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The impact of sleeping in an elevated upper body position during acclimatization to high altitude on acute mountain sickness and pulmonary artery systolic pressure

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Original article

Abstract

Background: The effect of sleeping positions during acclimatization to high altitude on Acute Mountain Sickness (AMS) and High Altitude Pulmonary Edema (HAPE) is unknown. We tested whether sleeping with the upper body raised by 5° reduces prevalence and severity of symptoms of AMS as well as of elevated pulmonary artery systolic pressure (PASP) values as a risk factor of HAPE.

Methods: Randomly assigning trekking tourist volunteers n = 44 (25 m, 19 f; mean age 42.9 yr) sleeping at 4280 m or 5170 m to the experimental group (upper body elevated by 5°), or to the control group. After exclusion of other reasons for AMS-like symptoms those assumed to be related to AMS were rated by Lake Louise Score questionnaire in the evening and the following morning of the study. Transthoracic echocardiography was performed on both occasions to estimate PASP.

Keywords

- acute mountain sickness
- pulmonary artery systolic pressure
- sleeping positions
- acclimatization

Contribution

A – Preparation of the research project
B – Assembly of data
C – Conducting of statistical analysis
D – Interpretation of results
E – Manuscript preparation
F – Literature review
G – Revising the manuscript

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Conflict of interest

None declared.

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Results: In the study group, symptoms of AMS were significantly reduced in younger subjects ($p = 0.021$), prevalence of AMS was reduced in women ($p = 0.156$), and PASP values were significantly reduced in older subjects and men ($p = 0.032$; $p = 0.031$ respectively).

Conclusion: Results suggest that sleeping with the upper body in elevated position during a high altitude ascent may benefit those suffering from AMS or at risk of HAPE due to elevated PASP values.

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Introduction

Tens of thousands of trekking tourists travel to high altitude destinations each year. The proportion of older people and those with preexisting medical conditions amongst these travelers has increased in recent years.[1] In the Nepalese Mt. Everest region, acute mountain sickness (AMS) and high altitude pulmonary edema (HAPE) remain relevant health risks. At above 3000 m, a prevalence of AMS of up to 42% as well as a 6% prevalence of HAPE at 4550 m has been reported.[2–5] At 4730 m, a mean pulmonary artery systolic pressure (PASP) of 39.9 ± 7.7 mm Hg and a mean Lake Louise Score (LLS) of 3.8 ± 3.2 were found.[6] The rise of PASP due to high altitude hypoxia-induced vasoconstriction is subject to a high interindividual variability, and the mechanisms not fully understood.[7,8] Another factor may be a volume shift of blood by cold-induced constriction of peripheral vessels. However an increased PASP is the main indicator of susceptibility to HAPE.[9] A pulmonary artery systolic pressure (PASP) of more than 40 mm Hg correlates closely with a high risk of developing HAPE.[10–12] Young men who underwent physical stress are most likely to suffer from HAPE .[11] High LLS scores, corresponding to AMS, are also associated with elevated PASP.[13] Women and young people are more likely to develop AMS.[14–16] Obviously there is a close relationship between PASP and all those clinical findings.

In hydrostatic pulmonary edema caused by left ventricular failure, an upright position facilitates symptoms. However, the underlying pathology of HAPE is different as it is caused by elevation of PASP due to hypoxic pulmonary vasoconstriction at high altitude.[11] Within German and Austrian literature,[17–20] a hypothesis suggested several times states that sleeping in an elevated upper body position during a high altitude stay compared to sleeping without an elevation of the upper body helps acclimatization by: a) reducing the prevalence and severity of symptoms of AMS and b) reducing elevated PASP values, a suggested symptomatic precursor of HAPE. As this hypothesis has never been verified, we tested this in the Nepalese Mt. Everest region in a realistic setting at a high altitude through a field study.

Materials and methods

The study was a prospective observational pilot study. All participants signed an informed consent form prior to participating in this study. The study was approved by RWTH Aachen Technical University ethical committee (Study no. Ek 196/11). Inclusion criteria were: lowlander Caucasians, 18+ years of age, intellectually able to understand the proband information and to agree to participate. All participants were interviewed concerning pre-existing diseases, drug intake, and history of AMS, HAPE, or high altitude cerebral edema HACE).

The participants were randomly assigned to the experimental group and control group prior to the collection of data in the evening. The subjects in the experimental group slept with their upper body raised by 5°. This was achieved by adjusting the height of the two bedposts upwards where the head rests. Data was collected sequentially in the evening and in the morning at altitudes of 4280 m (Pheriche) and 5170 m (Gorak Shep).

All participants were asked to evaluate themselves for AMS using the LLS and clinical examination of peripheral edema, ataxia and mental status was performed. The diagnosis of suspected AMS was clinically proven and differential diagnoses excluded individually by a physician trained in altitude medicine.

Echocardiographic assessment of pulmonary arterial hemodynamics was performed by a fully trained operator in the left lateral decubitus position using the Vivid i system (GE Healthcare, Little Chalfont, GB). Pulmonary artery pressure was calculated as the sum of the maximum systolic transtricuspid pressure gradient (Figure 1) and the estimated right atrial pressure according to the recommendations of the American Society of Echocardiography.[21,22] Right atrial pressure was estimated from the diameter and the extent of inspiratory collapse of vena cava inferior. PASP was defined as pathologic when exceeding 36 mmHg.[22]

LLS and PASP results were collected looking for significant differences in prevalence and severity of AMS and elevated PASP. To evaluate whether age plays an important role two subcollectives were defined in a second evaluation: <50 years and ≥50 years. Statistical

evaluation was performed using SPSS version 20 (IBM SPSS Statistics, Armonk, NY, USA) and Microsoft Excel version 2010 (Microsoft Corp., Redmond, WA, USA) software. Because all data was not normal distributed (Kolmogorv-Smirnov-test, Levine test) non-parametric tests were used (Mann-Withney-U-test, Chi square test, Wilcoxon rank test). P < 0.05 was defined as significant. The variables examined were age, gender, altitude and sleeping position before and during the study night as well as the use of acetazolamide.

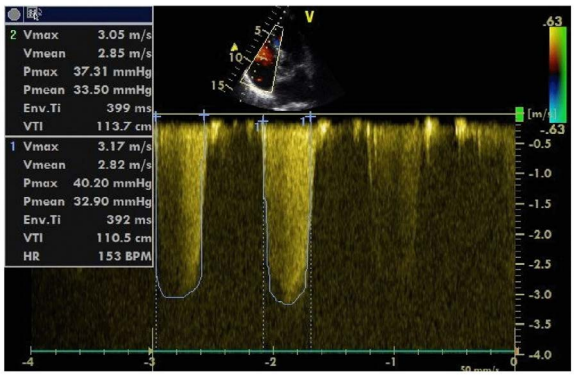

Figure 1. Echocardiographic assessment of transtricuspid pressure gradients to calculate PASP

Results

Subjects who volunteered to participate in the study were mainly European trekking tourists n = 44 (25 males – 43.2%, 19 females – 56.8%), with a mean age of 42.9 ± 16.0 years (median 42, range 21–66). Subjects in Pheriche were significantly older than in Gorak Shep (mean 35.9 vs. 48.8 years; $p = 0.003$).

Amongst all subjects, 6.8% (n = 3) had been diagnosed with arterial hypertension, 15.9% (n = 7) suffered from bronchial asthma, one had undergone a lobectomy, 18.2% (n = 8f) took female hormone products. 20.4% (n = 9) used acetazolamide (Diamox®) and n = 1 dexamethasone. The anthropometric data of the collective were as follows: mean body height 171 cm (median 171, range 155–191), mean body weight 69.6 kg (median 70, range 49–95) and mean BMI 23.8 ± 3.5 kg/m^2 (median 23.4, range 18.4–37.4). Mean duration of ascent from Lukla to Gorak Shep (with one day for acclimatization in Namche Bazaar (3440 m m) included) was 8.9 ± 2.9 days (median 9.5, range 5–13), corresponding to a mean daily gain in altitude of 330 m. 22.7% (n = 10) of the participants had slept in an elevated body position during ascent prior to the study night and 77.3% (n = 34) had slept in a horizontal position. The experimental group included n = 24 subjects and the control group included n = 20 subjects.

AMS/LLS

From all participants, 38.6% suffered from AMS. Women were affected more often than men ($p = 0.096$). Subjects aged ≥50 years had significantly less AMS than subjects ≤30 years ($p = 0.021$); a statistically significant difference was also found between Pheriche and Gorak Shep ($p = 0.008$ in favor of Pheriche), correlating closely with the age difference between the two groups. The prevalence of AMS decreased overnight in the study as well as in the comparative group. Mean LLS of all participants was 5.0 ± 2.3 in the evening and 4.8 ± 1.8 in the morning ($p = 0.42$) (Figures 2–3).

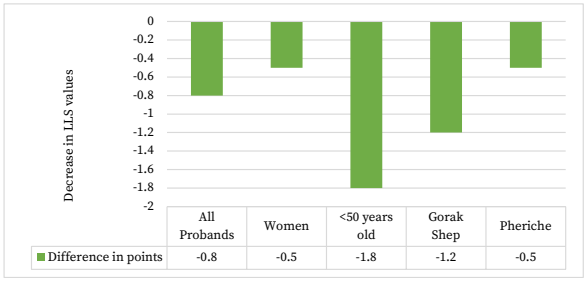

Figure 2. Mean overnight decrease in LLS values in the study groups compared to all probands

Figure 3. Mean overnight decrease in prevalence of probands of the study group with pathologic LLS values compared to all probands

Nine participants used acetazolamide; in this subgroup, mean LLS results improved significantly over night ($p = 0.006$). Mean LLS results in the acetazolamide-free participants (n = 35) also improved significantly ($p = 0.014$), although in this subgroup, absolute scores were lower.

Taking into account the sleeping positions, women sleeping in an upright position suffered less from AMS

(p = 0.156) and had some tendency to lower LLS than men. The older age group suffered less from AMS. The overnight improvement of AMS severity in an upright position with decreasing altitude (p = 0.042) also correlates with the age difference between the study groups (Figures 2–3).

PASP

Mean PASP of all participants was 36.1 ± 7.7 mmHg (median 34.7, range 18.6–50.5) in the evening and 37.0 ± 7.8mmHg (median 36.7, range 22.7–58.1) in the morning (p = 0.378). Comparing the subgroups (age, gender, altitude) without looking at sleeping positions, no statistically significant difference could be found between evening and morning PASP values.

However, mean PASP values were higher in the experimental groups (37.2 ± 8.5 mmHg in the evening vs. 37.6 ± 6.2 mmHg in the morning when sleeping in an elevated position only in the study night (n = 18) and 41.1 ± 8.3 mmHg in the evening vs. 41.5 ± 10.1 mmHg when sleeping in an elevated position during the entire stay at high altitude (n = 6). In the control group, the results were 34.1 ± 6.6 mmHg in the evening vs. 35.4 ± 8.0 mmHg in the morning (n = 16). 29.6% of all participants showed pathologic PASP values at both echocardiographic assessments.

Looking at individual subjects, PASP values decreased when sleeping in an elevated body position. This effect was particularly strong in subjects aged ≥50 years (p = 0.032) and in men (p = 0.031) (Figure 4). The prevalence of pathologic PASP values increased tendentially in subjects <50 years (p = 0.344) and probably in men (p = 0.431). PASP values showed a decreasing although not significant tendency in Gorak Shep (p = 0.401) as well as in Pheriche (p = 0.022), where a significantly stronger effect was found, correlating closely with the age difference between the subjects in Gorak Shep and Pheriche. Prevalence of pathologic PASP values also decreased in Pheriche but this was not significant (p = 0.299).

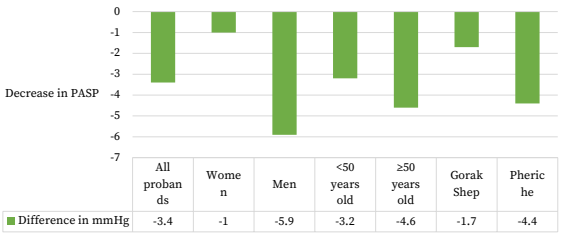

Figure 4. Mean overnight decrease of PASP [in mmHg] in the study group compared to all probands

Absolute mean PASP values in the subgroup that used acetazolamide showed no difference compared to the subgroup that did not use acetazolamide, also when comparing overnight changes (p = 0.525 vs. p = 0.165).

Ten of the 17 subjects suffering from AMS had pathologic PASP values. Mean PASP values in subjects suffering from moderate AMS (LLS 3-5) were 40.1 ± 2.5 mmHg in the evening and 41.3 ± 5.1 mmHg in the morning (p = 0.358). In subjects with severe AMS (LLS > 5), mean PASP values were 44.8 ± 4.6 mmHg in the evening and 42.4 ± 5.9 mmHg in the morning (v = 0.087). No subject showed clinical symptoms of HAPE.

Discussion

The study aimed to examine the hypothesis that sleeping in an elevated upper body position during acclimatization to high altitude might reduce PASP and AMS symptoms. First of all, the relatively high incidence of AMS is striking, although the test subjects have an altitude profile of 330 meters per day, which largely corresponds to the general recommendations for the prevention of AMS.[23]

The results seem to indicate an influence of sleeping positions on both factors. The reduction of AMS prevalence and severity by sleeping in an elevated position was particularly strong in women, whom are one of the subgroups to suffer most from AMS. A significant reduction of AMS prevalence and severity was also found in the older age group. Concerning elevated PASP values, older people as one subgroup of the most predisposed patients for elevated PASP values at high altitude, presumably benefit most from a prophylactic elevation of the upper body part during sleep while ascending to high altitude. These effects should be further evaluated using larger study cohorts and considering other potential influencing factors.

The age and gender-dependent distribution of AMS diagnoses complies with multiple studies.[14–16,24–25] A diurnal variation of AMS severity could not be found although this has been often reported since more than 100 years.[26–31] This might be explained by the timing of data collection: In contrast to earlier studies, LLS was taken in the evening right after arrival to the new altitude and before rest, which could explain higher scores.[31,32] AMS prevalence declined over night in all subgroups. Facilitated breathing and a reduction of facial edema and headache with an elevated sleeping position may lead to similar effects. However, a decrease in sleep quality with increasing altitude has been reported.[33] This is also a well-known fact since more than a century.[26–30,34] Reconciling such a distinct effect of little relaxing sleep

seems astonishing, suggesting a non negligible effect of elevated body positioning. Still, individual habits and preferences represent important factors of sleep quality as well as sleep will lead to improved well-being in either position. Following a doctor's instruction of sleeping in an elevated position to alleviate altitude-related illness might also ease fear and thus improve well-being. A controversially discussed, but possible effect of enhanced hypoxic ventilatory response when sitting up with better acclimatization through facilitated oxygenation has been described.[35,36]

Bilateral associations of AMS and pathologic PASP values have been reported.[9,13] A similar effect could be observed in 50% of our subjects. Mean PASP values as well as their age and gender dependent distribution correspond well to prior studies.[6,12,22,37] The crucial factor in reducing the risk of HAPE is the absolute level of PASP values which was effectively lowered overnight considering the whole collective that slept in an elevated position. In contrast, PASP values increased overnight in the participants that slept in a horizontal position, suggesting a direct effect of body positioning on PASP levels. A horizontal position has been described to increase PAP-levels.[36] Sleeping in an elevated position seems to most effectively reduce PASP values in the older age group which is frequently affected by pathologic PASP and by PASP-enhancing preexisting conditions[37] and will thus benefit most from a PASP-decreasing prophylactic procedure. Elevated positioning in the therapy of manifest HAPE leads to a volume shift out of the pulmonary circulation and thus lowers PASP as well as it eases breathing. Presumably, therapeutic options for manifest HAPE have been transferred to prophylactic procedures in the German scientific literature resources mentioned above.

However, it should be noted that here are several other factors which decrease sleep quantity and quality at high altitude. First of all hypopneas and apneas, typically with the pattern of Cheyne-Stoke's breathing.[38–42] This is also well-known since the end of the 19th century and has been investigated in detail by Angelo Mosso at Margherita Hut (4560 m).[26,28,30,43] The details of the underlying mechanism is still up for debate. Normally breathing frequency or breathing minute volume, respectively, are controlled by a negative feedback loop: decrease of oxygen partial pressure (pO_2) or increase of CO_2 partial pressure cause an increase of breathing via receptors in the Glomus caroticum.[44] By this "hypoxic ventilatory response" (HVR) the organism stabilizes its oxygen supplies. There is a significant variability caused by genetics, gender, age and other factors.[45–49] At sea level the organism stabilizes its oxygen level by the negative feedback loop. However, this loop takes a certain although short time to be effective. At altitude the decrease of CO_2 by hyperventilation becomes more and more important. Finally, its breathing stimulus is missing and a significant decrease or even an arrest of breathing occurs.[38] The following decrease of pO_2 causes massive stress for the organism ("arousal") resulting in a significant increase of breathing but also of heart frequency and systolic blood pressure.[38] Arousals increase with altitude from 21.7 per hour to 161 per hour at 7620 m.[50] This does not only change sleep structure significantly[51,52] but also causes significant stress on the cardiopulmonary system for most time of the night. Although some data indicate an increased risk for HAPE by arousals[53,54] this effect is still unclear, especially compared to the risk factors discussed in the actual paper.

Limitations of the study include the fact that preexisting medical conditions and medical treatments were not taken into account, because such subgroups were too small for any statistical evaluation: only one of the participants with asthma bronchiale used a regular bronchodilatory treatment and only three participants took antihypertensive drugs. The effect of estrogen treatment on PAP seems unclear.[55–57] Multiple studies have shown acetazolamide to be effective for the prophylaxis and the therapy of AMS and thus in lowering LLS results.[58] This effect could not be shown in the present study. Possible causes might be an incorrect dosage or application interval of the drug, or could relate to the point in time at which acetazolamide and study variables had been taken. An effect of acetazolamide on PASP could not be shown, corresponding to earlier studies as well.[37]

A significant bias by cold-induced peripheral constriction of vessels and a consecutive volume shift towards the pulmonary circuit can be excluded since the participants slept at comfortable temperatures.

With regard to the subgroups, the study collective was small, which limits multivariate analysis of the subgroups and the power of such analyses. The detailed evaluation of the subgroups must be interpreted carefully. We never tested a single participant at both altitudes. Therefore, it remains unclear whether the differences found between the groups at Gorak Shep and Pheriche are based on the age difference only or whether the altitude played a significant factor as well.

To adopt an elevated sleeping position of more than 5° does not seem feasible because sleep will be uncomfortable. When 10° were tested the participants avoided this position because they were afraid to slip down while they were sleeping. Furthermore, head down bed rest studies have established that a 6° head down position increases PASP.[59] Therefore, we concluded that

a 5° elevated position should be sufficient to show its effect if there was one.

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