carotene, varied from 15.5 to 39 with 4 rats having clearances above 21.

Summary. Vitamin A in the diet affects the magnitude of urea clearance in the rat. In avitaminosis A there is a 23 to 77% decrease in urea clearance. Urine examination and histological sections of the kidney showed no marked morphological alteration. It is a functional deficiency.

Administration of carotene in 5 of 7 rats resulted in a 30 to 170% increase in urea clearance above the level in avitaminosis A.

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The Potential Produced by Cardiac Muscle. A General and a Particular Solution.

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Let us consider a mass of cardiac muscle immersed in an extensive homogeneous volume conductor. The value of the potential at a point in the conductor, produced by any given distribution of depolarization or repolarization may be obtained theoretically in the following way:

Let v_2 denote the particular region or volume of the muscle mass which is undergoing depolarization at a given instant. Let us choose any point O as the origin of a rectangular coördinate system X, Y, Z. Let $(X_2\ Y_2, Z_2)$ be any convenient point within the region v_2. Let dv_2 be an element of volume of v_2 at the point (X_2, Y_2, Z_2). Let the magnitude of the vector $\boldsymbol{\emptyset}$ represent the intensity of depolarization of the element dv_2, and let the direction of $\boldsymbol{\emptyset}$ be that of a line drawn from the effective negative toward the effective positive ionic charge within the element dv_2. The vector quantity $\boldsymbol{\emptyset} dv_2$ is then the electric moment of depolarization.

Let us choose next any other (fixed) point (X_1, Y_1, Z_1) within the volume conductor, in the vicinity of the muscle mass, at which it is desired to know the value of the potential V due to the distribution of depolarization v_2. Let $\mathbf{r}_1$ and $\mathbf{r}_2$ be radius vectors drawn from O to the points (X_1, Y_1, Z_1) and (X_2, Y_2, Z_2) respectively. Let $\mathbf{r}$ be a vector drawn from the latter to the former point so that $\mathbf{r} = \mathbf{r}_1 - \mathbf{r}_2$. Since the elementary potential dV at (X_1, Y_1, Z_1) due to the elementary distribution dv_2 varies inversely with the square of the distance r and directly with the cosine of the angle $(\mathbf{r},\boldsymbol{\phi})$, we have $dV = \mathbf{r}.\boldsymbol{\phi}dv_2/r^3$. Consequently,

$$(1) \ldots\ldots \qquad V = \iiint \frac{r.\phi}{r^3}\, dv_2 = MAX\phi^*$$

where the triple integral is to be taken over the whole of the volume v_2. The validity of this relation is based upon a proper interpretation[2] of the membrane theory of cell excitation; upon the fact that a potential difference or electromotive force assumedly produced by an ionic charge distribution across a cell boundary may be represented by a vector or distribution of vectors; and upon an adequate demonstration[2] that certain well known laws which describe the electric field in volume conductors apply to the circumstances involved with sufficient accuracy to be useful. Equation (1) fails to take into account the finite boundary conditions of the medium surrounding the mass of cardiac muscle. Since the extent of this conductor is great, however, in comparison with all required values of r, the effect of the finite boundary upon the value of the potential is the same or nearly the same as would be the case if the extent of the conductor were infinite.

A similar relation must hold for the value of the potential produced by any given distribution of repolarization. In which case the quantity $\boldsymbol{\phi}dv_2$ becomes the electric moment of repolarization, and v_2 becomes the volume distribution of repolarization.

It has been shown theoretically that if the vector $\boldsymbol{\phi}$ represents the intensity of depolarization or repolarization during excitation of cardiac muscle, the Maxwellian of $\boldsymbol{\phi}$ gives the electric potential at the point (X_1, Y_1, Z_1) due to any distribution of depolarization or repolarization as the case may be. Let us illustrate the application of this relation to a particular electrocardiographic problem.

The accompanying curve represents the successive values of a series of potential differences produced at the tips of 2 non-polarizable electrodes by the passage of a region of depolarization (accession wave[3]) and region of repolarization (regression wave[3]) along a linear strip of turtle ventricle immersed in a large bath of normal saline. The recording was made with a galvanometer of

* See reference 1.

1 Vector Analysis, Gibbs, Wilson, E. B., Yale Univ. Press, 7th printing, 1931.

2 Wilson, F. N., Macleod, A. G., and Barker, P. S., Univ. of Mich. Press, Sc. Series 10, 1933.

3 Macleod, A. G., *Am. Heart J.*, 1938, **15**, 165.

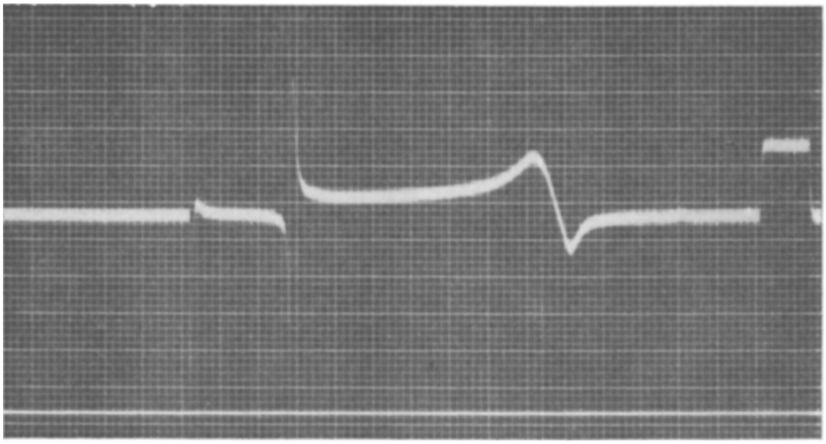

FIG. 1.

the Einthoven type. The contacts of the electrodes were attached to the terminals of the galvanometer in such a way that a positive potential at the tip of the exploring electrode E_1 produced a downward movement on the completed record. Let us denote the left hand end of the muscle strip by A and the right hand end by B. The tip of E_1 was placed near the surface of the muscle strip between AB in the vicinity of B, and corresponds to the point (X_1, Y_1, Z_1). The indifferent electrode E_2 was placed at a remote point in the bath 14 cm distant from the mid-region of the muscle strip. Under these circumstances, the potential V_1 at E_1 due to any distribution of depolarization or repolarization is sufficiently great in comparison with a simultaneous value of V_2 at E_2 that the latter may be neglected.[4, 5]

The left hand deflection, a sharp downward movement, is the artificial effect of stimulation at A with a galvanic current. The right hand upward movement is the usual standardization deflection produced by the introduction of 1 millivolt into the circuit. As the accession wave passed from A to B along AB, beneath the tip of the electrode E_1, the tall rapid diphasic accession deflection was recorded. As the regression wave passed along AB in the same direction a bit later, the low broad diphasic regression deflection was recorded. The order of the polarity of the two diphasic deflections is unlike. Thus the form of the regression deflection is similar to that anticipated by Wilson, *et al.*[2]

4 Wilson, F. N., Wishart, S. W., and Herrmann, G. R., PROC. SOC. EXP. BIOL. AND MED., 1926, **23**, 276.

5 Wilson, F. N., *Am. Heart J.*, 1930, **5**, 599.

Let us denote by v_o the uniform velocity of the accession wave, and by T the interval of time between the beginning and the completion of depolarization at a given point. The product v_oT then defines the length of the accession wave. It is also one of the 3 dimensions of v_2. Because of the extremely small value of v_oT* in comparison with the minimum value of r, we may look upon v_2 as a surface rather than a volume. Consequently, in the case of accession, dv_2 is equivalent to da_2, where the latter is an element of surface of the accession wave. Hence

$$(2) \quad MAX\emptyset = \iint \frac{r.\emptyset}{r^3} da_2$$

or

$$(3) \quad V_1 = \emptyset\Omega$$

Wilson[6]

where Ω is the solid angle subtended at (X_1, Y_1, Z_1) by the boundary of $a_2(= v_2)$. Inasmuch as depolarization has been considered instantaneous, its rate throughout the distance v_oT is immaterial, and we are thus permitted to regard $\emptyset$ as constant when performing the integration in equation (2). Furthermore, it is obvious from equation (3) that when we ascribe an appropriate value for the constant $\emptyset$, and propagate the distribution a_2 along AB with a uniform velocity v_o, the values of V_1 for successive instants of time will describe a curve similar in all essential particulars to that of the diphasic accession deflection. The fact that the final downstroke of the accession deflection does not return to the base line according to the description of equation (3) is due to the flow at this time of a current artificially introduced into the circuit to neutralize the effect during diastole of an electric field of injury.

Other applications of the expression MAXØ to problems of this general kind are available but their discussion is beyond the limits of this report.

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[6] Wilson, F. N., Macleod, A. G., and Barker, P. S., *Am. Heart J.*, 1931, **6**, 637.

* See reference 2.