Selection of Characteristics of Vectorcardiograms for Differential Diagnosis by Use of Adaline

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SUMMARY

Adaline was applied to select automatically the characteristics of the vectorcardiographic configuration of various conditions, taking vectorcardiograms from 114 cases by Frank's method. Among the 28 parameters, those showing a larger weight were selected. Some selected parameters were found to be relatively common for differentiation of pairs of various conditions and other parameters rather specific.

In addition, an attempt was made to decrease the number of parameters without changing the accuracy significantly. For some differentiations only several parameters were sufficient, but for others it can be decreased to less than half only with difficulty.

Additional Indexing Words:

Learning machine	Adaptive linear neuron	Pattern recognition
Automatic diagnosis of the electrocardiogram		Frank's method
Computer	Nilsson's error correction method	Forced correction method

A learning machine mechanism, Adaline (adaptive linear neuron), which was devised by Widrow¹⁾ for general pattern recognition, was applied to automatically select parameters from many parameters of the vectorcardiogram effective for differentiating each pathological entity. This attempt was made chiefly to find an effective usage of the computer for automatic diagnosis of the electrocardiogram with as small a number of parameters as possible without changing the result significantly, and the result would be useful for recognizing the characteristics of the vectorcardiographic configuration of normal and pathological states. A part of this attempt to differentiate normal states and left ventricular hypertrophy was reported previously by the present authors with Ohteru et al.²⁾; in this report all of the normal and main pathological states were studied, including normal and left ventricular hypertrophy with different patients. Another attempt of the authors to use Adaline as an automatic method for interpretation of the electrocardiogram and the vectorcardiogram was reported elsewhere.³⁾

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Received for publication May 10, 1969.

METHODS AND MATERIALS

Vectorcardiograms were taken by Frank's method⁴⁾ in 114 cases consisting of 20 cases of normal subjects, 20 cases of left ventricular hypertrophy, 16 cases of right ventricular hypertrophy, 18 cases of left bundle branch block, 20 cases of right bundle branch block, and 20 cases of myocardial infarction (15 of anterior infarction and 5 of posterior infarction).

The vectorcardiograms were measured according to the 28 parameters listed in Table I. Each parameter was divided into 12 divisions. As for the magnitude of the QRS vector, T vector and ST vector, the ratio of T/QRS, and the QRS duration, the maximum values of each parameter of 3.5 mV., 1.2 mV., 0.12 mV., 0.78 and 0.24 sec. were divided respectively into equal values of 0.3 mV., 0.1 mV., 0.01 mV., 0.065 and 0.02 sec. The angle of each vector was counted clockwise from the left horizontal line, for example, division 1 being from 0° to 30° and division 12 from 330° to 0°. As for the direction of inscription, only 4 divisions were used for clockwise rotation, counterclockwise rotation, figure eight inscription, and superimposition of

Table I. Parameters Used for Measurement of Vectorcardiograms

No.	1	Magnitude of spatial maximal QRS vector.
	2	Magnitude of spatial maximal T vector.
	3	Magnitude of maximal QRS vector in the frontal plane.
	4	Magnitude of maximal QRS vector in the horizontal plane.
	5	Magnitude of maximal T vector in the frontal plane.
	6	Magnitude of maximal T vector in the horizontal plane.
	7	Ratio T/QRS in the frontal plane.
	8	Ratio T/QRS in the horizontal plane.
	9	Angle of maximal QRS vector in the frontal plane.
	10	Angle of maximal QRS vector in the horizontal plane.
	11	Angle of maximal T vector in the frontal plane.
	12	Angle of maximal T vector in the horizontal plane.
	13	Angle of 0.02 sec. instantaneous QRS vector in the frontal plane.
	14	Angle of 0.02 sec. instantaneous QRS vector in the horizontal plane.
	15	Angle of 0.04 sec. instantaneous QRS vector in the frontal plane.
	16	Angle of 0.04 sec. instantaneous QRS vector in the horizontal plane.
	17	Angle of 0.06 sec. instantaneous QRS vector in the frontal plane.
	18	Angle of 0.06 sec. instantaneous QRS vector in the horizontal plane.
	19	Angle of half area QRS vector in the frontal plane.
	20	Angle of half area QRS vector in the horizontal plane.
	21	QRS-T angle in the frontal plane.
	22	QRS-T angle in the horizontal plane.
	23	Direction of inscription of QRS loop in the frontal plane.
	24	Direction of inscription of QRS loop in the horizontal plane.
	25	Direction of inscription of T loop in the frontal plane.
	26	Direction of inscription of T loop in the horizontal plane.
	27	QRS duration.
	28	Magnitude of ST vector.

Fig. 1. Diagram of learning by an adaline for determining characteristics. S_i : an input signal expressed by a binary digit of +1 or -1. $i=1,2,\dots,336$ (12 divisions of 28 parameters); C_{ik} ($i=1,2,\dots,336$) ($k=1,2,\dots,28$): a connecting constant expressed by 1 or 0; A_k ($k=1,2,\dots,28$): a value of weight for each parameter.

First, C_{ik} is started as 1. Then A_k is changed according to the following formula:

$$A_k = \sum_{i=12(k-1)+1}^k S_i \times C_{ik} \times \Delta A \times d_j$$

ΔA is a constant change of weight determined by the forced correction method and d_j is +1 or -1 according to one or the other disease in learning.

The output of the adaline gives the following sum for all learning cases.

$$U = \sum_{k=1}^m \sum_{i=12(k-1)+1}^k S_i \times C_{ik} \times A_k$$

Thus A_k is changed until U is equal or becomes larger than the desired value θ .

When the condition $U_j \geq \theta$ is achieved, the first learning is finished. Then

C_{ik} is determined by a feed back mechanism D_k as follows:

if $|A_k| \geq \sigma$, then $C_{ik(t)} = C_{ik(t+1)} = 1$, where t is number of learning.

Namely, S_i which is connected with this C_{ik} is used for the next learning.

if $|A_k| < \sigma$, then $C_{ik(t+1)} = 0$, and $C_{(t+1)k(t+1)} = 1$

2 limbs on a straight line. The measured values were expressed by a binary digit, according to whether it belongs to a division or not, and the sets of the binary digits were applied as input signals to the Adaline (S of Fig. 1). By changing the values of weight (A of Fig. 1) for each set of 12 binary digits the machine was made to learn to show the final sum of more than +30 units or less than -30 units to differentiate one state from the other. Thus parameters showing a larger weight were selected because they show characteristics for differentiation. When attempts were made to decrease the parameters without changing the accuracy, the ability of the Adaline to differentiate unknown cases was tested so that tentatively the final sum of more than +10 units or less than -10 units was regarded sufficient for this experiment to differentiate one state from the other. As a learning principle, Nilsson's error correction method⁵⁾ was employed. The computer S-360 (IBM) was employed for simulating the Adaline mechanism.

RESULTS

1. Characteristics of vector loops for differentiation

Since the chief differentiation lies in differentiating a normal state, left ventricular hypertrophy, right ventricular hypertrophy, left bundle branch block, right bundle branch block and myocardial infarction from each other, the Adaline was made to learn 15 pairs of differentiation, each pair employing 20 cases. As is shown in Table II, 10 to 16 parameters which showed a larger weight for differentiation of each pair were shown as crosses and these sets of selected parameters constituted the characteristics of each differentiation. For instance, for differentiating the normal state and left ventricular hypertrophy it was found that the magnitude of the maximal spatial QRS vector and of the maximal horizontal QRS and T vectors; the angle of the maximal horizontal QRS vector, of the maximal frontal and horizontal T vectors, and of the frontal and horizontal 0.04" QRS vectors; the angle between the maximal QRS and T vectors in the frontal and horizontal planes; and the duration of the QRS showed a larger weight, namely they were effective for differentiation.

Some of the parameters such as the angle of the maximal QRS vectors or the angle of QRS-T in the frontal plane were selected as being relatively common for many differentiations, and other parameters, such as the 0.02" QRS vector in the horizontal plane for the differentiation of left bundle branch block and right bundle branch block, were relatively specific.

2. Decrease of parameters without changing the accuracy of the results

After the Adaline was made to learn the above-mentioned cases, unknown vectorcardiograms were differentiated first with all of the 28 parameters. Next an attempt was made to decrease the number of parameters without changing the accuracy of differentiation significantly. The result is shown in Table III. For instance, when differentiation of the normal state and left ventricular hypertrophy was made with all 28 parameters, 10 out of 10 normal cases, namely all were judged as normal and 8 out of 10 cases of left ventricular hypertrophy were diagnosed correctly, one of them erroneously as normal and another as undecided. The parameters could be decreased to 6 without changing the result significantly. Namely, when the differentiation was made with 6 parameters consisting of a magnitude of the maximal spatial QRS vector of the maximal horizontal QRS vector and of the ST vector, the angle of the maximal frontal QRS vector, of the maximal horizontal T vector and of horizontal half area QRS vector, 10 out of 10 normal cases were judged as normal and 9 out of 10 cases of left ventricular hypertrophy were judged correctly as

Table II. Characteristics of Vector Loops for Differentiation

Differentiation	Mag. of spat. max. V	Mag. of max. QRS		Mag. of max. T		T/QRS		Ang. of max. QRS		Ang. of max. T		Ang. of 0.02" QRS		Ang. of 0.04" QRS		Ang. of 0.06" QRS		Ang. of half area QRS		QRS-T angle		Direct. of insc. of QRS		Direct. of insc. of T		QRS duration	Mag. of ST
		F	H	F	H	F	H	F	H	F	H	F	H	F	H	F	H	F	H	F	H	F	H	F	H		
Norm-LVH	×	×		×				×		×				×						×				×		×	
Norm-RVH	×	×		×				×		×																	
Norm-LBBB		×		×				×																			
Norm-RBBB	×					×				×																	
Norm-Infarct				×				×																			
LVH-RVH	×			×				×																			
LVH-LBBB		×				×		×																			
LVH-RBBB	×			×				×																			
LVH-Infarct	×	×						×																			
RVH-LBBB		×						×																			
RVH-RBBB																											
RVH-Infarct		×						×																			
LBBB-RBBB		×																									
LBBB-Infarct	×																										
RBBB-Infarct	×	×																									

Norm.: normal; LVH: left ventricular hypertrophy; RVH: right ventricular hypertrophy; LBBB: left bundle branch block; RBBB: right bundle branch block; F: frontal; H: horizontal.

Table III. Results of Decrease of Parameters without Changing Accuracy

Differentiation	No. of tested cases, unknown to the machine	No. of parameters	Correct ratio	No. of cases			No. of parameters	Correct ratio	No. of cases		
				Correct	Erroneous	Uncided			Correct	Erroneous	Uncided
Norm.	10	28	10/10	10			6	10/10	10		
LVH	10		8/9	8	1	1		9/10	9	1	
Norm.	10	28	7/7	7		3	6	7/7	7		3
RVH	6		5/5	5		1		5/5	5		1
Norm.	10	28	8/8	8		2	5	9/9	9		1
LBBB	8		8/8	8				8/8	8		
Norm.	10	28	8/8	8		2	7	10/10	10		
RBBB	10		10/10	10				10/10	10		
Norm.	10	28	9/9	9		1	6	10/10	10		
Infarct.	10		5/5	5		5		7/10	7	3	
LVH	10	28	4/4	4		6	4	8/9	8	1	1
LBBB	8		8/8	8				8/8	8		
LVH	10	28	6/7	6	1	3	8	8/9	8	1	1
RBBB	10		10/10	10				10/10	10		
LVH	10	28	6/6	6		4	8	5/6	5	1	4
RVH	6		5/5	5		1		6/6	6		
LVH	10	28	5/7	5	2	3	16	5/9	5	4	1
Infarct.	10		4/5	4	1	5		5/6	5	1	4
RVH	6	28	5/6	5	1		4	5/6	5	1	
LBBB	8		8/8	8				8/8	8		
RVH	6	28	3/4	3	1	2	5	2/6	2	4	
RBBB	10		9/9	9		1		9/9	9		
RVH	6	28	2/3	2	1	3	16	2/5	2	3	1
Infarct.	10		6/6	6		4		4/5	4	1	5
LBBB	8	28	8/8	8			5	5/5	5		3
RBBB	10		10/10	10				10/10	10		
LBBB	8	28	8/8	8			8	8/8	8		
Infarct.	10		10/10	10				10/10	10		
RBBB	10	28	7/7	7		3	7	4/6	4	2	4
Infarct.	10		7/7	7		3		8/8	8		2

Abbreviations are the same as in Table II.

left ventricular hypertrophy with one erroneous diagnosis as normal. The authors had an impression that the results of differentiation could be even better occasionally with a smaller number of parameters.

DISCUSSION

In order to design an automatic diagnosis of the vectorcardiogram or the electrocardiogram employing a computer or the Adaline itself, it is important to decrease the number of parameters without changing the result significantly. This study showed that the Adaline is useful for the logical decrease and that actually diagnosis could be made similarly or even better with several parameters in most pairs.

Some attempts were made by several authors to seek for discrimination functions for differentiating various states.^{6), 7)} In such studies composing parameters were selected usually by the "experience" of the authors, namely, rather arbitrarily. By the Adaline mechanism it was found that one is able to select these parameters automatically and logically. Constants are also decided automatically at the same time.

Going into details, in this study a special attempt to divide complete and incomplete bundle branch blocks was not made. The reason is that an attempt to divide them by the QRS duration of 0.12 sec. was made in the authors' previous report³⁾ with a different design and here another attempt was made. As a matter of fact, however, eventually no cases of incomplete bundle branch block were included in this study.

We did not test the angle of the 0.08" QRS, because it was inaccurate when the duration of QRS was short. But, since the angle of 0.06" QRS was not very useful in differentiation between the normal state and the right bundle branch block, for instance, in retrospect some information about the terminal QRS vector may have been useful in addition.

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