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# A RADIO TELEMETERING SYSTEM AND THE CHANGES OF EKG AND HEART RATE OF THE SUBJECTS ENGAGING IN MOUNTAINEERING AT GREATER ALTITUDES

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ABSTRACT

EKG and heart rate engaging in mountaineering as well as at rest were recorded by the telemetry on three subjects of the 1965-1966 Nagoya university scientific and mountaineering expedition to the Andes at altitudes of 4200 to 7000 m (near the summit of Mt. Aconcagua, Argentina). Resting heart rate, 51-61 beats/min at sea level rose to 99-108 beats/min by a quick transition to an altitude (4200 m above sea level), but it became increasingly less during the course of high altitude acclimatization and reached 70-84 beats/min. Daily variation of the resting heart rate, within 12-14 beats/min at sea level, rose to 25-35 beats/min at an altitude of 5000 m. Heart rate reached 130 beats/min in subject N., 136 beats/min in subject I. and 163 beats/min in subject O. during engaging in mountaineering at the altitude of 4200-5000 m. The ceiling level of the heart rate seems to be 145 beats/min for the three sujects, and 163 beats/min of subject O. which is 20-25 beats/min above the ceiling level will be explained by another unknown mechanism. Heart rate of subject I. did not exceed 145 beats/min even in mountaineering at an altitude of 7000 m. Heart rate fell markedly during sleep at 6200 m in all subjects. In subject O., it decreased to the resting heart rate at sea level and with such a marked fall in hesrt rate the subject could not perform strenuous mountaineering next day. Resting EKG of the subject was normal at 4200 m after altitude acclimatization, and as far as the heart rate was within the ceiling level, there was observed no abnormal events in EKG. With increased heart rate to above 140 beats/min, depression of ST segment, ectopic beats and marked arrhythmia were observed in subject O.

Recording of heart rate and EKG as well as the other cardiorespiratory parameters during exercise at high altitudes is important in studying the mechanism of high altitude acclimatization. They have been customally re-

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corded during graded treadmill or bicycle ergometer running at a fixed station in which the test subject may be influenced physically by restriction of the wires and psychologically by knowing the experimental procedures. It also seems to be of importance in physiological investigation to measure momently the change of those parameters during that the subject is performing a climb, but it is practically impossible to carry delicate and bulky recording devices which should be protected from severe climates and shocks. A radio telemetry can be a satisfactory technique in recording those parameters without such disturbance by removing the main recording apparatus and the investigators from the test area to a convenient remote place. One of the purpose of the 1965–1966 Nagoya university scientific and mountaineering expedition to the Andes was to acquire a precise momently information of heart rate and EKG pattern of the climbers under such difficult circumstance in mountaineering at the altitude of 4500–7000 m. The outline of the telemetering system and the results obtained are described in this paper.

## APPARATUS AND METHODS

The telemetry set which was carried by the subjects consists of the following three main parts: 1) A transmitter package which measures $150 \times 150 \times 35$ mm in dimension and 450 g in weight contains a high gain transisterized differential amplifier, a subcarrier and an FM transmitter. The transmitter, the output of which is approximately 84.8 MC, 0.5 Watt, has a maximum range of 5 km. The frequency of the subcarrier is 2.3 KC. 2) A timer which provides intermittent transmission of the EKG signals obtained with the subjects measures $81 \times 57 \times 37$ mm in dimension and 400 g in weight. An electronic switch connected to the power supply controls the amplifier and transmitter to be triggered to function by a signal from the timer for 60–100 seconds. To avoid the mixing-up of the measurands on the oscillograph paper, three different period of the signal out of the timer circuit was used; a) 60 seconds transmission in every 9 minutes and 30 seconds, b) 80 seconds transmission in every 10 minutes and c) 100 seconds in every 10 minutes and 30 seconds. EKG of the three different subjects were easily checked on the same channel of the oscillograph at the same time in this experiment. With the spring wound up completely, the timer is capable to function for one week without rewinding. 3) A battery box which contains total 12.5 V of column batteries (S 104) measures $135 \times 120 \times 35$ mm in dimension and 800 g in weight. The batteries are capable to operate continuously up to one week. Those three parts were kept in pockets of the vert of the subjects. The block diagram of the transmitting system and the photograph of the transmitter package are shown in Figs. 1 and 2.

During mountain climbing the VHF wave from the 70 cm lod antenna

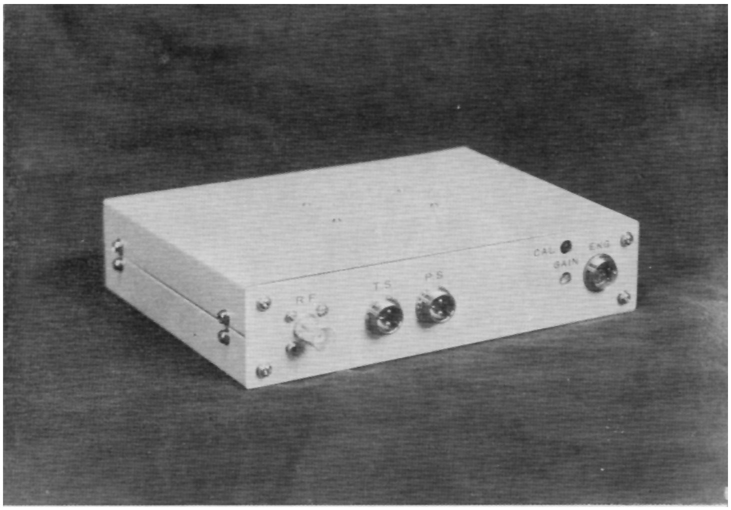


FIG. 1. Transmitter package. RF; to the antenna, T.S; to the timer switch, P.S; to the battery package, E.K.G. is the input connecter of EKG leads.

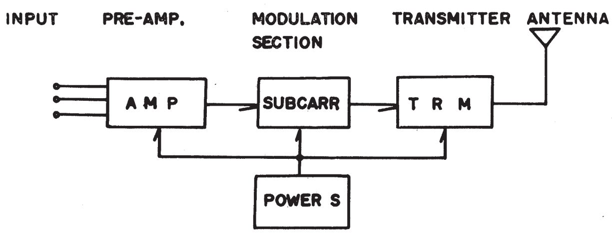


FIG. 2. Block diagram of the transmitting system.

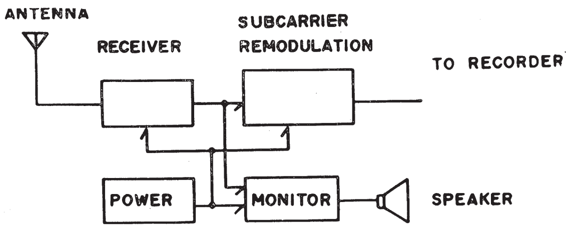


FIG. 3. Block diagram of the receiving system.

which was carried by the subject's back was received by the FM receiver antenna at the remote receiving station and the EKG changes were recorded on the oscillograph through the remodulation circuit section (Figs 3, 4). The oscillograph paper moved in 25 mm per second for the same period of time in which the receiver recorded the transmitted VHF wave from the transmitter.

FIG. 4. The receiver station (4400 m above sea level).

Power supply to all instruments at the receiver station was 100 V. 60 cycle generated by an AC generator and a gasoline engine.

Two EKG electrodes consisting of electroconductive flexible rubber plate ($20 \times 12$ mm) covered with saline paste were applied to the chest; one just under the apex beat and the other on the sternum at the height of the second intercostal space. The indifferent electrode was applied on the skin between the two electrodes. A special caution was made to prevent drying up of the paste during the experiment by making shallow hollow on the plate, in which the paste was filled and the entire electrodes were covered by celloidin not to be displaced (Fig. 5).

Three subjects, subject N (30 years), subject I (28 years) and subject 0 (22 years) were selected out of the 14 members of the Nagoya university scientific and mountaineering expedition to the Andes. On December 17th, they moved by mules in one day to the base camp (4200 m above sea level) of Mt. Aconcagua, Argentina from Puente del Inca (2730 m above sea level) where they stayed for one week. After staying at the base camp for a considerable time and being well acclimatized to an altitude of 4200 m, they started to climb to further higher altitude on December 28th and reached $C_1$ at an altitude of 5000 m on the same day. They spent one night at $C_1$ and then again they ascended to $C_2$ (approximately 5200 m above sea level) next day, where they spent another night. On December 30th, all subjects descended to the base camp where they stayed until January 3rd. In the morning of January 3rd, they ascended to 6200 m by mules and spent the night in a rescue house

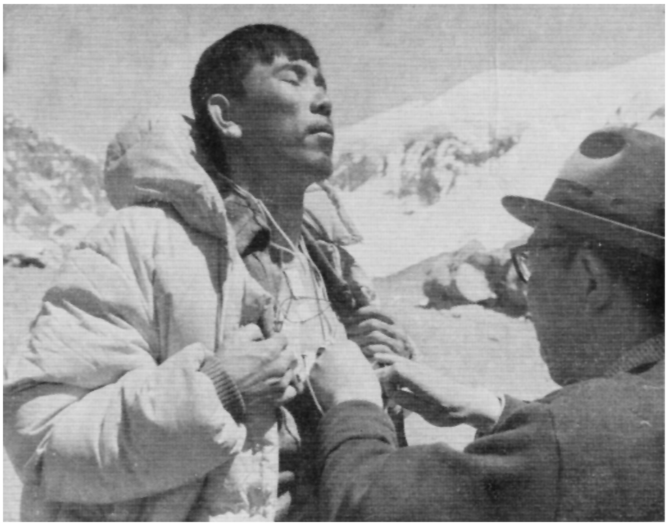

FIG. 5. Subject 0. attached with the EKG electrodes by one of the authors (K. T.).

and then next morning one subject (subject I) went up to the peak of the mountain at an altitude of 7000 m. Map and profil of the slope showing the interrelation between the points are in Figs. 6 and 7.

The EKG were continuously recorded at the receiver station from which the half of the trails and the top of the mountain were clearly observed. The heart rate was measured by counting the QRS spikes of the EKG on the oscillograph.

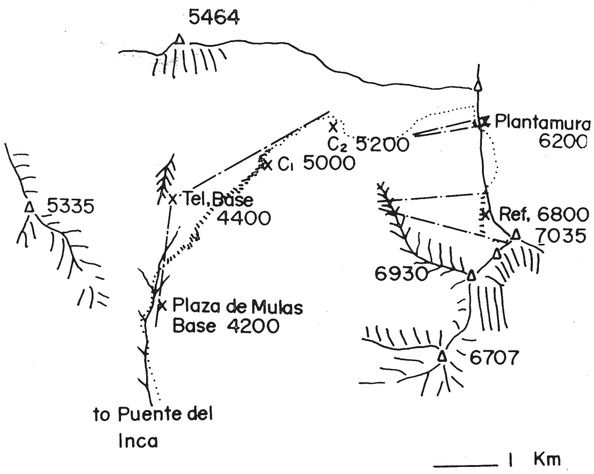


FIG. 6. Map of Mt. Aconcagua showing the trail by which the subjects climbed. Hatched areas are the areas from where the information was received clearly.

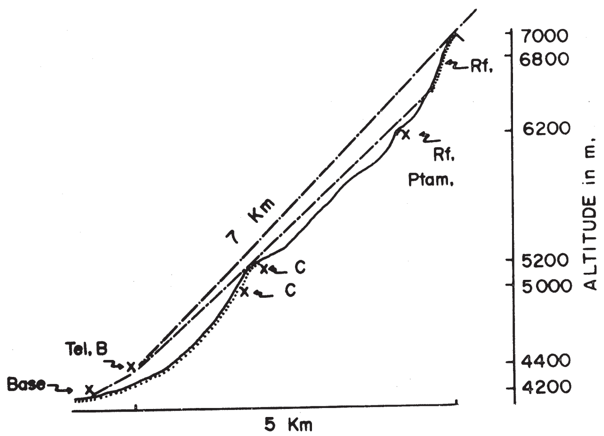


FIG. 7. Schematic showing of the relationship between the each points. During climbing on the unshaded slope, no information was obtained due to the interruption of the waves by the peaks between the telemetry receiving station and the subjects.

RESULTS

Fig. 8 shows the resting heart rate of the three subjects measured in the morning at sea level and at an altitude of 4200 m. The heart rate, 56–61 beats/min at sea level rose to 99–108 beats/min by the quick transition to the altitude. However, the heart rate became increasingly less during high altitude acclimatization and reached 70–84 beats/min during the following 12 days of sojourn. The daily fluctuation of the resting heart rate was within 12–14

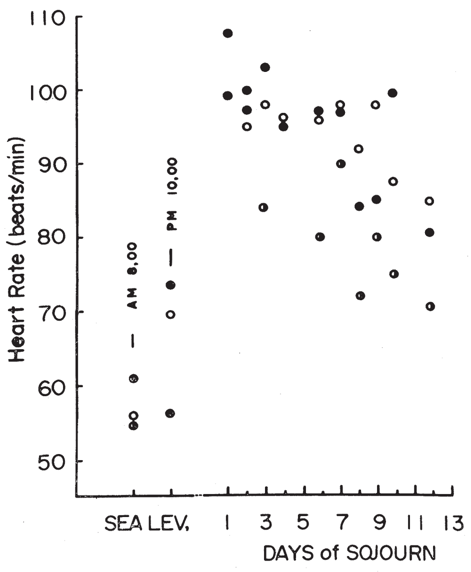


FIG. 8. The heart rate of subject 0: -○-, subject I: -●- and subject N: -◑- at sea level and at an altitude of 4200 m. The values at sea level are the means of ten days' measurements at 8;00 am. and at 10;00 pm. At an altitude of 4200 m, the heart rate was measured at between 8;00 and 10;00 am. every day.

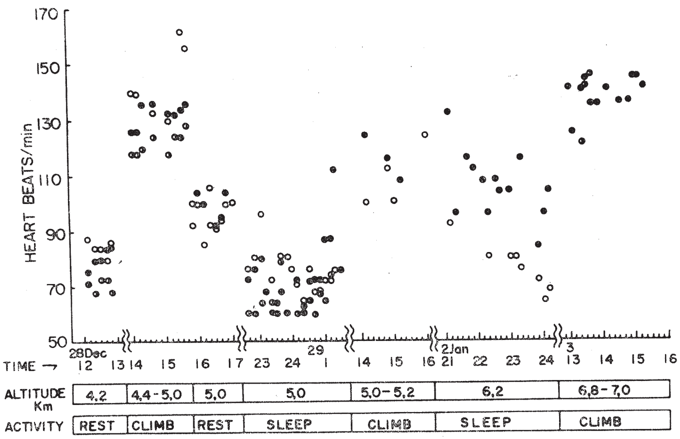


FIG. 9. Heart rate counted by EKG spikes which were transmitted by radio telemetry. -○-; heart rate of subject O., -●-; of subject I., -◑-; of subject N. Time, altitude and activity are shown under the figure.

beats/min at sea level, but that at an altitude of 5000 m was within 24-34 beats/min.

During engaging in mountaineering at the altitude of from 4200 to 5000 m, the heart rate (working heart rate) increased to 130 beats/min in subject N. and 136 beats/min in subject I, but that of subject O. reached 163 beats/min (Fig. 9). When the working heart rate became to 150 beats/min, marked arrhythmia and extrasystoles were observed in the EKG of the same subject (Fig. 10). He could not continued to engage in mountaineering but sat down on the slope for a while. The heart rate decreased to about 90-100 beats/min but it never decreased to the resting level at an altitude of 4200 m.

The resting heart rate fell markedly during sleep and the mean resting heart rate during sleep at an altitude of 5000 m was lower than that during sitting at the base camp. On the next day the heart rate during engaing in mountaineering did not rise to the same level of the last day, even though the altitude was higher than that of the last day. The heart rate decreased gradually during at an altitude of 6200 m. Especially the heart rate of subject O. decreased markedly and reached the sea level value at an altitude of 6200 m. He could not ascend to further higher altitude next morning.

One of the three subjets (subject I) ascended to 7000 m next day. His heart rate did not reached 150 beats/min during engaging in such strenuous mountaineering at the altitude of 7000 m. At rest recording of the EKG was normal at an altitude of 4200 m on the 12th day of acclimatization to the altitude. During mountaineering the ectopic beats and a slight depression of ST segment were observed in subject O (Fig. 10). Those abnormal EKG events

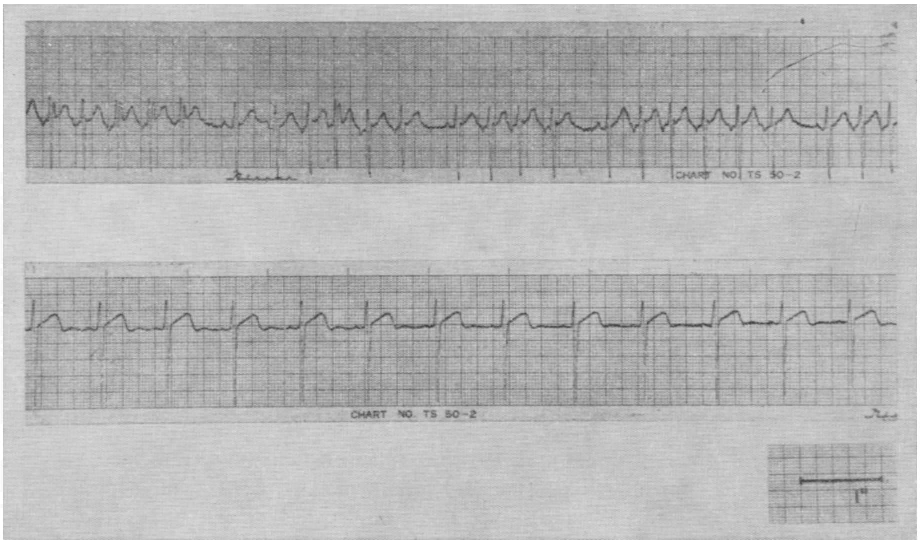

FIG. 10. EKGs of subject O. recorded during engaging mountaineering (upper tracing) and during sleep (lower tracing) at the altitude of 5000 m.

were aboundantly observed when the heart rate increased to more than 140 beats/min in the same subject.

## DISCUSSION

By using the radio telemetry, the scope of the research can be broadened in field study especially in high mountain expedition. The test subject will be quite free from the restrictions which might interfere the data and the researcher in leading to a better qualitative understanding of normal physiological reactions to experimental stress conditions. There was technically no problem to transmit most of the physiological data by this telemetry, but the authors chose the EKG change as the parameter which could be sent from a remote place in this investigation. The only inconvenience in using this technique is that when the subject is out of sight from the receiver station, the signal-noise ratio increases to disturb the recordings of normal EKG by an decreased strength of the transmitted waves.

Resting heart rate at an altitude of 4200 m. The resting heart rate became increasingly less during the course of altitude acclimatization (Fig. 8). This result seems to be consistent with the findings reviewed in the articles[2)~8)] except the one of Dejours *et al*[1)], which showed the progressive rise in heart rate throughout the three weeks of staying at Barcroft laboratory (3800 m above sea level). Since Christensen and Forbes' observation[9)], it has been a well established fact that there is a positive relation between the heart rate and the oxygen consumption at high altitude as well as at the other stress conditions[10)~12)]. Oxygen consumption of the subject during the course of the altitude acclimatization decreased progressively with the value of 12.3 ml/kg/min at the 12th day of sojourn and 10.2 ml/kg/min at the end of three weeks of sojourn at an altitude of 4200 m[6)]. This result can confirm well the validity of the data on the heart rate change obtained in this investigation.

The heart rate at an altitude of 5000 m seems to fluctuate twice as much as that at sea level in a day (Fig. 8, 9). This will be an indication of a large diurnal fluctuation in oxygen intake of the subject exposed to a chronic hypoxia. However, oxygen intake was less at high altitude than at sea level[13~15)] and the subjects showed more or less mountain sickness symptoms in the morning by an impaired pulmonary ventilation, so that this larger variation can be attributed to the too much fall in oxygen intake during sleep at high altitude.

Heart rate during climbing at the altitude of 4200–7000 m. The heart rate during physical exercise at fixed work loads became increasingly less during high altitude acclimatization and that of the subject after acclimatization seems to approach to a relatively low ceiling at maximum work rate[2)]. Mountain climbing at high altitudes was accompanied with a very high heart rate, well above the maximum obtained on the bicycle ergometer[2)], so that the ceiling of the heart rate was 135 beats/min in subject I. and 130 beats/min in subject N. in this investigation. The very high heart rate of subject O. coula be probably explained by an unknown different mechanism, because he could not walk further and had to stopped for a while to wait the reovery of the heart rate to rather lower level. The abnormal EKG of the subject suggests that the heart muscle was much strained even with an increase of 35% of the heart rate above the ceiling, and the stroke volume might decrease with such higher pulse rate.

The subjects reported their suffering from mountain sickness when they ascended to a further higher altitude even after the acclimatization to the altitude of 4200 m has been accomplished. The subjects must have been in a new stress condition, but contrary to expectation, the heart rate did not reach the level of the previous day. Even during mountaineering at an altitude of 7000 m in the following day, there was observed only a slight increase of the heart rate (from 135 beats/min at an altitude of 5000 m to 140 beats/min at an altitude of 7000 m). Those results show that the ceiling level of the heart rate was fixed and could not be easily shifted by an increased altitude. This inability may be caused by limited pulmonary ventilation[2)]. The capacity for physical work became definitely restricted by the limitation of the respiratory muscles to move the volume of air required to such higher altitude.

The heart rate during sleep was interesting. On the first night at an altitude of 6200 m, the heart rate became increasingly less and reached nearly the sea level value in subject O. With such a marked fall in the heart rate, in other word a fall in oxygen intake, the subject was not able to reserve enough power to perform maximum work at the altitude. A marked prolonged hypoxia of the heart muscle or other tissues during sleep may be a cause of this inability of performing muscle exercise at the altitude. Analysis of the EKG and the mechanism of the ceiling of heart rate at a maximum work will be studied in conjunction with data obtained in the experiments done in the hypobaric chamber in another chance.

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