A Blueprint for High Altitude Acclimatization Prior to High Altitude Competition for Professional Athletes

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Author names:

1. Rashi Ramchandani
2. Shyla Gupta
3. Emaad Mohammad
4. Tereza Florica
5. Reem Al Rawi
6. Ricardo Sebastian Galdeano
7. Jorge Sotomayor-Perales
8. Adrian Baranchuk

Degrees and Affiliations:

1. BHSc, MSc. Faculty of Medicine, University of Ottawa, Ottawa, Ontario. Institute of Health Policy, Management and Evaluation, University of Toronto, Toronto, Ontario.
2. BHSc. Faculty of Medicine, University of Ottawa, Ottawa, Ontario.
3. BSc, MD. Faculty of Medicine, Queen's University, Kingston, Ontario.
4. BSc, MD. Faculty of Medicine, Queen's University, Kingston, Ontario.
5. BSc(c). Faculty of Medicine, Queen's University, Kingston, Ontario.
6. MD. Programa Sonqo Calchaqui. Distrtito Tucumán Sociedad Argentina de Cardiologíam, Argentina.
7. MD. Hospital III EsSalud Juliaca, Puno, Perú.
8. MD, FACC, FRCPC, FCCS, FSIAC. Faculty of Medicine, Queen's University, Kingston, Ontario

ORCID:

https://orcid.org/0000-0002-6144-6423
https://orcid.org/0000-0001-5568-5148
https://orcid.org/0009-0002-8409-5686
https://orcid.org/0000-0001-9316-399X
https://orcid.org/0009-0006-7644-8874
https://orcid.org/0000-0001-6150-4673
https://orcid.org/0000-0002-3042-6569

About the author: Rashi is currently a third year medical student (of a total of four years) at the University of Ottawa. She has been extensively involved in numerous research studies looking at cardic physiological and electrocardiographic changes in high altitude populations. Having published over 10 peer-reviewed pubications she was also recently awarded the Have-a-heart-bursary from the Canadian Cardiovascular Society.

Corresponding Author: Adrian Baranchuk: Adrian.Baranchuk@kingstonhsc.ca

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Abstract

Introduction: Among professional athletes, high altitude training is a popular technique due to its documented success on improving cardiovascular health and athletic performance. Nevertheless, there is little consensus on the guidelines for high altitude training and competition. This review sought to summarize existing literature for acclimatization recommendations for competing at high altitudes and suggests a blueprint that could be followed by athletes and trainers.

Methods: This paper is part of the Altitude Nondifferentiated ECG Study (ANDES) project. A non-systematic search was conducted using Pubmed, EMBASE and MEDLINE databases.

Results: Six studies were included, all of which recommended a gradual ascent before competition. The duration of acclimatization ranged from 4 days to 2 weeks depending on the magnitude of ascent. Athletes are encouraged to have pre-ascent assessments of ferritin, transferrin, hemoglobin mass, ECG, and weight with close monitoring of adverse altitude-induced complications.

Conclusion: This study provides insight on key recommendations for athletes and trainers to consider when training and competing at high altitudes. These strategies can optimize athletic performance and mitigate deleterious altitude effects that can hinder functionality and training.

Keywords: Guidelines, Acclimatization, High altitudes, Athletes, Competition, Training

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Introduction:

High altitude training is a popular approach among athletes to enhance their endurance and competitive performance (Grover, 1986). However, studies show that high altitude training can impact short and long-term cardiovascular health (Parodi, 2023). A recent systematic review by Ramchandani et al., explored electrocardiographic changes in individuals temporarily ascending to high altitudes finding notable changes in T wave inversion in the precordial leads, and significant rightward deviation of the QRS complex in the inferior leads (Ramchandani, 2023). Limited consensus among sports regulatory bodies and a lack of recent, large-scale investigations adds confusion for athletes and coaches regarding optimal high altitude training guidelines (Ramchandani, 2024). Acclimatization time is a crucial consideration for athletes and coaches, as it directly impacts performance at high altitudes. Unlike other factors, like diet and training intensity, which can also affect performance but may be more challenging to control, acclimatization time is a variable that athletes can directly influence to optimize their overall health and athletic performance. To date, there is limited literature on ideal acclimatization times and associated considerations for sea-level athletes ascending to altitudes for competition. This paper aims to review existing literature on acclimatization time for competing at high altitudes and suggests a blueprint for athletes and coaches to consider when ascending to high altitudes for competition.

Methods:

While there is no universal classification for altitude levels, in this paper, we use the commonly followed altitude thresholds in the literature: <1500m for low altitude, 1500-2000m for moderate altitude, and >2000m for high altitude (2). This non-systematic review is part of the Altitude Nondifferentiated ECG Study (ANDES) project that aims to uncover electrocardiographic and physiologic changes in populations at high altitudes.

An electronic non-systematic review of the published data was conducted in PubMed, EMBASE, and MEDLINE databases. For each database, representative MeSH terms were chosen for each of the four subtopic categories relating to the scope of our paper: adapting, training, altitude, and humans. MeSH terms chosen for each database and Boolean commands can be found in Appendix 1. Two blinded authors (EM and RA) independently screened the titles and abstracts of the identified papers. First, the relevance of papers based on title and abstract was determined. Selected publications were then further reviewed for relevance using the full text. Disagreement was solved by consensus meetings where discussion between the two reviewers took place. A secondary search was conducted by reviewing the reference lists of the included papers.

Screening identified those papers meeting the inclusion criteria, which included the following: 1) prospective or retrospective investigations for athletic training at high altitudes and pronouncements of professional associations and scientific societies; 2) English language and 3) papers referring to four inclusion themes: a) acclimatization to altitude, b) preparation for altitude training, c) recommendations for training at altitude, and d) adverse effects of high-altitude training. Studies were excluded if the full text was not accessible or if their content did not involve acclimatization to altitude, or pertained to simulated ascent, animal studies or biochemical investigations. Studies were also excluded if they were case reports, systematic reviews, case series, and clinical trials.

The focus of this paper was on consensus statements, position statements, guideline papers, pronouncements of professional associations and scientific societies. These documents are typically developed by reputable organizations and experts in the field, ensuring that the information and recommendations provided are based on current scientific evidence, expert consensus and standardized practices. Furthermore, guideline papers that reference consensus and position statements are more likely to be accepted and adopted by healthcare providers, policymakers, and other stakeholders. This acceptance can facilitate the implementation of recommended practices and improve patient care outcomes. Overall, due to the diversity of sources, the authors opted for a non-systematic approach to provide thorough recommendations by encompassing a broader scope of the existing literature.

Results:

From a total of 1268 references obtained in the first search, 6 documents have been considered for this non-systematic review all of which were prospective observational studies for athletic training at high altitudes and pronouncements of professional associations and scientific societies (Table 1).Based on these recommendations, a blueprint was created for professional athletes to follow when competing at high altitudes (Figure 1).

A key component in training and competing at high altitude is ensuring sufficient acclimatization time, defined as ascending to high altitude and either remaining sedentary or engaging in low-moderate exercise before a competition date (Bartsch, 2008). All included studies recommended an acclimatization period, defined as a preset period of residing at altitude before beginning training or competition. The duration of this period ranged from 4 days to a maximum of 2 weeks depending on elevation above sea level as suggested in Figure 1. For instance, Koehle et al., recommended a no-training based acclimatization period such that athletes should reside, and not train, at the competition altitude for a minimum of 4-5 days to a maximum of one week prior to performance day (Koehle, 2014). Conversely, Bergeron et al. recommend athletes ascend 2 weeks prior to competition, rest for 1-2 days and subsequently resume low-intensity training (Bergeron, 2012). Moreover, Girard et al. recommend a 7-day, 1-2 week and >2-week adaptation period for low, moderate, and high altitudes, respectively (Girard, 2013). However, the exact values delineating these altitude classifications was not specified. Residence at high altitudes beyond 14 days was not recommended due to increased potential for harmful hypoxia-induced hematological consequences, such as excessive erythrocytosis, thrombosis, and hematological hyperviscosity (Girard 2013). In contrast, Constantini et al. suggested engaging in a competition 48-72 hours upon return to sea level, advocating benefit in having competing at sea level after acclimatization to hypoxic high altitude conditions (Constantini, 2017). It was hypothesized that this gives athletes sufficient time to re-establish a baseline homeostasis after a rigorous competition, making them ready for additional physiological strain that may occur during the descent.

To mitigate hypoxia overload, some studies investigated ascent increment. Koehle et al., recommended that for altitudes above 3000m, athletes should ascend 300-600 m/d with a rest day for every 1000m gained (Koehle, 2014). This was supported by Girard et al., who cautioned altitude training above 3000m claiming that slow, incremental altitude changes are needed to control manifestations of extreme hypoxic environments, including high-altitude cerebral edema (HACE) and high-altitude pulmonary edema (HAPE) (Girard, 2013). It was generally supported by all studies that training and competition at low to moderate altitudes required less time for acclimatization (Parodi, 2023).

Studies also suggested pre-ascent considerations. Bergeron et al. suggested baseline ferritin measurement and recommended oral supplementation if levels were under 30 µg/l for women or 40 µg/l for men (Pedlar, n.d.). Baseline measurement of iron stores was supported by Constantini et al., who further suggested a thorough pre-ascent health assessment of co-morbidities and injuries that may make the altitude acclimatization more difficult, similar to the study by Garvican-Lewis et al. (Garvican-Lewis, 2016).

Several of the papers concurrently investigated the live high, train low (LHTL) strategy where athletes reside at high altitudes to stimulate physiological adaptations, such as increased red blood cell production, and subsequently train at lower altitudes. The combination of elevation change allows for optimized performance at sea level by supporting higher-intensity workouts and improved recovery. Koehle et al. emphasizes the effectiveness of the LHTL strategy for enhancing performance at lower altitudes but highlights limited research beyond 2000m (Koehle, 2014). Girard et al. suggest the potential application of live-high train-low (LHTL) approach, particularly in return-to-sport scenarios or to intensify training without imposing additional mechanical load on the musculoskeletal system (Girard, 2013). Constantini et al. suggest optimal training and performance may occur between 2000-2500m and recommends low intensity training at higher altitudes, and high intensity training (Constantini, 2017). Such an approach would mitigate harmful effects of hypoxia on athletic performance and allow for matching of workout intensity with ambient oxygen conditions. In contrast, Bartsch et al. cautions against LHTL, particularly when playing at or near sea level or at moderate to high altitudes due to the incidence of harmful side effects (Bartsch, 2008). Notable effects include High Altitude Cerebral Edema (HACE), High Altitude Pulmonary Edema (HAPE), and polycythemia due to increased oxygen-hemoglobin demand. Other less prominent side effects noted were acute mountain sickness (AMS), sleep fragmentation, dehydration, and muscle soreness. The incidence of these effects varies with altitude, with higher altitudes showing higher incidence rates. While side effects have a low overall incidence, athletes should remain vigilant for their signs and symptoms, as their onset can significantly impact performance, especially in high-stakes competitions.

Discussion:

These studies provide valuable insights into the complexities of altitude training for athletes. The published literature emphasizes the importance of a controlled ascent approach, including a sufficient acclimatization period and appropriate health assessments, to prevent adverse outcomes. In the ascent-based competition blueprint (Figure 1), we recommend starting with a baseline assessment of serum ferritin, transferrin, and hemoglobin mass. Additionally, a comprehensive evaluation of an athlete's past medical history, previous injuries, and baseline electrolytes—specifically, potassium, sodium, and magnesium—is essential. These measures ensure baseline hydration, nervous system regulation, and healthy myocardial activity, all of which can be compromised in hypoxic environments during ascent. Treating abnormalities found from these investigations before ascent can improve tolerability of the altitude for athletes and minimize risk altitude-induced side effects, most notably HAPE and HACE. Importantly however, tolerability cannot be guaranteed as, even with appropriate iron supplementation, some athletes showed hematological adaptation (Stellingwerff, 2019) while others do not (Koiviso-Mork, 2021) Therefore, it is vital to do a comprehensive baseline evaluation prior to ascent to minimize the risk of undetected triggers.

While there is a lack of consensus regarding optimal duration of acclimatization, the suggested results from studies included in this paper ranged from 4 days to 2 weeks. The duration of the acclimatization period was found to depend on the magnitude of elevation. As such, in our blueprint we suggest low altitudes, defined as elevations <1500m, to have an acclimatization period ranging from 4-days to 2-weeks. In contrast, moderate altitudes, defined as 1500-2000m, and high altitudes, being elevations >2000m above sea level, are recommended to have an acclimatization period of 1-2 weeks. During the ascent and acclimatization period, strategies may be employed to ease the hypoxic effect of the high altitude, including exogenous oxygen supplementation, and using training altitude simulation facilities while training or sleeping, the latter of which has debated efficacy.

Finally, apart from pre-ascent testing and ensuring a sufficient acclimatization period, from the findings in the included studies we recommend conducting ongoing assessments of serum ferritin, transferrin and hemoglobin mass alongside oxygen saturation levels, ECG readings and weight monitoring (Pedlar, n.d.). These measurements at peak altitude and during descent can mitigate negative effects of training at high altitudes which include HACE, HAPE, sleep fragmentation, dehydration, and arterial hypoxia. Coaches and athletes should carefully monitor for the onset of these side effects when ascending, acclimatizing, or descending from high altitudes.

The LHTL strategy garnered attention, showcasing its potential benefits for enhancing performance at lower altitudes, but concerns were raised about limited research beyond 2000m. The LHTL approach was also explored for rehabilitation purposes and training intensity optimization with a lack of clinically significant findings and minimal consensus on its effects.

Notable side effects to high altitude exposure, mainly AMS, HACE and HAPE were highlighted, necessitating careful consideration of preventive measures and treatment options. There is debated treatment regimens for these conditions with none showing unequivocal efficacy. Some recommend the use of acetazolamide as first line therapy, or dexamethasone as second line to treat AMS, HACE and HAPE; however, both these medications have been banned during competition by the world anti-doping agency and thus have significant limitations for use by competitive athletes (Eide, 2012). Alternative treatments are sildenafil (Dang, 2024), moderate NSAID use, supplemental oxygen and incremental ascent as suggested by Bartsch et al., though these treatments lack significant evidence for their efficacy (Bartsch, 10). While the blueprint provides a structured approach, it's crucial to recognize that the incidence and severity of side effects can vary significantly among athletes due to differences in training regimens and individual characteristics. Therefore, coaches and athletes should use the blueprint as a guideline and carefully tailor their ascent acclimatization and monitoring based on the athlete's specific needs, the nature of the sport, and the magnitude of ascent. These individual needs, which may include factors such as previous altitude experience, medical history, and physiological responses to altitude, should be assessed and considered prior to ascent (Mallet, 2021). Therefore, while there is significant need for further prospective, randomized, and controlled research in this field to develop high-quality, evidence-based recommendations for athletes training at altitude, Figure 1 proposes a blueprint for athletes and trainers to broadly follow based on the currently existing studies included in this review.

Limitations:

Due to the scope of this paper, it is possible that some relevant papers were missed. The authors tried to be thorough in incorporating relevant references, but there may have been limitations in the capture of literature as this was a non-systematic review.

Conclusion:

Evidence-based guidelines and statements for athletes engaging in altitude training consider factors such as acclimatization duration, ascent increments, and the intricate balance between training intensity and altitude. The six papers included in this non-systematic review recommend gradual and controlled ascent to high altitudes, alongside performing pre-ascent and ongoing evaluations. The findings from the included studies in this review were used to create a blueprint that shows the sequential consideration of factors for athletes or coaches wishing to compete at altitudes above sea levels. The suggested blueprint (Figure 1) can help to better prepare athletes for altitude changes during competition to minimize performance deficits and the onset of adverse side effects. Importantly, even with adopting the blueprint, coaches and athletes must be vigilant of individual athlete variability in metabolism, medical history and physiologic needs to tailor ascent regimens accordingly. Overall, the implications of these findings will help to improve clinical guidelines for high-altitude training and inform future research.

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Acronyms

ANDES: Altitude Nondifferentiated ECG Study

AMS: Acute Morning Sickness

HACE: High Altitude Cerebral Edema

HAPE: High Altitude Pulmonary Edema

LHTL: Live-high, train-low

Legend for Figures

Study author (year)	Recommended acclimatization period	Pre-Ascent Considerations	Observed Side Effects
Koehle et al. (2014)	2-3 days to 1 week	Gradual altitude exposure; oxygen supplementation	AMS; HACE; HAPE
Bergeron et al. (2012)	Arrival 2-weeks prior to competition with rest for 1-2 before commencing training	Baseline serum ferritin and with appropriate correction prn	AMS
Girard, O et al. (2013)	Low altitude (<1500m): 3-7 days; Moderate altitude (1500-2500m): 1-2weeks; High altitude (>2500m): >2 weeks	Evaluation of co-morbidities, previous sports injuries, baseline electrolytes and hydration.	Cardiac arrythmias; Dehydration; Sleep fragmentation
Constantini, K et al. (2017)	Up to 14 days	History of injuries, altitude sickness, and baseline ferratin	Dehydration; Sleep quality; V/Q mismatch
Pedlar, C et al. (2011)	5 days to 4 weeks	Ferritin, Transferrin, and hemoglobin mass	AMS; HACE; HAPE; Sleep fragmentation; Dehydration; Sunburn; Weight loss
Bartsch, P et al. (2008)	Low altitude (<1500m): 3-5days; Moderate altitude (1500-2500m): 1-2weeks; High altitude (>2500m): >2 weeks	N/A	AMS

Table 1: Summary of key findings from studies included in this non-systematic review.

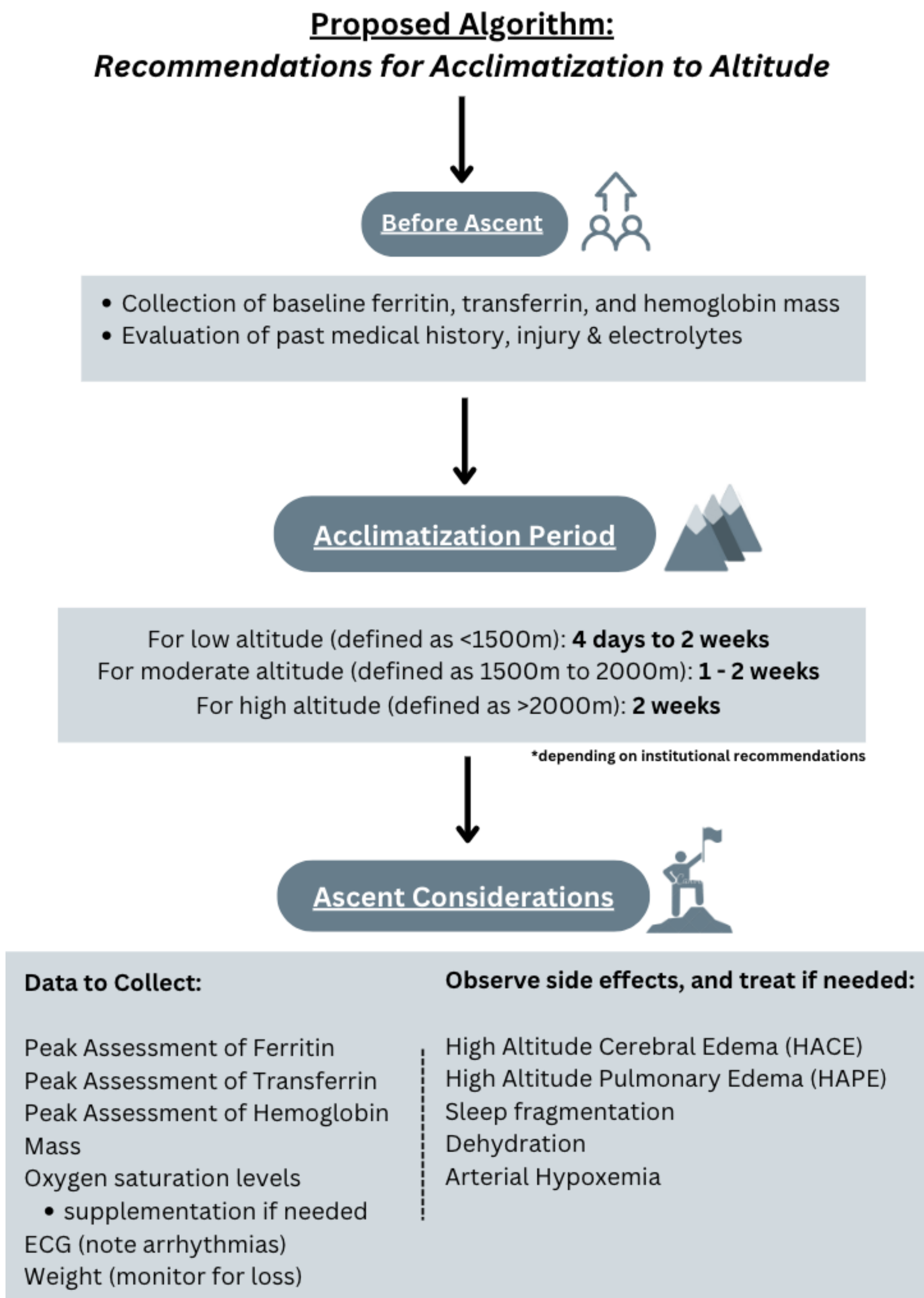

Figure 1: Blueprint for pre-ascent and ascent monitoring considerations with key side effects highlighted relevant for athletes and trainers.