; BMI, body mass index; SD, standard deviation.

active ascent towards a potential patient, and therefore serving as proof-of-concept. The measured rSO2 values roughly reflect known ranges from other high-altitude populations.[17,18] A high inter-variability of delta rSO2 could be observed when looking at the mountain rescuers' values individually. This was not directly reflected by the degree of hypoxemia measured by SpO2 (%) which were at levels that are comparable to previous literature.[13,19,20] Many confounders that could not be assessed may have played a role. However, it must be remembered that the participants were all relatively young, very fit, and generally healthy. This, and the low degree of subjective and objective physical exhaustion in the study subjects,[13] make the results even more interesting and lead to additional questions: (1) Are there factors influencing cerebral oxygenation that are independent of physical fitness and mountain experience? And (2) Is individual adaptation of cerebral oxygenation at high altitudes maybe the more promising method of assessing and determining task performance in mountainous settings? These questions are in line with previous findings. For instance, Hadolt, et al also found a more pronounced depletion in cerebral than in peripheral oxygenation in Himalayan trekkers,[18] whereas Manferdelli, et al reported individuals being more prone to AMS when they showed low cerebral oxygenation values both at rest and during exercise. It was suggested that those individuals were unable to increase microvascular blood volume and therefore maintain oxygenation in hypoxic surroundings.[21]

The theory of decreased cognitive function in hypobaric hypoxic conditions is well-established.[17,22,23] High-altitude ascents undoubtedly pose a (patho-)physiological cerebrovascular challenge,[24] and a reduction of cerebral oxygenation is thought to be the primary cause of AMS.[18,23] It has previously been shown that the physical strain of an alpine ascent potentially leads to a reduction in performance quality performed of mountain rescuers, and that respective guidelines (for instance on cardiopulmonary resuscitation) are thus potentially not a good fit to alpine surroundings.[13] Performing an active on-foot ascent to get to a patient or victim in alpine surroundings is regularly necessary, as the use of HEMS is not always possible.[13] Also, individuals transported to high altitudes with a helicopter have previously shown unfavorable neurocognitive[25] and practical[19] performance, probably due to changes in cerebrovascular reactivity.[26] Vuyk, et al reported that *Acetazolamide* may dampen the exercise-induced depletory effect of high altitudes on cerebral oxygenation.[27] Accordingly, *Sildenafil* is thought to improve rSO2 at altitude.[28] Whether such pharmacological interventions could be an option to improve performance of mountain rescuers after they had to perform strenuous ascents remains unknown and could be the goal of future research.

Other supportive tools of MRS such as mechanical chest compression devices have already been tested in alpine settings[29] and may be worthwhile to use when optimal human performance cannot be guaranteed because rescuers are simply not oxygenated enough.

Due to rising numbers of complex medical cases in mountainous regions,[10–12] the performance of rescue teams should indeed be moved more into the spotlight of research – cerebral oxygenation and its modulation could play a vital role.

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Limitations

This study was merely a pilot trial to show proof-of-concept and to develop suggestions about potential applications and future research possibilities. The small sample size as well as the lack of a complete picture of potential confounders for rSO2 in individual mountain rescuers could have impacted on the results substantially. These data showed a wide variability in outcome measurements among the study subjects. There was no information about the exact permanent residence altitude of the participants (however, all of them lived in the general mountainous vicinity of the study area). Subject number four (Table 3) did not show any difference in NIRS values. As more information on the subject was not available, it can only be speculated about the reasons for this: they could have been especially adapted to high altitudes due to more or very intense training than the others.

Conclusion

Cerebral oxygenation (rSO2) was depleted in healthy and fit mountain rescuers at high altitude after a steep ascent and was significantly lower than in the valley. There were considerable inter-individual differences concerning delta rSO2, the origins of which remain unexplained. Since cognitive impairment in hypobaric hypoxic conditions is known, using rSO2 to assess performance-readiness in mountain rescuers and individual proneness to cognitive dysfunction or AMS could be further research goals.

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Author Contributions

AE, VF, KT, MN, WS, HH, and *DR* contributed to data acquisition and study design. *SS* crafted the manuscript and executed data analyses. *TU, WS, HH,* and *DR* supervised the study process and amended the manuscript. *SS, AE, VF, KT, MN, TU, WS, HH,* and *DR* critically revised and approved the final version of the manuscript.

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