THE DETERMINATION OF VENTRICULAR PREDOMINANCE FROM THE ELECTROCARDIOGRAM

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Two recent articles containing much speculation and few facts have directed my attention to the necessity for a review of the subject of the electrocardiographic diagnosis of hypertrophy of one or the other ventricle of the heart. The original observations on this subject were that cases in which hypertrophy of the left ventricle might be expected showed a relatively tall R wave in Lead 1, with absence of an S wave in this lead, while Lead 3 shows a relatively small or absent R wave and a deep S wave. In like manner, cases in which hypertrophy of the right ventricle might be expected showed a relatively small R wave in Lead 1 and a deep S, while the S wave was absent in Lead 3 and the R wave relatively tall.¹ Einthoven demonstrated the fact that if the actual values of the largest waves of the Q R S group in Leads 1 and 3 were added together, the result would be equal to the value of the largest wave of this group in Lead 2. There is some slight error in this addition owing to the fact that the peaks of the waves do not occur at the same instant of the heart cycle in all three leads. He showed that throughout the Q R S group and in fact throughout the whole electrocardiogram if we consider the parts of the curve in the three leads which occur at the same instant of time then the value in Lead 1 + value in Lead 3 = value in Lead 2.² From the relative size and direction of these values in the three leads there can be calculated the direction of flow of current within the heart at that instant.

It soon developed that it was not the actual hypertrophy of one or the other ventricle which caused the changes in the electrocardiogram, but the relation of the state of hypertrophy of each ventricle to the other. If a heart had mitral stenosis and had also to oppose an increased blood pressure, then both ventricles would become hypertrophied and the electrocardiogram might show a normal relation of the height of the R waves in the three leads. Neither ventricle in this case would be predominantly hypertrophied, and for this reason it has become necessary to speak of the records as showing right or left ventricular predominance instead of hypertrophy.

1. Einthoven, W.: Le Telecardiogramme, Arch. Internat. de Physiol. **4**:132, 1906.

2. Einthoven, W.: Weiteres u. d. Elektrokardiogram, Arch. f. d. ges. Physiol. **122**:576, 1908.

Various methods have been suggested for deriving from the electrocardiogram a mathematical expression of this relative predominance of one or the other ventricle. Einthoven considered that the current at the instant of the highest peak of the Q R S group would give such an index, and calculated from the size and direction of these peaks in the three leads the direction of the current within the heart which had caused these high peaks. This calculation was made by quite sound mathematics, and a table was published by him,³ by the use of which it was very easy to determine the direction of the current within the heart which had produced corresponding waves in the three leads. This is simple enough when the peaks of the waves occur at the same instant of the heart cycle in all three leads, for then the formula $\text{Lead 1} + \text{Lead 3} = \text{Lead 2}$ will be exactly fulfilled. When they do not occur at the same instant they are spoken of as being "out of phase," but even in such records it is usually possible to determine by inspection which parts of the Q R S groups of the other two leads correspond in time with the high peak of the lead showing the largest deflection. This is aided by bearing in mind that in right predominance it is usual to have the peaks of the R waves in Leads 2 and 3 practically simultaneous while the corresponding instant in Lead 1 will lie somewhere on the downward stroke between the peaks of R and S. Likewise, in left predominance records the peaks of R are practically in phase in Leads 1 and 2, and this instant will fall in Lead 3 at a point on the downward stroke between the R and S peaks. Rarely, however, a record will defy even this attempt at analysis.

Having determined the direction of the current which produced the largest deflection, Einthoven considered that those hearts which showed this angle within the sector between 40 and 90 degrees below a line drawn horizontally to the patient's left were hearts which showed a normal balance of the ventricular elements. Those which gave an angle above 40 degrees showed left predominance, while those which gave an angle which was to the patient's right of 90 degrees showed right predominance. This was in general agreement with the previous idea as to the relation of the R and S waves in Leads 1 and 3 to ventricular predominance, for the S waves become more prominent than the R, in Lead 1 at 30 degrees and in Lead 3 at 90 degrees.

Lewis suggested a method of obtaining an index of predominance by adding the value of R1 — R3 to the value of S3 — S1.⁴ He probably did this, although he did not attempt a theoretical explanation of this formula, from a belief that as R1 and S3 vary together, the first grow-

3. Einthoven, Fahr and de Waart: Ueber die Richtung und die Manifeste Grösse der Potentialsehwankungen, etc., *Arch. f. d. ges. Physiol.* **150**:275, 1913.

4. Lewis, T.: Observations on Ventricular Hypertrophy, etc., *Heart* **5**:367, 1914.

ing smaller and the latter larger with increasing left predominance they must be governed by the left ventricle, and for a similar reason S1 and R5 must be governed by the right ventricle.

White has suggested that $(U1 + D3) - (D1 + U3)$ considering that U, the upper deflection and D, the largest of the downward deflections, whether it be a Q or an S, would represent opposing ventricles.⁵ His figure will, of course, only differ from Lewis' figure when Q is larger than S, so that it becomes the largest downward deflection.

Carter has suggested that the sum of the downward deflections of each lead be subtracted from the upward, and that the resulting figures for the three leads be used to determine the direction of the current within the heart.⁶ When the resulting figures for the three leads cannot be made to agree with Einthoven's rule of $\text{Lead 1} + \text{Lead 3} = \text{Lead 2}$, by a little judicious scaling of the figures, he then recommends that the Lead 1 and Lead 3 values be used to determine the direction of the current, totally disregarding Lead 2.

COMPARISON OF L/R WEIGHT RATIOS AND ELECTROCARDIOGRAPHIC PREDOMINANCE AS DETERMINED BY FOUR METHODS

Case	L/R Weight Ratio	Angle as Found by Einthoven's Method	Angle as Found by Carter's Method	Lewis' Formula	White's "Index"	Value Largest Wave of QRS Group	Lewis' Formula Reduced to R : 10
I	2.63*	-10	-30	29.5	29.5	16.5	17.9
II	2.60	-70	-60	19.0	19.0	15.0	12.6
III	2.55*	-74	-75	17.5	16.5	15.0	11.7
IV	2.04	14	16	19.0	19.0	12.5	15.2
V	1.97*	79	75	-10.0	-8.0	13.0	-7.7
VI	1.94	45	30	8.0	8.0	11.0	7.3
VII	1.87	0	10	12.5	12.5	10.0	12.5
VIII	1.82	18	35	4.5	4.5	6.0	7.5
IX	1.60	82	115	-7.0	-7.0	6.0	-11.6
X	1.55*	4	-30	9.0	9.0	7.0	12.9
XI	1.38	78	90	1.5	1.5	6.5	2.3
XII	1.30*	79	95	-3.5	-5.0	5.0	-7.0
XIII	0.82*	101	150	-6.0	-6.0	6.0	-5.8
XIV	0.82	105	128	-15.5	-15.5	11.0	-14.1
XV	0.41	131	160	-77.0	-76.0	44.0	-17.5

* The cases marked with asterisk are from Cotton's series, the remainder are from Lewis'.

A great deal could be said about the theoretical merits of these different methods of estimating ventricular predominance. It can all be discarded, however, in the face of direct evidence such as we are able to obtain from two series of observations. One series of nine cases by Lewis⁴ and one of six cases by Cotton,⁷ have been reported in which the electrocardiogram and the actual weights of the ventricles

5. White, P. D., and Bock, A. V.: Electrocardiographic Evidence of Abnormal Ventricular Preponderance, etc., *Am. J. M. Sc.* **156**:17, 1918.

6. Carter, E. P.: The Electrocardiogram and Ventricular Predominance, *Arch. Int. Med.* **24**:638 (Dec.) 1919; also Carter, Richter and Greene: *Bull. Johns Hopkins Hosp.* **30**:162, 1919.

7. Cotton, T.: Observations on Hypertrophy, Heart, **6**:217, 1917.

were obtained in the same patients. These fifteen cases have been arranged in the accompanying table according to the ratio of the ventricular weights as determined by Lewis and Cotton. From the published measurements of the Q R and S waves in the three leads, the electrocardiographic "predominance" has been calculated by the four methods which have been mentioned. The first column is the value of L/R obtained from the ventricular weights. The figures for the angle of the largest current as obtained by Einthoven's method are shown in the second column; the angle as obtained by Carter's method is in the third column; the figures by Lewis formula are in the fourth column, and White's "index" occupies the fifth column.

It is evident that all of these formulas give figures which follow in a general way the actual relation of the ventricular weights, but it is also evident that none of them enables us to place the heart very accurately in the scale of left or right predominance as actually determined by the weight relation. The normal variations of the L/R weight ratio have been determined in two series of thirty-four normal persons, whose ventricles were separated and weighed by Lewis⁴ and by Cotton.⁷ The average L/R ratio was approximately 1.80, the extreme variations being 2.17 and 1.47, the former probably representing a moderate left predominance and the latter a moderate right predominance. Three of the cases of the table have an L/R ratio larger than 2.17, and therefore may be considered to show definite left predominance, while five have a ratio less than 1.47 and show, therefore, a definite right predominance.

Figure 1 is a series of curves constructed from the table by using the values in the first five columns to obtain the height from the base line and the order of the cases from 1 to 15, as determined by their L/R weight ratio, to obtain the distance from the left hand ordinate. The weight ratio forms a smooth steadily declining curve, while all of the other curves, though in general declining, have many departures from smoothness. Individual cases vary considerably from the position in these irregular curves which they would be expected to occupy considering their L/R ratio. The dotted line drawn through each curve indicates the average course of this curve, and along this line our cases should lie. It is evident that the variations from this average obtained by the Lewis or the White formulas are less than the variations obtained by the other formulas, and, moreover, only three persons who had a normal weight ratio would be classed as having predominance by these methods while either of the other methods would have thus misplaced four cases.

In considering the basis of the Lewis and White formulas, it is evident that the size of the largest wave in the Q R S group, R or S,

Fig. 1.—Series of curves constructed from the table by using the values in the first five columns to obtain the height from the base line.

as the case may be, will be an important factor in the resulting figure. The values for the largest waves in the electrocardiogram of each individual are shown in the sixth column of the table, and it is very interesting to note that they are larger in the right and left predominance cases than they are in those showing a normal balance. This is a wholly unexpected finding, and will well warrant a further study which is at present in progress. Considering this varying value of the largest waves, and the fact that the Lewis and White formulas as so evidently dependent on this value, it is not surprising that the curve of these cases obtained by these formulas show at first a steep descent as the diminishing degrees of left predominance are recorded, a more or less level stretch and then another steep descent as the increasing right predominance is met with. This fact made it seem advisable to correct the Lewis formula for the value of the largest wave in the record of the individual changing the Lewis figure, so that it would be proportional to a value of 10 mm. for the largest wave. This formula would be "Lewis' figure : $X = R : 10$." The figures obtained thus form the last column of the table. The variations in a curve constructed from these figures would be very great, so that this correction for the size of the largest wave offers no advantage.

Other formulas were tried attempting always to find a method of treatment of the electrocardiogram of these cases which would place the individual case near to the average position in the series which might be expected from the L/R ratio. They were all unsuccessful, none being any better than Lewis' formula which has such a desirable simplicity. The following were tried, but it seems unnecessary to publish the figures in view of their negative value.

1. $Q_1 + R_1 + S_3 - Q_3 - R_3 - S_1$, a formula suggested by Lewis' recent analysis of the electrocardiogram.⁸

2. $Q_1 + S_3 - Q_3 - S_1$ was tried because the R wave has probably a factor from both ventricles, while Q and S have not.⁸

3. $R_1 + S_3 - S_1 - R_3 + \text{value of largest wave}$: another attempt to correct for the varying value of the R wave which has been noted with predominance of either ventricle.

4. $\frac{Q_1 + R_1 + S_3}{Q_3 + R_3 + S_1}$ an attempt to obtain an L/R ratio from the waves of the electrocardiogram which, according to Lewis,⁸ depend on the respective ventricles.

5. The figure obtained by this last method was divided by the value of the largest wave.

8. Lewis, T.: The Spread of the Excitatory Process in the Vertebrate Heart, Phil. Tr. Roy. Soc. London **207**:221, Series B, 1916.

DISCUSSION

As has been said, none of these methods attained the desired result of a uniformly varying series of figures, such as is given by the L/R weight ratio.

Let us consider possible reasons why this object could not be achieved. (1) It cannot be considered that the QRS group is not governed by the ventricular weight ratio for *all* of the formulas derived from the records give figures which agree in a general way in their placing of these cases in the series of predominance. (2) It is possible that the cutting and weighing of the hearts might have been inaccurate so that the L/R ratio obtained does not express the proper position of the heart in the predominant scale. This cannot be considered, for it would not cause more than relatively slight variations in the L/R ratio for relatively large errors in cutting, and so would not account for more than a very slight displacement of the heart from the position in the scale of predominance. (3) There may have been errors in taking the electrocardiogram, but this cannot be considered at all likely in the hands of technicians who are familiar with the instrument as these men were. (4) It is possible that the individual hearts varied in some other way than in their ventricular mass so as to change the electrocardiographic record from what it would otherwise have been, thus displacing it in the scale of predominance. (a) The possibility that any of the cases of this series were suffering from blocking of one bundle branch may be discarded, for both of the workers are thoroughly familiar with the effect of this lesion on the record, and with the lack of relation between such curves as it would produce and the problem of ventricular predominance which they were investigating. They would have discarded such cases. (b) The anatomical position of the heart within the chest might vary sufficiently to be responsible for these electrocardiographic variations. The respiratory movements of the diaphragm may cause a variation of as much as 30 degrees in the electrical axis of the heart,³ and as it is a matter of common knowledge that in some types of individuals the heart may be more or less transversely placed on a high diaphragm as with full expiration, or in others may be more or less vertically placed with a low diaphragm as in full inspiration. The transverse type of heart, if otherwise normal, gives an electrocardiogram approaching the left predominance type, while that of the vertical heart approaches the right predominance type, and it is suggested that it is probably such differences in position as this which are responsible for the electrocardiographic variations which have caused the normal cases of this series to appear to have a ventricular predominance. By a similar mechanism a heart with a slight left predominance might give an electrocardiogram within the normal

limits of variation if it were vertically placed, or a slight right predominance might give a normal record if the heart were horizontal. The same mechanism would give to the electrocardiogram a form characteristic of a greater degree of predominance than the heart muscle actually shows if the left predominance case should lie transversely and the right predominance vertically. (c) Still another possibility has been suggested,⁹ for the discrepancies existing between the ventricular weight ratio and the electrocardiographic "predominance." The size of the ventricular cavity may vary for the same weight of muscle. This may be expressed as dilatation. A small thick-walled ventricle may weigh the same as a large thin-walled ventricle. The different distribution of the electrical potential which this would cause

Fig. 2.—Two electrocardiograms taken from the same person; A, in the relaxed sitting position; B, in the erect sitting position.

would in all probability have its effect on the electrocardiogram, and might well lead to such variations as were observed in this series. This point of view has been elaborately discussed quite recently by Fahr,¹⁰ and certainly should command attention from anyone who considers this problem. It is a most difficult hypothesis to investigate, however, as it necessitates careful measurement of ventricular diameters as well as of ventricular weight.

Either of these latter suppositions would explain why the electrocardiograms of this series which vary from their expected position in the predominance scale, vary in the same direction, i. e., toward right or

9. Personal communication from Dr. Hubert V. Mann.

10. Fahr, G.: An Analysis of the Spread of the Excitation Wave, etc., *Arch. Int. Med.* 25:146 (Feb.) 1920.

toward left predominance, by whatever method the electrocardiogram is analyzed. The electrocardiogram has been caused to vary from the form which it would derive from the ventricular weight ratio by an unusually transverse or vertical position of the heart, or by what virtually amounts to a deformity of the heart, a dilatation of one chamber. It is impossible to decide between these hypotheses on theoretical grounds, but I must say that the former appears to be the more attractive theory.

Figure 2 shows two electrocardiograms taken one after the other from the same individual. Both were taken while he was sitting upright in a chair, but the one to the left, A, was taken with the erector spinae relaxed, the back bowed forward and the thorax fallen downward upon the abdomen so that the diaphragm was pushed up within it: the typical relaxed sitting position. The other record, B, was taken while he was sitting with the back straight and the chest forward in a normal, erect, sitting position. The electrical axis of record A is 6 degrees, while that of B is 46 degrees, the change by the Lewis formula is from 12 to 7, a change in this case due entirely to a change in the position of the diaphragm from high to normal. This patient was examined with the fluoroscope, and the anatomic axis of the ventricles roughly estimated in each position. This axis was found to rotate about 30 degrees. The degree of variation in the electrocardiogram which may result from a different position of the diaphragm is evident from this experiment, and also the fact that the anatomic axis varies at the same time in a similar manner.

CONCLUSIONS

The conclusions which may be drawn from these considerations are:

1. That the form of the QRS group of the electrocardiogram is dependent in otherwise normal hearts on the relative weights of the two ventricles. An increase in the L/R ratio, such as would result from the left ventricle becoming relatively heavier, is accompanied by characteristic changes in the electrocardiogram, while if the L/R ratio is decreased, as by the right ventricle becoming relatively heavier, there are other equally characteristic changes in the record. These changes are the ones which have always been associated with the predominances; a tendency for R_s to be relatively small, and R_1 and S_s to be relatively large in left predominance, while R_1 is small and S_1 and R_s are relatively large in right predominance.

2. Attempts to devise a formula from the QRS waves by which the heart can be placed properly in a series of ventricular predominance are successful only in a general way. Individual electrocardio-

grams vary greatly from the position in the scale of ventricular predominance which the ventricular weights alone would lead us to expect them to occupy.

3. Of all the formulas which have been considered for determining the ventricular predominance from the electrocardiogram, the simplest to apply, the one giving the smallest apparent error in this series of fifteen cases, and the fewest variations of individual hearts from the position in the predominance scale which would be expected from the L/R weight ratio, is the formula suggested by Lewis of $(R1 + S3) - (S1 + R3)$.

4. It is suggested that the cause of these variations may well be that the hearts which varied from their expected position in the scale of predominance were of the markedly transverse or vertical type so that the electrocardiogram was distorted by this position of the heart.

5. The suggestion as to ventricular dilatation causing these variations is also worthy of consideration.

The diagnosis of ventricular predominance is far from being the most important information which the electrocardiogram gives us, but it is nevertheless very suggestive and important in certain cases. It is well, therefore, that we should realize that our conclusions as to predominance are not always in agreement with the ventricular weights, and that we earnestly try to find what are the factors which interfere with this agreement. The present suggestion as to the cause of the inexactness of the electrocardiogram seems to me to be quite reasonable, but reasonableness alone, without an experimental basis, should never be the foundation of any medical diagnostic procedure. It is hoped that this discussion will stimulate many observers to note the anatomic position of the heart in relation to the electrocardiographic "predominance" which is shown, and that as many as possible will combine with these factors the necropsy data, consisting of the actual relation of the ventricular weights, using Lewis' technic for cutting and weighing the ventricles⁴ so that the results may be comparable with his, and also proper measurements of the ventricular size. Only in this way can the subject be eventually placed on a firm foundation.