Simple Method for Measuring Heart Vector of Isolated Animal Hearts

Abstract. The spatial dipole moment of a perfused animal heart suspended at the center of a fluid-filled sphere can be found in magnitude and direction to a good approximation by three sets of bipolar measurements. The method has been applied in finding the vectorcardiograms of turtle and rabbit hearts.

The method for measuring the heart vector of isolated animal hearts is based upon the facts that (i) the potentials at the surface of a fluid-filled insulating sphere due to a dipole at the center are equal to 3 times the values they would have at the corresponding points if the medium extended to infinity, and that (ii) at sufficiently remote points the heart's electrical activity is determined by its resultant dipole moment.

The first fact is not very well known outside the field of electrocardiology and cannot be found explicitly stated in textbooks of electricity or hydrodynamics. The first statement of the relation was apparently made by Canfield (*1*), but the derivation was not shown. Wilson (2) derived the equation by differentiating the free-space equation and setting the derivative equal to zero at the boundary. Hicks (*3*) made the first treatment of a source and sink at any points within a sphere and showed that the image of a source is a source at the inverse point plus a line sink distribution from the inverse point to infinity. The equation he presented yields the stated result when solved for the case of a dipole at the center. Equations for an eccentric dipole have also been derived by Wilson and Bayley (*4*), who used a method of Helmholtz (*5*), and by Frank (*6*), who used spherical harmonics. These equations also give the same result when solved for the centric dipole, if the higher order terms are neglected, and if the pole separation is small compared with the radius.

Craib (*1*) showed that when terrapin or rabbit hearts were placed at the center of a glass sphere, 11 in. in diameter, filled with Ringer's solution, the resulting potential field satisfied the dipole equations at points as close to the heart as one-third the radius for the terrapin heart and one-half the radius for the rabbit heart. Hartmann, Veyrat, Wyss, and Duchosal (*7*) showed that vectorcardiograms representing the entire heart could be obtained at points at a greater distance than at least two diameters of the heart. At points closer than this, presumably multipole representations (*8*) will be necessary.

Canfield pointed out that the magnitude and direction of the resultant dipole could be obtained from four potentials on the surface of the sphere. Craib, however, apparently did not make use of this fact, for he was mainly concerned with testing the validity of the dipole hypothesis. The object of the present report is to show how the dipole moment can be determined from three bipolar measurements.

Assume a current dipole of magnitude M at the center of a sphere and with direction defined by the angles α and β (Fig. 1). Angle α is defined as the angle between the vector and the horizontal plane; β is the angle between the projection of the vector on the horizontal plane and the $+x$-axis. It is easily shown (*9*) that the potential at the surface on the $+x$-axis is given by

$$V_{+x} = \frac{3\rho}{4\pi R^2} M \cos \alpha \cos \beta + V_0 \quad (1)$$

where ρ is the resistivity of fluid in the sphere in ohm-centimeters; R is the radius of the sphere; and V_0 is the additive constant. The units of M are milliampere-centimeters if V is expressed in millivolts, or microampere-centimeters if V is expressed in microvolts.

Also the potential at the surface on the $-x$-axis is

$$V_{-x} = -\frac{3\rho}{4\pi R^2} M \cos \alpha \cos \beta + V_0 \quad (2)$$

If E_x is equal to $V_{+x} - V_{-x}$, then

$$E_x = \frac{3\rho}{2\pi R^2} M \cos \alpha \cos \beta \quad (3)$$

Similarly,

$$E_y = \frac{3\rho}{2\pi R^2} M \cos \alpha \sin \beta \quad (4)$$

$$E_z = \frac{3\rho}{2\pi R^2} M \sin \alpha \quad (5)$$

From these, it is found that

$$\tan \beta = E_y/E_x \quad (6)$$

$$\tan \alpha = E_z/(E_x^2 + E_y^2)^{1/2} \quad (7)$$

If E_x, E_y and E_z are measured, α and β can be found from Eqs. 6 and 7, and the results can be substituted in Eqs. 3, 4, or 5 to find M.

If potentials are measured with respect to any point on the sphere, the potential of this point with respect to infinity can be designated V_0. When subtracting—for example, Eq. 2 from Eq. 1—V_0 drops out. The bipolar measurement of the three leads XX, YY, and ZZ is therefore sufficient for the complete determination of M.

The equations were first checked by means of artificial dipole experiments. Two different transparent plastic spheres, having diameters of 15.1 and 25.0 cm, were used for the measurements of the animal heart. Silver electrodes were mounted on the inside wall and projected through the wall in watertight bushings. The bipolar leads were amplified and applied to an oscilloscope and photographed with a Grass moving-film camera.

Table 1. Magnitude and direction of peak vectors during QRS and T in six experiments on turtle heart.

Wave	M (μa-cm)	α	β
QRS	64	−64°	96°
T	53	−22°	−51°
QRS	106	−71°	−98°
T	57	73°	28°
QRS	100	−22°	−12°
T	75	−9°	−143°
QRS	80	−50°	92°
T	66	−69°	17°
QRS	63	−48°	153°
T	33	−13°	−14°
QRS	80	−36°	128°

Hearts were removed from painted turtles about 6 in. long and weighing about 700 g. The heart was suspended on a perfusion cannula at the center of the smaller sphere, and the sphere was filled with Ringer-Locke solution. By using Eqs. 3 to 7, spatial vectorcardiograms were obtained. On the basis of six experiments, the average peak vector for QRS was 82 μa-cm, pointing downwards to the right (Table 1).

The T vectors were more variable, but generally pointed somewhat downwards and to the left; the average peak value was 57 μa-cm. The maximum P vector was about 7 μa-cm.

In four rabbit heart experiments in the larger sphere, the average peak vecvalue was 57 μa-cm for QRS and 100 μa-cm for T. Two main vectors were found, occurring at different times in the cardiac cycle. This sphere had elec-

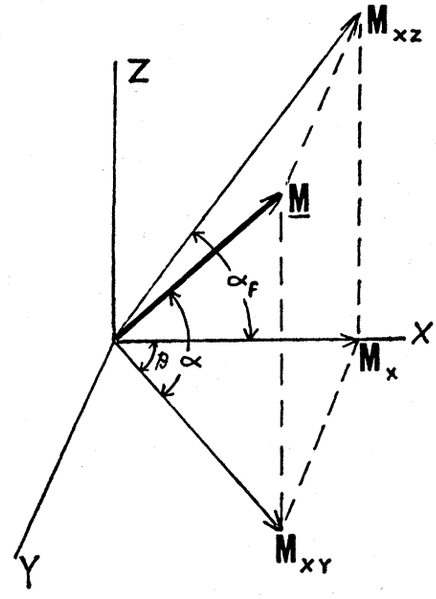

Fig. 1. Definition of coordinate system and angles.

trodes mounted at 30° intervals all over the inside wall, so that the heart vector could also be calculated by integration of the surface potentials (*10*). The simplified method was not as accurate, but gave a good approximation to the correct values (*11*). The data on the rabbit and turtle hearts are presented only to illustrate the nature of the results that can be obtained by the method described. The results suggested that there is a correlation between the weight of the heart and the magnitude of the peak vector (*12*).

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11. The "resultant dipole moment" denotes a vector, the magnitude, direction, and location of which are functions of time during the cardiac cycle. The simple bipolar method neglects changes in location of the vector, but a central location is not necessary for the integration method.
12. Further experiments are in progress to study this relation and to obtain better statistical averages. This project was supported by grants from the U.S. Public Health Service (H-2590) and the Maine Heart Association.

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Indole-like Urinary Stress Reactant in Man

Abstract. Paper chromatograms on extracts from serial 6-hr urine samples from humans of both sexes on indole-controlled diets revealed either the appearance of or marked increment in "spot 32" (*1*) after ACTH gel injections. This corresponds in time and duration with the rise in 17-hydroxycorticoid excretion. 5-Hydroxyindoleacetic acid and 28 other urinary indoles failed to show this rise predictably.

There have been several conflicting reports in recent years concerning abnormalities in indole excretion in schizophrenic patients compared with neurotic, "normal," or other control groups (*2, 3*). Kety, in his recent articles in *Science* (*4*), has speculated extensively concerning various systematic experimental errors which may account for these differences. It has been our general purpose to explore some of these "extraneous" factors in an effort to explain with documentation some of the findings reported in the area of indole research on schizophrenic patients. We are currently engaged in an evaluation of the effect of nonspecific stress factors on urinary indole excretion. This report presents a heretofore unreported phenomenon associated with activation of part of the physiologic stress mechanisms by ACTH injection—that of a predictable change in the excretion of indole-like compound.

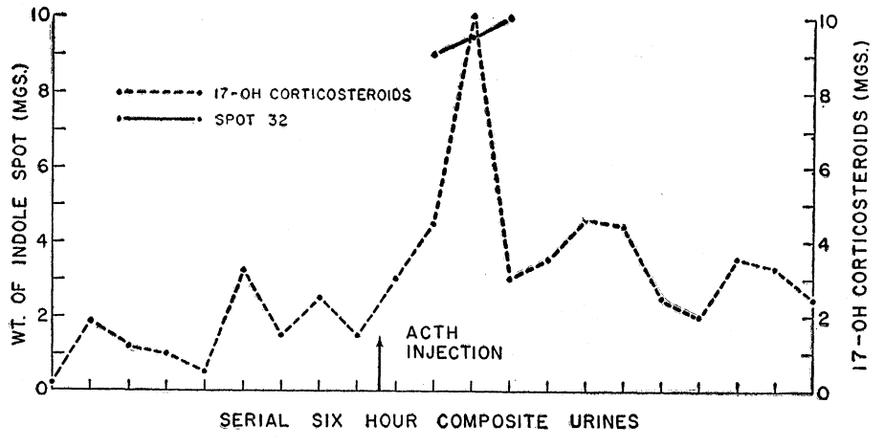

Fig. 1. A typical response of the indole-like "spot 32" and 17-hydroxycorticosteroids to ACTH gel injections. Spot 32 is visible down to a size corresponding to 6 mg weight. Spot 32 was not present except where indicated.

Hospitalized neurotic, psychotic, and psychopathic patients who had not been on drugs were placed on a standardized, high-calorie, high-protein diet that was free of indoles except for the tryptophan contained in the protein (*5*). Twelve 6-hr urine specimens were collected before and nine after the intramuscular injection of 40 units of ACTH gel. Urinary extracts were made and chromatographed according to the method of Armstrong *et al.* (*1*) with the exception of the application of extract equivalent to 2 mg of creatinine for chromatography. The bidimensional solvent systems were isopropanol-ammonia-water (8:1:1) and benzene-proprionic acid-water (10:7:5). 17-Hydroxycorticosteroids were determined by the method of Silber and Porter (*6*). The chromatograms were analyzed semiquantitatively by cutting out and weighing the spots. Using known indoles, we found, as did Masuda *et al.* (*3*), that there was a linear relationship between the amount of indole present and the size of the spot as indicated by its weight in the quantity range being measured.

Exogenous indoles from dietary sources due to previous uncontrolled food intake disappeared in 24 to 36 hr, resulting in relatively stable indole chromatograms from period to period except for the consistent diurnal variation (*7*). After the injection of 40 units of ACTH gel, there was no predictable change in any of the 30 or more indole spots manifested by most patients with the exception of spot number 32. This spot was absent in pooled urines from the psychiatric staff and in most of the patients studied during the control period. It appeared usually between 6 and 12 hr after the injections and peaked in density and size during the period of maximum 17-hydroxycorticosteroid excretion (Fig. 1). It disappeared most commonly in 18 to 24 hr. Spot 32 failed to appear in those patients who, for some reason, did not respond to ACTH with a rise in excretion of 17-hydroxycorticosteroids. The appearance of this spot appeared to be unrelated to the diet, bowel status, or urinary volume and specific gravity. The response of this spot is probably unrelated to changes in the creatinine referent, because creatinine excretion did not change significantly with ACTH injection. The determinations of the 29 other indoles which likewise used creatinine equivalents of urine did not evidence this change predictably. In addition, its appearance was independent of age, sex, or diagnostic category of the subjects. Its R_f (0.07, 0.01), ultraviolet sensitivity, relative position, and development characteristics with *p*-dimethylaminobenzaldehyde suggest strongly that it is an indole or indole-like compound and is identical with spot 32 of Armstrong *et al.* (*1*). We are currently engaged in characterizing this response further by using corticoids, epinephrine, and psychological stress. Efforts are likewise being made to characterize this compound chemically.

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