ANALYSIS OF CARDIOTOPOSCOPIC DATA WITH THE "URAL-1" DIGITAL COMPUTER

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Digital computers have been used to analyze electrocardiograms [4, 5].

When the method of electrocardiotoposcopy is used to study the electrical field of the human heart many numerical data are obtained [1-3], the analysis of which may be undertaken in various directions. Above all it is interesting to obtain generalized data, showing the fundamental principles governing the distribution of the cardiac potentials on the surface of the chest. The object of the present investigation was thus to analyze electrocardiotoposcopogram in order to obtain statistically significant data characterizing the distribution of the potentials in particular phases of activity of the heart. The obtaining of generalized, mean indices for the normal state and for certain diseases is of diagnostic interest. The diagnosis can also be made with a computer by means of the automatic comparison of data obtained from a patient with that stored in the computer's memory.

The Ural-1 computer was used for making the analysis (programmer Z. Filina). Data were analyzed from four groups of persons: healthy, patients with hypertrophy of the left ventricle, patients with hypertrophy of the right ventricle, and patients with a block of the right branch of the bundle of His.

By means of the method of electrocardiotoposcopy it is possible to record 50 chest leads in the form of luminous points and, at the same time, in the form of luminous columns. The luminous points on the screen of the oscilloscope are distributed in the same order as the electrodes on the anterior surface of the chest wall. The brightness of the points and the height of the columns change in step and in proportion to the magnitude of the cardiac potentials. An increase in the brightness of the points and in the height of the columns corresponds to electronegativity. A fall in the initial level of brightness of the points and height of the columns indicates the development of electropositivity.

The height of the columns was determined for analysis of the results of electrocardiotoposcopy by the computer. For analysis of the cardiac cycle with a film speed of 64 frames/sec, 30-40 frames are needed. Each of them represents 50 values. Only 10 frames were subjected to mathematical analysis (the last frame of the PQ interval, the QRS complex, the initial part of the period T_A). Generalizations were obtained on the computer by comparing the homonymous points on the motion picture frames corresponding to the same phases of cardiac activity.

The results of measurement of the height of the column characterizing the electrical activity were fed into the computer. These results for each patient numbered from 0 to n were represented as 10 (for the number of frames) matrices of the following type:

$$\left\| \begin{matrix} a^f_{1,1} & \cdots & a^f_{1,10} \\ \cdots & \cdots & \cdots \\ a^f_{5,1} & \cdots & a^f_{5,10} \end{matrix} \right\|,$$

or by the abbreviation $\| a^f_{ij} \|$, where (as also in the subsequent formulas) $f = 1, \ldots, 10$ – the frame number; $i = 1, \ldots, 5$ – the number of the line on frame f; $j = 1, \ldots, 10$ – the number of the column on frame f; $a^f_{ij} \geq 0$ – the decimal number in relative units equal to the size of the column at the point of intersection of the line i and the column j on the frame f.

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The first frame, corresponding to the last moment of the PQ interval (matrix $||a^1_{ij}||n$), was regarded as the background. By averaging on the computer the "mean a" was determined:

$$a_{mean} = \frac{1}{50}\sum_{i=1}^{5}\sum_{j=1}^{10} a^f_{ij}.$$

This value (a_{mean}) was the closest to the size of the columns during minimal cardiac activity. The values of a_{mean} differed from one patient to another (different tuning of the recording apparatus), and the data for each patient were therefore standardized relative to the corresponding a_{mean}. For the statistical analysis the information was recorded in the computer on 4 levels of a two-digit binary code:

$$b^f_{ij} = \begin{cases} 00, & \text{if} \quad a^f_{ij} < \frac{1}{2} a_{mean} \\ 01, & \text{if} \quad \frac{1}{2} a_{mean} \leqslant a^f_{ij} < a_{mean} \\ 10, & \text{if} \quad a_{mean} \leqslant a^f_{ij} < \frac{3}{2} a_{mean} \\ 11, & \text{if} \quad \frac{3}{2} a_{mean} \leqslant a^f_{ij}. \end{cases}$$

The first two levels (00, 01) reflect electropositivity, the next two (10, 11) correspond to electronegativity.

Eight patients were chosen with each disease (see above), with sufficiently characteristic symptoms. As mentioned above, each patient was characterized by 10 (according to the number of frames) matrices of the type:

$$||b^f_{ij}||n,$$

where n = 1, . . . , 8.

From these, 10 matrices of new types were obtained, enabling the character of the disease to be judged with greater statistical reliability than from single measurements (for one patient).

Each type of matrix was obtained in accordance with one of 4 programs.

Program No. 1 formed generalized matrices $||C^f_{ij}||n$ on the basis of coincidence of the corresponding points taken relative to a_{mean} in different patients from one group of diseases in more than 50% of cases. In these circumstances the work of the computer was determined by the formulas:

$$C^f_{ij} = \begin{cases} 0, & \text{if} \quad \sum_{n=1}^{8} \alpha^f_{ij} < 4 \\ 1, & \text{if} \quad \sum_{n=1}^{8} \alpha^f_{ij} \geqslant 4 \end{cases}$$

$$\alpha^f_{ij} = \begin{cases} 0, & \text{if} \quad b^f_{ij} = 00 \quad \text{or} \quad b^f_{ij} = 01 \\ 1, & \text{if} \quad b_{ij} = 10 \quad \text{or} \quad b^f_{ij} = 11. \end{cases}$$

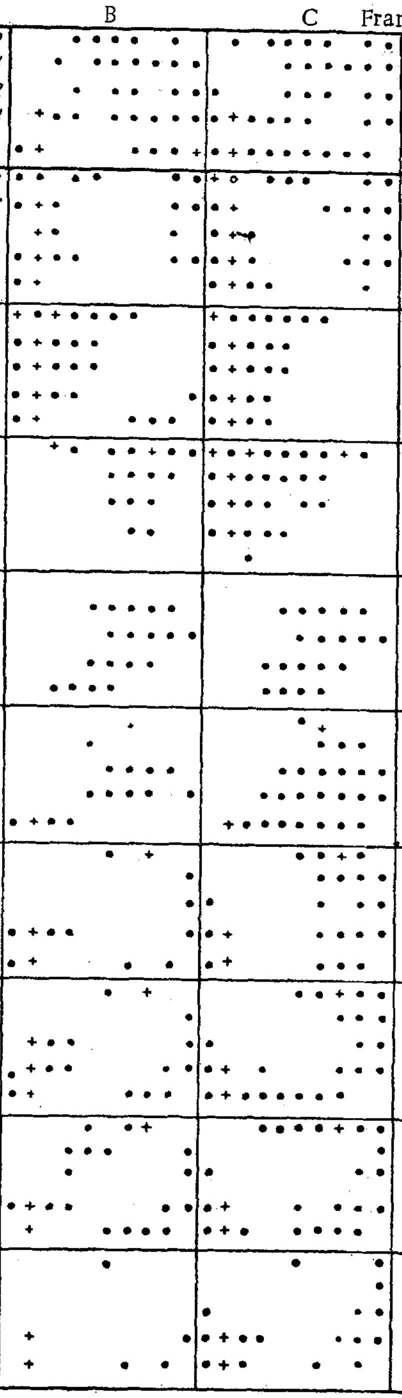
The matrices thus obtained give an idea of the distribution of the potentials on the anterior surface of the chest wall in the disease as a whole, for the points not characteristic of the disease (random artefacts, peculiarities of the patient) are rejected by averaging. For the sake of clarity, in the figure, section B, instead of the number 1, a dot is inserted at the corresponding place, and instead of zero (0) the place is left blank.

Program No. 2 for obtaining generalized matrices $||d^f_{ij}||$ differed from program No. 1 in the fact that comparison was carried out relative to $^2/_3\, a_{mean}(a^f_{ij} \geq a_{mean})$, so that the regions with maximal electronegativity could be detected. The work of the computer was determined by the following formulas:

$$d^f_{ij} = \begin{cases} 0, & \text{if} \quad \sum_{n=1}^{8} \beta^f_{ij} < 4, \\ 1, & \text{if} \quad \sum_{n=1}^{8} \beta^f_{ij} \geqslant 4, \end{cases}$$

where $\beta^f_{ij} = \begin{cases} 0, & \text{if} \quad b^f_{ij} = 00 \quad \text{or} \quad b^f_{ij} = 01 \quad \text{or} \quad b^f_{ij} = 10, \\ 1, & \text{if} \quad b^f_{ij} = 11 \end{cases}$

A										Frame No.
X	8	X	10	10	11	11	X	10	8	1
8	X	10	8	10	11	10	10	11	11	
8	X	9	10	9	10	10	9	10	12	
9	X	10	10	9	11	10	10	10	14	
13	X	8	8	8	7	10	10	10	X	
X	14	X	12	12	9	8	X	12	16	2
15	X	12	6	6	4	2	4	12	16	
9	X	10	8	4	6	4	2	10	18	
12	X	10	10	6	4	4	8	12	15	
14	X	4	3	3	4	4	6	8	X	
X	24	X	20	18	10	10	X	8	5	3
25	X	23	20	10	2	0	2	5	0	
20	X	24	22	10	5	0	0	0	0	
18	X	18	15	6	0	0	2	6	15	
16	X	0	2	4	6	18	20	18	10	
X	8	X	10	8	14	25	X	22	22	4
5	X	8	8	6	18	20	20	17	4	
0	X	2	2	6	18	20	24	8	2	
2	X	2	2	5	8	10	10	8	2	
0	X	2	2	3	5	6	5	6	X	
X	0	X	2	0	3	3	X	2	0	5
2	X	2	4	14	30	18	16	12	6	
2	X	2	4	6	21	20	25	20	10	
2	X	4	8	18	25	25	18	8	6	
6	X	25	22	20	18	6	4	0	X	
X	5	X	6	8	4	4	X	4	4	6
2	X	4	6	10	8	7	8	8	8	
4	X	6	9	9	10	12	13	12	8	
6	X	8	9	13	10	11	10	7	10	
10	X	11	10	9	8	8	4	6	10	
X	2	X	6	8	10	6	X	6	3	7
7	X	7	7	8	7	4	6	8	10	
6	X	8	8	6	8	6	2	8	10	
10	X	10	10	8	4	2	8	8	12	
12	X	5	5	5	6	10	8	10	X	
X	0	X	7	9	10	8	X	8	4	8
6	X	6	8	8	8	5	6	9	11	
8	X	10	11	9	9	6	2	6	12	
10	X	10	10	8	6	2	9	10	16	
14	X	6	6	6	6	15	15	10	X	
X	0	X	6	10	9	11	X	8	4	9
4	X	8	10	10	10	4	6	8	10	
6	X	8	10	8	8	4	4	8	10	
10	X	10	10	9	6	4	9	10	16	
14	X	6	6	8	10	11	10	11	X	
X	5	X	8	8	10	8	X	8	5	10
7	X	7	8	8	7	4	5	6	8	
6	X	8	8	6	8	5	1	5	8	
9	X	9	9	7	5	2	8	8	12	
10	X	5	5	7	8	10	8	10	X	



Results of analysis of a normal electrocardiotoposcopic investigation by means of the Ural-1 digital computer. Explanation in text.

These formulas reveal the regions of greatest electronegativity ($a_{ij}^{f} \geq 3/2\ a_{mean}$).

The determination of the region of greatest electropositivity was carried out by program No. 3, in which the comparison was made relative to $1/2\ a_{mean}$ ($a_{ij}^{f} \leq 1/2\ a_{mean}$), as a result of which the matrices $\|e_{ij}^{f}\|n$ were formed, where

$$e_{ij}^{f} = \begin{cases} 0, & \text{if } \sum_{n=1}^{8} \gamma_{ij}^{f} < 4 \\ 1, & \text{if } \sum_{n=1}^{8} \gamma_{ij}^{f} \geqslant 4, \end{cases}$$

and moreover

$$\gamma_{ij}^{f}=\begin{cases}0, & \text{if} \quad b_{ij}^{f}=00, \\ 1, & \text{if} \quad b_{ij}^{f}=01 \quad \text{or} \quad b_{ij}^{f}=10, \quad \text{or} \quad b_{ij}^{f}=11.\end{cases}$$

In this way the places of greatest electropositivity can be estimated ($a_{ij}^{f} \leq {}^1/_2\ a_{mean}$).

In contrast to the conditions of the analysis described above, program No. 4 demanded 100% coincidence of points with a value greater than a_{mean}.

Program No. 4 may be represented in the following form: the matrix $||f_{ij}^{f}||$ is formed, where

$$f_{ij}^{f}=\begin{cases}0, & \text{if} \quad b_{ij}^{f}=00 \quad \text{or} \quad b_{ij}^{f}=01 \quad \text{for all} \quad n, \\ 1, & \text{if} \quad b_{ij}^{f}=10 \quad \text{or} \quad b_{ij}^{f}=11 \quad \text{for all} \quad n,\end{cases}$$

in other cases it may be determined additionally at the investigator's discretion.

The results obtained by means of this formula reveal the most characteristic points of the topogram encountered in all subjects with that particular disease. Analysis of the electrical field of the heart on the anterior surface of the chest wall showed that the use of program No. 1 gave statistically significant mean data, program No. 2 identified the regions with maximal electronegativity, program No. 3 reflected the projection of the region of maximal electropositivity, and program No. 4 introduced the greatest demands, namely 100% coincidence.

As an example of the distribution of the potentials in a healthy person the results of measurement (investigation No. 133) of the height of the columns may be given, in which leads with above-mean value are denoted by dots (see figure, A, B).

For comparison, under C in the figure are shown the results of analysis by the Ural-1 computer using program No. 1. Analysis of the data in the figure shows that the distribution of the potentials as obtained on the computer (C) coincides on the whole with the distribution of the potentials given in the example (B).

Comparison clearly shows that in the QRS period the zone of electropositivity lies in the middle part of the chest (frame No. 2). On the next frames (3, 4, 5, 6) movement of electronegativity can be seen along the diagonal from right to left and from above down. It is interesting that at the end of the QRS complex (frame No. 6) a widening of the area of electronegativity is observed, and this was found in many investigated patients. The beginning of the period T_A is characterized by electronegativity anteriorly in the middle part of the chest.

Mathematical analysis along these lines on the computer was carried out in cases of congenital heart defects, separately for patients with hypertrophy of the right and the left ventricles, and also on patients with a block of the right branch of the bundle of His.

The results obtained by use of programs Nos. 2 and 3 on the Ural-1 computer gave the pattern of distribution of the cardiac potentials on the anterior surface of the chest wall in the form of isopotential lines at 4 levels. This variant of the analysis of the results of cardiotoposcopy is of considerable interest, for it enables a fuller graphic picture of the electrical field of the heart to be obtained.

The use of program No. 4, with the demand for 100% coincidence of the electrical activity of the points to be compared, showed that the generalized data lost their specificity. For example, when attempts were made to differentiate the groups of patients indicated above, negative results were obtained.

As a result of the use of the above-mentioned four programs, it was found that with coincidence of the points in more than 50% of cases (program No. 1) statistically significant results were obtained. For this reason, averaged data for three groups (healthy, patients with hypertrophy of the right ventricle, and patients with hypertrophy of the left ventricle) were fed into the Ural-1 computer. Next, investigations were carried out to make a diagnosis in patients by comparing the readings obtained with the patients with the data for the above-mentioned groups.

SUMMARY

Electrocarditoposcopy data relating to the QRS period were processed by means of a "Ural-1" digital electronic computer on four programs. Summarized significant data were obtained on the distribution of cardiac potentials on the anterior surface of the thorax in healthy persons, in patients with hypertrophy of the right and left ventricles as well as with right bundle-branch heart block. In part of those examined by means of the "Ural-1" computer the electrical field of the heart appeared as isopotential lines of variable level.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of the first issue of this year.
