Potential Benefits Of A Computer ECG Interpretation System For Primary Care Physicians In A Community Hospital

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Abstract: One hundred fifteen ECGs from a hospital service were interpreted by 2 primary care physicians and 2 expert electrocardiographers. When their interpretations were compared with one another and with the Marquette MAC II ECG Interpretation Program, there was great variability. Computer ECG interpretations appeared to benefit primary care physicians most by providing a backup opinion. This second opinion was also of use to expert electrocardiographers. Additional long-term benefits that may be derived from computer systems include improvement of physician interpretation ability, reduction in interpretation time, and standardization of electrocardiographic nomenclature and criteria. (J Am Bd Fam Pract 1989; 2:17-24.)

An estimated 15 percent of the approximately 100 million ECGs recorded in the United States during 1983 were processed by computer.[1] It is likely that an even greater percentage are so processed at the current time. Although a number of studies have compared the accuracy of computer ECG analysis systems with interpretations by independently blinded cardiologists, most reports have not included primary care physicians in their design.[2-9] As a result, the questions of whether computer ECG analysis programs are useful and improve accuracy of interpretation by primary care physicians in a community hospital environment remain unanswered. The purpose of this study was to investigate these issues.

Methods

One hundred fifteen ECGs were collected for use in the study. Study tracings were obtained on consecutively admitted patients to the Family Practice Service at Alachua General Hospital in Gainesville, Florida, between January 29 and February 29, 1984. Each ECG was processed by the Marquette MAC II ECG Interpretation Program.

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In the initial phase of the study, the 115 ECGs were interpreted by 2 primary care physicians with an interest in electrocardiography and 2 expert electrocardiographers. The number of ECGs distributed at any one time was limited to 25 tracings. Computer interpretations and clinical data for each electrocardiogram were blacked out except for the age and sex of the patient. Interpreters were given a copy of the terminology used by the computer system, but it was not mandatory that they use it. The minimal information requested for each ECG analysis was heart rate and rhythm, mean QRS axis, ST-T wave changes, chamber enlargement, and evidence of myocardial infarction. Additional comments on miscellaneous findings were encouraged, and interpreters were specifically asked: (1) to comment on the probable significance of any ST-T wave abnormalities (e.g., changes suggestive of ischemia, infarction, left ventricular "strain," or nonspecific); (2) to include probability statements (e.g., definite, probable, or possible) for the categories of chamber enlargement and infarction; (3) to indicate, for left ventricular hypertrophy (LVH) in particular, whether voltage criteria alone were satisfied or whether repolarization changes were also present; and (4) to localize changes (i.e., anterior, inferior, or isolated lateral infarction) and to estimate the age of infarction (i.e., acute, remote, or undetermined age). Written analyses were completed on all 115 tracings (*precomputer* interpretations) by each of the 4 interpreters.

In the second phase of the study, the 115 ECGs were redistributed to the 4 interpreters with the computer analysis of each tracing attached to the initial interpretation. They were asked whether they agreed with each computer statement or whether they wished to alter their initial interpretation in any way (*postcomputer* interpretations). All 9 interpretations for each of the 115 ECGs (i.e., pre- and postcomputer interpretations and the computer interpretation) were then coded for each of eight categories: rate and rhythm, axis, bundle branch block, chamber enlargement, myocardial infarction, ST-T wave changes, Q-T interval prolongation, and miscellaneous findings. Changes between pre- and postcomputer interpretations were noted in these categories and in the probability statements about chamber enlargement and infarction.

Results

Overall Agreement among Expert Electrocardiographers

Among the experts, there was total agreement (on the presence of all ECG findings and in the likelihood of their occurrence) in 25 of the 115 tracings (22 percent). Disagreement on one electrocardiographic finding was noted in 32 tracings (27 percent), on two findings in 25 tracings (22 percent), and on three or more findings in the remaining 33 tracings (29 percent). Fifteen ECGs (13 percent) were interpreted normal by at least 1 of the 4 interpreters. The experts disagreed on the classification of 5 of these 15 tracings (33 percent).

Influence of Computer Reading on Initial Interpretations

The 2 primary care physicians (each with 115 tracings) altered their initial interpretations in 103 of 230 tracings (45 percent) after being provided with computer readings of each ECG. In 82 of these 103 tracings (80 percent), only one change was made, two changes were made in 16 tracings (15 percent), and three or more changes were made in the remaining 5 tracings (5 percent).

Experts altered their initial interpretations in 90 of 230 tracing (39 percent). In 69 of these 90 tracings (77 percent) only one change was made. Two changes were made in 19 tracings (21 percent), and three or more changes were made in 2 tracings (2 percent).

Postcomputer interpretations were compared with precomputer interpretations, and the changes were assessed for clinical importance.

For the primary care physicians, 14 changes (10 percent) were judged to be clinically important, 55 (42 percent) were believed to be of potential clinical importance, and 63 (48 percent) were not thought to be important. Findings were judged clinically important when there was an addition of possible or probable acute myocardial infarction (n = 2), a deletion of possible acute myocardial infarction (n = 2), a change in the likelihood of possible or probable acute myocardial infarction (n = 7), an increase in the likelihood of LVH (n = 1), and addition of intraventricular conduction delay (IVCD) (n = 2).

For the experts, 6 changes (5 percent) were judged to be clinically important, 50 (44 percent) were believed to be of potential clinical importance, and 58 (51 percent) were not thought to be important. Findings were judged clinically important when there was a change in the likelihood of acute myocardial infarction (n = 1), an increase in the likelihood of LVH (n = 3), an increase in the likelihood of right ventricular hypertrophy (RVH) (n = 1), and addition of IVCD (n = 1).

Pre- and postcomputer tracings were examined to determine what percentage of changes resulted in a final interpretation that was in better agreement with the interpretation of the experts. Tracings were also examined to determine whether final interpretations were more or less like the computer analyses.

For the primary care physicians, 66 (50 percent) changes resulted in a final interpretation that was in better agreement with the interpretation of the experts, and 22 (17 percent) showed poorer agreement. In the remaining 33 percent, it was not clear what effect the changes had. One hundred nineteen (90 percent) changes made by the primary care physicians had a final interpretation that was in better agreement with the computer analysis; 10 changes (8 percent) were in poorer agreement. In the remaining 2 percent, the effect was not clear.

For the expert electrocardiographers, 72 (63 percent) of the 114 changes resulted in a final interpretation that was in better agreement with the other expert; 34 (30 percent) resulted in poorer agreement with the other expert. The effect was not clear in the remaining 7 percent. Ninety

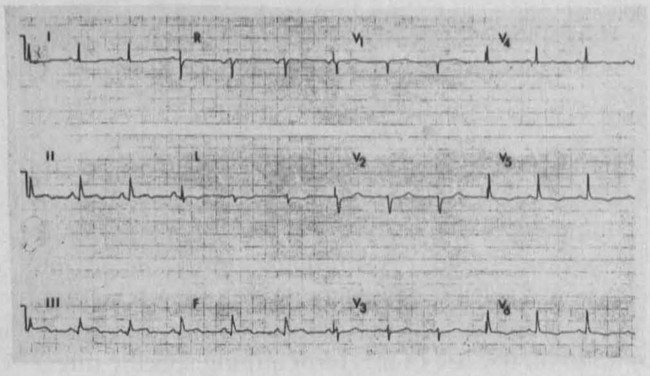

Figure 1: ECG from a 53-year-old woman with an evolving inferior myocardial infarction.

(79 percent) changes resulted in a final interpretation that was in better agreement with the computer analysis; 13 (11 percent) were in poorer agreement. In the remaining 10 percent, the effect was not clear.

Acute Myocardial Infarction

Probable or definite acute myocardial infarction was noted on 8 of the 115 tracings. In each instance, the experts agreed on this finding. While the primary care interpreters did not overlook these infarctions, they sometimes indicated infarction of unknown age or possible acute infarction instead of specifying probable or definite acute infarction. In contrast, the computer analysis did not make a strong indication of acute infarction or ischemia on 3 of these 8 tracings.

One example of an infarction tracing not picked up by the computer is shown in Figure 1. Small q waves are seen inferiorly with accompanying coved S-T segment elevation. Each of the 4 interpreters noted that the tracing was suggestive of inferior infarction, possibly (or probably) acute. The computer interpretation was: "normal sinus rhythm; nonspecific ST-T wave abnormality; prolonged Q-T interval or TU fusion—consider myocardial disease, electrolyte imbalance, or drug effects; abnormal ECG."

Chamber Enlargement

Agreement among the 4 interpreters and the computer analysis for right atrial enlargement (RAE), left atrial enlargement (LAE), and left ventricular hypertrophy (LVH) is shown in Table 1. Right ventricular hypertrophy did not occur often enough to evaluate.

Note that for agreement to occur, enlargement of a particular chamber had only to be *mentioned* in an interpretation. No attention was paid to the assigned likelihood for chamber enlargement. Agreement would be lower if distinction was made between possible chamber enlargement and probable or definite chamber enlargement.

Comparison between the 2 primary care physicians' interpretations shows that RAE was mentioned by at least one of them on 11 of the ECGs in the study. Both identified possible RAE in the same ECG in 9 instances (for an agreement rating of 9/11 = 82 percent). In contrast, agreement was much less for LAE (38 percent); that is, *both* identified LAE in only 8 of the 21 ECGs on which LAE was mentioned by one of them. Agreement for

Table 1. *Interpreter Agreement on RAE, LAE, and LVH.*

Type of Interpreter	Specific Interpreter	Agreement on RAE	Agreement on LAE	Agreement on LVH
Primary care vs. primary care	A vs. B	9/11 (82%)	8/21 (38%)	25/34 (74%)
Primary care vs. computer	A vs. X	7/12 (58%)	11/18 (61%)	24/39 (62%)
	B vs. X	8/13 (62%)	10/22 (45%)	21/35 (60%)
Primary care vs. expert	A vs. C	6/11 (55%)	10/19 (53%)	31/47 (66%)
	B vs. C	6/11 (55%)	11/21 (52%)	25/45 (56%)
	A vs. D	9/17 (53%)	13/30 (43%)	24/37 (65%)
	B vs. D	8/18 (44%)	13/33 (39%)	26/30 (87%)
Expert vs. expert	C vs. D	6/17 (35%)	16/30 (53%)	23/47 (49%)
Expert vs. computer	C vs. X	5/11 (45%)	12/21 (57%)	27/47 (57%)
	D vs. X	7/17 (41%)	15/32 (47%)	20/38 (53%)
	Combined Agreement	71/138 (51%)	119/247 (48%)	246/399 (62%)

A, B = Primary care physicians; C, D = Expert electrocardiographers; X = Computer analysis; RAE = right atrial enlargement; LAE = left atrial enlargement; LVH = left ventricular hypertrophy.

Table 2. *Interpreter Use of the Terms "Strain," "Ischemia," and "Nonspecific ST-T Wave Abnormalities" (NS ST-T).*

Interpreter	Strain Used*	Ischemia Used*	NS ST-T Used*
A†	15	22	38
B†	22	34	34
X	13	28	26
C†	30	3	37
D†	17	4	51
Average Use	19.4	18.2	37.2

*Total use in the 115 study tracings.
†Indicates *final* interpretations (i.e., interpretations *after* review of computer analysis).
A, B = Primary care physicians; C, D = Expert electrocardiographers; X = Computer analysis.

LVH was 74 percent, because both concurred with this finding in 25 of the 34 tracings on which LVH was at least mentioned by one of them.

It is of interest that among the 41 ECGs in which atrial enlargement (i.e., RAE and LAE) was mentioned by one of the experts, no mention of any atrial abnormality was made by the other in 20 instances (49 percent). In particular, one indicated probable or definite LAE or RAE in 19 instances in which no mention at all of atrial enlargement was made by the other.

A similar discrepancy existed for LVH. In 29 tracings, probable or definite LVH was indicated on the final ECG interpretation of one of the experts, but only 14 of these 29 instances (48 percent) were identified by the other. One indicated probable or definite LVH in 12 instances in which no mention of LVH was made by the other.

ST-T Wave Changes

The frequency with which interpreters and the computer used the terms "strain," "ischemia," and "nonspecific ST-T wave abnormalities" is shown in Table 2. "Ischemia" was not a common term used by the experts. One who used the term "nonspecific ST-T wave abnormalities" most often used "strain" and "ischemia" least often. ST-T wave changes believed to represent ischemia by the primary care physicians or the computer were often described as "nonspecific" by one expert. The one who used the term "strain" or its equivalent most often used "ischemia" infrequently. For him, ST-T wave changes were frequently described as repolarization abnormalities consistent with LVH, but similar changes were described as representing ischemia by others.

Descriptors

Use of the descriptors COPD (chronic obstructive pulmonary disease pattern) and PRWP (poor R wave progression) is summarized in Table 3. One expert used the descriptor COPD far more than the computer and the others (16 times). Agreement on the use of this term among specific interpreters and between them and the computer was extremely poor. Although two interpreters mentioned COPD on 19 different ECGs, they agreed in only 2 instances (11 percent). Among interpreters, agreement was less than 35 percent in all but one case.

Agreement was equally poor for use of the descriptor PRWP. This term was noted 25 times by one expert, 18 times and 7 times by the primary care physicians. It was not used at all by the other expert or the computer. Review of all tracings did not show the term to be used as a substitute for anterior infarction of old or unknown age. Agreement among interpreters who used the term was less than 30 percent.

Discussion

The purpose of this study was not to compare the accuracy of a computer ECG analysis program with human interpreters. Clearly, many more tracings, a greater number of interpreters, and better correlation between clinical and pathologic information with ECG findings would be needed to accomplish this. Instead, our goal was to investigate whether computer ECG analysis systems might be useful and improve accuracy of interpretation by primary care physicians in a community hospital.

Agreement among Expert Electrocardiographers

Before assessing the impact computer ECG interpretations may have had on the primary care physicians in our study, the level of agreement of each expert with the other and of each expert with the computer should be examined. Interpretations of the experts showed complete agreement for only 22 percent of the 115 tracings. Disagreement on *three* or more electrocardiographic findings was present in 29 percent of the tracings. Most of the disagreements were not clinically important, and

Table 3. *Interpreter Agreement on COPD and PRWP.*

Type of Interpreter	Specific Interpreter	Agreement on COPD	Agreement on PRWP
Primary care vs. primary care	A vs. B	4/7 (57%)	5/20 (25%)
Primary care vs. computer	A vs. X	2/8 (25%)	
	B vs. X	2/9 (22%)	
Primary care vs. expert	A vs. C	1/7 (14%)	
	B vs. C	1/8 (13%)	
	A vs. D	2/19 (11%)	9/34 (26%)
	B vs. D	4/18 (22%)	3/28 (11%)
Expert vs. expert	C vs. D	3/16 (19%)	
Expert vs. computer	C vs. X	2/6 (33%)	
	D vs. X	2/19 (11%)	

A, B = Primary care physicians; C, D = Expert electrocardiographers; X = Computer analysis; COPD = Chronic obstructive pulmonary disease pattern; PRWP = Poor R wave progression.

many were due to differences in the diagnostic criteria or in the use of terminology. Nevertheless, these results compare with the observations of others and suggest that *interobserver* variability in ECG interpretation among experts is substantial.[10] Significant variability in electrocardiographic classification persists even when interpreters agree to use identical criteria.[11] Although our study did not control for *intraobserver* variability in ECG interpretations, others have reported this range between 10–20 percent.[10]

Disagreement in the classification of what constitutes a normal ECG was also seen in our study. Among the 15 ECGs that were interpreted as normal by at least 1 of the 4 interpreters, disagreement between the 2 experts occurred in 5 instances (33 percent). Similar disagreement has been reported in the literature, and a number of studies show a lack of consensus on normal ECGs in as many as 25–35 percent of cases.[6,8,12,]

Differences in Terminology and Diagnostic Criteria

Despite the efforts of experts,[11] standardization of terminology and diagnostic criteria has not been achieved. As a result, differences in the use of terminology and diagnostic criteria continue to pose a major obstacle to objective evaluation of ECG interpretations. An excellent example of this is the description of ST-T wave abnormalities, where similar electrocardiographic findings may be interpreted by different observers as being within the normal range of variation, as representing a nonspecific abnormality, or as consistent with strain, ischemia, subendocardial injury, electrolyte disturbance, or digitalis effect.[8,13]

Multiple diagnostic criteria for similar conditions are also in use; e.g., more than 30 sets of criteria have been proposed for the electrocardiographic diagnosis of left ventricular hypertrophy (LVH).[14,15] None demonstrates a sensitivity greater than 60 percent, and which ones are used for the interpretation of any particular ECG seem to depend most on the personal preference of the interpreter.[6]

Assessing Computer ECG Interpretation Programs

Our results highlight the difficulty of interpreting data in which computer ECG analysis systems and human interpreters are compared. In addition to differences in terminology and diagnostic criteria, results of computer programs also depend on the methods of analysis used in evaluation. Thus, it is possible for a particular computer program to agree with a physician on the existence of one or more abnormalities despite marked disagreement on their meaning. Accuracy of a computer ECG interpretation program therefore hinges on how agreement is defined. In general, one might expect better agreement when physicians are asked simply whether they agree with a computer interpretation than when their written interpretations are compared with the computer analysis.[3,6]

In our study, investigators were initially blinded from computer interpretations and asked to write their analysis for each ECG. They were then provided with the computer interpretation of each tracing and asked if they agreed with the computer and whether they wished to alter their initial interpretations. This sequence of analysis could have produced an attitude of defensiveness among interpreters who may have felt a need to justify their initial interpretations. This would have been more likely to occur in instances where semantic differences in terminology arose or borderline criteria for a condition were present. In such cases, interpreters may have opted to go with their initial interpretations rather than alter them to conform to the wording of the computer. Thus, it is possible that a higher level of agreement might have been obtained if physicians had been asked at the outset to comment on whether they agreed with the computer interpretation without first analyzing the ECG themselves.

Another point to consider in assessing a computer program is the composition of the study population.[13] Differences in the frequency of electrocardiographic abnormalities may be the reason why dramatically different conclusions about the accuracy of a computer program are reached when the same panel of experts evaluates the same computer program in different clinical settings.[16] For example, most computer programs are exceedingly accurate in detecting normal sinus rhythm and in interpreting normal ECGs, but they are much less so in their analysis of complex dysrhythmias.[1,17-20] One would expect, therefore, better results from a computer program when used in a setting where a high number of normal persons make up the test population. In contrast, in a hospital setting where abnormal ECGs are the rule, a much greater level of disagreement is likely to exist between computer interpretations and a panel of experts.

The final point to consider in assessing accuracy of computer ECG analysis programs is the need for a universally accepted reference standard of interpretation. Unfortunately, adequate nonelectrocardiographic means for validating many ECG findings simply do not exist.[17] This is particularly true for interpretive statements that deal with conduction defects or cardiac arrhythmias and for measurements such as mean QRS axis. In other cases, morphologic changes such as ST-T wave abnormalities defy precise evaluation. Even for description of anatomic conditions such as chamber enlargement, objective correlation by nonelectrocardiographic means often is not possible.[21] Confirmation of pathophysiologic conditions such as prior myocardial infarction can be reliably determined at autopsy; however, correlation between this anatomic finding and antemortem electrocardiographic evidence of infarction still leaves much to be desired.[22]

Clinical Implications: Benefit of Computer ECG Interpretations to Primary Care Physicians

Because no universally accepted reference standard exists for ECG interpretation and tremendous variability in terminology and diagnostic criteria occurs, the clinician is faced with the perplexing problem of how best to use the information contained in the computer report. That such information is used is suggested by our findings. Primary care physicians altered 45 percent of their interpretations after being provided with computer results. Although only 10 percent of these changes were believed to be clinically important, these interpreters nevertheless chose to modify their initial interpretations when given an opportunity to do so. Accuracy of primary care physicians' postcomputer interpretations appeared to improve because their final interpretations in general showed better agreement with the interpretations of the experts.

Some of the changes made by the primary care physicians probably resulted from the opportunity to review their initial interpretation (i.e., intraobserver variability). However, the fact that 90 percent of these changes led to a final interpretation that was more in agreement with the computer analysis suggested the majority of changes were due to availability of the computer reading. It also supports the validity of the computer reading in providing a backup opinion to the primary care physician's interpretation.

Benefit of Computer ECG Interpretations to Expert Electrocardiographers

It is unlikely that the computer can improve on the accuracy of experienced electrocardiographers who are meticulous in their interpretations. Nevertheless, experts in our study altered their initial interpretations surprisingly often (39 percent) after being provided with computer readings of each ECG. Although only 5 percent of the changes were believed to be clinically important, this finding suggests that even expert electrocardiographers may benefit from the availability of a second opinion on their interpretation. Most of the changes resulted in a final interpretation that was more in agreement with the computer analysis and with the interpretation of the other expert.

Many experienced electrocardiographers advocate the timesaving feature of the computer as its most important practical benefit. The average time spent by a cardiologist in the manual interpretation of an ECG has been estimated to be 97 seconds (range = 60–180 seconds).[23] Some authorities believe that this time may be reduced by 50–75 percent with proper use of the computer analysis.[18] This is particularly true for physicians who read a large number of ECGs in their daily practice, especially when many of the tracings are normal and complex arrhythmias are uncommon. Others dispute the claim that computer ECG interpretations save time, arguing that overreading each computer statement ultimately slows them down.[24] The computer is of less use to these persons.

Conclusion

Because of the small number of physicians involved in our study, our conclusions cannot be accepted as representative of ECG interpretation practices throughout the country. Nevertheless, our results suggest that in a community hospital, computer ECG interpretations may be of benefit to primary care physicians by the backup opinion they provide. This second opinion may also benefit expert electrocardiographers, especially if they have a large number of tracings to interpret. We also observed that use of a computer ECG interpretation program in a community hospital facilitates communication among physicians by promoting standardization of nomenclature and criteria among users of the same system. It is our opinion that after a period of familiarization, the computer system may instill sufficient confidence to relieve the physician of the tedious task of determining rate, axis, amplitudes, and intervals and thus result in a substantial reduction in the time required for interpretation.

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Editorial Comment

The topic addressed by this article is timely and represents an effort to assess the potential value of a technical aid widely available but poorly standardized. The observations made by the authors are descriptive and could be classified as largely empirical. The reader is appropriately cautioned not to generalize the results.

Although the methodology used in the study is subject to some criticism, there are a number of salient points illustrated. It is important that we as clinicians be reminded that there really is no "gold standard" for electrocardiographic interpretation. This study illustrates (although not necessarily "proves") the existence of both *intra-* and *inter*observer variability.

This article also reminds us of the necessity to use all of our basic clinical skills in the diagnosis and management of heart conditions. The electrocardiogram is only one of many clinical and laboratory devices that can assist the physician. Electrocardiograms must be interpreted in the context of other useful data. I wonder how the interpretations of the ECG tracings in the study would have changed if the several interpreters had taken histories and examined the patients.

If computerized ECG interpretations really do facilitate communication among physicians by promoting standardization of nomenclature and criteria among users, then they could be a real asset. On the other hand, if users became dependent on the computerized interpretation only, there is potential for serious error, both clinically and legally. It would be imprudent for a physician who is not independently trained and practiced in EKG interpretation to rely solely on a computerized system of interpretation. This practice would expose the physician to errors in clinical decisions as well as possible liability problems.

The intent of publishing this report is to raise the level of awareness of the reader about the potential value of computerized electrocardiograph interpretation in the hands of primary care physicians. Also, it is intended to remind the reader that there continues to be variability among clinicians in the interpretation of electrocardiograms.

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