velocity as before. The recorded curve will then be identical with the previous one.

By placing the right-hand electrode upon the right auricle of the dog at a point distant from the sinus node and the left-hand electrode at a point distant from the heart, electrograms identical in all essential particulars with the curves plotted from equation (2) are obtained. Knowing the velocity of the excitation process in the auricle the effective distance (2a) over which the excitation wave extends may be determined. It is very short, apparently 10 mm. or less. We conclude from such experiments that auricular muscle produces electrical effects during the period of activation and deactivation only. When fully active it exerts no influence upon the electrocardiogram. The period of activation at any point probably lasts 0.01 sec. or less.

The process of deactivation produces a curve similar to that produced by activation except that the phases of the curve are reversed, the amplitude is less and the effective distance (2a in formula 2) over which the wave of deactivation extends is greater than in the case of activation.

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The Form of the Electrocardiogram. III. Opposed Potential Differences.

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At the onset of ventricular systole the excitation process is spreading within the ventricular muscle in many different directions simultaneously. Many of the electrical forces, or potential differences, produced are opposed by forces opposite in direction, and their effects are consequently neutralized. Other potential differences are not opposed; it is these potential differences and these alone which have an effect upon the electrocardiogram.

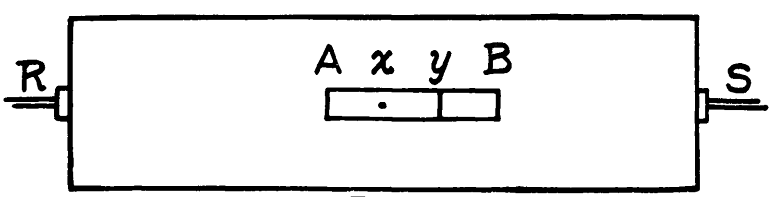

FIG. 1.

Consider the simple strip of muscle AB (Fig. 1) immersed in a large body of physiological saline solution or other similar conducting material. Place one electrode at *R*, and a second electrode at *S* and connect these electrodes to a string galvanometer in such a way that relative negativity at *R* will cause an upward deflection when the electrogram of the muscle is recorded. Given that *RX* equals *SX* (Fig. 1). Stimulate this muscle at *X;* given that XA equals XY. It is obvious that the excitation process will spread toward *A* and toward *Y* simultaneously; that the potential differences produced by the spread in one direction will be completely neutralized by the spread in the opposite direction and that no deflection will result until that part of the muscle lying between *A* and *Y* has completed its period of activation. Such deflections as do occur will result from activation of that part of the muscle lying between *Y* and *B*.

If instead of the strip of muscle *AB* we have a circular sheet of muscle and stimulate this muscle at its center, the center being equidistant from *R* and *S*, the excitation process will travel radially in all directions and since no unopposed potential differences will be produced no deflections whatsoever will occur. The same result will be obtained from a spherical shell of muscle if all points on the interior surface of the shell are stimulated at the same instant.

Each of the cardiac ventricles may be considered a spherical shell of muscle from which a segment at the ventricular base has been removed. If the ventricular walls were of uniform thickness and the entire endocardial surface was activated at all points simultaneously, all of the potential differences produced by each ventricle would be neutralized except those resulting from activation of the region at the apex opposite the opening in the spherical shell at the base.

The observations made by Lewis and Rothschild[1] indicate that all points on the endocardial surface of both ventricles, except points on both sides of the upper septum and possibly points on the endocardial surface of the conus, are activated before the inscription of *R* in lead II begins.

When one electrode is placed upon the ventricular surface and the other at an indifferent point an intrinsic deflection is obtained. The onset of this deflection indicates that the excitation wave, traveling from within outward, has reached the epicardial surface. Since, as pointed out in article II of this series[2] the excitation process extends over a very short distance, the appearance of an intrinsic deflection

[1] Lewis and Rothschild, *Phil. Trans. Roy. Soc.*, 1915, ccvi-B, 328.

[2] Wilson, MacLeod, Barker, PROC. SOC. EXP. BIOL. AND MED., 1930, xxvii, 588.

under the above conditions indicates that the subjacent muscle has been completely activated and is, therefore, no longer producing potential differences. If potential differences directly opposed to those which were produced by the activation of this subjacent muscle, now complete, are still existent they will produce an effective potential difference of such a character as to indicate relative negativity on that side of the body on which the investigated point lies.

Considerations such as these lead us to conclude that *R* of the normal human electrocardiogram is produced by unopposed potential differences resulting from activation of the apical regions of the heart, and that the *S* deflection is produced by unopposed potential differences resulting from activation of the thick ventricular walls at the cardiac base.

They also lead to the conclusion that in bundle branch block the average spread of the excitation wave during the inscription of the chief initial deflections is from the contralateral toward the homolateral side.

We have also applied these considerations to the analysis of the curves which depict ventricular preponderance and to the analysis of the *T*-deflection of the electrocardiogram.

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The Form of the Electrocardiogram. IV. The Mean Electrical Axis and the Center of Stimulation.

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Just as a material body may be considered the sum of an infinite number of material particles differing from each other only with respect to their orientation in space, so the ventricular muscle may be considered the sum of an infinite number of units differing only with respect to the direction in which the excitation process passes over them, and consequently in the direction of the potential differences which they produce during ventricular activation.

The analysis of the electrocardiogram is greatly complicated by the fact that not all of the muscle units are activated at the same time. This difficulty may be eliminated by determining the mean deflection in each of the 3 standard leads over any desired interval. The mean deflection in lead *I* (Me_I) during the QRS interval may be expressed by the following equation: