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Computer Analysis of Serial Electrocardiograms*

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Initial efforts in computer analysis of the electrocardiogram (ECG) have been aimed primarily at interpretation of the contour of the ECG complex or the rhythm pattern of the ECG. Programs designed to analyze these features have been developed at this facility and elsewhere throughout the country. As these programs have begun to reach a state of relatively high reliability in their interpretation, the need for programs to perform comparative analysis of ECG's taken at different instances in time has become increasingly more important. For example, a study conducted at the Latter-day Saints Hospital in Salt Lake City to measure the amount o f ECG interpretation time saved by the cardiologist having access to computer interpretations (rhythm and morphology) of the ECG's showed little time saving if the cardiologist was required to make serial comparisons with previous tracings on the patient. Thus, a program comparing tracings would save cardiologists time as well as increase the amount of information available to him for proper decision-making.

Such a program is now included as a part of the routine automated interpretation of the ECG at the Latter-day Saints Hospital. Upon completion of a computerized ECG analysis, a search is made through the patient's computer medical record to determine whether or not the results of a previous ECG have been stored on that patient. If an ECG has been stored, a comparative analysis of the parameters measured from the present tracing and the most recent previous tracing (at least 6 hr prior) is made. A report is generated indicating what changes, if any, are found on the present ECG.

Figure 1 shows a typical report from the serial analysis program. As seen in the figure, the report gives the date of the present analysis as well as the date of the analysis with which the changes are being compared. If there is no previous ECG recorded on the patient's medical record, a report will not be generated and a message displayed to the technician indicates that fact.

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Changes since 11/16/71.
Upright T wave present in lead Y.
Atrial fibrillation no longer present.
Heart rate has decreased from 107 to 85

Fig. 1. Example of a Serial ECG Comparison Report.

Since the present computer system at the Latter-day Saints Hospital does not have the facility for recalling a patient's record from a previous admission to the hospital, the comparative program is operative only in the case of those patients who have two or more ECG's taken during a particular admission to the hospital. With this restriction on the data base, the program is used primarily to follow the serial changes on patients with acute infarctions in the coronary care units.

In the development of this program an important secondary benefit of the program became apparent. The

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comparative program provides additional quality control for all computerized ECG interpretations. Since the primary source of error in ECG interpretation by computer is the presence of noise or artifact in the original signal, repeat measurements from the same patient may not give similar results if noise is present. Thus, the first explanation to be considered when an ECG diagnosis differs from that made from a prior recording on the same patient is that an error has occurred due to noise. Since the results of this comparative report are displayed immediately to the ECG technician, she can directly visualize on a computer terminal the quality of the signal which has been transmitted to the computer by requesting a plot of this data on this same terminal. If the tracing appears "noisy" she may (since the patient is still connected to the computer) transmit new data to the computer for interpretation. In such a case the computer will ignore the "noisy" ECG and compare this new ECG with the one previously used as a baseline for comparison.

Design Criteria for Comparative Statements

Comparative statements are generated for changes both in rhythm and contour. If there are no changes found between the two ECG's the report will be "no changes since XX/XX/XX (the proper date inserted)". With only one exception (heart rate), all comparative statements about rhythm are generated exclusively on the basis of the classifications of the rhythm as determined by the rhythm analysis program. If a different rhythm is reported on the two occasions only information about an abnormal rhythm is given. For example, if the previous ECG shows a normal sinus rhythm and the present ECG shows atrial fibrillation, the statement would be "atrial fibrillation now present." In a situation where the rhythm of both ECG's is abnormal but different, the state of both abnormalities is given. By reporting only the state of the abnormality it is hoped that the report will give optimal information to the clinician. In noting changes in heart rate, the actual change is given only if this change crosses the boundaries of pre-set limits, i.e., 60 beats per minute as a slow heart rate and 100 beats per minute as a fast heart rate. Therefore, a patient who has a change in heart rate from 70 beats per minute to 90 beats per minute will have no change reported, whereas the patient whose heart rate changes from 90 beats per minute to greater than 100 beats per minute will have that recorded as a part of the serial analysis.

The criteria for generating comparative statements for morphological changes (QRS complex or ST-T segment) considers not only the diagnostic classification from the contour analysis program, but also the actual values of certain parameters measured by that program.

The statements about the *QRS* complex are determined solely from the computer classification of the two ECG's under consideration. As with the rhythm changes only the state of an abnormal condition will be indicated. Thus, for the *QRS* complex the output of this program states the difference in classification of the ECG by the morphology analysis program on the two different occasions. It is felt at present that this is the optimal manner of reporting since confusing statements could be present between the analysis of the particular ECG and the report given by the serial program. This occurs for two reasons. The first is an error in the analysis of *QRS* morphology. In such an instance an erroneous diagnosis would be reported on one of the ECG's and it is impossible for the serial program to determine which reading is in error. The real conflict, however, arises in the borderline ECG, that is, the ECG which lies very close to the criteria limit for some diagnostic category. It is then possible that on one reading sufficient criteria will be found for diagnosis of that category, whereas in the other instance such will not be the case. For example, suppose the *Q* wave in lead *Y* had been measured on one occasion as -90 μV and on another occasion as -100 μV. Given also the appropriate values of other parameters the second reading might have had sufficient criteria for diagnosis of "questionable *Q* wave in lead *Y*, consider inferior wall infarction", whereas that may not be true in the first reading. Obviously, the *Q* wave has not really changed significantly. However, the report from the contour analysis program is different on each ECG. The question arises as to what should be reported by the comparative program. Clearly, by comparing the measured *Q*-wave parameters, the serial program would detect that there was no significant change and as such would report no changes in the electrocardiogram. However, to the clinician viewing these ECG's, confusion would arise by noting the difference between the first report, that is, that the criteria is satisfied for inferior infarction, and the serial program reporting that there is no change in the ECG. The criteria now used in interpreting

changes in the *QRS* complex compares only the diagnostic statements. The wording of the report attempts to indicate this fact by stating that a particular criteria is "satisfied" or "not satisfied" for interpretation by the contour analysis program.

In assessing changes in the *ST-T* segment, however, a different philosophy is taken. For these comparisons the actual magnitudes of the parameters under consideration take precedence over the diagnostic statements on the two ECG's. This is done because of the great frequency of borderline cases of nonspecific *ST* or *T*-wave changes. Without these additional criteria the reports generated by the serial program became very large and meaningless in many cases. Hence, even though criteria may now either be "satisfied" or "not satisfied" for nonspecific *ST* changes no indication of such a change is made unless the appropriate change within the specific parameter controlling that classification is of sufficient magnitude to indicate that a real change has taken place. In those cases where the *ST-T* segment is abnormal in both ECG's the magnitude of the specific parameter will be compared to detect if continued changes are occurring. For example, if there is *T*-wave inversion in both ECG's the magnitude and area of the *T* wave are compared in the two ECG's. If there is a significant change in one, say the depth of inversion, the report would be "*T*-wave inversion increasing in lead *X* (*Y* or *Z*)." Table 1 lists the parameters considered in the *ST-T* segment as well as the limits used in determining diagnostic changes

TABLE 1

PARAMETERS USED IN *ST-T* DECISIONS

1. Average *ST* levels in leads *X Y Z*
2. Magnitude of *T* wave in *X Y Z*
3. Area of *T* wave in Leads *X Y Z*

within these parameters. In setting the limits for these parameters two considerations were made; first, the limits must be of sufficient magnitude so that they are clearly noticeable on the ECG tracing seen by the cardiologist; and, second, parameter changes must be clearly outside the limits or reproducibility of the contour analysis program in measuring that parameter. In other words, the variability of the program in measuring a given parameter on the same patient on different occasions must be smaller than the limits set for change detection when in fact no significant change has taken place in the ECG.

Problems Encountered in the Development of the Program

The greatest problem encountered in generating meaningful statements about changes in an ECG from one time to the next, results from errors in the interpretation of either the morphology or rhythm in one or both of the ECG's. The errors may occur either in the measurement of some parameter or in the final diagnostic decision. This error will then be reflected in the report of differences between the two ECG's. For example, if on one occasion the interpretation were to take place on a "noisy" tracing, the possibility of error in measurement of the width of the *QRS* is greatly enhanced. If such a width is measured greater than the actual width of the *QRS*, a conduction defect will be reported and a "change" in *QRS* width will be noted by the comparative analysis program. The problem is compounded in the comparative program since analysis of a subsequent tracing recorded on the same patient under conditions where the signal is uncontaminated by noise, will again show a *QRS* width of normal duration. Thus, in this situation the report from the morphology analysis program will be correct, but the statement generated by the comparative analysis program will state that a change in the width of the *QRS* duration from abnormal to normal has taken place. Hence, we see in the case of the comparative program a single error will result in two reports which have erroneous statements.

One of the obstacles to reliable computer analysis of the ECG is the presence of "noise" on the signal; a comparative program is even more sensitive to such artifacts in the signal. This fact has been put to good use,

however, by employing the serial analysis program as a quality control device. If a change is recognized by the comparative program since the previous ECG, the technician is instructed to look for technical sources and to repeat the procedure.

Elimination of noise will not completely resolve the difficulties mentioned above in the case of the borderline ECG. The dilemma that was mentioned in the previous section as to which criteria should have precedence as a basis for comparison of two ECG's still exists; the diagnostic statement of the clinical programs or the values of the measured parameters. In addition, a second problem arises in the formation of the statements themselves. If all minor changes are reported the report can become large and cumbersome, making it less useful to the cardiologist. It may very well be that only those changes which are considered by the cardiologist to be clinically significant should be reported in the diagnosis part of the printout, and all other changes merely indicated as parameter changes. Interpretation of these changes should be left to the cardiologist.

The Evaluation of the Sequential Analysis Program

To assess the performance of this program in a clinical setting, a study was conducted to determine how often the program is useful in detecting changes. In order to eliminate the type of errors considered in the previous section, only pairs of ECG's where both tracings in the sequence had been properly interpreted by the computer were included. The changes detected by the program were rated as follows: (1) no change, (2) minor changes (no change in diagnostic statements), and (3) major change (change in diagnostic statement). The test group consisted of 50 pairs of ECG's. These ECG's were all taken from in patients at the Latter-day Saints Hospital with the only criterion for inclusion within the study being that of proper interpretation of both ECG's by the rhythm and contour analysis programs. Within this set, 22 pairs had no change, 22 had minor changes, and 6 had major changes. Table 2 lists the changes which were considered major. The minor changes occurred mostly in the area of the *ST-T* segment. The usefulness of such a comparative analysis program is clearly indicated in this study since 28 of the 50 patients indeed had changes of a minor or major nature between the two tracings. Even if we consider only those which had major changes we see that 6 of the 50 cases (12%) had such changes. With this high frequency of changes the need for such comparisons by the computer is clearly

TABLE 2

CHANGES DETECTED IN SIX PATIENTS WHICH WERE OF MAJOR VALUE

One patient changed from normal sinus mechanism to atrial fibrillation.
Two patients developed first degree AV black.
One patient changed from normal ECG to abnormal.
One patient changed from atrial fibrillation to normal sinus mechanism.
One patient's heart rate decreased to within normal limits and premature ventricular depolarizations were no longer present.

evident if the computer is to be used as a mechanism for relieving some of the burden from the cardiologist in the interpretation of the electrocardiogram.

Developmental work is now under way to add additional diagnostic statements to confirm a tentative diagnosis as indicated by the rhythm or morphology programs. With the success already experienced in this area, greater emphasis is being placed by the cardiologist on the computer as a means for solving the problem of ECG interpretation.

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