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BIOPHYSICAL HEART—BODY MODEL

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A biophysical heart—body model consisting of a liquid bulk conductor, filling a hollow transparent vessel shaped like a human torso, and with an isolated perfused dog's heart immersed in it, is described. Metal electrodes for the various ECG leads are distributed on the inner surface of the vessel. The bulk conductor consists of NaCl solution. The amplitude of the derived signals was shown to depend on the NaCl concentration. With NaCl in a concentration of 0.004% the amplitude of the ECG obtained on the model was similar to that of the human ECG in the same leads. With an increase in the concentration of the solution the amplitude of the ECG falls rapidly, and with a 0.9% NaCl concentration it becomes almost indistinguishable. To protect the heart from injury by the hypotonic solution, an artificial pericardium made of electrically conducting rubber film is used. The method of placing the heart in the model of the torso also is described. It is suggested that the heart—body model can be used to study problems connected with the experimental investigation of ECG changes in different leads associated with intentionally induced injuries to or changes in the state of the heart.

KEY WORDS: electrocardiography; biophysical model.

The distinctive geometric shape of the thorax in animals and its great differences from the human thorax impose severe limitations on the extrapolation of experimental ECG interpretations to clinical electrocardiography. In the history of electrocardiography there is a well-known error connected with the careless transfer of electrocardiographic signs of branch block of the bundle of His obtained in experiments on dogs to clinical practice [3]. As a result of this mistake, an incorrect idea of the electrocardiographic features of these disturbances to conduction was held for more than 10 years. The cause of this error was the difference between the shape of the thorax of the dog and man.

Attempts to surround an animal's heart by a bulk conductor shaped like the human body have been undertaken now for a long time. However, the use of the cadaver as a model of the human body has several important disadvantages and can be very difficult to organize. It is preferable to use artificial models of the thorax, consisting of a hollow vessel shaped like the human torso, filled with an electrolyte, and with electrodes distributed over the thorax to record the electrocardiogram. Such models have been used to study the properties of electrocardiographic leads, by introducing a physical dipole [2, 4, 6, 7] and also for biological experiments [8].

The heart—body model to be described below consists of a hollow cast of the torso of an adult man of normosthenic constitution, filled with NaCl solution, in which the isolated, perfused heart of a large dog weighing 20-35 kg was immersed (Fig. 1A). The heart was isolated and perfused by the method described in [1]. So that during the use of the model

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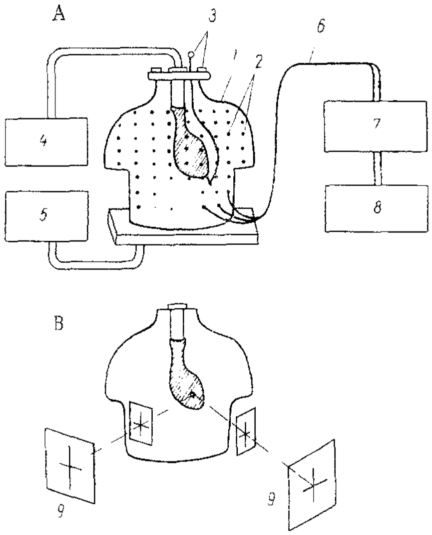

Fig. 1

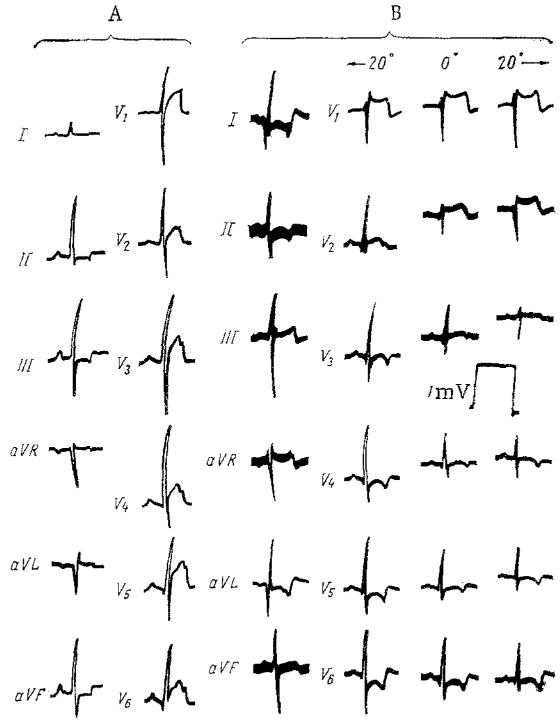

Fig. 2

Fig. 1. Biophysical heart–body model. A) Block diagram of apparatus, B) method of placing isolated animal's heart in biophysical model of human torso: 1) model of torso filled with hypo-osmotic NaCl solution; 2) recording electrodes; 3) coordinate system; 4) artificial circulation apparatus; 5) thermostat; 6) cable of electrocardiographic leads; 7) commutator of leads; 8) electrocardiograph; 9) sighting system. Isolated dog's heart in artificial pericardium made of electrically conducting rubber film is shaded.

Fig. 2. Effect of geometric differences in bulk conductor on appearance of ECG. A) ECG of dog weighing 27 kg anesthetized with morphine and thiopental, lying in the supine position; B) derivation from electrodes of model of human torso. Arrows indicate directions of rotation of isolated heart around long axis clockwise and anticlockwise.

parallels could be drawn with the human ECG, the isolated dog's heart was placed in the model of the torso in the same wasy as the human heart is placed in the thorax. For this purpose a special device was constructed, in the form of two preadjusted sights, oriented at an angle to each other. The dog's heart was placed so that the optical axis of each sight passed through the geometric center of the ventricles (Fig. 1B). To move the heart and fix it in the chosen position, a system of coordinates is provided, so that the heart can be moved in the following directions: upward–downward, right–left, and forward–backward. The heart can also be rotated around its longitudinal axis, and also in the frontal and sagittal planes of the body. The heart was oriented so that its anterior surface faced the anterior surface of the thorax. The precise setting of the heart was achieved by small angular displacements of the organ around the longitudinal axis so that the intermediate zone of the precaudial ECG coincided with derivations V_{2-3} (0° in Fig. 2).

When physiological saline was used as bulk conductor, potentials of the heart derived from the electrodes were found to be very small, and it was virtually impossible to analyze the electrocardiographic tracings. This was because of shunting of the field currents of the heart by the low resistance of the solution (specific resistance about 55 Ω·cm). To increase the amplitude of the ECG signals recorded, the conductivity of the solution had to be reduced, by considerably reducing the concentration of the electrolyte. However, under these circumstances the osmotic concentration of the solution fell, and this led to edema and injury of the myocardium.

Fig. 3. Amplitude of ECG with different concentrations of NaCl solution filling model of human torso. Isolated heart of dog weighing 34 kg immersed in the model. Electrocardiographic lead V_5. 1) Distilled water, 2) 0.004%; 3) 0.008%, 4) 0.45% concentration of NaCl.

To increase the derived potential difference and also to protect the isolated heart from injury and death, the following technique was developed: The hollow model of the torso with the recording electrodes mounted in it was filled with a solution of very low ionic concentration. The isolated perfused dog's heart immersed in this solution was surrounded by a close-fitting bag made of electrically conducting rubber film to protect it from injury. The film was made from latex, in which finely dispersed carbon was introduced to make it electrically conducting. Since the film and the solution surrounding the heart had a specific resistance of the same order, the presence of the film did not lead to any significant changes in the amplitude of the potentials recorded. By contrast, the electrical resistance of the solution filling the model of the torso had a very considerable influence on their amplitude (Fig. 3). The amplitude of the derived ECG was maximal when the resistance of the solution was highest (distilled water). However, under these circumstances there was often considerable induction of an alternating current. An increase in the NaCl concentration quickly led to a decrease in the derived signal, which became hardly distinguishable when the model was filled with physiological saline (0.9% NaCl), even with maximal amplification of the electrocardiograph. The optimal NaCl concentration was found to be 0.01-0.04%, for under these circumstances the ECG recorded from the model was closest in amplitude to the human ECG recorded by the same leads.

The effect of differences in geometry of the bulk conductor on the appearance of the ECG is illustrated by Fig. 2, which shows the ECG obtained from a dog (A) and from the model (B) in 12 customary derivations. It will be clear from Fig. 2 that transfer of the heart from the dog's thorax into the model of the human torso led to a change in the direction of the QRS electrical axis in the frontal plane, to the appearance of a distinct transition zone in the chest leads, and to changes in the QRS formula, the position and configuration of the ST segment, and the shape and sign of the T wave. The similarity to the human ECG is thereby significantly increased.

It is suggested that the model described above can be used to study problems connected with the topographic distribution of ECG changes in different derivations during intentionally induced injuries to and changes in the state of the heart.

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