Computer Analysis of Electrocardiograms With Six and Twelve Leads

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THE REPRODUCIBILITY of electrocardiograms and the validity of their interpretation in U.S. and foreign population studies have been critically analyzed and compared (*1*). Telephone transmission and computer analysis of ECG's have made rapid, accurate interpretations possible that correlate closely with physicians' readings (*2*). Most computer programs, however, require 12 leads for analysis—six standard frontal plane leads plus six chest leads. Incomplete interpretations are usually given when fewer leads are available. Nevertheless, Schneider and Birch, believing that less than 12 leads would be sufficient, proposed screening in which only the standard six-lead ECG would be interpreted by the physician (*3*). This method was applied in 1965 and 1967 to the computer analysis program of the Medical Systems Development Laboratory, Heart Disease and Stroke Control Program, National Center for Health Services Research and Development, Public Health Service.

At the time of the study Dr. Schneider was a commander in the Medical Corps of the U.S. Navy, stationed at the U.S. Naval Hospital, Philadelphia, Pa., and an associate in medicine at Jefferson Medical College in that city; he is now a member of DePersia-DuPree Medical Associates and assistant in cardiology, Underwood-Memorial Hospital, Woodbury, N.J.

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Commander Birch, an anesthesiologist at the U.S. Naval Hospital, Philadelphia, Pa., at the time of the study, is now at the U.S. Naval Hospital, Oakland, Calif.

Dr. Dwyer who at the time of the study was a commander in the Medical Corps, U.S. Navy, stationed at the U.S. Naval Hospital, Philadelphia, Pa., is now head of the cardiovascular laboratory, Roosevelt Hospital, New York City.

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Methods

Since 1950, the Alexandria (Va.) Health Department has conducted an annual 1-week open clinic for adults known as the Multi-Test Screening Program. Details of that program are described elsewhere (*4*). During the annual screening in 1967, six-lead and 12-lead electrocardiograms were obtained on men over 40 years of age. The six-lead ECG's were taken by a system of rapid application previously described (*5*), in which the patient remains seated. Both of the patient's feet are placed on electrodes moistened with saline or alcohol; his index fingers are inserted into tension clamps (see illus-

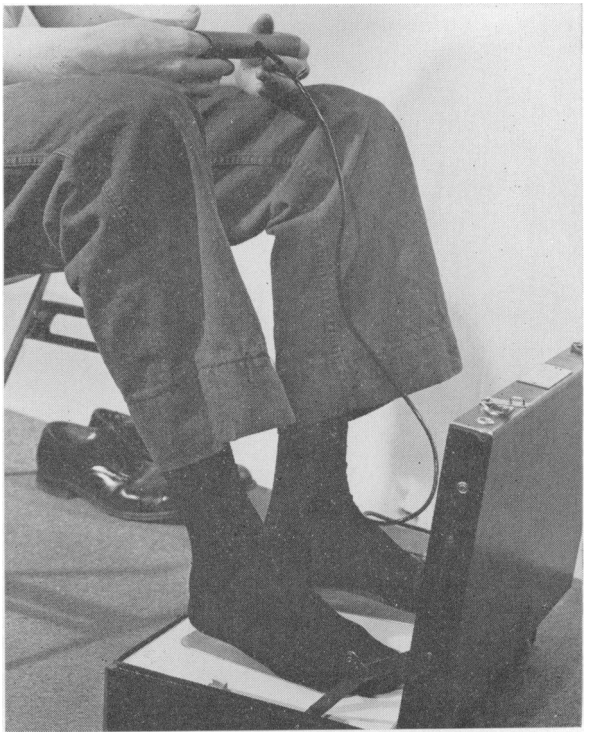
tration). In many instances, satisfactory tracings were obtained without removal of the patient's stockings, which takes time. The same technique might have been used to obtain the full 12-lead ECG. Schneider promptly interpreted each six-lead ECG as normal or abnormal. Conventional 12-lead ECG's were obtained with ordinary ECG electrodes and paste while the subject was recumbent.

Participation in the Multi-Test Screening Program was voluntary, and the men were allowed to bypass one type of ECG if they so desired. All 332 subjects allowed both the six-lead ECG in the upright position and the conventional 12-lead ECG to be taken. The type taken first depended on which queue was shorter.

All ECG's were fed into a data acquisition unit. This device records the physiological signal in analog form on tape along with other information, such as the patient's identification number and age. After brief training, public health nurses operated the equipment at the recording location—the health department clinic. The recorded tape was delivered to the site of the computer, where it was played back into a preprocessing system and converted into a computer-compatible form. The computer then analyzed the signal and derived an interpretation. This interpretation was printed and, in our project, returned to the health department for use.

A total of 309 12-lead ECG's were available and technically satisfactory for comparison with the six-lead ECG's. These six-lead and 12-lead ECG's were interpreted by two different cardiologists (Schneider and Dwyer) on two different occasions without knowledge of the prior reading of the other cardiologist or computer. The ECG's were classified as normal or abnormal. The two physicians then jointly reviewed the interpretations, and a consensus diagnosis was made for both the six-lead and 12-lead tracings. The diagnosis obtained from the 12-lead ECG's was used as the reference against which the other methods were compared.

The interpretations by the computer of the 12-lead and six-lead ECG's were compared with the reference, and the variability of the interpretations of the six-lead ECG's by two observers, as well as by a single observer on two occasions, was evaluated. The criteria for interpretation were those of the Medical Systems Development Laboratory (*6*), Grant (*7*), and Massie and Walsh (*8*). Isolated ECG results that were accepted as normal were (*a*) RaVL greater than 1 but less than 12 mm., (*b*) incomplete right bundle branch block, (*c*) nonspecific ST segment and T wave changes, (*d*) junctional ST segment and T wave changes, and (*e*) short PR interval.



The frontal plane leads can be rapidly placed on the subject, who remains seated and does not remove his stockings

Results

A total of 332 six-lead ECG's were obtained with the system of rapid electrode replacement in which the subject remains seated. All these six-lead tracings were submitted to the computer for analysis; 207 were completely acceptable to the computer, and all six leads were analyzed. In 73 of the unaccepted tracings, the voltage was too low in one or more leads; in 19, there was arrhythmia (15 of which were premature ventricular contractions); in 10, there were artifacts and in 23 others, one or more

leads were rejected for unexplained reasons. Review of these 23 ECG's showed no apparent reason for rejection of these leads. We found similar rejections when we reviewed the 12-lead ECG's. Rejection or failure to analyze one lead does not necessarily prevent the computer from achieving a diagnosis because redundancy exists even in six-lead electrocardiograms.

Of the tracings obtained on the 332 subjects who had both types of electrocardiograms taken, only 13 of 664 (2.9 percent) were not analyzed by the computer. Ten ECG's could not be matched because of coding errors. Although the ECG's were taken by "technical novices" (the public health nurses), this proportion compares well with that obtained when professional computer technicians have done the recordings (*9*). The computer reported 67 abnormal 12-lead tracings which were in fact normal. In 25 instances, miscalculation by the computer could be demonstrated. Intraventricular conduction delay and P-wave abnormalities were the most commonly reported false-positive readings. Computer diagnoses of the false-positive six-lead and 12-lead ECG's are given in table 1.

Of the 309 12-lead ECG's analyzed by the cardiologists jointly and used as the reference, 241 were rated normal and 68 abnormal. The enumeration of the abnormal group was as follows:

Abnormality	*Incidence*
Nonspecific ST segment and T wave changes	21
Left axis deviation greater than minus 30	14
Suspected old infarct	12
Left ventricular hypertrophy	12
Miscellaneous:	
Left bundle branch block	3
Left atrial hypertrophy	3
Right bundle branch block	3
Arrhythmia	6
Right axis deviation, right ventricular hypertrophy, or intraventricular conduction delay	3

The computer failed to detect significant abnormality in six of the tracings that were abnormal according to the reference (false negatives) and interpreted 67 of the normal 12-lead ECG's as abnormal (false positives). Ability to detect major abnormality with 12-lead ECG's by computer analysis (sensitivity) was 91 percent; the computer detected 62 of the 68 ECG's classified as abnormal in the reference diagnosis. Likewise, ability to diagnose normality correctly (specificity) by the computer method was 72 percent for 12-lead ECG's; the computer classified as normal 174 of the 241 tracings rated normal in the reference diagnosis.

Six-lead ECG's analyzed by computer yielded somewhat different results—228 normal tracings and 81 abnormal, 37 false positives and 16 false negatives. False-negative results occurred more than twice as frequently in the six-lead ECG's as in the 12-lead (table 2). Specificity of the computer's analysis of six-lead tracings was 85 percent and sensitivity, 77 percent. The computer's analysis of six-lead and 12-lead ECG's is compared in table 3.

Variability in the physicians' interpretations of six-lead ECG's was then assessed. One phy-

Table 1. Computer diagnosis of the false-positive ECG's

Diagnosis	Incidence	
	12 leads	6 leads
Intraventricular conduction delay	17	--
Abnormal P wave	11	15
Atypical q V2 V3	7	--
Early repolarization	4	--
ST-T wave changes	3	8
Miscalculations by computer:		
Left axis deviation	2	6
PR interval	7	2
QRS-T angle	4	4
RaVL greater than 10 mm	5	5
QT interval	3	--
Poor R progression	4	--
Miscellaneous	9	--
Infarction suspected	--	5
Number of ECG's	67	37

Table 2. Significant false-negative ECG abnormalities

Diagnosis	Incidence	
	12 leads	6 leads
ST-T change	1	12
Abnormal left axis deviation	3	2
P wave abnormality	1	2
Right bundle branch block	0	2
QRS prolongation	0	2
Left ventricular hypertrophy	0	2
Anterior infarction	0	1
Inferior infarction	1	0
Number of ECG's	6	16

sician disagreed with his original reading of the six-lead ECG in 31 instances (10 percent) and disagreed with the other physician's interpretation in 38 instances (12 percent). Both physicians were wrong 23 times (7 percent) in their diagnosis of the six-lead tracing as compared with the reference. Both physicians agreed that a six-lead ECG was normal 212 times (88 percent specificity) but detected abnormality in 44 instances (35 percent sensitivity) (table 3). False-negative reports occurred four times more frequently than in the computer's analysis of 12-lead ECG's (table 3). Complete agreement by both cardiologists and the computer that the comparable six-lead and 12-lead ECG's were normal or abnormal was reached in 70 percent of the series. This result compares favorably with results reported by Dobrow and associates (*2*). The accuracy of both cardiologists in our study approximated 85 percent. Similar results have been reported by others (*1*, *10*, *11*).

Discussion

Before rapid computer analysis of electrocardiograms was available, investigations were directed toward rapid screening of limited-lead ECG's. The results were at best fair. With only lead I as a screening device, Dawber and associates (*12*) reported 49 percent accuracy and Weintraub (*13*) reported 26 percent. Sodeman and Logue (*14*) reported 95 percent accuracy when they used two frontal plane leads and V5 in screening patients with known heart disease. Still others have advocated using "modified" leads, but such a practice would introduce a new variable in ECG interpretation without increasing accuracy (*15*, *16*).

Scant attention has been given to critical analysis of the frontal plane leads as a screening technique. Cooper and associates (*4*) cited a 35 percent prevalence of detectable abnormalities when standard leads were analyzed in a computer survey of 9,660 ECG's. Their data were supplied by Whiteman (*6*) and were based on computer interpretation of 12-lead ECG's, followed by interpretation of the same ECG's without inclusion of the chest leads. Ten percent more abnormalities were found when 12 leads were used as opposed to six. When Schneider and Birch (*3*) compared their analyses of six-lead and 12-lead ECG's with those in another study, they found a high degree of accuracy for the six-lead tracings. The specificity and sensitivity of the six-lead screening exceeded 96 percent, a proportion comparing favorably with that in an earlier study by Makous (*17*).

Although the electrocardiogram lacks sensitivity, it still remains a valuable test in the detection of heart disease (*2*, *12*, *17*, *18*). As the following table shows, wide variations have been noted in the percent of specificity and sensitivity of 12-lead ECG interpretations:

Study	*Sensitivity*	*Specificity*
Dawber and associates (*12*)	43. 0	89. 3
Makous (*17*)	71. 5	85. 1
Witham and Jones (*18*)	82. 5	89. 1
Dobrow and associates (*2*)	91. 0	81. 0
Our study	91. 0	73. 0

With the same basic criteria for computer analysis of telephone-transmitted 12-lead

Table 3. Comparison of computer's and physicians' analyses of ECG tracings with the references for abnormality and normality assumed to be correct

Correlation with reference	Computer analysis of—				Physicians' consensus on 6-lead ECG	
	12-lead ECG		6-lead ECG			
	Number	percent	Number	percent	Number	percent
Abnormality						
Agree (sensitivity)	62	91	51	77	44	65
Disagree (false negatives)	6	9	16	23	24	35
Normality						
Agree (specificity)	174	72	205	85	212	88
Disagree (false positives)	67	28	37	15	29	12

ECG's as we used, Dobrow and associates (*2*) achieved results closely parallel to ours.

Computer analysis of the frontal plane six leads presented no unusual difficulties. In the majority of instances when a lead in the six-lead ECG was rejected, a similar rejection was found in the 12-lead ECG. Moreover, use of the special sitting position for the subject with the ECG technique enabled us to obtain the six leads in less than 1 minute, as compared with the 5 minutes necessary to apply the conventional electrodes and record the full 12 leads. As expected, the sensitivity of the six-lead screening was less—77 percent—as compared with 91 percent for the 12 leads.

The information provided by this type of study can assist the public health planner in determining what technique to use in screening for heart disease. Improvement in the programing of the computers used in ECG interpretations will increase the accuracy and efficiency of future ECG surveys. Better programing has been achieved at the Medical Systems Development Laboratory since completion of our study. The programer can more easily estimate what he will trade off by using a faster, less expensive system, that is, the extent of the loss in sensitivity and specificity as compared with the traditional system. No one system, however, can be labeled "best," since each has advantages.

Summary

An investigation of the value of several methods of screening with electrocardiograms (ECG's) was undertaken by the Bureau of Medicine and Surgery, U.S. Navy, and the Heart Disease and Stroke Control Program, Public Health Service. Since rapid computer analysis of electrocardiograms had become available, it seemed feasible to compare the accuracy of interpretation with limited numbers of ECG leads. A system of rapid application of the six frontal plane electrodes was used. The patient was seated; both his feet were placed on electrodes moistened with saline or alcohol, and his index fingers were inserted into tension clips. Application of the electrodes took approximately 1 minute. The six leads were then recorded. Conventional 12-lead ECG's were obtained with ordinary ECG electrodes and paste while the subject was recumbent. This procedure usually took 4 to 5 minutes. Both six-lead and 12-lead ECG's were fed into a data acquisition console.

As a standard for comparison, 309 full 12-lead ECG's were obtained and interpreted by two cardiologists independently. Differences of interpretation were then discussed, and an assumed correct interpretation was obtained. This reading was compared with the readings by digital computer of the 12-lead ECG and of a special six-lead (no chest leads) ECG, as well as with a physician's analysis of the six-lead tracing. The interpretations of the 12-lead ECG's by computer were found to be 91 percent sensitive and 72 percent specific; the interpretations of the six-lead ECG's by computer were found to be 77 percent sensitive and 85 percent specific. The interpretations by the physician of the six-lead ECG's were found to be 88 percent sensitive and 65 percent specific.

The ability to detect abnormality was less with the six-lead screening method (23 percent) than with the 12-lead. Overdiagnosis occurred more frequently in the interpretation of the 12-lead ECG by computer (28 percent). For large computer studies, the rapid frontal plane electrode application system is feasible in detecting normality, but it conceivably could miss a considerable number of abnormal electrocardiograms. Further investigation of this rapid application system in conjunction with selected precordial-lead ECG's seems indicated.

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Tearsheet Requests

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National Academy of Sciences to Create an Institute on Medicine

The National Academy of Sciences will create an Institute on Medicine to address the larger problems of medicine and health care. The present Board on Medicine of the Academy will serve as the nucleus of the new organization. Dr. Walsh McDermott, Livingston Farrand Professor and chairman of the department of public health, Cornell University Medical College, is chairman of the Board on Medicine.

It is anticipated that the eventual membership of the institute may reach 200 or more, all of whom will serve fixed terms. Most members will be engaged in medical education, medical practice, or biomedical research, but a substantial fraction will be drawn from such closely allied professions as nursing and public health and from the practice of law and academic fields such as economics, political science, and other social and behavioral sciences.

Since its creation by the Academy in November 1967, the Board on Medicine has been concerned with the overall aspects of medicine and the health sciences in general. For example, their statement on the ethics of cardiac transplantation, the first to be issued after the initial heart transplants, has formed the basis of current accepted practice in this field internationally.

Recently the board co-sponsored with the Fogarty International Center of the National Institutes of Health a colloquium on student unrest at medical schools in the United States and abroad. A resulting publication was made available by the Academy in May 1970. Also, a panel of the board has just completed a study on the role and training of the physician's assistants and expects to publish its report in a few months.

Other major activities of the board include a study of contrasts in health status, under the staff direction of Dr. David M. Kessner. This is a large-scale comparative analysis of health, disease, and the systems for their management in various segments of society.