Monophasic Curve Analysis and the Ventricular Gradient in the Electrogram of Strips of Turtle Ventricle

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Experiments were performed to test the validity of representing the bipolar electrogram as the algebraic sum of two monophasic curves and the validity of Wilson's concept of the significance of the area, AQRS plus AT. An electronic integrator was employed to measure the areas of bipolar leads recorded from a strip of turtle ventricle which could be stimulated at either end. The close correspondence of the experimental findings with the predictions derived from the representation of the bipolar curve as the algebraic sum of two theoretical monophasic curves supports the validity of the concept tested.

In 1877 Marchand suggested that the biphasic curve of the electrocardiogram could be represented as the algebraic sum of two theoretical monophasic curves. Later Burdon-Sanderson offered experimental support for this method of analysis. Many workers have since applied this method to the theoretical analysis of a variety of electrocardiographic phenomena. In 1934 Wilson, MacLeod, Barker and Johnston employed it as the point of departure in their presentation of their concept of the significance of the area of the electrocardiogram.

This paper reports the results of experiments designed to test the applicability of theoretical monophasic curve analysis and the concept of the ventricular gradient to the electrogram of strips of turtle ventricle.

METHODS

A strip of ventricular muscle from the turtle heart was passed through a small opening in a septum which divided a bath of Ringer's solution into two parts (fig. 1). The strip was stimulated at one end (A). A bipolar lead from one bath to the other (B-A) records largely the electrical effects of the depolarization and repolarization of the short element of the strip (W-Y) that is gripped by the opening in the septum.

The action potentials of other elements of the strip are largely short-circuited by the conducting medium that surrounds them and acts simply as an extension of the electrodes. The electrogram recorded from such a short element of ventricle has a very simple form (fig. 2) that lends itself better to analysis than do more complex forms. Furthermore, the path of excitation through the element can be reversed by stimulating the strip at either end, and, finally, the rate of repolarization at either end of the element can be changed by altering the temperature of the Ringer's solution of the appropriate bath.

The area measurements were accomplished by electronic integration. Errors that might have been introduced by integration of the stimulus were eliminated in several experiments by em-

\[ \text{FIG. 1. The strip of turtle ventricle, } M, \text{ is drawn through a hole in a plastic septum, } S, \text{ which divides the bath into two compartments } A \text{ and } B. \text{ } S_A \text{ and } S_B \text{ are stimulating electrodes used to activate the muscle strip. } E_A \text{ and } E_B \text{ are wick electrodes employed in recording the electrogram. The electrograms recorded under these circumstances are largely derived from the activation of small segment } W-Y \text{ of the muscle strip that is enclosed by the hole in the plastic septum, } S. \]
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RESULTS

Effects of Change in the Path of Excitation. If the biphasic electrogram recorded in a lead B-A from such a preparation is to be represented as the algebraic sum of two theoretical monophasic curves (fig. 3), then the upper monophasic curve represents the depolarization and repolarization of the leftward end, (W) of the element of muscle (fig. 1), and the lower, inverted monophasic curve represents the depolarization and repolarization of the rightward end (V) of the element. In figure 3 Top A these theoretical monophasic curves are drawn in their proper sequence for stimulation of the strip at A, and their durations are adjusted so that their algebraic sum will approximate the electrogram actually recorded when the preparation was stimulated at A (compare fig. 3 Top A with fig. 2A). In figure 3 Top B the same two theoretical monophasic curves are drawn in the proper sequence for stimulation at B and it can be noted that their algebraic addition now approximates fairly well the actual record obtained when the preparation is stimulated at B (compare fig. 3 Top B with fig. 2B). Moreover, it is to be noted that in the theoretical figure 3 Top A, Q-T is longer than in figure 3 Top B because in the former it is determined by the duration of the lower monophasic curve plus part of the duration of QRS, while in the latter it is determined by the duration of the lower monophasic alone. The actual record (fig. 2 A and B) shows that the Q-T duration behaves as predicted in the theoretical diagrams.

Theoretically, the net area AQRS + AT is equal to the difference in the areas of the two monophasic curves (fig. 3 Bottom) that some effect from portions of the muscle strip outside of the segment W-V is being recorded. This effect would change the shape of the monophasic curve when the path of accession is changed but it would hardly change its area.
Therefore, if we can assume that the area of neither the upper nor the lower theoretical monophasic curve changes when the path of excitation is reversed, then the net area of AQRS + AT cannot change as a result of reversal of the path of excitation (fig. 3 Bottom). Examination of the integration curves of the actual record (fig. 2) shows that the net area of AQRS + AT remains unchanged when the path of excitation is reversed. This experimental finding is, therefore, in accord with Wilson's concept of the significance of the area of the electrocardiogram. It shows that the area of the electrocardiogram remains unchanged when the direction of flow is reversed.

**Fig. 4** Top. Theoretical representation of the effects of variation of the rate of repolarization at the two ends of the segment $W-V$ of the muscle strip of figure 1. In each diagram the upper monophasic curve represents the depolarization and repolarization of the left end (L) of the segment $W-V$ (fig. 1) while the lower monophasic curve represents the corresponding electrical activity of the right end (R) of the segment. In $A_a$ the duration of the lower monophasic curve is made less than that of the upper monophasic curve to correspond to the expected effect of increasing the rate of repolarization of the rightward end (R) of the segment, by warming the right end (B) (fig. 1), while the rate of repolarization of the left end (L) remains unchanged. Note that an upright T is expected from this change (compare with fig. 2). In $A_b$ and $A_c$ are seen the theoretical representation of the progressive decrease of the rate of repolarization at the right end of the muscle segment which might be expected if we permit the right end of the segment to become progressively cooler: duration of the lower monophasic curve is progressively increased to represent the progressive slowing of repolarization at this end, that results from cooling. The $B$ series of diagrams represents the construction of the effects of reversing the path of accession, accomplished by reversing the time sequence of the same two monophasic curves that appear in the corresponding diagram of the $A$ series. Note that the duration of QT is greater in $B_a$ than in $A_a$; that it remains constant in the $A$ series until T becomes inverted and that it remains constant in the $B$ series even after it increases in the $A$ series ($c$, $A$ and $B$).

**Fig. 5** Bottom. A relative quantitative representation of the diagram of figure 4. Note that theoretically as the right end of the segment of muscle strip is permitted to cool the quantity AQRS + AT diminishes in magnitude but that it is unaffected by reversal of the path of accession.
gram is independent of change in the path of excitation, and, moreover that it is the only characteristic of the electrogram that is unaltered by change in the path of excitation, for QRS, T and the duration of Q-T are changed under these circumstances.

Effect of Change in Rate of Repolarization. If the rate of repolarization becomes more rapid at the right end of the element of the strip of ventricular muscle while that at the left end remains unchanged, this new state of affairs can be represented theoretically by diminishing the duration of the lower monophasic curve (fig. 4 A,a). The T-wave should then become upright. When the path of excitation is reversed the electrogram should have the appearance shown in figure 4 B,a. Also, the Q-T duration should now be greater in figure 4 B,a than in figure 4 A,a because in the former it is determined only by the duration of the upper monophasic curve while in the latter it is determined by the duration of the same monophasic curve plus part of the duration of QRS. The quantity \( AQRS + AT \) should now have the positive sign (fig. 5 A,a and B,a) and it should, of course, not be affected by reversing the path of excitation.

If the rate of repolarization at the right end of the element of ventricular muscle is diminished progressively, while that at its left end remains constant, the lower monophasic curve should theoretically become progressively longer (fig. 4 A,b and c; B,b and c), while at the same time the upper monophasic curve remains unchanged. Under these circumstances the T-wave in the A series should become progressively smaller and finally inverted while the T-wave in the B series become progressively smaller and may finally become inverted but remains upright even after that in the corresponding member of the A series has become inverted. The Q-T duration should remain constant in the A series until T becomes inverted; it should remain constant in the B series even after it has increased in the A series (fig. 4). Finally, the value of the net area \( AQRS + AT \) should diminish progressively (fig. 5) for it is equal to the difference in the areas of the two monophasic curves, but it should remain unaffected by change in the path of excitation.

Elevation of temperature increases the rate of repolarization. It is well known that increased temperature diminishes the duration of monophasic action potential curves. Accordingly, the theoretical representations depicted in figures 4 and 5 were examined experimentally by increasing the temperature in the bath B (fig. 1) to 28 C. while that in the A bath was left at room temperature, 23
C. Records were made of the electrogram resulting from stimulating the strip at one end (A) and then the other (B) and this was repeated as the temperature in the B bath fell spontaneously to room temperature.

Examination of figure 6 shows that the experimental records reproduced all of the features anticipated in the theoretical representation. The duration of Q-T is greater in figure 6 B, than in A, the duration of Q-T remained constant in the A series until the T-wave became inverted, the duration of Q-T remained constant in the B series even after it had become greater in the A series, and finally, the net value of AQRS + AT was unaffected by reversing the path of excitation but diminished rapidly as the temperature in bath B diminished.

DISCUSSION

The close correspondence of the experimental findings with the predictions derived from the representation of the biphasic curve as the net sum of two theoretical monophasic curves supports the validity of the latter approach to analysis and synthesis of the electrogram and also the validity of the concept that the area of the electrogram is independent of the path of excitation (a mathematical derivative of that approach).

Since the area AQRS + AT is equal to the difference in the areas of the two monophasic curves and since the area of each monophasic curve is an expression of the rate of repolarization of the end of the element represented by that monophasic curve, it follows that the quantity AQRS + AT is an expression of the net electrical effects of the differences in the rates of repolarization.

Certainly the ventricles may be regarded as being composed of a multitude of such elements of myocardium as that investigated in this study. Accordingly, the electrical effects of the ventricular events may be regarded as the summation of a multitude of electrograms such as those recorded here, for the whole must be equal to the sum of its parts. Therefore, the area of any lead of the electrocardiogram is equal to the sum of the projections upon that lead of the areas of the electrograms of the constituent elements. It must follow, then, that the area of the electrocardiogram (AQRS + AT) (like that of any of its constituent elements) is independent of the path of excitation and that the magnitude of this quantity is a measure of the net electrical effect of local differences in rate of repolarization in the ventricles and is, therefore, very sensitive to local changes in the rate of repolarization.

SUMMARY

An experimental approach was made to the concept of the monophasic curve analysis of the electrogram and to Wilson's concept of the significance of the area AQRS + AT. An electronic integrator was employed to measure the areas. The experimental findings support both concepts in the case of a small segment of a strip of turtle ventricle.
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SUMMARIO IN INTERLINGUA
Un methodologia experimental esseva elaborate pro investigationes relative al concepto del analyse de curvas monophasic del electrogramma e al concepto de Wilson con respecto al signification del area AQRS + AT. Un integrator electronic esseva emplanted pro mensurar le areas in question. Le constata- tiones experimental supporta le duo conceptos in le caso de un micro segmento de un banda de ventriculo de tortuca.

REFERENCES
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