

Pre-acclimatization Benefits in Occupational Travelers with Repeated High-Altitude Exposure: A Case Series of Thai Engineers at Argentina's 4,000-meter Salt Pans

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Abstract

OBJECTIVES: To evaluate cumulative acclimatization and pharmacological prophylaxis trends in occupational travelers undergoing repeated, cyclical high-altitude exposure.

MATERIALS AND METHODS: This retrospective case series involved Thai engineers completing cyclical work assignments at a 4,000-meter mining facility in Argentina between July 2023 and June 2025. The schedule comprised 7–16 days at altitude followed by 3–6 rest days at a moderate altitude (1,200 m). Acclimatization status was assessed using the 2018 Lake Louise Score (LLS) for the diagnosis of acute mountain sickness (AMS), while prophylactic acetazolamide use was tracked through clinical records.

RESULTS: Five healthy Thai engineers (four males and one female, aged 29–55 years) completed six separate assignments. One participant met the criteria for moderate-to-severe AMS during the initial cycle (1/5 participants, 20%; 1/6 trips, 16.7%). By the third cycle, symptoms at 24 hours had resolved in 4/5 participants (80%) across 5/6 assignments (83.3%). One participant (Case 3) continued to exhibit mild AMS at 24 hours during cycles 2–6; however, from cycle 3 onward, the 48-hour scores consistently improved to a non-diagnostic level. Additionally, acetazolamide prophylaxis was ceased entirely by the third cycle in 3/5 participants, 60%; 3/6 trips, 50%. Wearable-derived SpO₂ data from one participant showed improved SpO₂ stability and higher minimum saturation values during later cycles.

CONCLUSION: Occupational travelers on a cyclical schedule with short rest periods at a moderate altitude can achieve cumulative acclimatization, resulting in decreased symptom severity and a trend toward pharmacological de-escalation. These findings suggest that adaptation is sufficiently preserved over short breaks to mitigate the burden of subsequent ascents.

Keywords: pre-acclimatization, occupational health, high-altitude illness, acetazolamide, lake louse score, travel medicine

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High-altitude exposure presents significant hypoxic challenges for occupational travelers who must rapidly ascend to remote worksites.^{1,2} Acute mountain sickness (AMS), along with life-threatening high-altitude pulmonary edema (HAPE) and cerebral edema (HACE), are consequences when rapid ascent outpaces physiological acclimatization. In cohorts involving rapid ascent to altitudes near 5,000 m, AMS incidence has been reported as high as 60–62% during the first exposure cycle.^{2,3} Standard prevention strategies include gradual ascent, pharmacological prophylaxis, and pre-acclimatization—the process of inducing adaptive physiological changes through hypoxic exposure prior to travel.⁴

While pre-acclimatization benefits for single ascents are well-documented^{5–7}, a knowledge gap persists regarding the retention of these benefits during cyclical occupational travel. The kinetics of de-acclimatization in these patterns remain poorly characterized, and existing evidence is mixed (Table 1). Research on Chilean miners found that resting at sea level resulted in persistent AMS symptoms with every

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new ascent up to 4,600 m over a 2.5-year period.⁸ Conversely, the AltitudeOmics study demonstrated that AMS protection at 5,260 m was completely retained after a 7-day rest period at 1,525 m, though these benefits diminished when the rest period was extended to 21 days.⁹ To address this, we report a case series of five Thai engineers performing repetitive work

cycles at 4,000 m in Argentina. This series evaluates their adaptive status across repeated high-altitude exposures and discusses the practical application of pharmacological prophylaxis and pre-travel consultation for cyclical high-altitude occupational travelers.

Table 1: Summary of Terrestrial Repeated High-Altitude Exposure Literature

Study	Year	Population	Cyclical Exposure Pattern	Benefits upon Reascent
Schneider et al. ¹⁰	2002	827 mountaineers	>3,000 m (>4 days) → Sea Level (up to 2 months) → Re-ascent to 4,559 m	• Halved AMS prevalence (from 58% to 29%) in susceptible cohorts.
Richalet et al. ⁸	2002	29 Chilean miners	3,800–4,600 m (7 days) → Sea Level (7 days) → Repeated Shift Cycles	• No significant AMS reduction over 2.5 years. Symptoms and sleep disturbances persisted with every re-ascent after resting at sea level
Subudhi et al. ⁹	2014	21 lowlanders	5,260 m (16 days) → 1,525 m (7 or 21 days) → Re-ascent to 5,260 m	• AMS incidence dropped from 81% to 0% after a 7-day rest. • Blood oxygen levels improved from 76% (unacclimatized) to 82% (re-ascent), though this benefit diminished by 21 days
Pun / Furian / Waldner et al. ¹⁻³	2018-2025	21 lowlanders	Day 5,050 m / night 2,900 m (7 days) → 520 m (7 days) → Cycle 2 Re-exposure	• AMS incidence fell from 62% to 29% in the second cycle. Blood oxygen levels were higher during re-exposure (80.0% vs. 82.8%).

Materials and Methods

Study Design and Participants

This retrospective case series included five Thai engineers who completed six separate assignments at a lithium-brine facility located on the high-altitude salt pans of Argentina at an elevation of 4,000 m. The cases comprised all five engineers who presented to the hospital for pre-travel consultation and post-travel follow-up between July 2023 and June 2025. During the study period, all identified individuals were eligible, approached, and provided written informed consent for the retrospective use of their clinical data.

Travel and Work Schedule

The travel itinerary involved a flight from Bangkok, Thailand (sea level), followed by an overnight stay in Salta, Argentina (1,200 m), and a subsequent flight to the mining site at 4,000 m. Each assignment consisted of three to six repeated work cycles, with each cycle comprising 7–16 days at high altitude followed by 3–6 rest days in Salta. Participants were accommodated in container-style facilities at the remote worksite, where medical resources were limited.

Pre-travel Medical Assessment and Prophylaxis

Before departure, participants underwent medical consultation to assess their fitness to work at high altitude. Pre-existing cardiovascular, respiratory, or other chronic conditions that could affect peripheral oxygen saturation (SpO₂) or increase the risk of altitude illness were considered contraindications to travel.

Following medical screening and education regarding the prevention and recognition of altitude illness, participants were prescribed acetazolamide at a dose of 125 mg twice daily, beginning one day before ascent and continuing for the first two days at altitude, for a prescribed total dose of 750 mg per cycle. For safety at the remote worksite, each participant was also provided with two additional 250-mg tablets, corresponding to a total reserve dose of 500 mg per cycle.

Participants were informed that residual acclimatization from previous cycles might reduce the risk of AMS during subsequent ascents. However, they were also advised that evidence supporting the discontinuation of prophylaxis during later cycles remained limited. Consequently, all dose modifications or discontinuations reported in this study were initiated by the participants.

Assessment of AMS

As part of standard clinical care, participants were instructed to self-monitor symptoms of AMS using the 2018 LLS at 24 and 48 hours after each ascent. During each work cycle, participants independently recorded their symptoms on paper without onsite clinical supervision. These records were primarily intended for individual safety monitoring and were subsequently verified through clinical interviews conducted during post-travel follow-up.

According to the 2018 LLS consensus criteria, AMS was defined as the presence of headache together with a total score of ≥ 3 based on four self-reported symptoms: headache, gastrointestinal discomfort, fatigue, and dizziness. Each symptom was rated from 0 (none) to 3 (severe or incapacitating), resulting in a total possible score of 0–12.¹¹ AMS severity was classified as mild for scores of 3–5 and moderate to severe for scores of 6–12.⁴

Data Collection and Outcome Measures

Demographic characteristics, symptom profiles, LLS values, and acetazolamide use were retrospectively extracted from clinical records. Non-AMS health complaints, including insomnia, were identified through open-ended clinical interviews during post-travel follow-up. Continuous SpO₂ measurements recorded by a smartwatch and voluntarily provided by one participant were also reviewed.

The primary outcomes were the occurrence and severity of AMS across repeated work cycles and changes in acetazolamide use. Secondary observations included symptom resolution, SpO₂ trends, sleep disturbance, other health conditions, and the occurrence of HAPE or HACE.

Data Analysis

Participant characteristics, AMS occurrence, symptom patterns, and acetazolamide use were summarized descriptively. Categorical data are presented as frequencies and percentages, while medication doses are reported as means and ranges. Owing to the small sample size and descriptive nature of the case series, no inferential statistical analyses were performed.

Results

Participant Characteristics

The case series included five Thai engineers—four males and one female—aged 29–55 years, who collectively completed six assignments. None of the participants had underlying cardiovascular, respiratory, or other chronic conditions considered relevant to altitude illness risk or SpO₂ measurements. All participants were undertaking high-altitude occupational work for the first time.

Initial Exposure and Symptom Patterns

During the initial ascent, symptoms corresponding to an LLS of ≥ 1 were reported by all participants across all assignments (5/5 participants, 100%; 6/6 trips, 100%) (Table 2). One participant met the criteria for moderate-to-severe AMS during the initial cycle, with an LLS of 6 (1/5 participants, 20%; 1/6 trips, 16.7%).

Case 3 continued to experience mild AMS at 24 hours during subsequent work cycles (LLS = 5). Although the 48-hour score remained diagnostic during cycle 2 (LLS = 3), it improved to a non-diagnostic level (LLS = 1) from cycle 3 onward. Among the remaining participants, high-altitude symptoms generally resolved by the third work cycle (Figure 1, Panel B).

Acetazolamide Use and Pharmacological De-escalation

The improvement in clinical symptoms was accompanied by a trend toward pharmacological de-escalation (Figure 1, Panel A). All participants used acetazolamide prophylaxis during their initial ascent. By the third cycle, prophylaxis had been discontinued entirely by three participants (3/5 participants, 60%; 3/6 trips, 50%).

Across the 16 cycles in which acetazolamide was used, the mean total dose was 710.9 mg, with a range of 250–1,250 mg. Strict adherence to the prescribed 750-mg regimen occurred in 37.5% of medicated cycles (6/16). The prescribed dose was exceeded in 18.8% of cycles (3/16), whereas lower doses were used in 43.8% (7/16).

Case 3 discontinued prophylaxis after the first cycle despite experiencing moderate-to-severe AMS during the initial ascent (LLS = 6). At 48 hours during cycle 2, the participant's score continued to meet the diagnostic criteria for AMS (LLS = 3). However, from cycle 3 onward, the 48-hour score improved to a non-diagnostic level (LLS = 1) without prophylaxis. Clinical records indicated that this self-initiated discontinuation was based on perceived symptom improvement rather than medication-related adverse effects. During post-travel follow-up, Case 3 reported that the decision was also influenced by wearable-device SpO₂ measurements, which he considered acceptable and indicative of sufficient acclimatization.

Objective Oxygen Saturation Trends

Continuous smartwatch data provided by Case 1 supported the observed clinical improvement. The data demonstrated greater SpO₂ stability and slightly higher minimum oxygen saturation values during later work cycles compared with the initial trip (Figure 2).

Sleep Disturbance and Recurrent Minor Symptoms

Despite the overall improvement, minor symptoms corresponding to LLS values of 1–2 recurred during later cycles in several participants after periods without symptoms (3/5 participants, 60%; 3/6 trips, 50%).

Sleep disturbance, particularly insomnia, was commonly reported across all assignments. During post-travel interviews, participants identified sleep disturbance as the principal contributor to fatigue and dizziness during later cycles. These symptoms were managed without resuming acetazolamide prophylaxis.

Other Clinical Events

Case 3 developed symptoms of COVID-19, including cough and sore throat, on the final day of the fourth work cycle. During the subsequent rest and isolation period in Salta (1,200 m), the participant maintained stable oxygenation, with a reported SpO₂ of 98%, received symptomatic treatment, and was medically cleared to resume the routine work schedule.

The symptoms developed after completion of the 48-hour LLS assessment for the fourth cycle. Furthermore, the participant's 24- and 48-hour scores during cycles 5 and 6 (LLS = 5 and 1, respectively) were identical to the pre-infection pattern observed during cycle 3. Therefore, the infection was not considered to have materially affected the observed AMS trend. No cases of HAPE or HACE were documented during the study period.

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Table 2: Acetazolamide Use and Lake Louise Scores Across Repeated High-Altitude Work Cycles

Case	1 st Cycle	2 nd Cycle	3 rd Cycle	4 th Cycle	5 th Cycle	6 th Cycle	Other Problems
	Dose, LLS	Dose, LLS	Dose, LLS	Dose, LLS	Dose, LLS	Dose, LLS	
Case 1 (Trip 1)	1,000 2/2	1,000 2/2	500 0/0	0 0/0	0 2/2	—	Insomnia
Case 1 (Trip 2) †	500 2/2	0 1/1	0 0/0	0 0/0	0 0/0	—	Insomnia
Case 2	750 1/1	625 1/1	0 0/0	0 0/0	0 1/1	0 1/1	Insomnia
Case 3	1,250 6/6	0 5/3	0 5/1	0 5/1	0 5/1	0 5/1	COVID-19, Insomnia
Case 4	750 1/1	500 0/0	250 0/0	—	—	—	Insomnia
Case 5	750 1/2	750 0/0	750 0/0	750 0/0	625 0/0	625 1/0	Insomnia

Note: Dose = Total Acetazolamide (mg) taken per cycle. LLS = Lake Louise Score at 24h / 48h post-ascent. (—): Indicates work cycles not assigned to the participant. † Trip 2: Participant 1 returned after a 6-week interval at sea level

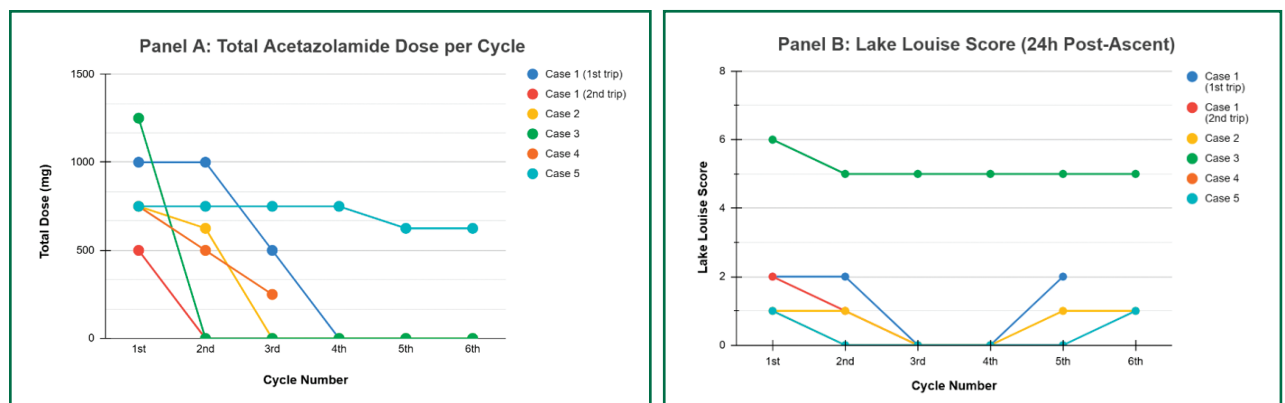


Figure 1: Trends in pharmacological prophylaxis and symptom severity across repeated work cycles. Data represent six distinct occupational trips involving five engineers. Panel A displays the total dose of acetazolamide (mg) administered in each high-altitude work cycle. Panel B shows the corresponding self-reported LLS at 24 hours post-ascent.

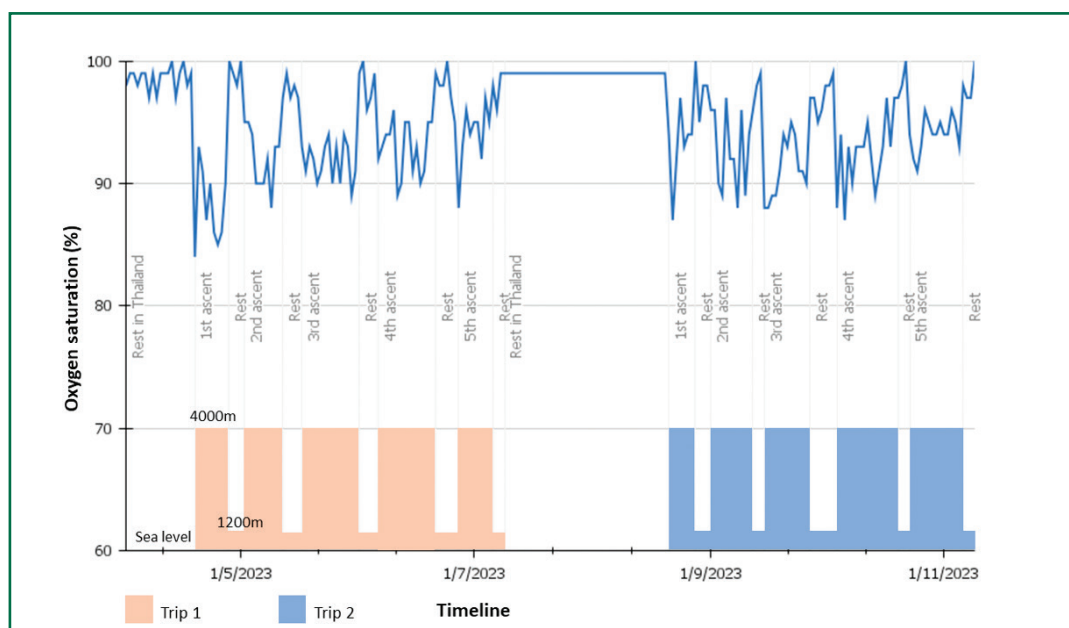


Figure 2: Longitudinal oxygen saturation trends for Case 1 across two separate high-altitude assignments. Daily SpO₂ recordings collected via smartwatch are shown as individual data points, with lower bars on the X-axis representing the duration and altitude of each work cycle. Trip 1 and Trip 2 were separated by a six-week recovery period at sea level in Thailand.

Discussion

This case series provides real-world evidence of cumulative acclimatization. LLS remained stable or improved even as acetazolamide was discontinued by the third cycle in three out of five participants (60%), representing half of the six assignments. While acetazolamide is a standard preventive measure for high-altitude travelers, this study is distinct for observing the retention of adaptive benefits into later cycles even as the pharmacological measure was tapered. This finding complements previous research where medication was typically restricted or excluded by protocol.^{1,2,10} This sustained benefit likely stems from the engineers' short rest periods (3–6 days) at a moderate altitude (1,200 m), which preserved physiological memory across cycles. This observation aligns with the AltitudeOmics study showing retained protection after a 7-day rest at 1,525 m⁹; conversely, workers resting at sea level experience persistent symptoms with every shift in a cohort of Chilean miners,⁸ indicating that rest altitude is as critical as duration for maintaining adaptive benefits. Case 1's experience following a six-week sea-level interval further illustrates this dynamic: despite initial de-acclimatization during the break, he achieved rapid re-acclimatization and medication cessation by his second cycle of the second trip, a trend corroborated by qualitative smartwatch data showing improved SpO₂ stability and higher minimum saturation values in later cycles.

Despite the general trend of improvement, we observed individual variation, as seen in Case 3's persistent mild symptoms (LLS 5 at 24 hours) throughout later cycles. This highlights that individual susceptibility remains a key factor in altitude illness even with repeated exposure¹⁰. Furthermore, recurrent minor symptoms (LLS 1–2) were largely attributed to reported insomnia and occupational fatigue. These reports support the 2018 Lake Louise Consensus to remove 'disturbed sleep' from diagnostic criteria, as sleep impairment at altitude is often a direct effect of hypoxia independent of the AMS syndrome.¹¹ Research on occupational travelers confirms that while AMS scores and oxygenation improve with repeated cycles, subjective sleep quality often remains similarly impaired.^{1,3} Finally, the participant who contracted COVID-19 underscores the importance of robust pre-travel preparation and self-management capabilities in settings with limited medical resources.

These observations have important implications for pre-travel consultation. While repeated exposure with short rest intervals may facilitate cumulative acclimatization, decisions regarding acetazolamide prophylaxis in subsequent cycles should be individualized during pre-travel consultation, with clear instructions to avoid unsupervised dose modification. Furthermore, we observed considerable adherence issues with acetazolamide dosing in this real-life setting; while the recommended total dose was 750 mg per cycle, actual intake across medicated cycles ranged from 250 mg to 1,250 mg. Strict adherence occurred in 37.5% of medicated cycles; higher-than-prescribed doses were taken during some early

cycles, whereas lower doses were used during later cycles as overall symptom trends improved. This variation also reflects the practical challenges of subjective dose adjustment and dosing errors in remote environments. This underscores that consultation must include education on dose consistency, a need further reinforced by a study suggesting that approximately 21% of travelers do not read or understand acetazolamide instructions.¹² Ultimately, these workers require a comprehensive approach that bridges altitude-specific prevention with broader occupational health strategies, including managing sleep disruption and ensuring robust preparation for concurrent illnesses in remote settings.

Limitations

This case series is limited by its small sample size and retrospective design, which preclude definitive conclusions about causality or generalizability to larger occupational cohorts. The lack of inferential statistical testing means the trends described should not be interpreted as having population-level significance. Social desirability bias may also be present in this employee sample, where occupational travelers may under-report symptoms to remain fit for work. Furthermore, the cohort featured a low proportion of female participants (1/5) and an absence of elderly individuals, which limits the assessment of age or sex-related physiological differences. Finally, the reliance on subjective LLS introduces inherent subjectivity, and the smartwatch SpO₂ data should be interpreted cautiously because of the potential limitations of consumer wearable measurements at high altitudes.¹³

Conclusion

This case series suggests that occupational travelers on a cyclical schedule with short rest periods (3–6 days) at a moderate altitude (1,200 m) can achieve cumulative acclimatization, resulting in decreased symptom severity and a trend toward pharmacological de-escalation. These real-world findings suggest that physiological adaptation is sufficiently preserved over short breaks to mitigate the burden of subsequent ascents. While individual susceptibility and occupational confounders like sleep disruption persist, these observations highlight the potential contribution of repeated exposure and pharmacological prophylaxis to symptom reduction during cyclical high-altitude work. Ultimately, managing this unique population requires a comprehensive approach that bridges altitude-specific prevention with broader occupational health strategies.

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Conflicts of Interest

The authors declare no conflicts of interest.

Ethics Statement

This study was conducted in accordance with the principles of the Declaration of Helsinki. The case series protocol was reviewed and approved by the Bangkok Dusit Medical

Services Institutional Review Board (BDMS-IRB). Written informed consent was obtained from all participants prior to inclusion for the retrospective use of their clinical data and relevant records.

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