ORIGINAL ARTICLE

Survival adaptation in Everest: Metabolic response during acclimatization in lowlander and sherpa climbers

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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Abstract

Background and Study Aim: There is no comparative data on the metabolic and hematologic response in lowlander and sherpa climbers during step-by-step acclimatization to extreme altitudes. We are going to evaluate the response of sherpa and lowlander climbers in Everest base camp (BC) conditions.

Meterial/Methods: Group 1 (12 lowlanders climbers); group 2 (6 sherpa climbers); group 3 (6 persons in BC). The laboratory was set up in BC, capillary blood samples were taken every week for two months from each participant and 24 blood parameters were measured.

Results: The group 2 had lower urea level and higher level of CK compared with group 1. Glucose, triglycerides and cholesterol profile were relatively stable in group 2. In group 1, triglycerides and total cholesterol began to decrease significantly after five weeks of acclimatization. Mg^{2+} increased drastically at the end of the study only in group 1, whereas Ca^{2+} increased drastically in week 7 in both experimental groups. The initial HCT and hemoglobin were lower in group 2. HCT increased, hemoglobin did not change and MCHC decreased in all groups. Granulocytes and platelets increased in group 2.

Conclusions: The sherpa climbers responded with lower level of protein catabolism, increased levels of CK, stable levels of energy substrates, Mg^{2+} and increased polycythemia.

Key words: blood parameters • acclimatization • extreme altitude • Everest • sherpa climbers

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Blood parameters – amounts of different components in a given unit of blood.

Extreme altitude – above 5500 m (near the limit of human tolerance).

Acclimatization – the physiological adaptation of an organism to changes in climate or environment, such as light, temperature, or altitude.

Background

Several studies related to human metabolic adaptation to **extreme altitudes** (>5000 m) during **acclimatization** were carried out with the participation of professional mountaineers. The place most visited and best known to climbers is **Everest** base camp (BC) (5200 m) where, during 2 months (April-May), there are up to 100 climbers and support staff assembled. There are two high-altitude native populations (sherpas) involved in supporting the climbers in BC: 1) **sherpa climbers** who arrange the ascent route and accompany foreign climbers during acclimatization to extreme altitude, 2) sherpas who work only in BC.

Intermediate camps were established (at 6000, 7000 and 8000m) and acclimatization included a series of ascents-descents ("step-by-step acclimatization"): to sleep one or more nights and return to BC. Various aspects of metabolic adaptation to the extreme altitude were investigated [2,6,9,15–17,24.25] during acclimatization. In most studies, measurements were made before and after a certain period. We didn't find studies that compared the metabolic response in lowlander climbers with sherpa climbers during the acclimatization to extreme altitude. So the idea of this work is to evaluate the possible differences in metabolic responses between these two groups of climbers during the two months of acclimatization in Everest BC conditions comparing it

Everest – the highest mountain in the world. 8848 m. (29,028 ft). The mountain is located on the border between Nepal and Tibet, in the Himalayas.

Sherpa climbers – members of a Himalayan people who are skilled mountain climbers and who are often employed as guides by visiting climbers.

with the response of people who remained in the base camp all the time.

Material and Methods

Participants

The data on the participants (all men) who completed the study are presented in Table 1. Group 1 was formed by lowlander climbers, group 2 by sherpa climbers and group 3 (control group) by 3 sherpas cooks and 3 foreigners who remained all the time in BC (all of them were native to 2000–2800 m altitude). The presence of the control group was determined by the necessity to evaluate the metabolic effects of a long stay at the BC altitude (5200 m) that includes the effect of negative energy balance produced by a decreased caloric intake.

Table 1. Participants data.

	N	Years	Weigth kg
Gruop 1	12	42.9±7.1	73.8±11.5
Gruop 2	6	35.2±5.9	71.3±6.8
Gruop 3	6	38.3±5.7	73.9±7.3

All participants were informed of the objectives and characteristics of the study. Written informed consents were obtained from them.

The mountaineers of the experimental groups (1 and 2) had a similar acclimatization pattern to extreme altitude. Before coming to BC, the study participants had remained a week in Katmandu (1300 m) on average, and then for 4–7 days walked about 90 km (up-down) from the altitude of 2800 m (Lukla) to 5200 m (BC). That means that, in the BC, everyone came to a certain degree of acclimatization accelerated by the aerobic exercise. All the participants reached an altitude of 8000–8300 m during the acclimatization. Finally, 5 climbers in group 1 and 4 in group 2 managed to climb the summit (8848 m). All participants were fed similar rations in the same dining room at BC. They consumed mainly carbohydrates (approximately 80%) with little protein especially eggs, the daily calorie intake was about 2500 calories a day.

Samples and processing

A laboratory was set up in a tent in BC with two equipments for complete blood analysis: photometer Microlab 200 (with temperature control in the measuring cell and measuring 1 cm cuvette – 30 μl), QBC equipment (Becton Dickinson) and micro centrifuge. RANDOX reagent were used for biochemical measurements (16 parameters) and QBC capillary for the determination of 8 hematologic parameters as hematocrite (HCT), hemoglobin (HB), ratio HB/HCT (MCHC), platelets, total leucocytes (WBC) concentration, granulocytes and agranulocytes (lymphocytes + monocytes) in capillary blood.

The energy was obtained from rechargeable batteries with a gasoline generator. The technique developed for monitoring of elite athletes was used: samples of capillary blood (finger) were drawn in BC in the morning in a fasted state every week during the 8-week study (in case of group 3) whereas in the experimental groups we drew samples immediately after the descent from the intermediate camps (normally in the morning). The samples were processed the same day. The air temperature was between 0°C and 10°C during the day and at night reached –10°C, that is why photometers and reagents were kept at night in the tent of the researcher (0°C). We tried to process the samples at noon when, with the sun, the temperature inside the laboratory increased to 15°C. The initial level corresponds to the measurement made during the first week of April (while still fasting) when all participants arrived at BC. The descriptive statistics and variance analysis (Student's t-test) were used to analyze the results (SPSS Statistic program).

Results

Figure 1 shows the altitude dynamics of the two most experienced mountaineers: in group 1 (A) and group 2 (B) during the two months of acclimatization. The other climbers from both groups had similar dynamics of acclimatization depending on their experience. A lower performance corresponds to a shorter permanence in medium altitudes. As we see, the entire acclimatization period included three stages: adaptation to 6000–6500 m altitude in the first two weeks, to 7000–7500 m in weeks 3–4, and to 8000–8500 m in weeks 5–6 to return to BC or lower (3900 m in weeks 6–7) before making the final attempt at the end of May.

The frequent ascents of sherpa group in the first weeks were related to the preparation of the climbing route (before 6000 m), which included putting up aluminum ladders and ropes for support. In general, the dynamics of acclimatization were similar in both groups.

The urea response (A) and creatine kinase (CK) activity (measured at 25°C) (B) are presented in Figure 2. The urea level increased in group 1 and decreased rapidly in group 2 from the second week. The changes in urea concentration during acclimatization were not significant in either group compared with the initial level. Neither significant difference with the other groups nor changes during acclimatization (32.6±2.7 mg/dl) were observed in the control group.

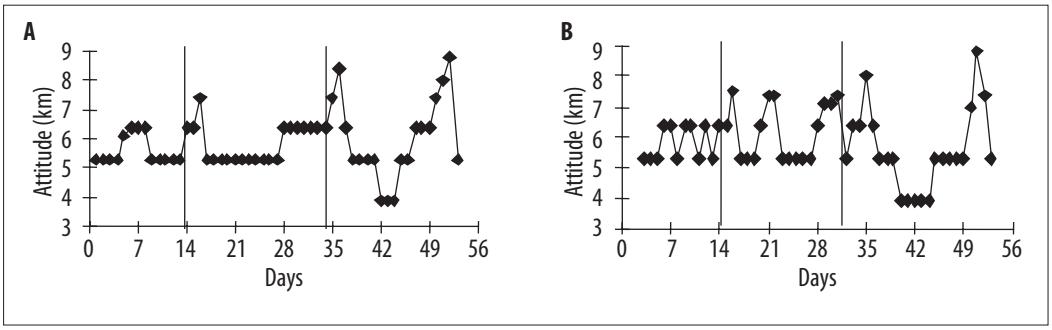

Figure 1. Dynamics of step-by-step acclimatization of experimental climbers groups ((**A**) – lowlander climbers and (**B**) – sherpa climbers).

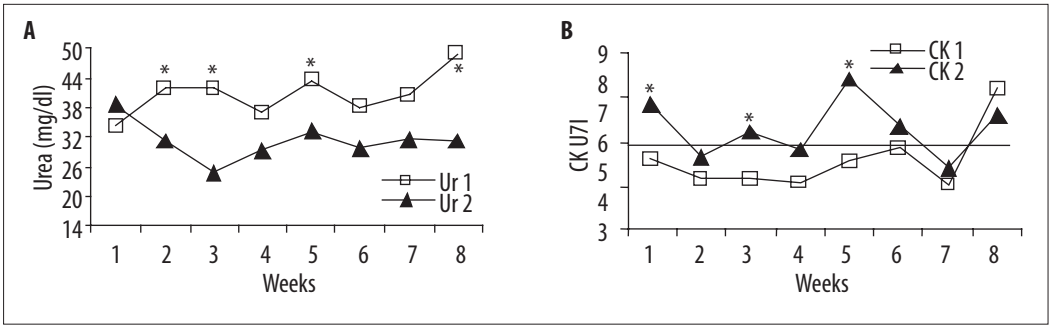

Figure 2. Changes of urea concentration (**A**) and activity of CK (**B**) during acclimatization in experimental groups. * p<0.05 (between groups).

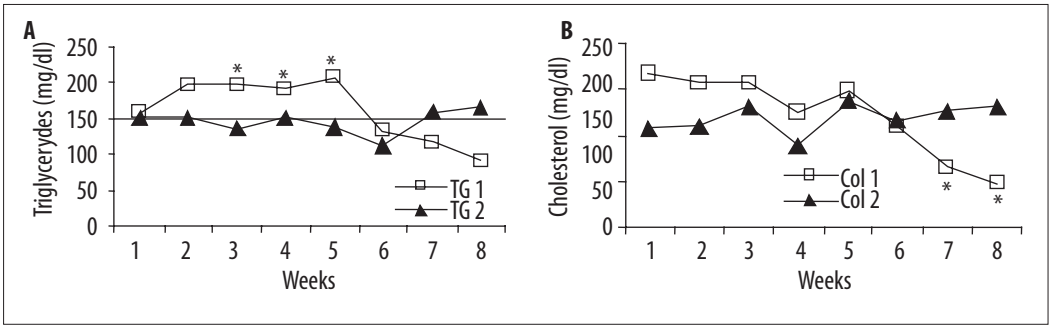

Figure 3. Changes of triglycerides (**A**) and cholesterol (**B**) concentrations during acclimatization of experimental groups. * p<0.05 (between groups).

In group 1, CK activity decreased (Figure 2B) and in group 2 CK levels were all the time above 70 U/l. During acclimatization, a significant difference ($p<0.05$) with the initial level of CK was observed only in group 2 in week 4. In the control group, changes during acclimatization were not significant (78.5±14.0 U/l) and there was no difference with the experimental groups.

Another marker of muscle damage (lactate dehydrogenase activity, LDH) showed no significant difference between groups or compared to the initial level in each group (277±40; 263±56 and 262±34 U/l in groups 1–3 respectively).

The concentration of glucose did not show differences between groups (79.0±6.7; 74.6±5.6, 77.0±3.4 mg/dl respectively) but showed a tendency to decrease in the experimental groups in the last three weeks (data not presented). The concentration of triglycerides (TG) (Figure 3A) was significantly greater in group 1 compared with group 2 in weeks 3–5. There was not any significant difference in the experimental groups compared with initial level, but in group 1 there was a decrease in the last weeks which was significant ($p<0.05$) in weeks 7 and 8 when compared to week 5. No differences were observed in TG levels between control (150±20 mg/dl) and experimental groups during acclimatization.

The total cholesterol level was significantly lower in group 1 than in group 2 in the last two weeks (Figure 3B). There were no significant changes of cholesterol in the control group (248±16.8 mg/dl) but the level was significantly

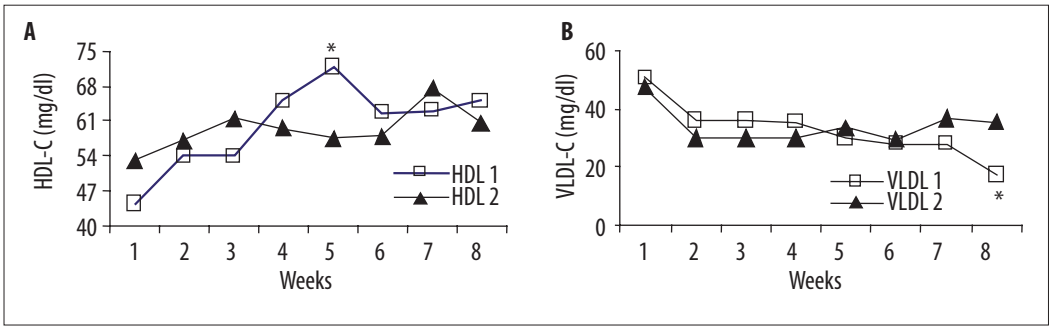

Figure 4. Changes of HDL-C (**A**) y de VLDL-C (**B**) during acclimatization in experimental groups. * p<0.05 (between groups).

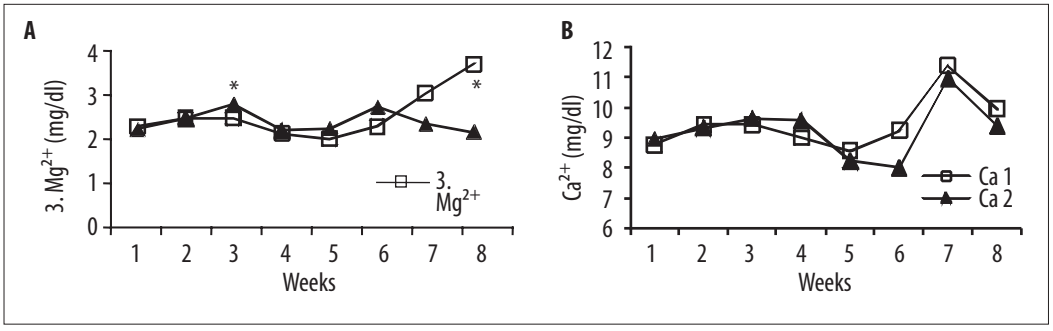

Figure 5. Changes of Mg^{2+} (**A**), Ca^{2+} (**B**) concentrations in experimental groups. * p<0.05 (between groups).

higher compared with groups 1 and 2 (p=0.004 and 0.001 respectively) (data not presented). No differences in LDL-C levels were observed either between any of the groups (128±38; 124±39 and 143±16 mg/dl, in groups 1–3 respectively) or during acclimatization.

HDL-C increased in group 1 compared with the initial level (p<0.05 in weeks 3, 4, 6 and 7). In group 2 and 3 (62±5.6 mg / dl), the changes in HDL-C were not significant.

VLDL-C decreased in both groups (Figure 4B) without changes in the control group (42.6±4.5 mg/dl). Consequently, the proportion (LDL + VLDL)/HDL decreased gradually (p<0.05 from week 3) in group 1, and did not change in group 2 (2.7±0.9) or in the control group (3.1±0.4). Only the initial level of this ratio was higher in group 1 (4.3, p<0.05) compared with group 2 (2.8) and the control group (2.7) (data not presented).

The level of total proteins did not change in any group (7.5±0.4, 7.6±0.3 and 7.4±0.5 g/dl respectively) during the study. The protein profile did not change in group 2 or in the control group. But in group 1, compared with group 2, albumin was higher (5.9 vs. 5.2 g/dl, p=0.033) and globulin lower (1.8 vs. 2.8 g/dl, p=0.068). (data not presented).

In group 2 during the first three weeks of acclimatization, there was an increase of Mg^{2+} that was significant in week 3 (p<0.05) whereas no change were observed in group 1(Figure 5A). But from the seventh week on, there was a significant increase only in group 1, reaching 3.8 mg/dl which is outside the normal range. In the control group there were no significant changes during the study (2.3±0.3 mg/dl).

The Ca^{2+} (Figure 5B) was a decrease in both groups that was significant in week 5-6 in compared with week 3 (p<0.05). But the level of Ca^{2+} increased dramatically in the seventh week (p<0.05) in both groups reaching the peak 11 mg/dl (outside the normal range). It is noteworthy that in week 7 there were two cases with a level of Ca^{2+} higher than 13 mg/dl in group 1 and higher than 15 mg/dl in one of the sherpas of group 2. There was also a significant increase of Ca^{2+} in the control group (p<0.05) in week 7, but in lesser degree (10 g/dl, within the normal range). That is, the increased Ca^{2+} level in 7th week were caused by the stay in BC and the acclimatization process. There was no significant change in the concentration of Cl^{-1} and inorganic phosphorus in any group during the study, except a lower level of Cl^{-1} in group1 compared with group 2.

The level of HCT increased in both experimental groups (p<0.05 from week 4), but in group 1 it was higher throughout the study (Figure 6A). HCT response in the control group was similar to that in group 2. Then, the increase of HCT in the experimental groups was determined mainly by the stay at BC altitude.

Only the initial level of HB was significantly higher in group 1 (18.5 vs. 16.4 g/dl, p<0.05) compared with group

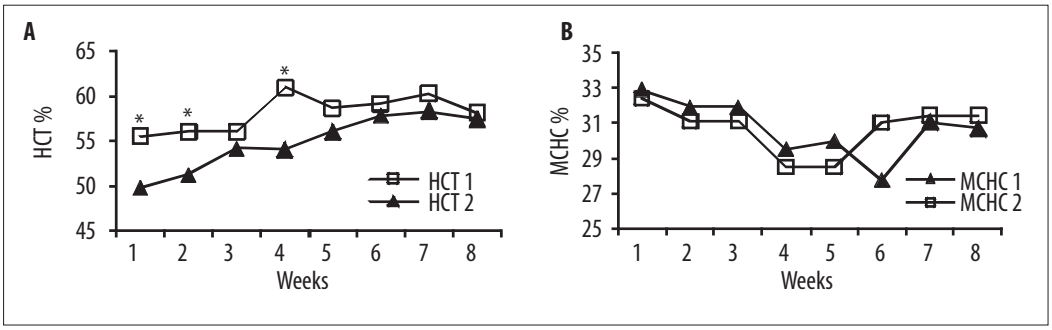

Figure 6. Changes of HCT (**A**) and MCHC (**B**) in experimental groups. * p<0.05 (between groups).

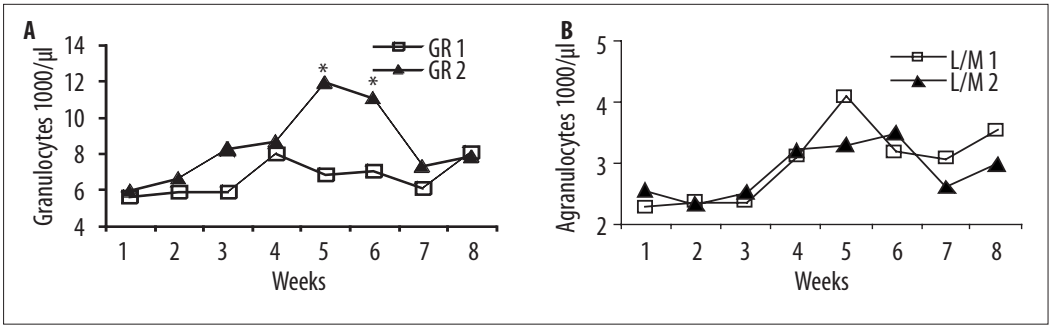

Figure 7. Changes of granulocytes (**A**) and agranulocytes (**B**) in experimental groups. * p<0.05 (between groups).

2. During acclimatization HB changes were not significant in all groups compared with initial levels (data not presented). The MCHC decreased significantly until week 5 in experimental (Figure 6B) and control group that means that changes in MCHC were determined by the long stay in BC.

The level of granulocytes increased moderately in group 1 (Figure 7A) and control, whereas in group 2 the increase was greater than in group 1:11700 vs. 8040 in week 5 ($p<0.01$ in weeks 5 and 6), confirming that increase in granulocytes in group 1 was mainly determined by the long stay in BC and the granulocyte drastic increase in group 2 was caused by step-by-step acclimatization.

The level of agranulocytes (Figure 7B) increased in both groups and was significant only in group 1 ($p=0.03$, 0.058 and 0.06 in weeks 4,5 and 7) without difference between groups. In the control group, there were no significant changes in this parameter during the study (3000±300/μl), confirming that the mentioned increase was caused by step by step acclimatization. The initial level of platelets was greater in group 1 compared with group 2 (440±53 vs 328±23 1000/μl). No significant changes were observed during the study in group 1 and control group, whereas in group 2 it was observed a gradual increase (590±124 vs. 300±178 1000/μl in group 1.

The interpretation of measurements in serum was hampered by the possible change in plasma volume during the two months of acclimatization. Several studies show that during acclimatization, at altitudes of 3500–4500 m plasma volume decreases in men by 20–25%. Half of this decrease occurs within the first 24 hours and continues to decline for a month to stabilize in the following month [18,20]. In our study, the climbers spent about one week in Kathmandu (1300 m) before coming to BC, and, later, they had one week of strenuous walk from Lukla (2800 m) to BC (5200 m). Then, there was a two week period of active pre-acclimatization including prolonged aerobic exercise. We expected that, for that reason, the change in plasma volume did not exceed 5% during the stay in BC. The absence of significant changes in hemoglobin and total protein in all groups during acclimatization confirmed this assumption. In this case the increase of HCT was probably related to the increase of erythrocyte mass and not with changes in plasma volume [18,20].

Discussion

Highlander sherpas have greater prevalence of red fibers (60% vs. 50% in lowlanders) [14], decreased fiber cross-sectional area, mitochondrial volume density and the level of intramuscular TG [11]. It has also been shown that they have a metabolic regulation that favors the use of carbohydrates as energy sources [10,11]. It was, probably, for this reason that the parameters of fat in the blood of the sherpas in group 2 were relatively stable during acclimatization. Several studies showed that, in lowlanders, during prolonged altitude acclimatization over 4000 m, the importance of blood glucose as energy source also increases [5.6,21].

The stability of TG and total cholesterol in group 2 during acclimatization and in group 1 during the first half of it coincides with the well known decrease in the use of fat for energy production [5,10.11,21], but the drastic decrease of these parameters in the last three weeks in group 1 showed possible activation of the use of fat in the energy process in this period. Levels of HDL-C and VLDL-C in group 1, on the contrary, changed in the first half of acclimatization and stabilized in the second part, which indirectly supports our assumption.

In this study, fasting glucose presented no significant changes during acclimatization or between groups and showed a tendency to increase during the 6 weeks of acclimatization which is consistent with data from two other studies [5,11]. But there was a decrease in the last two weeks in group 1, which coincided with data from another study [4] where glucose was measured at 9 lowlanders at sea level and after ascent to Everest. This decrease of glucose coincided with a decrease in the parameters of fat in the same group, and indirectly confirms our assumption about the stimulation of the use of fat as energy supply in group 1 from week 5.

Throughout the period of acclimatization, climbers in group 1 had a higher level of protein catabolism compared with group 2, although the physical workload in the first weeks was higher in group 2. By contrast, the level of CK activity – reflecting muscle damage and probably the muscle membrane permeability – was higher in group 2. It is rather unlikely that the high urea level in group 1 reflected muscle destruction as part of the body weight decrease due to hypoxia [19,22] because the muscular enzyme CK activity decreased.

Up to 30% of the total weight decrease was related to the destruction of muscle tissue determined by hypoxia and by low caloric intake in BC [7,22]. This may mean that the decreased protein catabolism in sherpa climbers during acclimatization reflects a better metabolic adaptation to altitude and low caloric intake. These data support the assumption of other authors about the direct effect of severe hypoxia on protein metabolism [8]. In a recent study [4], after acclimatization in Everest BC, it was not observed a significant increase in cortisone in lowlander climbers but it was observed a significant decrease in testosterone. It is likely that imbalance in these two hormones is the reason for the high protein catabolism in group 1. But the basal levels, in the aforementioned study, were measured at sea level making it difficult to interpret the results and to compare them with our study.

The interpretation of the parameters of CK as the only indicator of muscle damage can not explain the changes in the opposite direction in urea concentration and CK activity in blood of group 1 compared with group 2. We observed changes in the opposite direction in CK and urea during the monitoring of top athletes in endurance sports when maximum training loads were applied (unpublished study). When urea level was low and CK activity was high the athlete felt subjectively better than in the opposite case. We supposed that the increased CK level reflects in significant part the elevated muscle membrane permeability and consequently the better interchange cell-blood of small molecules with decrease in protein catabolism.

A tendency to the increase in Mg^{2+}, Ca^{2+}, Cl^{-1} and inorganic phosphorus was observed during the first 3 weeks of acclimatization only in group 2 and it was significant in the case of Mg^{2+}. The concentration of Mg^{2+} in group 1 in the last two weeks increased drastically while in group 2 their levels were stable. That is, at an altitude greater than 8000 m dramatically increases the level of Mg^{2+} in lowlander climbers. We found no data about the behavior of Mg^{2+} at extreme altitudes. According to one study [13], the concentration of Cl^{-1} increases moderately during acclimatization. In our study, there were practically no changes during acclimatization in any group. Only in group 1, chloride had significantly lower levels than in group 2 in some weeks during acclimatization.

We assume that our data are the first ones about the response of Ca^{2+} during acclimatization to extreme altitudes and Ca^{2+} levels increased drastically and similarly in both experimental groups in week 7 (after elevating to 8000 m). It seems that more than 8000 m altitude causes an excessive release of Ca^{2+} in muscle and consequently in blood. The Ca^{2+} has a crucial role in muscle contraction and stimulation of glycogenolysis in muscle. As the decrease in fat parameters in group 1 coincided with a significant decrease in Ca^{2+} it is likely that the decrease in the level of Ca^{2+} depressed glycogenolysis and consequently stimulated the use of fat in this group.

Most studies on the response of the electrolytes during acclimatization were devoted, to measure the response of potassium, sodium, aldosterone, and showed the strong effect of extreme altitude on the balance of electrolytes. It is assumed that the decrease of aldosterone is, with the decrease of potassium, the principal mechanism of development of pulmonary or cerebral edema [1]. As we see, a drastic change in the electrolytes measured in this study was seen mainly in altitudes higher than 8000 m.

The initial level of HCT was significantly higher in group 1 during the first 4 weeks compared with groups 2 and

3, this confirms that the sherpas are adapted and economize the use of oxygen during acclimatization. The HCT increase and the MCHC decrease were mainly determined by the stay at BC altitude. The average initial level of HB was lower in group 2 and all along remained below group 1 level; this coincides with a study showing that the natives of the Himalayas have a lower HB level (two digits) than the natives of the Peruvian Andes and the native lowlanders living at altitude [3]. In response to acclimatization to the altitude of 8000 m in the group of sherpa climbers the polycythemia was stronger than in the lowland climbers group, especially in regard to granulocytes and platelets. The increase of agranulocytes was similar in both experimental groups and there was no change in the control group. In most studies the stability of leukocytes and platelets has been observed, but they have been carried out at lower altitudes of 4500 m, with relatively short residence times and with people not trained in mountaineering [12,23].

Conclusions

Differences in metabolic response between the experimental groups are:

1. The response of energy substrates in the blood was stable in the sherpa climbers while there are signs of stimulation of fat metabolism in the Lowland climbers from week 5.

2. The level of protein catabolism was significantly lower in sherpas during the acclimatization period while the activity of the muscle enzyme CK was higher than in the lowlander climbers.

3. The adaptation to altitudes over 8000 m causes a drastic increase in Mg^{2+} only in the lowlander climbers.

4. The polycythemia in response to the ascent to 8000m was higher in the sherpa climbers.

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