CHANGES IN THE HUMAN ELECTROCARDIOGRAM ON BREATHING OXYGEN UNDER PRESSURE AND THEIR RELATIONSHIP TO A COMPENSATING PRESSURE APPLIED EXTERNALLY TO THE BODY (VECTOR ANALYSIS)

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Respiration under increased pressure was first studied in Russia by P. P. Einbrodt in 1860 [5]. Recently it has been widely used both in the practice of aviation, and clinically. It has been shown that breathing under pressure is well tolerated in man provided the excess pressure in the lungs does not exceed 25-30 mm Hg. Higher pulmonary pressures may be tolerated for a certain time but only when an equal external compensating pressure is applied. In practice various forms of compensating devices are used, the best of which is the height-compensating suit [4].

The purpose of the present work has been to study the effect of the value of the compensating pressure on the electrical activity of the myocardium, while the subject was breathing under increased pressure.

The problem has been studied by G. V. Altukhov and N. A. Agadzhanyan [1] by V. S. Gurfinkel', D. I. Ivanov, A. E. Ivanov, and V. B. Malkin [3]; a special study of this problem has also been made by Mahoney and Kennedy [6], who showed that an increase of pulmonary pressure from 30 to 60 mm Hg without external compensation causes sinus arrythmia, an increase in the Q-T interval, and a rotation to the right of the electrical axis of the heart (α) and of the vectors AQRS and AT. When the excess pressure in the lungs is 50-100 mm and a counter-pressure is applied from outside, there is practically no change in the ECG; at a pressure exceeding 100 mm Hg, a compensating suit is no longer effective in preventing the ECG changes already described, which occur both when the experiment is conducted either at ground level or in a rarefied atmosphere corresponding to a height of 20,000 m above sea level.

We have carried out two series of observations both at normal atmospheric pressure and at a pressure corresponding to a height of 20,000 m. To breathe under excess pressure, an oxygen device was used which produced an intrapulmonary pressure of 145 mm at a "height" of 20,000 m; it incorporated a hermetically sealed helmet and a special compensating suit type VKK-2 "M" which allowed pressure to be applied separately to the abdomen thorax, thighs, shoulders, lower legs, forearms.

The ECG was recorded by means of the 3 standard leads and 2 chest leads (CR_{II} and CR_V). A six-beam oscillograph was used, and simultaneous recording was made of the respiratory movements of the thorax, the electromyogram of the intercostal muscles, and of the oblique abdominal muscle. First a study was made of the effect of different values of externally applied pressure while the subject breathed under excess pressure; next the effect was tried of increasing the pressure on different parts of the body. In both experiments the excess pulmonary pressure was kept constant for each investigation. For different "ground" conditions it was made equal to 55, 104, 126, and 135 mm Hg, and at "high altitudes" it was kept at 104 mm mercury.

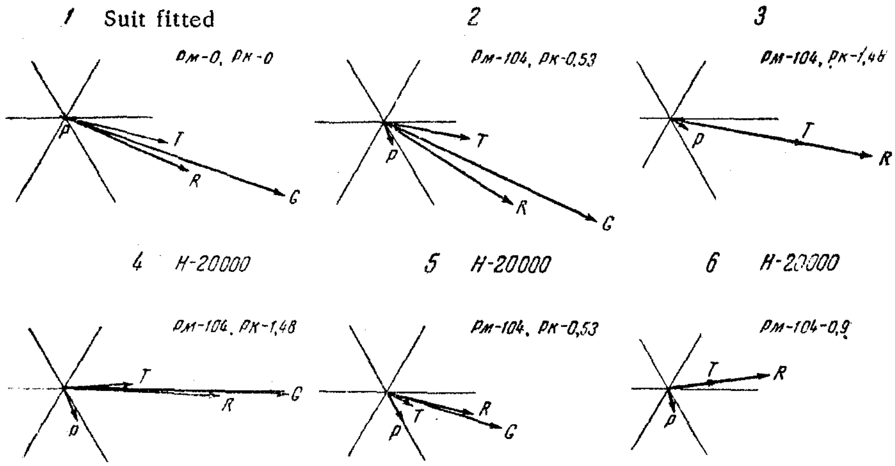

Fig. 1. Frontal vector cardiogram. Subject P-in, February 5, 1957. 1, 2, 3) "Ground level" conditions; 4, 5, 6) "high altitude" conditions (20,000 m): P_m) excess pulmonary pressure (in mm Hg); P_k) external body pressure: 0.53-70 mm less than the intrapulmonary pressure; 1.48) equal to intrapulmonary pressure; 0.9-50 mm Hg less than intrapulmonary pressure; P) the AP vector; R) AQRS (AR) vector; T) AT vector; g) "auricular gradient."

In the first set of experiments, the pressure within the pressure suit was varied so as to apply a pressure to the body of 70, 50, and 30 mm Hg more or less than that in the lungs. At the start, a pulmonary pressure of 60 mm was established without external compensation. Recordings were then taken for the same interpulmonary pressure after the pressure suit had been put on but no pressure established in it. Then a particular intrapulmonary pressure was established, and the pressure in the suit changed as described above. The same sequence was observed at both "ground level" and "high altitudes."

In the second set of experiments, pressure was applied separately to the abdomen, thorax, etc. At "ground level" and at an arbitrary pulmonary pressure of 55 mm Hg, a pressure equal to the internal value was applied alternately to the areas named above. Then, after the subjects had rested, a second series of observations were made at an intrapulmonary pressure of 104 mm Hg, and the opposing external pressure was reduced (usually to zero) over the same areas. "High altitude" studies were carried out, just as at "ground level", at an excess pulmonary pressure of 104 mm. A total of 69 studies were made, 49 in the first and 20 in the second series.

RESULTS

The results of the first set of the experiments showed that at excess pulmonary pressures of from 55-136 mm Hg and an equal externally applied pressure, at "ground level" the electrical cardiac axis (alpha), and the AP, AQRS, and AT vectors and the "auricular gradient" (G) showed some deviation to the right, without any special separation, so that a rotation of the heart to the right about a sagittal axis and a deviation of the apex backwards were indicated. We think that in this case positional changes in the ECG occur as a result of the more vertical position of the heart in the thorax, which is brought about by a fall in the diaphragm due to the increased intrapulmonary pressure.

Changes in lead III were caused by an excess pressure of 60 mm in the lungs without external compensation. Then the P_{2-3} waves were increased and changed in shape, the AP vector was rotated to the right through 15-40°, and somewhat increased. The AQRS, AT and G vectors were also deviated to the right away from their original position by 10-35°. The amplitude of the auricular vectors was usually reduced, AQRS by 10-15μ vs, AT by 5-10μ vs, a result which indicated a relative oxygen deficiency of the myocardium.

Under these conditions, the pressure suit caused considerable alterations in the ECG. Even putting on the suit without introducing any pressure reduced the deviation to the right of the cardiac vectors.

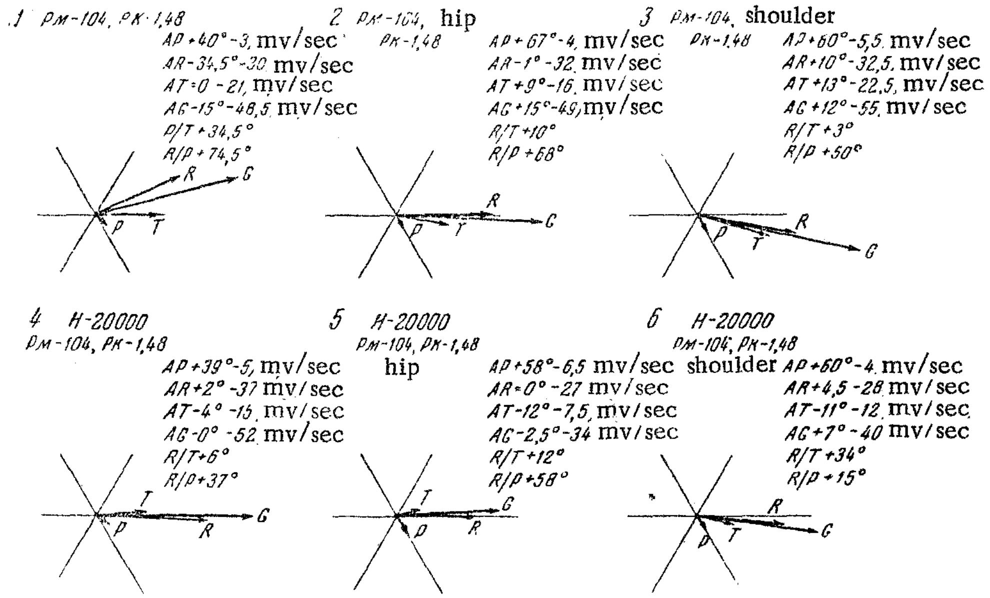

Fig. 2. Frontal vector cardiogram. Subject P-in, March 26, 1957. 1, 2, 3) "Ground level" conditions ; 4, 5, 6) "high altitude" (20,000 m) conditions. Other indications as in Fig. 1.

At "ground level" increasing or decreasing the external pressure by 30-50 mm relative to the intrapulmonary pressure caused no significant alteration of the changes of the ECG induced by the increased pulmonary pressure, i.e., the typical changes already described as due to breathing air at an increased pressure remained. However, the R/T (AQRS/ AT) and R/P (AQRS/AP)* ratios were greater the smaller the body pressure in relation to the intrapulmonary pressure (Fig. 1, 2). These ratios indicate the spacial relationships of the vectors representing excitation and recovery of the ventricular myocardium (R/T) as well as the spatial relationships of the vectors of the potentials of the ventricular and auricular myocardia (R/P).

In working at "ground level" we failed to observe any appreciable changes in the P–Q, Q–T intervals or in the systolic index. In certain cases there was an increase in the $S-T_{2-3}$ line, which might be interpreted as an indication of the preponderance of vagal tone, and indications of incomplete block of the right fork of the bundle His, which can be explained as due to a relative overload of the right ventricle.

Changes in the ECG in the corresponding experiments made at a reduced atmospheric pressure (at an "altitude" 20,000 m), were basically the same, except that the reduction in the ventricular vectors was better shown. Then, the smaller the pressure in the suit, the smaller were the vectors, particularly the AT vector. There was also considerable separation in space of the AP and AQRS vectors (Fig. 1, 5, and 6).

Under "ground level" conditions, in the second set of observations when there was a 55 mm excess pulmonary pressure, application of an equal external pressure to the abdomen, whose muscles play an important part in breathing out against an increased pressure caused alterations in the ECG; there was some separation of the vectors in space and a rotation, particularly of the AP vector through 20-30° to the right. There was also an increase in the R/T and R/P ratios. Applying the same pressure to the thorax or limbs caused only the same kind of changes in the ECG. The amplitude of the vectors, the duration of the P–Q and Q–T vectors, and the systolic index scarcely differed from their initial values. The changes in the ECG described are due to the position of the heart which is altered by the raised intrapulmonary pressure.

At an excess pulmonary pressure of 104 mm or above, and when an equal counter pressure was applied externally, the reduction of the pressure of the different areas, either at "ground level" or at "high altitudes" induced more complex ECG changes (Fig. 2). The amplitude of the vectors, particularly of the AT vector was

* The ratio which we have proposed [2].

considerably reduced. The AP vector deviated to the right, there was a separation of the AP and AQRS vectors in space and an increase of the R/P ratio.

The fact that there was also a separation of the AQRS and AT vectors and a leftward rotation of the electrical axes showed that in addition to positional ECG changes there were also circulatory disturbances of the myocardium.

The most marked changes in the ECG occurred when the external pressure in the region of the abdomen was reduced, and the effect was even more marked for the thighs (see Fig. 2, 5). There was then not only a considerable separation in space of the auricular and ventricular vectors, but there was also a marked increase in the number of cardiac contractions, the $S-T_{2-3}$ interval fell below the baseline, and there was an increase of 14-28% in the systolic index. These changes show that when air is breathed under increased pressure, the counter-pressure applied to the thighs, belly, and thorax plays an important part in preventing circulatory disturbances.

Vector analysis of the ECG therefore allows us to conclude that when a subject breathes air at an increased pressure, there is an overload first of the right auricle, and then of the whole of the right heart. This method enables positional ECG changes to be distinguished from functional disturbances of a particular region of the heart. When the pulmonary pressure is increased to 136 mm, variations in the value of the compensating pressure up to 50 mm of mercury have no appreciable effect on the condition of the myocardium. If under these conditions insufficient compensation is applied to the abdomen or thighs, there is a marked disturbance of the cardiovascular system, and of the myocardium in particular. The ECG changes serve as an important objective indication of the extent to which a particular individual may tolerate an increased intrapulmonary pressure.

SUMMARY

Two series of observations were made in which the atmospheric pressure was reduced to a value corresponding to an altitude of 20,000 m. In the first, a study was made of the effects of a counter pressure applied externally to the body; in the second series the pressures were applied to separate areas of the body. When the excess pressure in the lung reached 136 mm Hg, and when an equal counter pressure was applied externally, the electrical axis and cardiac vectors deviated to the right. Variations of the external pressure up to 50 mm Hg applied while the intrapulmonary pressure is held constant, do not by themselves cause any significant changes in the ECG. When the pressure applied to the abdomen and thighs is insufficient, the cardiac vectors diminish, and circulatory disturbances occur. Vector analysis of the ECG shows that during respiration under increased pressure, the first changes occur in the right heart.

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* Original Russian pagination. See C. B. Translation.