INVESTIGATION OF CHARACTERISTICS OF LEADS FOR MEASURING TRANSVERSE COMPONENT OF THE CARDIAC VECTOR

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In order to measure precisely the component of the total electrical vector (dipole moment) of the heart in the direction of any geometric axis the lead used for this purpose must keep a constant scale of measurement and must be insensitive to all other parameters of the cardiac generator [1]. On the basis of the assumption usually made in electrocardiography that the sources of the electric current distributed in the region of the heart are surrounded by a purely resistive, linear, homogeneous conductor, bounded by the surface of a body of arbitrary shape, Gabor and Nelson [3] and Geselowitz [4] showed that the component of the cardiac vector along any axis i can be determined by the integral for the surface of the body:

$$D_i = \gamma \oint \varphi_s dS_i, \quad (1)$$

where γ represents the specific conductivity of the medium, φ the potential on the surface, and dS_i the projection of the area vector of the surface element on the axis i. In practice it is impossible to measure the potential over the whole surface of the body, and all known systems of leads provide for measurement of potentials at a limited number of points.

The properties of leads are described quantitatively by lead tensors, the components of which characterize the sensitivity of the leads to corresponding components of the heart tensor. For each lead of an ideal orthogonal vector-cardiographic system, all components of the tensors, with the exception of one component of the lead vector, must be equal to 0, and the signals in three leads of such a system are determined by the equations:

$$\varphi_x = D_x l_x, \quad \varphi_y = D_y l_y, \quad \varphi_z = D_z l_z, \quad (2)$$

and $l_x = l_y = l_z$. Because of the great length of the body in a longitudinal direction (along the y axis) a sufficiently accurate lead for measuring the component D_y of the cardiac vector can be obtained comparatively easily. The problem is rather more difficult for the component D_x, and the greatest difficulties arise during measurement of the transverse (anteroposterior) component D_z, because in this case the electrodes are close to the heart region and the influence of multipoles of higher orders is particularly perceptible. For this reason, to measure the component D_z, a large number of electrodes with specially selected balance resistors must be used. Such leads essentially perform approximate integration of the potential instead of the precise integration obtained with Eq. (1).

To determine what increase in quality of lead Z is obtained by increase in quality of lead Z is obtained by increasing the number of electrodes, the characteristics of four types of leads were determined by means of physical models and a very simple theoretical model.

EXPERIMENTAL METHOD

The test leads Z_1, Z_2, Z_5, and Z_8 contain 1, 2, 5, and 8 electrodes respectively, located on the surface of the chest wall (Fig. 1). The signal of lead Z_1 (coinciding with the standard chest lead V_2) is measured between the chest electrode placed opposite the geometric center of the heart, and Wilson's zero terminal. Lead Z_2 is formed by the chest electrode of lead Z_1 and a spinal electrode located on the posterior surface of the chest opposite the center of the heart. Lead Z_8 is an anteroposterior lead of the

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Comparison of Results of Theoretical Calculations and Experimental Measurements of Components of Lead Vectors

Lead	Scale of measurement						Component of lead vector					
	comp.	experiment				theor. calc.	comp.	experiment				theor. calc.
		model 1		model 2				model 1		model 2		
		homogeneous	with lungs	homogeneous	with lungs			homogeneous	with lungs	homogeneous	with lungs	
Z_1	l_z	−1,74	−1,89	−2,00	−2,32	−1,66	l_x	0,02	−0,07	0,05	−0,06	0
							l_y	−0,01	0,09	0,04	0,08	0
							l_z	1	1	1	1	1
							l_n	0,02	0,11	0,06	0,10	0
Z_2	l_z	2,14	2,26	2,50	2,71	2,14	l_x	−0,02	0,09	−0,05	0,06	0
							l_y	−0,03	−0,15	−0,02	−0,12	0
							l_z	1	1	1	1	1
							l_n	0,04	0,18	0,05	0,13	0
Z_5	l_z	1,05	1,13	1,06	1,01	1,12	l_x	0,04	0,10	0,04	0,02	0,04
							l_y	0,02	−0,11	0,02	−0,14	0
							l_z	1	1	1	1	1
							l_n	0,04	0,15	0,04	0,14	0,04
Z_8	l_z	1	1	1	1	1	l_x	0,04	0,09	−0,04	−0,06	0,02
							l_y	−0,02	−0,26	0,04	−0,25	0
							l_z	1	1	1	1	1
							l_n	0,04	0,28	0,05	0,26	0,02

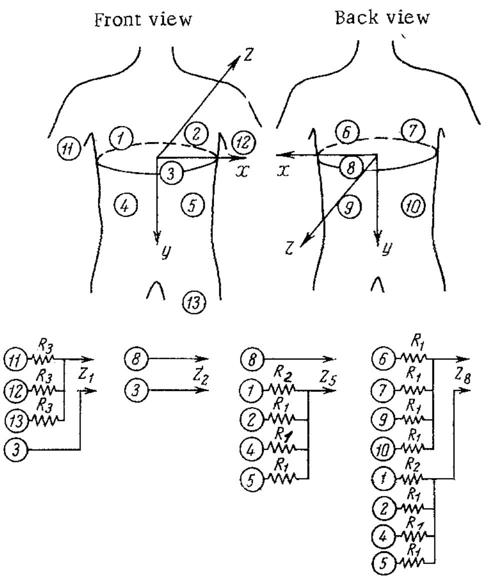

Fig. 1. Position of electrodes and electrical circuits of leads. R_1 = 100,000 Ω, R_2 = 70,000 Ω, R_3 = 5,000 Ω.

corrected orthogonal system SVEC III [1]. Lead Z_5 is obtained from lead Z_8 by replacing the four spinal electrodes by the one spinal electrode of lead Z_2.

The parameters of the leads were determined experimentally on two electrophysical models of the human body. Hollow models made to natural size from dielectric material were filled with liquid electrolyte. An artificial current generator with known parameters was placed in the region of the heart and signals were measured in leads whose electrodes were located at the corresponding anatomical points. Measurements were made both on homogeneous models and on models with artificial lungs, with only one-sixth of the specific conductivity of the surrounding electrolyte. The experimental method has been described more fully elsewhere [1, 2]. For a theoretical assessment, the simplest model of a conducting medium was used—a homogeneous conductor of infinite extent in space. The field potential of point generators in such a theoretical model can be expressed by simple equations. For calculating the theoretical assessments, the coordinates of the lead electrodes were chosen as the mean between the corresponding coordinates of the two experimental models.

EXPERIMENTAL RESULTS AND DISCUSSION

The results of analysis of the experimental measurements and theoretical calculations are given in the table and in Fig. 2. The relative sensitivity of the leads to a useful signal, i.e., to component D_z of the cardiac vector, is shown in column one of the table. The unit adopted here is the component l_z of the vector of lead Z_8. The sensitivity of the leads to components D_x and D_y of the cardiac vector, indicating the degree to which the leads are nonorthogonal, is shown in column two of the table in the form of components l_x and l_y, relative to component l_z. The absolute value of the total component of the lead vector perpendicular to the useful component l_z is also given here; this value $l_n=\sqrt{l_x^2+l_y^2}$ is also given relative to l_z. The ratio

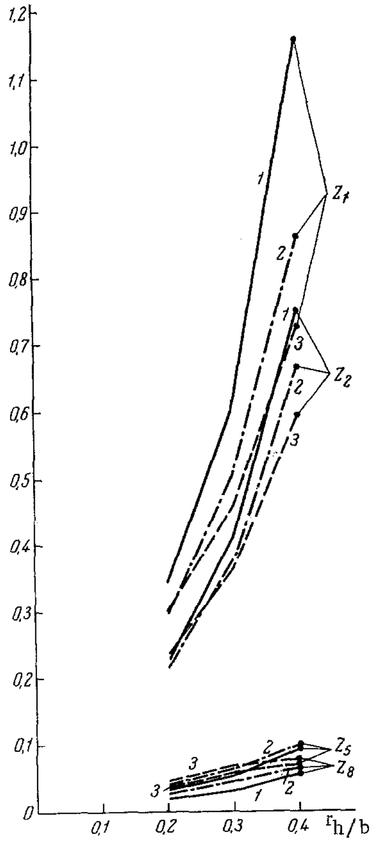

Fig. 2. Mean-square contribution of all nondipole components of equivalent generator to lead signal expressed as ratio of mean-square contribution of dipole. 1) Theoretical estimate; 2) homogeneous model; 3) model with lungs.

between the mean-square contribution of all the nondipole components of an equivalent generator to the lead signal and the mean-square contribution of the dipole is shown graphically in Fig. 2, in which it is plotted against the relative radius of the heart (i.e., the region occupied by the current generators). These characteristics were found to be very close for the two experimental models despite the considerable difference in their geometric shape, and they are therefore given as a mean value only.

The results obtained show that the sensitivity of the multielectrode leads Z_5 and Z_8 to the nondipole components of the equivalent generator is one order lower than the sensitivity of leads Z_1 and Z_2; for a heart of maximal size the mean-square contribution of nondipole components to the signal of leads Z_5 and Z_8 is less than 10% of the mean-square contribution of the dipole. In relation to orthogonality, in most cases these leads are similar to leads Z_1 and Z_2, but particularly marked disturbances of orthogonality were found in lead Z_8 for the nonhomogeneous model; in other cases the "harmful" components of the lead vector do not exceed 15% of the useful component.

It is theoretically possible to improve multielectrode leads still further by increasing the number of electrodes. It must be remembered, however, that in the leads investigated individual positioning of each electrode is provided for by means of anatomical guides, and there are practical difficulties interfering if a large number of electrodes are used. Even the use of lead Z_8 is inconvenient in practice, particularly in connection with fixation of the four spinal electrodes. A simplified variant of this lead with one spinal electrode, namely lead Z_5, is therefore of interest. Experimental results showed that its parameters are hardly inferior to those of lead Z_8, and in the case of a nonhomogeneous model, they may even be superior as regards orthogonality. Lead Z_5 can therefore be recommended for measurement of component D_Z of the cardiac vector instead of lead Z_8.

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