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Some Objective Methods for Electrocardiographic and Vectorcardiographic Diagnosis

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PRESENT STATUS of ECG and VCG diagnosis has still various difficulties, for instance, obscure borderline between normal and abnormal findings, empirical judgement of shape of the waves or loops, or random correspondence of findings to diseases. In order to overcome these difficulties, the following measures may be offered: (1) re-arrangement of ECG and VCG informations, (2) design of a new apparatus for objective interpretation of the findings which have been judged empirically, and (3) employment of electronic computer. Although there may be various ways for their actualization, we will limit the problems to the following three subjects.

1. Diagnosis of Left Ventricular Hypertrophy by Orthogonal Leads.

Various kinds of criteria have been offered for diagnosis of LVH. Recently, N. Kimura¹⁾ and Mori²⁾ have proposed new criteria which are based on VCG findings. In this viewpoint it seems more advantageous to use orthogonal leads for diagnosis of LVH than to use routine 12 leads.

The orthogonal X, Y and Z leads of Frank³⁾ were taken in 32 cases with hypertension, 8 with aortic valve diseases and 34

normal controls. Various combinations of height of the waves indicated in Fig. 1 were selected as the possible indices for LVH.

Fig. 1. A Comparison of Positivities of Indices for LVH.

Black area shows percentage of cases in which the value of indices exceeds the rejection limit obtained in normal control (critical level of 5%). X, Y and Z are Frank's orthogonal leads.

Any of these indices had statistically significant differences between disease and normal. The rejection limit was obtained with a critical level of 5% in each index and the cases showing a value beyond this limit were regarded as having LVH. The percentage of such cases may express the accuracy or positivity of respective indices. The highest accuracy was obtained when Rx/Ry was used, as seen in Fig. 1.

TABLE I COMPARISON OF POSITIVITIES OF VARIOUS CRITERIA FOR LVH

	No. of cases	$Rx./Ry.$	ΣLVP (Mori)		Sokolow and Lyon
			$Ry_5 + SaVF + Sv_2 > 45 (55) mV$	any of all items	$Sv_1 + Ry_5 > 35 mV$
Hypertension	32	68.8%	42.9%	64.3%	64.3%
Aortic valve disease	8	62.5	50.0	62.5	37.5
Normal control	34	2.9	11.0	21.0	17.0

Table I shows a comparison of positivities of R_x/R_y with those of criteria of Mori ($R_{V_5} + S_{aVF} + S_{V_2} > 45$ or 55 mm) and Sokolow and Lyon ($S_{V_1} + R_{V_5} > 35$ mm)⁴⁾. R_x/R_y had larger values either in hypertension or aortic valve disease than other criteria and its false positivity was lowest.

Correlation of the values of the formulae listed in Fig. 1 to the cardiothoracic ratio was also investigated. $R_x + S_y + S_z$ had a higher correlation than R_x/R_y . This suggests that $R_x + S_y + S_z$ is a better index for degree of LVH, while R_x/R_y is useful for differentiation of LVH from normal.

2. Use of differential curves of ECG for recognition of shape of the waves.

There have been reported no proper measures to discriminate objectively the coronary T or peaked T waves from usual one. The recognition of these waves are based not only on their height but also on their shape, i.e. steepness and concavity of ascending and descending limbs. The steepness or concavity can be expressed as some values by mathematical differentiation.

Fig. 2 is a sketch of differential curves of the first and second order of ECG, recorded

Fig. 2. A Sketch of Original ECG Tracings and Their Differential Curves.

by an apparatus designed by us for this purpose. The coronary T wave exhibited a vertically nearly symmetrical biphasic configuration in the differential curve of the first order, as expected from its isocles triangle-like shape in its original tracing. However, the differential curve of usual negative T wave had also a biphasic configuration, which was not so different from that of coronary T wave.

The differential curve of the second order of the T wave showed a W-shaped configuration in disease as well as in normal. In the cases with coronary T wave its initial negativity was deeper than succeeding, while in the cases with usual T wave both negativities were almost same deep or initial was shallower. This difference seemed to be more easily distinguishable than that in the differential curves of the first order.

The differential curves are also useful to discriminate the RS-T elevation with upward concavity often observed in myocardial infarction from non-specific one showing rather concavity. In the differential curve of the first order, the latter exhibited a positive wave immediately after the spike which corresponds to the QRS deflection, while in cases with myocardial infarction such a positive wave was not present.

Thus, the differential curves of ECG are considered to be useful for diagnosis of abnormalities in the RS-T and T wave.

3. Statistical diagnosis of diseases by ECG findings with the aid of Bayes theorem using electronic computer.

In our opinion, the process of ECG interpretation can be divided in the following three steps: (1) process of examination of individual wave and segment, (2) process of summarizing the information obtained in the first step, i.e. process of ECG diagnosis, and (3) process of diagnosing the disease by referring the ECG to other clinical findings.

The application of electronic computer to ECG diagnosis has already been attempted. Steinberg, et al.⁵⁾ and Pipberger, et al.⁶⁾ have realized recently apparatus which is capable to measure ECG values automatically. These attempts concern the first step of the processes above mentioned. As for the second step, Rikli, et al.⁷⁾ and Cady, et al.⁸⁾ have reported studies in which diagnosis of LVH was made by aid of statistical analysis using electronic computer, and Okajima, et al.⁹⁾ have devised a pattern recognition system for ECG by use of multiple adaptive matched filters.

Our plan is somewhat differed from those

above described. Its purpose is to diagnose the disease by ECG findings with the aid of Bayes' theorem without referring to other clinical data. This study was suggested by Warner's paper¹⁰⁾ in which Bayes' theorem was used for differential diagnosis of congenital heart diseases.

Seventeen diseases or groups of diseases and forty ECG findings were selected, as listed in Tables II and III. Sex and age were added. The incidences of each ECG finding in each disease were investigated in 825 cases, making a disease-ECG matrix.

Following two formulae were used for calculation :

$$Py_1(x_1, x_2, \dots, x_j) = \frac{Py_1 \cdot Px_1/y_1 \cdots Px_j/y_1}{\sum_{all k} Py_k \cdot Px_1/y_k \cdots Px_j/y_k} \quad (1)$$

and

$$Py_1(x_1, \dots, \bar{x}_n, \dots, x_j) = \frac{Py_1 \cdot Px_1/y_1 \cdots (1 - Px_n/y_k) \cdots Px_j/y_1}{\sum_{all k} Py_k \cdot Px_1/y_k \cdots (1 - Px_n/y_k) \cdots Px_j/y_k} \quad (2)$$

where x_i is ECG finding, y_i is disease and Py_i incidence of disease. Px_j/y_k means incidence of ECG finding x_j in disease y_k , and $Py_i(x_j)$ probability of disease y_i when ECG finding x_j is present. Only positive findings were calculated in formula 1, while negative findings were included in formula 2. $\bar{x}_n$ means a negative finding. TOSBAK 3100 was used for computation.

Some of the results of calculation are indicated in Fig. 3. The left-side circles were

obtained by using formula 1 and the right-sided by formula 2. The black area indicates the probability of the disease which was diagnosed clinically in respective cases. This area corresponds to percentage of "correct answer". Spotted area means a "partly correct answer".

Almost correct answer was obtained in cases with myocardial infarction. In a case showing a giant negative T wave the probability of infarction was calculated as nearly 65%. A case of malignant hypertension was found to be either aortic valve disease or hypertension with renal insufficiency. As listed in Table II, hypertension with renal

insufficiency was classified as an electrocardiographic diagnostic unit in this study.

In cases of combined valvular diseases, dominating valvular disturbance showed a larger probability than combined valvular disease, as illustrated in case 4 of Fig. 3. As to cor pulmonale, fairly excellent results were obtained and in a case showing deep Q wave in the chest leads the probability of cor pulmonale exceeded that of myocardial infarction. It must be mentioned that a fairly correct

TABLE II LIST OF DISEASES

y_1	mitral stenosis
y_2	mitral insufficiency
y_3	mitral stenoin insufficiency
y_4	aortic stenosis
y_5	aortic insufficiency
y_6	aortic stenoin insufficiency
y_7	combined valvular diseases
y_8	congenital heart diseases involving mainly right-sided heart (ASD, pulmonary stenosis, tetralogy of Fallot, Eisenmenger's complex, etc.)
y_9	congenital heart diseases not included in y_8 (for instance, VSD, PDA, etc.)
y_{10}	chronic cor pulmonale
y_{11}	hypertension
y_{12}	hypertension with coronary heart disease, excluding myocardial infarction
y_{13}	coronary heart disease without hypertension, excluding myocardial infarction
y_{14}	myocardial infarction
y_{15}	hypertension with renal insufficiency including uremia
y_{16}	neurocirculatory asthenia
y_{17}	functional disturbances of stimulus formation (extrasystoles, paroxysmal tachycardia, auricular fibrillation, etc., excluding WPW syndrome)

Fig. 3. Results of Calculation in Various Cases. Left-sided circles indicate the results calculated with formula 1 and right-sided with formula 2. Black and spotted areas show percentage of "correct" and "partly correct" answers, respectively. Inf: myocardial infarction, ren: hypertension with renal insufficiency, HT: hypertension, 9: congenital heart diseases y_9 .

answer was found in a case with neurocirculatory asthenia, particularly when formula 2 was used.

Throughout these calculations we were surprised that only two or three names of diseases appeared out of seventeen diseases listed in Table II, in spite of absence of characteristic ECG findings. It is needless to say, such information is very valuable for diagnosis of diseases.

SUMMARY

ECG and VCG diagnosis has still various difficulties. In order to overcome these difficulties, following studies were attempted:

1) Various combinations of height of the waves recorded by Frank's orthogonal leads

TABLE III LIST OF ECG FINDINGS

x_1	P_{II} 0.2 mV or higher
x_2	P_I duration 0.1" or more
x_3	P_{II} duration 0.1" or more
x_4	P_{III} duration 0.1" or more
x_5	P_{V1} 0.1 mV or higher
x_6	Duration of negative phase of P_{V1} 0.08" or more
x_7	Auricular fibrillation
x_8	$Q_{II} = 1/4 R_{II}$ or more
x_9	Q_{III} 0.5 mV or deeper
x_{10}	Q_{II} duration 0.03" or more
x_{11}	Q_{III} duration 0.04" or more
x_{12}	Q_{aVF} 0.5 mV or deeper
x_{13}	Q_{aVF} duration 0.04" or more
x_{14}	QS in V_1 alone
x_{15}	QS in V_1 through V_3
x_{16}	$Q = 1/4 R$ or more either in V_2 - V_6
x_{17}	R_{II} 2.0 mV or higher
x_{18}	R_I duration 0.06" or more
x_{19}	R_{II} duration 0.06" or more
x_{20}	R_{V1} 0.5 mV or higher
x_{21}	R larger than S in V_1
x_{22}	R' larger than R in V_1
x_{23}	R_{V5} or R_{V6} 2.6 mV or higher
x_{24}	QRS axis -30° or more (left axis deviation)
x_{25}	QRS axis $+120^\circ$ or more (right axis deviation)
x_{26}	J_I or $RS-T_I$ depression 0.05 mV or more
x_{27}	J_{II} or $RS-T_{II}$ depression 0.05 mV or more
x_{28}	J or $RS-T$ depression either in V_1 to V_6 0.05 mV or more
x_{29}	$RS-T$ elevation either in I , II or III 0.1 mV or more
x_{30}	$RS-T$ elevation either in V_1 to V_4 0.2 mV or more
x_{31}	$RS-T$ elevation in V_5 or V_6 0.1 mV or more
x_{32}	T_I inversion -0.1 mV or deeper
x_{33}	T_I flat or biphasic
x_{34}	T_{II} inversion -0.1 mV or deeper
x_{35}	T_{II} flat or biphasic
x_{36}	T inversion either in V_1 to V_4 -0.5 mV or deeper
x_{37}	T inversion either in V_1 to V_4 -0.1 to -0.49 mV
x_{38}	T inversion in V_5 or V_6 -0.5 mV or deeper
x_{39}	T inversion in V_5 or V_6 -0.1 to -0.49 mV
x_{40}	T flat or biphasic in V_5 or V_6
x_{41}	age 19 yrs or less
x_{42}	age 20 to 39 yrs
x_{43}	age 40 to 49 yrs
x_{44}	age 50 to 59 yrs
x_{45}	age 60 yrs or more
x_{46}	male
x_{47}	female

were compared as index for left ventricular hypertrophy. R_X/R_Y was most useful to differentiate LVH from normal and had larger positivity than some other criteria presented by various authors. On the one hand, $R_X + S_Y + S_Z$ was thought to be a better index for degree of LVH.

2) Differential curves of the second order of coronary T wave is considerably differed

from that of usual negative T wave. Differences are also observed in the differential curve of the first order between the RS-T elevation in myocardial infarction and non-specific elevation. The differential curves are useful for objective recognition of shape of the waves.

3) Statistical diagnosis of disease by ECG findings was attempted by using Bayes' theorem without referring to other clinical data. Calculation with electronic computer showed fairly correct answers in various actual cases. Some of the results are indicated.

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