Deacclimation Period in Ventricular Function after High Altitude Expedition

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Summary Day-by-day changes in ventricular-ejection time/heart-rate ratio (VET/HR) and in ejection time index (ETI), determined by an impedance method in a decompression chamber, were more labile in the mountaineers who had experienced high altitude (above 6,000 m) within the past 1 year, and the ETI values in the first hypoxic exposure were significantly high in these subjects, though close to those of the non-experienced group in the later exposures, suggesting that the effect of hypoxic acclimation on cardiac function might remain at least 1 year after return to sea level.

Key words: hypoxia, deacclimation, ventricular function.

Many reports have suggested that several months are needed for hypoxic deacclimation, particularly in the pulmonary function of rats (see references cited by FRIED and REID, 1984) and also in man (FORSTER *et al.*, 1971; MASUYAMA *et al.*, 1986), with earlier recovery in the hematological changes. For cardiovascular function, on the other hand, such long-term studies are lacking, though some parameters in man seem to recover within several days after descent from high-altitude stay (VOGEL *et al.*, 1967; BALASUBRAMANIAN *et al.*, 1978), and rats with cardiac hypertrophy induced by intermittent exposure to simulated high altitude showed the regression with a half-time of about 7 days (SIZEMORE *et al.*, 1973). In this study, we compared the ventricular function of the mountaineers who had made high-altitude expeditions at different periods before the present experiment, with those who had never experienced them.

The 18 volunteer test subjects were male, aged between 22 and 40. Sports activities had been frequent, though less so than in athletes. Nine had experienced high altitude above 6,000 m prior to the experiment—3 months before in 2 subjects; 1 year before in 5; and 2 years before in 2—while the other 9 subjects had no high altitude experience.

All of the subjects were exposed stepwise to increasing simulated altitudes in a decompression chamber, usually in 1,000-m steps from 3,000 (0.69 ATA) to 7,000 m (0.40 ATA). The total exposure time was 4 to 5 h a day. The similar experimental protocol was applied to each subject for 4 to 5 days successively. In these experiments in the decompression chamber, subjects' safety was assured by an observer who wore an oxygen mask inside the chamber and by other routine monitorings described elsewhere (MORI *et al.*, 1982).

Ventricular ejection time (VET) and heart rate (HR) at rest and in exercise, both in a sitting position, were measured at each altitude by the impedance method of Kubicek (KUBICEK *et al.*, 1966). An impedance plethysmograph (Nihon Kohden, AI-600G) was paired with a differentiator (Nihon Kohden, EC-600G). The exercise load imposed was of moderate intensity (300 and 600 kp · m for 4 min each in most cases) by a bicycle ergometer (Monark, Sweden). This moderate exercise at sea level (0 m) often exhausted subjects above 6,000 m (0.47 ATA), resulting in suppression of the maximum heart rate (MORI *et al.*, 1982, 1983). Since the mechanism of suppression is not known, only the data under 6,000 m in altitude were collected in the present study. Accordingly, 6–12 points of the measurement were obtained for each subject in each exposure.

A linear inverse relationship between VET and HR for each subject in each exposure was well maintained with the correlation coefficient above 0.9, as exemplified in Fig. 1, implying no direct effect of acute hypoxia on this relationship. The parameters examined were a slope (VET/HR ratio) of the regression line and an ejection time index (ETI), i.e., an estimated VET value at zero of HR for the regression line. The ETI has been often referred to as a valuable parameter to describe heart function, since its constancy and reproducibility were found by WEISLER *et al.* (1963) in normal adults and children. Stability of these values in each subject and day-by-day changes of the values were compared between the subjects who had and those who had not experienced high altitude.

In Fig. 2, the variation of VET/HR ratio (○ linked vertically) is paired with that of ETI (● linked vertically) for each subject against the respective scale, arbitrarily arranged for easy comparison. The findings from the figure are as follows. Firstly, the values are relatively steady throughout the experiment for each subject who had not experienced high altitude (NE group in the figure), although they often differ from subject to subject. Secondly, when the values of VET/HR ratio disperse widely, the ETI values show a similar scatter in the same subject, suggesting that the slope factor (VET/HR ratio) may be an effective determinant of ETI in the present experimental condition. Thirdly, both parameters dispersed significantly more (*t*-test, $p < 0.05$) in the group in which the subjects had experienced high altitude one

Fig. 1. Determination of VET/HR ratio and ETI. An inverse relationship between VET and HR in the 4th hypobaric experiment for subject 001 is exemplified. The regression equation is for data below 5,000m (○). Although points for above 6,000m (●) fit the equation well, they were discarded in the present analysis; the reason is given in the text. r , correlation coefficient. SD, standard deviation.

Fig. 2. Variation of VET/HR ratio (○ linked vertically) and ETI values (● linked vertically) for subjects who had never experienced high altitudes (NE), those who had experienced them 3 months before (3M), 1 year before (1Y), and 2 years before (2Y). Note that the extent of variation tends to be greater in 1Y and 3M than in NE.

Fig. 3. Day-by-day shifts of VET/HR ratio (upper) and resting HR at sea level (0 m) measured before hypoxic exposure (lower). VET/HR ratios from Fig. 2 are rearranged for upper panel. Abbreviations are the same as in Fig. 2.

year before (1Y group in the figure), when compared with the NE group. Additionally, the dispersion is much greater in the 3-month subjects (3M in the figure), whereas they range close to or within those for the NE group in the 2-year group (2Y in the figure). The third and additional findings indicate that contractile responses of the heart will be labile and unsteady for at least one year in the recovery processes (deacclimation).

The daily changes of VET/HR ratio were characterized in 3M and 1Y by decrease of the value of days 2 and 3, as shown in Fig. 3 (upper) wherein those values from Fig. 2 were rearranged, while the decrease was not always demonstrable in 2Y. In NE, on the other hand, the values rather tended to increase on the identical days. Furthermore, when the resting sea-level (0 m) HRs measured before decompression were plotted in like manner (Fig. 3, lower), they showed a tendency opposed to the above shifts in every group. These discrepancies may also provide supporting evidence for a difference in the cardiac response between NE and 3M or 1Y.

In Fig. 4, the day-by-day changes of ETI are shown. The mean values with their SD are plotted for NE and 1Y, respectively, and the individual values for the other subjects. The mean for NE was significantly lower than that for 1Y (*t*-test, $p < 0.05$) only on the 1st day. Note that in the figure the pattern of time course in 2Y is similar to that for NE but not for 1Y.

Fig. 4. Day-by-day changes in ETI. Abbreviations are the same as in Fig. 2. Values for NE and 1Y are mean $\pm$ S.D. * Statistically different (t -test, $p < 0.05$).

It is difficult at present to discuss the underlying mechanisms for the unsteadiness and initial augmentation of the ventricular response to hypoxia in the subjects who had experienced high altitudes, since the parameters determined in the present study are only VET and ETI, and no comparable reports are available so far. However, all evidence observed above for cardiac response suggest a considerably long duration for hypoxic deacclimation, which is roughly comparable with that stated above for the recovery in pulmonary function. There may be a close relationship between both recovery processes. The stroke volume and cardiac output data are still being analyzed.

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