Determinants of Acclimatisation in High Altitude

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Abstract

Background: A total of 31 cases of effects of high altitude were admitted to a field hospital from a particular sector during the year 2008. This study was hence undertaken to see the efficacy of acclimatisation as well as outline the determinants of acclimatisation. **Methods:** The study monitored the transients in the acclimatisation period as well as laid down the guidelines to certify their fitness after the acclimatisation period.

Result: Almost 4.70 % of transients were found unfit to proceed to higher altitudes even after acclimatisation. Tachycardia with oxygen saturation below 90 % by digital pulse oximetry were the parameters found to be statistically significant as an indicator to declare a person as not fully acclimatised or otherwise.

Conclusion: The administrative authorities must ensure that an individual is fully acclimatized, based on the fitness certificates issued, before being dispatched to their units located in high altitude areas.

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Key Words : Acclimatisation; Pulse oximetry; High altitude area

Introduction

The key altitude ranges, as defined by the Indian army, which are used during the acclimatisation schedules in high altitude areas (HAA) for its troops are 2700m - 3600m, 3600m - 4500m and > 4500m. The three stage acclimatisation schedules extend up to 14 days for stage III to reach altitudes > 4500m. Stage I acclimatisation lasts for six days for altitudes ranging from 2700m to 3600m. To achieve stage II and stage III an additional four days each are required, for altitudes 3600m to 4500m and > 4500m. During re-entry to HAA, after 10 to 30 days of absence from HAA, four days at each stage need to be spent. After a break of more than 30 days, full acclimatisation schedule as fresh inductees needs to be followed [1]. The scientific basis of acclimatisation to HAA is to gradually allow the body to adapt itself to the changing oxygen environment by giving complete rest followed by gradually increasing physical effort.

The adverse effects on human physiology below 2700m are quite uncommon, and even if present, are of a mild nature. However, beyond this altitude the effects become prominent, causing serious problems if not adequately tackled. In addition, there is reduction in physical performance. The chances of adverse health effects as well as interference with physical performance increase with increase in altitude. The environmental conditions of HAA which cause these

adverse physiological processes are the lowered atmospheric pressure of air (commonly referred to as “thin air”) and consequent lowered partial pressure of oxygen in the air. This lowering of partial pressure of oxygen, in turn, leads to reduction in availability of oxygen in the blood, thereby triggering off profound physiological changes. Acute mountain sickness (AMS), high altitude pulmonary oedema (HAPO) and high altitude cerebral oedema (HACO) are known conditions affecting troops serving in HAA [2]. Other problems include pulmonary arterial hypertension of high altitude, chronic mountain sickness, high altitude retinopathy, snow blindness and thrombotic episodes. However, the major issues from the operational perspective include HAPO and HACO.

Management of cases of AMS and HAPO have improved over the last several years, yet the mainstay of treatment of effects of high altitude is urgent evacuation to lower altitudes and admission for institutional treatment [3]. A total of 31 cases of effects of high altitude were admitted to our field hospital from a particular sector during the year 2008, pointing to lacunae in the acclimatisation procedures. A study was therefore undertaken to see the efficacy of acclimatisation (at 1st stage) as well as outline the determinants of acclimatisation. Despite clear instructions on the subject, occurrence of such a large number of cases of effects of high altitude was a disturbing trend and hence the study was designed to monitor the transients in the acclimatisation period. As

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the existing guidelines on the subject to declare a person fit or otherwise after acclimatisation are vague, these were required to be formalised.

Material and Methods

A prospective cohort study of all troops reporting to the transit camp (located at a height of 10370 ft / 3142 m i.e. 1st stage of acclimatisation) was conducted over a three month period. They were divided into first entry (FE) i.e., those troops reporting to this HAA for the 1st time and as re-entry (RE), i.e., if reporting after leave or absence of more than 10 but less than 30 days from HAA. The procedure laid down for monitoring of transients in acclimatisation during entry to HAA was recording of routine epidemiological data, specifically pulse, blood pressure (BP) and oxygen saturation (SpO₂) by digital pulse oximetry on 1st day and also on the final day of acclimatisation [4]. On the final day, if the pulse was >100/minute or BP >140/90 mm of Hg or SpO₂ < 90%, these troops were advised an additional extended acclimatisation period of three days. Only if these readings were normal, were the individuals certified to be fit to proceed further to their designated posts.

Two precautionary protocols were observed to improve the reliability of the readings. Firstly, to account for differing levels of prior activity, each subject was seated so as to rest for at least 15 minutes prior to examination. Secondly, it was ensured that fingertips were at body temperature by making everybody wear gloves to prevent low oxygen saturation readings due to vasoconstriction in cold fingers.

Finally, to test for fitness all persons, were subjected to a brisk walk of one km on the 6th day and again their parameters were monitored and statistically analysed.

Results

During the study period there were 278 transients who were FE and 244 RE. Most of the FE troops (97.8%) hailed from the plains while only 2.2% were from the hills (0.72% were Gorkhas and 1.48% from Garhwal) and in the RE group the corresponding figures were 98.8% and 1.2% (from Himachal) respectively. These troops, though from the hills,

were actually settled and domiciles of plain areas. In the FE group there were nine (3.2%) officers, 15 (5.4%) junior commissioned officers (JCOs) and 254 (91.4%) other ranks (ORs) while the corresponding figure in the RE was four (1.7%), 10 (4.1%) and 230 (94.3%) respectively. The average age of the officers in the FE group was 29.4 years, JCOs 38.1 years and of the ORs 24.9 years. The corresponding figures in the RE group was 31 years, 40.04 years and 25.5 years respectively. In the RE group, 114 persons (46.7%) were away for periods ranging from 11-30 days and 26 (10.7%) were away from the HAA for >30 days. Out of the 278 in the FE group, 105 (37.8%) were found to be unfit based on the above mentioned criteria, while out of the 244 in the RE group, 77 (31.6%) were found to be unfit on the 1st day of acclimatisation (Table 1).

On the 1st day of acclimatisation, in the FE group 69.5% were found unfit for tachycardia (pulse>100), with the maximum pulse found to be as high as 157 and a mean of 107.8. Similarly, 28.6 % were hypertensive on initial examination with a mean BP of 145/100 mm of Hg. At 10,000 ft altitude, the SpO₂ drops down from 98-99% at mean sea level (MSL) to about 91-92% [5]. From the cases admitted as 'effects of HAA' (HAPO or AMS), it was noted that in this sector most cases had a mean SpO₂ of 90% or less. The mean SpO₂ level amongst those unfit was 88.3% with 60% being detected to have low SpO₂ levels (Table 2). The corresponding mean values for pulse, BP and SpO₂ for RE group were 110/minute, 146.1/99.2 mm of Hg and 87.2% respectively.

After acclimatisation, the number of personnel considered to be unfit based on the criteria listed above decreased for the RE group, as compared to the FE group.

After undergoing acclimatisation for the prescribed duration, maximum pulse was 126/minute in FE group while it was 130/minute for RE group with a mean level of 102.8/minute and 106/minute respectively. However, the number of persons unfit as on the 1st day had decreased on acclimatisation from 41% to 38%. Similarly those who were hypertensive both in the FE and RE groups had mean values of 144.8/96 mm of Hg and 144.4/92 mm of Hg respectively, but SpO₂ levels had dropped to 76.8% (Table 3).

On analysis of the data of all persons whose parameters were considered in a combination (i.e., pulse >100/minute, BP>140/90 mm of Hg and SpO₂<90%) and were above the baseline recommendations, it was observed that 10.8% were unfit on the 1st day which reduced to 4.7% after acclimatisation. The similar figure for those in the RE group was 2.9% while on acclimatisation it was 0.9% (Table 4). Of the seven (2.9%) who were unfit in the RE group all were ORs and away from this sector for periods > 30 days.

Table 1

Total number of transients monitored

	First entry (FE)	Re entry (RE)
Category	Total (%)	Total (%)
Unfit on 1 st day	105 (37.8)	77 (31.6)
Fit	173 (62.2)	167 (68.4)
Grand Total	278	244

Table 2

Comparison of parameters during acclimatization-First Entry (FE) group

	First entry (1 st day)			First entry (last day)		
Unfit	Pulse > 100/minute	BP > 140/90 mm of Hg	SpO ₂ < 90%	Pulse > 100/minute	BP >140/90 mm of Hg	SpO ₂ < 90 %
Number	73	30	63	43	12	21
Percentage	69.5	28.6	60	41	11.4	20
Average	107.8	145/100	88.3	102.8	144.8/96	86.2

Table 3**Comparison of parameters during acclimatization-RE**

Unfit	Pulse > 100/minute	Re-entry (1 st day)			Re-entry (last day)		
		BP > 140/90 mm of Hg	SpO ₂ < 90 %	Pulse >100/minute	BP >140/90 mm of Hg	SpO ₂ < 90 %	
No	41	20	41	29	12	7	
%	53.2	25.9	53.2	38	15.6	9.1	
Avg	110	146.1/99.2	87.2	106	144.4/92	76.8	

Table 4**Personnel considered unfit based on 'combination of all parameters'**

Category	Unfit	1 st day			Last day		
		Pulse > 100/minute	BP > 140/90 mm of Hg	SpO ₂ < 90 %	Pulse >100/minute	BP >140/90 mm of Hg	SpO ₂ < 90 %
FE	Minimum	100	140/90	80	100	140/90	82
FE	Maximum	157	174/114	90	126	154/106	90
FE	Average	111.7	158.7/100	89	112.7	144/101.4	89
FE	n=30 (10.8%)				13 (4.7%)		
RE	Minimum	100	140/90	81	100	140	84
RE	Maximum	120	152/106	90	108	148	90
RE	Average	116.4	148/100	82	104	144/95	87
	n=7 (2.9%)				n=2 (0.9%)		

On comparison of effects of acclimatisation it is apparent that the parameters considered in a combination have decreased from the initial elevated levels and on statistical analysis, the base line data considered was appropriate, as the observed difference was 'real' (Table 5).

Similarly, it is apparent that for the RE group, parameters have decreased from the initial elevated level after acclimatisation. On analysis, , except for BP, the baseline data was considered statistically significant (Table 6).

To test for the fitness of the troops after acclimatisation, all those reporting for the final check up were subjected to a brisk walk of one km and all the parameters measured. On tabulation of the same it was seen that those in the RE group were better acclimatised (Table 7) possibly due to better physiological adaptation.

Discussion

Effects of HAA results in a great deal of morbidity and loss of trained manpower even in the army despite comprehensive instructions on acclimatisation. In a study on Indian soldiers in the north west Himalayas, Menon et al [6] found the incidence of HAPO to be 5.7/1000. This is due to the fact that the hallmark of treatment of HAPO is rapid descent to lower altitudes for better oxygenation and institutionalised treatment leading to long periods of absence [3]. Despite men in the army having a healthier physique than their civilian counterparts, it has been noted that physical fitness has no bearing on the development of HAPO [7].

High altitude term is used for heights above 1500m, but in medical parlance it is more defined and is based on alterations in human physiology. From 1500m to the summit of Everest (8850 m), there are three different

Table 5**Parameters on acclimatisation-FE group**

Parameter	t values*	d.f	Significance
Tachycardia	3.52	41	p<0.001
Systolic BP	5.2	41	p<0.001
Diastolic BP	4.7	41	p<0.001
SpO ₂	13.7	41	p<0.001

*Unpaired student's t-test

Table 6**Parameters on acclimatisation-RE group**

Parameter	t values*	d.f	Significance
Tachycardia	4.80	9	p < 0.001
Systolic BP	0.71	9	Not significant
Diastolic BP	0.8	9	Not significant
SpO ₂	5.6	9	p < 0.001

*Unpaired Student's t-test

altitude levels with different physiological reactions occurring at each. Low-level dwellers are optimally equipped for existence at normal air pressure of 760 mm of Hg and an oxygen concentration of 21%. With increasing altitude, though the concentration of oxygen remains the same, the atmospheric pressure decreases and with this the partial pressure of oxygen falls. This means that the number of oxygen molecules per breath is greatly reduced and this, in turn, reduces the amount of oxygen available to the blood and tissues in the body [8].

It was noted that when exposed to high altitude hypoxic environments, the body makes several adaptations over time. These acclimatisation responses

Table 7

Test for fitness on acclimatisation

	FE - after 1 km brisk walk			RE - after 1 km brisk walk		
	Pulse > 100/minute	BP >140/90 mm of Hg	SpO ₂ < 90 %	Pulse >100/minute	BP >140/90 mm of Hg	SpO ₂ < 90 %
Number	25	12	13	16	5	4
Percentage	24	11.4	12.4	21	6.5	5.2
Average	108	150/100	84	101	144/94	90

can take many forms. More red blood cells (RBCs) are produced to carry oxygen. The lungs increase in size to facilitate the gaseous exchange of oxygen and carbon dioxide. There is also an increase in the vascular network within muscles, which enhances the transfer of gases. On arrival at higher altitudes, there are a number of physiological changes also that occur, which enable the body to function optimally in the low oxygen environment, known as acclimatisation. The initial and most important adjustments are an increase in the frequency and depth of breathing. This begins to occur at altitudes of about 1500m. The heart pumps faster and BP rises. RBC production increases, resulting in an increased haemoglobin concentration, which is required to pick up oxygen and transport it around the body. These mechanisms are to ensure increased oxygen delivery to cells and efficiency of oxygen use.

Rupwate et al [10] demonstrated a rise in BP (systolic at lower and diastolic at greater altitudes) on the members of the Himalayan expedition (2001) which was attributed to incomplete acclimatisation.

Study on a group of climbers at 3,600m during an expedition to the Bolivian Andes found that acclimatised subjects could maintain their SpO₂ during prolonged exercise better than non-acclimatised subjects. The pulse rate of acclimatised subjects was consistently lower at the same work level than that of non-acclimatised subjects. Acclimatised subjects were able to reach higher levels of exercise than when they had first arrived at the HAA which implies that acclimatisation improves the delivery of oxygen to the tissues and those not adapted suitably suffer from effects of HAA [11].

During the year 2008 there were 31 cases of effects of HAA admitted to the hospital including one officer, out of which HAPO constituted 63.3%. Of the 19 cases of HAPO four (21.1%) cases occurred within 72 hours of induction to the 1st stage of acclimatisation, and five (26.3%) cases reported within 35-64 days of arrival at their unit areas (3800-4300m). Bhalwar et al [12], in a related study, found the latent period of occurrence of HAPO cases at 3600m to be 6-96 hours. Furthermore, it was noted that 15 (78.9%) cases were RE while only four (21.1%) were FE, in conformity to the existing trend [13]. Of the 15 RE cases, 09 (47.3%) cases were away for periods ranging from 10-30 days and on perusal of

the acclimatisation details it was seen that all of them were incompletely acclimatised (deinducting to lower altitudes during acclimatisation / proceeding to 2nd stage location after 1-2 days of acclimatisation etc), highlighting the need to be more stringent in monitoring the acclimatisation schedule being followed by all troops. No false sense of bravado should be associated with quick / incomplete acclimatisation.

In the FE group in this study analysis of the data of all persons whose parameters were considered in combination (i.e., pulse >100/minute, BP>140/90 mm of Hg and SpO₂<90%), the observed difference was 'real' while in the RE group, tachycardia and SpO₂<90% was enough to label a person as acclimatised or not. The discordant parameters (like elevated BP) for both these groups is due to the physiological changes of acclimatisation which have set in [8].

Some suggested administrative measures which could be incorporated to ensure full acclimatisation are:

- The Officer Commanding of the transit camp (where the transients stay for acclimatisation) should be the only person empowered to issue movement orders to all ranks so that everybody is fully acclimatised before proceeding to HAA, as 47.4% of the HAPO cases were those who had proceeded to HAA/lower levels during the acclimatisation period for various unit related duties (and returned periodically before the final day of acclimatisation), thereby negating the beneficial effects of acclimatisation.
- Second and third stage of acclimatisation should be given equal importance. Five persons suffered from HAPO on reaching a height of 13000 ft as they were immediately put on various duties before completing the 2nd stage of acclimatisation.

This study provides a database on acclimatisation and an insight into the parameters to be monitored. Though there are explicit instructions on acclimatisation at various altitudes, there are no guidelines to evaluate the efficacy of acclimatisation or to confirm whether a person is fully acclimatised or not. Commanders at all levels should be sensitized to this pressing issue as in our study there were 8-12% defaulters who had not been properly acclimatised and hence were at risk of

suffering from HAPO. The present study demonstrates the benefits of acclimatisation and provides the baseline values to declare a person as unfit to serve in HAA i.e., pulse >100/minute, BP >140/90 mm of Hg and $SpO_2 < 90\%$ for those ascending to HAA for the first time and tachycardia with $SpO_2 < 90\%$ for re-entrants [14]. The existing acclimatisation schedule is a time tested one and very effective if followed stringently, as was seen by the spurt in cases of effects of HAA during various operations carried out by the army in HAA when rapid induction of troops was warranted.

The limitations in this study were a few factors like respiratory rate, smoking, recent history of upper respiratory tract infections, exposure to severe cold etc. which were not taken into account and this may possibly have had an effect on the outcome.

Conflicts of Interest

None identified

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