THE ELECTROCARDIOGRAM OF HEALTHY RABBITS IN STANDARD AND CHEST LEADS AND METHODS OF RECORDING IT

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In spite of the fact that rabbits are widely used in experimental studies of the cardiovascular system, we have found no description in the accessible Soviet literature of the normal electrocardiogram in standard and chest leads or of methods of recording it.

In a few papers published abroad, various accounts are given of fairly laborious methods of recording the electrocardiogram in standard and chest leads, and also of different variants of the normal electrocardiogram. We found no description of the normal electrocardiogram in four chest leads. Some authors recorded the electrocardiogram with the animal in the normal position [8, 13], others with the animal lying in the supine position [6, 9]. Different method are described in individual papers: introduction of the electrode along with a tube into the esophagus (under x-ray control) [16], the application of plates or of coils to the epilated skin of three of four limbs, soaked in various solutions [4, 5] or to the surface of the chest on the right and left sides [8]; Slapak and Hermanek [15] and also other authors used injection needles as electrodes. Lepeschkin [7] mentions the bipolar chest lead, the so-called axial of Schinzel [14]. In this lead, one electrode is fixed to the right shoulder and the other in the region of the apex of the heart, corresponding to the anatomical axis. The recording is made in the usual way, or by Wilson's method.

In leads from the limbs, the electrocardiogram of the rabbit is usually of low voltage and the waves are not always clearly shown. In the chest leads the changes in the electrocardiogram appear sooner, last longer, are clearer and enable the potential of a given point of the heart to be determined.

The absence of details of the normal electrocardiogram of rabbits and of a single, simple method of recording it, led us to describe our own observations on this problem.

METHOD

Electrocardiograms were recorded in 36 young and healthy rabbits every 2-2½ months: in one group of 18 animals, for a period of one year, and in the other group for 20 months. In each rabbit the electrocardiograms were taken from 5 to 8-9 times; altogether 220 electrocardiograms were taken in the standard and the four chest leads. From 7-10 minutes before the electrocardiogram was recorded, the animals were secured to the bench lying on their back. For electrodes we used thin steel needles, which (after treatment with alcohol) were injected subcutaneously in the dorsal aspect of the distal segments of three limbs (2 forelimbs and the left hindlimb) for recording the standard leads. The electrocardiograms were recorded on an ÉKP-4m apparatus, with a sensitivity of 1 mv = 2 cm and a film movement velocity of 7-8 cm/sec. As in man, when we recorded the electrocardiogram in the chest leads, we took

Fig. 1. Position of the rabbit and points on the chest wall from which the electrocardiogram is recorded.

TABLE 1. Heart Rate, Duration of Waves, Magnitude of Electrical Systole of Ventricles and Arrangement of Electrical Axis of the Heart in Healthy Rabbits

Rabbit No.	Type of electrocardiogram	Range of variations, heart rate/min	Mean Heart rate per min	Duration of waves and intervals (in hundredths of a second)			Magnitude of electrical systole of ventricles Q–T (in hundredths of a second)
				P	PQ	QRS	
31	Mixed	330—300	300	0,03	0,06	0,04	0,14
51	Left	300—280	290	0,03	0,06	0,04	0,13
10	Vertical	300—280	290	0,04	0,07	0,04	0,14
12	Right	240—300	285	0,04	0,06—0,07	0,03—0,04	0,14—0,15
17	Left	280—220	250	0,04	0,06	0,04	0,15
19	Vertical	300	300	0,03—0,04	0,06	0,03	0,14
19a	Normal	300—260	280	0,04	0,07	0,03	0,14
20	Vertical	300—280	290	0,04	0,07	0,04	0,14
21	Left	280—260	270	0,04	0,07	0,04	0,15
23	Normal	260—320	300	0,03	0,06	0,03	0,14
24	Mixed	260—310	300	0,03	0,06	0,03	0,14—0,15
25	Right	230—240	240	0,03—0,04	0,07	0,03—0,04	0,15
26	Left	300—330	310	0,03	0,06	0,03	0,14
27	Vertical	300	300	0,04	0,06—0,07	0,03	0,15
28	»	240—330	300	0,03	0,06	0,03	0,13—0,15
28a	Normal	300—300	300	0,04	0,08	0,03	0,13
29	Right	300	300	0,03	0,06	0,03	0,14
29a	Vertical	270—260	260	0,03	0,07	0,05	0,14
30	Right	300—320	310	0,03—0,04	0,06	0,03	0,13—0,14
32	Vertical	250—300	270	0,03—0,04	0,07	0,03	0,15—0,14
32a	Right	300—280	290	0,04	0,07	0,04	0,14
33	Mixed	240—320	280	0,03—0,04	0,06—0,07	0,04—0,03	0,15—0,14
33a	Right	300—280	290	0,04	0,07	0,04	0,14
34	Normal	240—280	260	0,03—0,04	0,07	0,03—0,04	0,15—0,14
35a	»	280—300	290	0,04	0,06—0,07	0,03	0,14
36	Right	240—280	270	0,03	0,07	0,03	0,15
37	Normal	260—320	300	0,03	0,06	0,03	0,14
37a	Right	300—280	290	0,04	0,07	0,04	0,14
39	Mixed	300—300	300	0,03	0,05—0,06	0,03	0,14
39a	Normal	300—260	280	0,03	0,07	0,03	0,15
42	»	260—180	220	0,04	0,08	0 03	0,15
44	Right	300—270	280	0,03	0,06	0,03	0,14
45	Left	310—320	315	0,03	0,07	0,03	0,13
46a	Right	270—300	290	0,03—0,04	0,06	0,03	0,13
47	»	300—300	300	0,03	0,07	0,03	0,13
49	»	300—240	270	0,04	0,07	0,05	0,15

into consideration the peculiarities of the animal. The needle electrode corresponding to the right limb was treated with alcohol and then inserted beneath the skin of the lateral part of the right forelimb to a depth of 1.5-2mm, and the electrode corresponding to the left limb was introduced at the following points of the chest wall (at the heart level): points I (CR) and IV (CR_5), at the place of intersection of a vertical line corresponding to the anterior axillary line with a horizontal line at the level of the apex of the heart; points II and III (CR_1 and CR_4) at the intersection of the parasternal lines with the horizontal line, corresponding to the lower and lateral sides of the thoraco-abdominal angle (Fig. 1). In the selection of these points we were guided by the anatomical structure and topographical situation of the heart in the thorax [2].

RESULTS

Comparison of the electrocardiograms recorded with the rabbits supine with those taken with the animals in the normal position satisfied us, as it did Massman and Opitz [9], that no significant difference could be detected.

The rhythm and rate of the heart. The heart rate varied between 240 and 300 contractions per minute (mean 250). In one case a rate of 180, and in another, of 330 contractions per minute was observed (Table 1). We found no disturbances of the sinus rhythm nor other evidence of heterotopic sources of cardiac contraction.

Arrangement of the electrical axis of the heart. We observed five arrangements of the electrical axis. In the normal type (Fig. 2a) an R wave was present in all three leads (sometimes a small Q_I or Q_{III}). The right type (Fig. 2b) was characterized by absence (or very small size) of the R wave in lead I, by the presence of a well-marked S_I wave (often S_{II}) and also by the presence of a well-marked

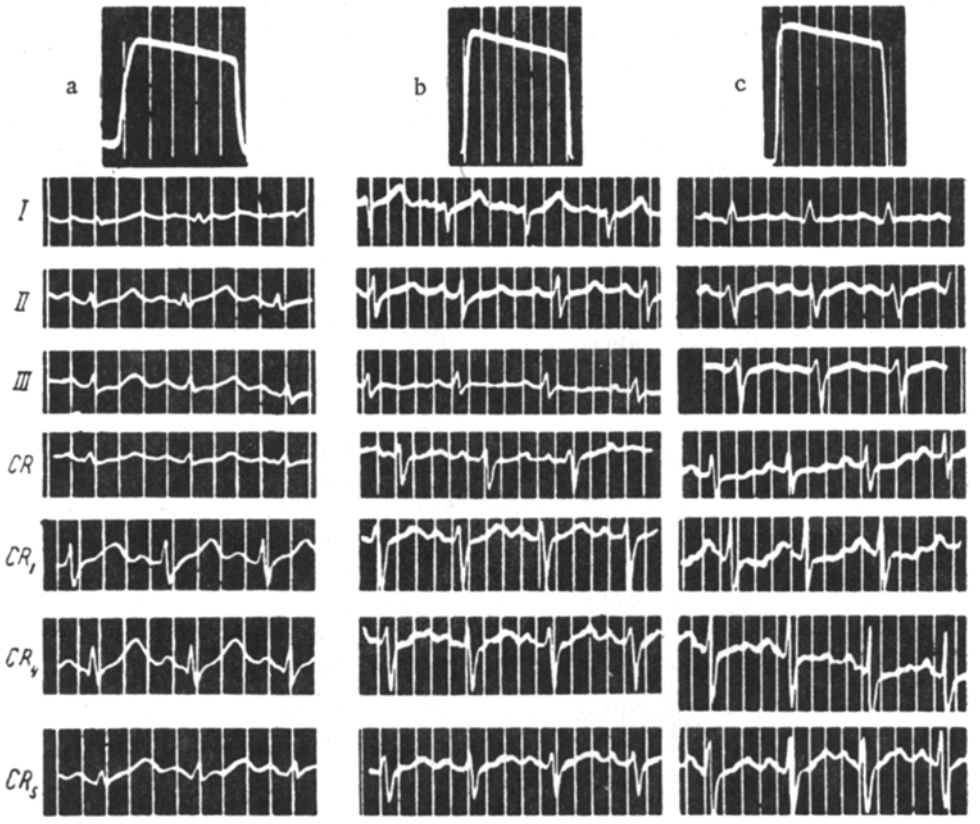

Fig. 2. Electrocardiogram of healthy rabbits in standard and chest leads. Variants of the arrangement of the electrical axis: a) normal; b) right; c) left.

R_{III} (sometimes a small R_{II}). Occasionally a deep Q_I was found instead of S_I, probably due to inversion of the entire QRST complex. Small Q_{III} and Q_{II} waves were often seen. In the left type (Fig. 2c) the R wave in lead I was quite well marked (often R_{II}). S_{III} was well defined. A small Q_I was often observed, and sometimes Q_{II}. The vertical type (Fig. 3a) was distinguished by the fact that in lead I the QRS complex was very low. In leads II and III the R waves were moderate in size and $QRS_I < QRS_{II} > or = QRS_{III}$ (sometimes Q_{III} was small). In the transitional type (Fig. 3b) it was difficult to determine the arrangement of the electrical axis, for the signs of the various types were mixed.

According to our findings, the electrocardiograms in the chest leads usually correspond to the types in the leads from the limbs. The principal feature of the normal and left types was the presence of an R wave in all the chest leads, which increased as the electrode moved in the direction toward the left position III (CR_4), but at the point CR_5 it was often low. The S wave was well defined in CR, CR_I and CR_4; depending on the direction of the electrical axis, however, this wave was present to a different degree in positions I and IV, and might even be absent. In the normal type in the right chest leads r < S or r=s, and in the left R > s or r=s (see Fig. 2a). The R wave was diminished in the vertical type in the left leads. In the left vertical and normal types, the S wave in leads III and IV (CR_4 and CR_5) was usually ill-defined and no higher than the R wave (see Fig. 2a, b, c), but in the right type it was well marked and often greater than the R wave. Lepeschkin [7] points out that a direct lead from the right ventricle gives rS, and one from the left Rs. In chest leads taken on the left, on the chest wall at the heart level, corresponding to the point V in man, Levin [8] found an S wave in half these tracings.

In 18 rabbits, i.e., in half the total number, a right (in 10 animals) and a vertical (in 8 animals) type of arrangement of the electrical axis of the heart was observed. Predominance of the right type of electrocardiogram in healthy rabbits is also reported by L. P. Peresad'ko [1] and Massman and Opitz [9]. The two last authors determined that the electrocardiogram was mainly of the right type according to Schlomka's index. Mayeda [10] found a right type of electrocardiogram in newborn rabbits under ten days old. Agduhr and Stenström [4] observed left and right types of electrocardiogram. Slapak and Hermanek [15] described three types of position of the axis – left, vertical and normal. Within the limits of these types they observed many variants of deviation. Like Lepeschkin [7] and Slapak and Hermanek [15], we also observed spontaneous changes in the type of electrocardiogram in the same rabbit. After a short time the normal type became vertical, the vertical

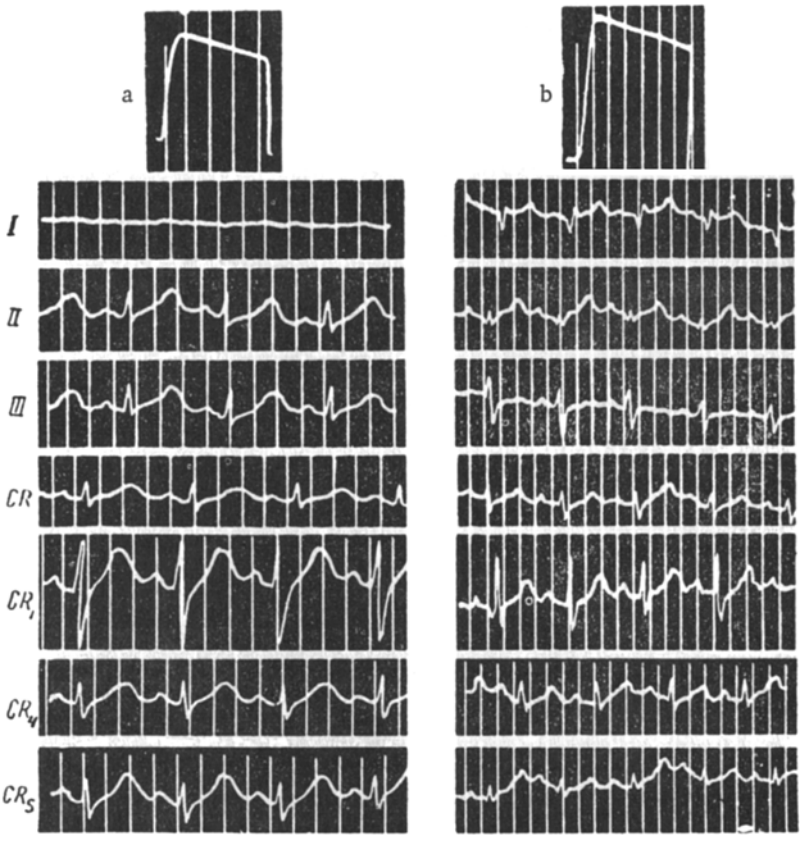

Fig. 3. Electrocardiogram of healthy rabbits in standard and chest leads. Variants of the arrangement of the electric axis: a) vertical; b) mixed.

became right, and so on. In conformity with the type, changes occurred in the relationship between the R/S waves in leads I-III and in the chest leads. These spontaneous changes, however, were mainly in connection with the transition between closely related types: for example, a normal into a left type, a vertical into a right type, and so on. A transition in a diametrically opposite direction, for example from right to left or vice versa, was never seen. Furthermore the new type of arrangement of the axis did not stay a long time fixed in its new variant, and often reverted to its original pattern. This account shows that changes in the type of electrical axis are associated not with changes in the muscle or in the conducting system of the heart, but with displacement of the heart in connection with changes in the position of the body, the height of the diaphragm (by a full stomach) and so on. This is confirmed by Boden and Neukirch [5], who observed changes in the type of electrocardiogram of the isolated rabbit's heart in accordance with rotation of the heart.

Changes in the waves and intervals of the electrocardiogram. The P wave was more pronounced in lead II and less so in lead III. In lead I it often was low or even obliterated. Lepeschkin considers that the P wave in lead I may be low or negative, but Slapak and Hermanek always found a positive P wave in all three leads. The degree of expression of the P wave often depended on the type of arrangement of the electrical axis of the heart. In the left type the P wave was more pronounced in leads I and II, and in the right and vertical types, it was more pronounced in leads III and II. The duration of the P wave was 0.03-0.04 seconds and its height 0.1-0.15 mv. These values agree with those cited by other authors (Table 2). The P wave in the chest leads was always positive. Its height varied from 0.03 to 0.025 mv, and its width from 0.03 to 0.04 seconds. Lepeschkin points out that in a lead from the apex of the heart, the P wave is always positive, and from 0.1 to 0.15 mv in height. Like Slapak and Hermanek and other authors, we were unable to find any obvious connection between the magnitude of the P waves and the arrangement of the electrical axis of the heart.

The Q wave was usually present in the left type in lead I and more rarely in lead II, and in the right type, in lead III and more rarely in lead II. The height of the Q wave usually did not exceed 0.1 mv. In one case, in lead I in the right and mixed types, instead of an S wave we found a Q, reaching a height of 0.4 mv. In the left, and also in the normal type of electrocardiogram, in the left chest leads and in CR_4 and CR_5, small Q waves (from 0.02 to 0.15 mv) were observed.

The P-Q (P-R) interval varied depending on the heart rate between limits of 0.07 and 0.08 seconds. Our values are close to the figures cited by Slapak and Hermanek, and

TABLE 2. Data of Various Authors on the Heart Rate, the Duration of the P Wave, P-Q Interval, QRS Complex and Ventricular Systole QT, and the Height of the P, R, S and T Waves

Authors	Range of variations in heart rate per minute	Mean heart rate per min	Duration (in hundredths of a second)				Height of waves in limb leads (in hundredths of a millivolt)									
							P			R			S		T	
			P	PQ	QRS	QT	minimum	maximum	mean	minimum	maximum	mean	minimum	maximum	minimum	maximum
Lepeschkin (Mayeda's figures)	150—365	250	0,03—0,04	0,05—0,10	0,015—0,04	0,12 at a rate of 250 contractions per minute	0,04	0,20	0,10	0	0,80	0,35	0	0,40	0,05	0,44
Slapak and Hermanek	187—352	200—300	0,03—0,06	0,05—0,07	0,02—0,03	0,11—0,15	0,10	0,20	0,15	0,03	0,80	—	—	—	0,02	0,40
Massman and Opitz	100—240	200	0,035—0,045	0,07—0,075	0,035—0,05	—	—	—	—	—	—	—	—	—	—	—
Ahdurh and Stenström	150—350	250	0,03—0,04	0,05—0,08	0,0175—0,03	0,10—0,15	—	—	—	—	—	—	—	—	—	—
Levin	174—282	225	—	0,06—0,09 occasionally 0.1 second	0,03—0,04	—	—	—	—	—	—	—	—	—	—	—
A. O. Saitanov	180—330	250	0,03—0,04	0,07—0,08	0,03—0,04 0.05 in two cases	0,13—0,15	0,03	0,25	0,13	0,02	0,70	0,40	0,02	0,50	0,02	0,5

are almost in agreement with those of Massman and Opitz (see Table 2). The P-Q interval was usually well defined in all leads and was disposed isoelectrically.

The QRS complex had a mean duration of 0.03-0.04 second (in two cases it was 0.05 second). Our values are close to those cited by Lepeschkin, and agree with those of Levin (see Table 2). The height of the QRS waves was different in each lead. The ratio between the R/S waves was mainly dependent on the direction of the electrical axis of the heart. The greatest height of the wave in the limb leads was 0.70 mv. Lepeschkin, and Slapak and Hermanek observed waves with a height of 0.80 mv (see Table 2). In the chest leads the duration of the waves was within limits of 0.03-0.05 second, and the height of the tallest wave was 0.9 mv. The depth of the waves reached 0.8 mv. According to Slapak and Hermanek the duration of the R wave in all cases was 0.03 second and the maximum height of the wave 0.9 mv (varying between 0.3 and 0.9 mv). In two healthy rabbits we observed for a short time a difference in the height of the R waves in one of the leads, which, in our opinion, was not pathological. Lepeschkin also draws attention to the possibility of spontaneous inversion of the QRST complex in leads I, CF_2 and CF_3.

The S-T interval was usually situated on the isoelectric line and was in the form of a straight line or, more rarely, slightly inclined. Sometimes in lead I (in the left type) or in lead III (in the right type) it was slightly convex upwards, and changed into a slightly biphasic (±) or, much more rarely, into a negative T wave. At the same time, in certain (2-5) leads we did not observe depression of a straight or curved S-T interval below the isoelectric line by more than 0.05-0.1 mv. Slapak and Hermanek [15] and also Mayeda [10] observed depression of the T-S interval only in exceptional cases. According to the findings of Massman and Opitz, the S-T interval was always isoelectrical, and the T wave did not arise from the R wave. Levin found in certain cases the appearance of a T wave without an isoelectrical interval, directly from the R and S waves, and Mayeda observed this to occur from the R wave only. High elevation of the S-T interval in one of the three types of electrocardiogram of the rabbit was described by Büchner and Licadov [6].

In some cases we observed in the chest leads an inclined, depressed (by more than 0.1 mv) S-T interval, leading to a positive T wave. In chest lead I (CR) an S-T interval convex uppermost was often encountered, which passed into a low and slightly biphasic (∓) T wave. The constant depression of the straight or curved S-T interval by more than 0.05 0.1 mv in certain standard or chest leads must be regarded as a sign of a pathological state of the myocardium.

The T wave was always positive in lead II and in most cases in Lead I. In lead III, more often than in lead I, it was considerably modified—depressed, smoothed out or even inverted, depending on the disposition of the electrical axis of the heart. In the vertical and right types the T wave was more positive in leads I and II and, in the majority of cases, in lead III. In lead III, however, the T wave was often low and even inverted. In the left type the T wave was often positive in lead I, but more frequently than in the other type it was low or even biphasic (∓). Our results are in agreement with Mayeda's observations. Massman and Opitz point out that in their findings a negative T wave in one lead was found in 3% of healthy rabbits, a flattened T wave in 30%, but an isoelectric T wave in certain leads was found in only 4 of 81 rabbits. The height of the positive T waves in the limb leads varied between 0.02 and 0.5 mv (in the majority, the average value was 0.3 mv). In most cases, the T wave was positive in all the chest leads. In the right type of disposition of the electrical axis, in a few cases it was flattened or smoothed out in the left leads (CR_4 and CR_5). In the left type, in a few cases the T wave in chest lead I (CR) and in lead II (CR_1) was flattened, smoothed out or, more rarely, biphasic (-+).

Whatever the type, the T wave in positions III and IV (CR_4 and CR_5) was always positive (in the left type it was occasionally low). In the remaining cases a persistent fall in the T wave in some chest leads always indicated pathological changes in the heart muscle. The maximum height of the T wave reached 0.6 mv. According to Slapak and Hermanek the height of the T wave was between 0.1 and 0.3 mv.

The electrical ventricular systole (Q-T) depended on the heart rate and varied from 0.13 to 0.15 second (see Table 1). A similar relationship between the duration of ventricular systole and the heart rate is noted by Lepeschkin, Agduhr and Stenström, Massman and Opitz, Ruskin and Decherd, and other authors.

For calculation of the normal electrical ventricular systole in relation to the heart rate, the following formula should be used (Lepeschkin):

$$Q - T = 2{,}8 \sqrt{R - R}$$

SUMMARY

Two hundred twenty-two electrocardiograms were recorded in 36 rabbits during a period of 20 months. Three standard and four chest leads were used.

Needle electrodes were introduced subcutaneously into the right, left anterior and left posterior extremity; the chest electrodes were introduced at the following points: points I (CR) and IV (CR_5) at the intersection of the vertical line (corresponding to the anterior axillary line) with the horizontal line at the level of the heart; points II and III (CR_1 and CR_4) at the crossing of the parasternal lines with the horizontal. Electrocardiograms recorded with the animal on its back did not substantially differ from those recorded with the animal in the normal position. Five different positions of cardiac electrical axis were observed: normal, left, right, vertical and mixed. These may be spontaneously converted into borderline types. The number of cardiac contractions ranged from 180 to 330 per minute, averaging 250. The duration of the waves and intervals was between 0.01 and 0.02 seconds, depending on the number of cardiac contractions. The value of electric systole depended on the frequency of cardiac contractions. The ECG of the rabbit possesses specific features which should be taken into account in evaluating the cardiac function.

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