ASSESSMENT OF THE PRINCIPAL COMPONENTS OF THE EQUIVALENT CARDIAC GENERATOR ON RECORDED ELECTROCARDIOGRAPHIC POTENTIALS

I. A. Toropchina

UDC 612.172.4.001.57

The relative contribution of the various multipolar components to the total surface potential was determined in experiments on the isolated heart located in a spherical volume conductor. These contributions were calculated for distances from the electrodes to the center of the cardiac ventricles that corresponded to the placement of standard and thoracic ECG recording electrodes in different age groups. On the basis of these results the optimal model of an equivalent cardiac generator can be chosen for a given electrocardiographic recording system.

KEY WORDS: Equivalent cardiac generator; parameters of the generator; electrocardiographic leads.

To describe the heart quantitatively as an electrical generator, the so-called equivalent cardiac generators are used at the present time [1]. The parameters of these generators can be calculated from measurements of the electric field potential on the surface of a volume conductor surrounding the heart [4-6].

An equivalent generator of multipolar type is widely known. To describe the electric field of the heart with an accuracy suitable for electrocardiography, it is evidently sufficient to determine only some of the first components of this generator. To decide how many of these components are required, i.e., to choose the optimal order of the multipolar equivalent generator, direct measurement of dipolar, quadripolar, and certain components of a higher order is necessary and their contribution to the potential recorded by the electrocardiographic electrodes must be estimated.

The present investigation was carried out for this purpose.

EXPERIMENTAL

Experiments were carried out on the isolated heart of an adult mongrel dog (7 experiments). The isolated heart was perfused with a stabilized donor's circulation. Synchronized recordings were obtained of unipolar electrocardiograms with leads from 266 points, using silver electrodes arranged uniformly on the spherical surface of a volume conductor (physiological saline) surrounding the heart. The winding speed of the recording tape was 500 mm/sec. The curves are presented in numerical form. For this purpose readings were taken of each components of the QRS complex at 15 points 4 msec apart. The signal value at each moment of time was expressed in millivolts.

As a result, data were obtained on the distribution of the potential over a spherical surface at each of 15 moments of the QRS complex. From this distribution the component of the equivalent generator and their contributions to the surface potential were determined. The method of calculation was described by Plonsey in 1966 [7].

The contribution of the various components of the multipole to the surface potential on the human chest was estimated on the assumption that the contribution of a multipole of the n-th order is inversely proportional to the distance of the recording electrodes from the center of the heart, taken to the $(n+1)$'th

Department of Experimental and Clinical Physiology, A. V. Vishnevskii Institute of Surgery, Academy of Medical Sciences of the USSR, Moscow. (Presented by Academician of the Academy of Medical Sciences of the USSR A. A. Vishnevskii.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 78, No. 12, pp. 12-14, December, 1974. Original article submitted June 28, 1974.

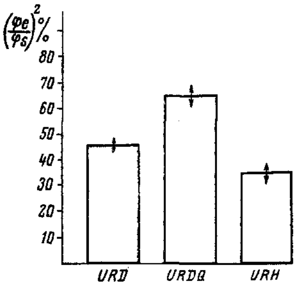

Fig. 1

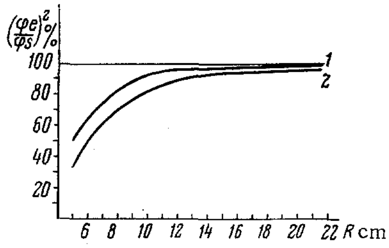

Fig. 2

Fig. 1. Relative contributions of different multipolar components of the cardiac generator to the total surface potential of a volume conductor. URD) contribution of dipolar component; URDQ) combined contribution of dipolar and quadripolar components; URH) combined contribution of higher multipolar components; φ_e) potential created by each component examined on the surface of the volume conductor; φ_s) total potential of spherical conductor. Arrows indicate scatter of values of contributions in 7 experiments.

Fig. 2. Relative contributions of different multipolar components of the cardiac generator to the total surface potential of the human chest as functions of distance of the recording electrodes from the center of the heart: 2) contribution of dipolar component; 1) combined contribution of dipolar and quadripolar components; φ_e) potential produced by each of the components examined on the surface of the spherical conductor; φ_s) total potential of the spherical conductor.

power. It was assumed that the heart of the healthy dog and of the healthy human subject are generators with a similar structure.

The mean-square potential of a spherical surface with radius equal to the distance of the electrodes to the center of the heart was taken as the potential of the thoracic electrode. To calculate these distances, corresponding to precordial electrodes from V_1 to V_6, the results of an anthropologic investigation of 6960 persons were analyzed (Scientific Report of the Institute of Anthropology, Moscow University, Moscow, 1957-1961).

On the basis of the anthropometric data, transverse sections through the chest at the level of the 4th-5th intercostal space were reconstructed, the coordinates of the center of the cardiac ventricles were then plotted on these sections [3], and the distances from it to the points corresponding to the thoracic electrodes were calculated graphically [2].

RESULTS

The contribution of the dipolar and quadripolar components on the average for the whole duration of the QRS interval of the cardiac cycle were practically identical for all seven experiments (the scatter of the data was less than 5%). This small scatter of the values of the contributions obtained shows that the heart of healthy dogs is stable as a generator and differs only slightly in different individuals. The mean results of all the experiments are given diagrammatically in Fig. 1. The relative contribution of the dipolar component of an equivalent multipolar cardiac generator to the total surface potential was evidently 46%, while that of the dipolar and quadripolar components together was 65%. The remaining 35% of the potential was determined by higher multipolar components.

The contributions of the various multipolar components of the same generator to the potential of the thoracic electrodes depended primarily on the distance of these electrodes from the point of application of the generator. To calculate these contributions it was therefore essential to know the distance from the thoracic electrocardiographic electrodes to the center of the heart. These distances are given in Table 1 for persons of three age groups: 7-14, 15-29, and 45-59 years. The data in Table 1 show that the distance actually varies substantially with age and that the distances are shortest for electrodes at the points V_1-V_3. The results of the calculation of the contribution of dipolar, combined quadripolar and dipolar, and of all multipolar components of a higher order together, for different distances of the recording electrodes from the center of the heart, are given in Fig. 2. Analysis of the curves in Fig. 2 shows that the potential of the

TABLE 1. Distance (in cm) from Center of Heart to Thoracic Recording Electrodes in Healthy Persons of Different Ages

Age (in years)	Number of persons investigated	Distance from center of heart to thoracic recording electrodes					
		V_1	V_2	V_3	V_4	V_5	V_6
7—14	2534	5,8	5,4	5,6	5,9	6,6	7,9
15—29	5293	6,8	6,9	7,2	7,4	8,1	9,6
45—59	1134	8,0	7,6	8,0	8,3	8,9	10,3

near precordial leads in adults (6.8-8 cm) contains a contribution of 60-70% from the dipolar components and of 75-80% from the combined dipolar and quadripolar components. Consequently, the contribution of the higher multipolar components was 20-25% of the surface potential. In children these recording electrodes are approximately 5.5 cm from the center of the heart. These elements of the multipolar generator are responsible for 45, 60, and 40%, respectively, of the surface potential. Even in the left thoracic leads in adults (9-10 cm) the relative contribution of the dipole is about 80-85%, the combined contribution of the dipole + quadripole is 90-95%, and the contribution of the higher components is about 5-10%. At a distance of 20-22 cm, equal to the distance from the left shoulder to the heart, the contribution of the dipole to the surface potential is 95%. Consequently, the potential of standard limb leads is due practically entirely to the dipolar component.

For all leads from the body surface the dipole makes the greatest contribution. However, if only a dipolar equivalent generator is used to describe the leads and if only its components are recorded (corrected orthogonal leads), some loss of information is unavoidable. This loss will be most serious when electrocardiographic chest recordings taken in children are analyzed. A study of the contribution due to the quadripolar component of a multipole makes the model more accurate.

The results should be taken into account when the optimal model of equivalent cardiac generator is chosen.

LITERATURE CITED

1. O. V. Baum, É. D. Dubrovin, and L. I. Titomir, in: Simulation and Automatic Analysis of Electrocardiograms [in Russian], Moscow (1973), p. 35.
2. A. V. Gol'tsman and I. T. Dmitrieva, Fundamentals of Electrocardiography [in Russian], Kiev (1960).
3. L. I. Titomir, Biofizika, No. 2, 307 (1967).
4. D. B. Geselowitz, Proc. IRE, 48, 75 (1960).
5. D. B. Heppner, IEEE Trans. Biomed. Eng., 15, No. 4, 298 (1968).
6. J. M. Hlavin and R. Plonsey, IEEE Trans. Biomed. Eng., No. 3, 98 (1963).
7. R. Plonsey, Biophys. J., 6, 163 (1966).