

Computerized Serial Comparison of Electrocardiograms - Program Performance in Acute Myocardial Infarction

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Abstract

We have developed a computer program, which is now available in the Philips Medical Systems TracemasterVue ECG Management System, that examines serial ECG changes in each of the diagnostic ECG categories by comparing the ECG waveforms and creates serial comparison reports. Taking into consideration the previous ECG, the serial comparison program further enhances the accuracy of ECG diagnoses, particularly diagnoses of acute myocardial infarction. Acute myocardial infarct diagnosis may vary from one ECG to the next due to biological variation, due to lead placement, or due to minor differences relative to the threshold values used in the ECG criteria. In the serial comparison program design, we have taken approaches such as grouping the infarct locations and defining ranges and levels of waveform serial changes to minimize such variations in ECG diagnosis. Comparing with an expert cardiologist ECG reader, our serial comparison program has shown a high agreement of 88% on edited ECGs, 79% on non-edited ECGs, and 85% in infarct evolution, respectively.

1. Introduction

Computerized analysis of electrocardiogram (ECG) including a serial ECG comparison algorithm has been a successful and widely accepted automated clinical application in the last few decades [1-5]. Commercial systems are available that provide valuable assistance in ECG management and automated serial ECG comparison analysis [6-7]. The increasing storage capacity and connectivity of modern electrocardiograph and computer systems make it possible to manage a large ECG database for online access. When a previous ECG is available, the cardiologist ECG reader not only determine the abnormal conditions of the current ECG, but also examines the serial changes in rhythm and morphology in reference to the previous ECG. The availability of a previous ECG

for serial comparison is one of the most important clinical pieces of information necessary to improve ECG diagnosis accuracy. The previous ECG becomes more important in ECG diagnosis if significant differences have arisen since the previous ECG. Significant changes in rhythm or morphology in reference to the previous ECG are of clinical concern. Expert cardiologists strongly believe that ECG diagnosis is incomplete without a comparison to previous ECGs.

This serial ECG comparison algorithm was originally developed in 1990 [1], and the algorithm has been since then routinely used at the Heart Station of University of Florida and the Heart Station of Duke University Medical Center. Recently, the program was further refined and enhanced, and is now integrated into the newly designed Philips TracemasterVue ECG Management System. The purpose of this paper is to report the newly revised serial comparison algorithm design, particularly in areas of acute myocardial infarct (AMI) and the performance results from recently conducted validation tests.

2. Serial Comparison Algorithm Design

A serial comparison algorithm is most helpful in AMI diagnosis and in tracking the evolution of an AMI. ECG presenting rapid changes. A single ECG often does not provide adequate information for diagnosis unless it is compared to a series of previous ECGs. In addition to comparing ECG statements and detecting significant waveform changes, our serial comparison algorithm is designed to track and report the infarct evolution to better serve the cardiologist ECG readers. The serial comparison work flow, definition for AMI evolution status, and criteria for serial changes in AMI are described in detail below.

2.1. Serial Comparison Work Flow

The algorithm compares two ECGs at a time based on combined waveform measurements and the diagnostic

statements generated by the Philips 12-lead analysis program on the electrocardiograph. The waveform measurements and the diagnostic statements are carried in each ECG file in an electronic form and stored in the database on the ECG management system. When a new ECG (“current ECG” = “cECG”) enters the management system, the serial comparison program begins to search for earlier ECGs in the database by the patient’s identification. The system then retrieves the most recent (“previous ECG” = “pECG”) ECG. The system requires that the pECG was acquired at least 30 minutes before the cECG, and the next pECG is selected if there is less than 30 minutes between the current and the previous. However, this time interval is configurable on the ECG management system.

The serial comparison algorithm works in the following manner:

1. The first step the comparison program takes is to determine the diagnostic categories of the statements from both the pECG and the cECG. Those categories that are represented in the ECG reports are then reviewed. Then, relevant measurements are examined to determine whether waveform changes have occurred in the selected categories.
2. In the cases where both ECGs contain a statement from the category with possibly different severities, waveform measurements are examined for changes. If no significant waveform changes are detected, the comparison program will report the statement with the higher severity and add a modifier “remains”. If significant waveform changes are detected, a “more prominent” or “less prominent” modifier is added depending on the progression or regression of the condition.
3. If the cECG contains a new diagnostic statement and there is no diagnostic statement in that category in the pECG, a modifier “now present” is added to the statement if significant changes are detected. If no significant changes are detected, a modifier “insignificant measurement” is added to the statement.
4. If the pECG contains a statement that there is no diagnostic statement in that category in the cECG, and corresponding waveform examination shows significant changes, a modifier “now absent” is added. Otherwise, the report keeps this statement with a modifier “remains”.
5. Rhythm comparison does not require waveform comparison. Heart rate changes are taken into

consideration in sinus rhythm and sinus arrhythmia. If the heart rate increases or decreases more than 20 bpm, the comparison program generates a statement to indicate such changes.

6. “Significant rhythm changes” is concluded only if heart rate increases or decreases by 20 bpm or more or if the rhythm mechanism changes from, for example, sinus rhythm to atrial fibrillation. Secondary rhythm changes such as a new “AV block” or “premature ventricular complex (PVC)” are not considered significant rhythm changes. “Significant contour changes” is concluded if relevant waveform changes occur in any morphology category.

Another important feature in the serial program design is to carry the comparison results to future comparisons. The results of a series of comparisons are cumulative. One diagnosis can be retained through an indefinite number of comparisons if no significant measurement differences are detected. If significant changes occur, the diagnosis will be replaced by a new diagnosis.

2.2. Definitions of AMI Evolution

When an acute myocardial infarct is first detected, the ECG acquisition date is defined as the “infarct date” that is used to track for infarct evolution through successive ECGs. The “infarct date” is carried in the AMI serial comparison report. A maximum time duration of 14 days is allowed for tracking an AMI evolution. Beyond 14 days since the first acute MI diagnosis, the evolution criteria no longer apply.

Acute infarct evolution criteria are defined as follows:

1. “Evolving infarct” - If the pECG is diagnosed as AMI for the first time, the cECG is within 14 days and is also diagnosed as AMI, and if the pECG and the cECG show significant changes according to the AMI serial change criteria listed in Table 1, then the cECG is classified as “evolving infarct”. The statement of “evolving infarct” will be included in the serial comparison report.
2. “Evolution continues” - If (1) the pECG reports an “evolving infarct”, and (2) the cECG is acquired within 14 days of the first AMI ECG and (3) the comparison of the pECG and the cECG shows significant changes according to the criteria listed in Table 1, then the serial comparison algorithm generates a report of “evolution continues”.
3. “No further evolution” - If the pECG is either

“evolving infarct” or “evolution continues” and no further serial changes are obtained from the measurement comparison, then the program generates a report of “no further evolution”. It is possible within the 14 day time window for “evolution continues” and “no further evolution statements” to follow each other in sequential ECGs.

4. “ST elevation persists” - Once the age of the infarct reaches 15 days, the evolution logic is discontinued. If there is an evolution statement in the previous interpretation, the current infarct statement is used. The exception to this rule occurs if an ST onset elevation of 0.1 mV remains in the involved leads. In that case, the “ST elevation persists” statement is generated.
5. If the pECG is a member of one of the above infarct categories and there is no infarct diagnosis in the cECG, the serial comparison algorithm will report the pECG evolution status with a modifier “now absent”.

2.3. AMI Serial Change Criteria

Serial measurement changes are defined for each MI category as threshold levels for amplitude and/or durations in the corresponding lead groups. If these thresholds are exceeded, the changes are defined as “significant changes”, otherwise, they are considered “insignificant changes”. Both AMI progression and regression are considered in the serial comparison program design. Progressive and regressive changes are considered equally in the evolution status and test for significance.

Table 1: ECG changes are captured in the corresponding lead groups. As an example, serial change criteria for the inferior myocardial infarct category are examined in the corresponding Leads II, III and aVF. The threshold values for significant Q wave, ST segment and T wave changes are required to occur in at least 2 leads.

cECG-pECG	II, III, aVF
ΔQ amp, dur	100 μV , 20 ms
ΔST	100 μV
ΔT	200 μV

3. Validation Test

We wanted to evaluate the serial comparison program performance quantitatively. The validation tests were

performed to test for accuracy in different AMI categories and for the correctness of the AMI evolution status.

3.1. Study Population

Two ECG data sets were used in this study. The first set consisting of 214 patients and 1,493 ECGs was mainly used for program improvements. A second database was used to validate the program performance, specifically in the area of acute myocardial infarct. This database contains 1,051 ECGs on 154 patients admitted to the hospital with acute myocardial infarctions confirmed by other clinical tests. Many had perfusion therapy. All ECGs were recorded on Philips electrocardiographs with a sampling rate of 500 sps.

3.2. Test Methods

Serially recorded ECGs were read by an expert cardiologist (JCG, Jr.). The reading results served as a “Gold Standard”. Serial comparisons were performed on each paired ECGs to test the validity of the serial comparison program.

The first approach was to test on edited pECG and cECG to better understand the performance of the serial comparison logic. The second approach was a reality check by comparing edited pECG with non-edited cECG to simulate routine use in a clinical environment. The third approach was to test the validity of the AMI evolution status.

4. Results

Test results are tabulated by category in Table 2. The agreements between cardiologist and program in AMI vary from 79% to 95% with an average of 88% if both pECG and cECG are edited, and vary from 71% to 84% with an average of 79% if cECGs are not edited. The high agreements between the expert cardiologist reader and the serial comparison algorithm are very encouraging. These results also confirm the usefulness in AMI management as concluded in previous publications [8-9].

Table 2. Agreement between cardiologist and serial comparison algorithm in acute myocardial infarcts by category.

Category	Edited ECG			Non-Edited ECG		
	n	Agreed	%	n	Agreed	%
IMI	190	167	88	190	159	84
AMI	130	117	89	147	108	74
LMI	14	12	86	14	10	71
ALI	56	44	79	59	45	76
PMI	75	71	95	83	69	83

Table 3 summarizes the agreement for the specific

evolution statements within the MI categories where the pECGs have been edited. We have also included the results for “posterior wall involvement” that were used extensively to address the issue of grouping infarct location.

Table 3: Agreement between cardiologist and serial comparison algorithm in evolution status in combined AMI categories.

Infarct Status	n	Agreed	%
Evolving MI	57	44	77
Evolving MI continues	19	16	84
No further evolution of MI	20	19	95
Persistent ST elevation	8	8	100
Posterior wall involvement	75	65	87
Total	179	152	85

5. Discussion and Conclusions

Different opinions exist among cardiologists on whether ECGs should be interpreted in isolation, or other clinical information should be incorporated in ECG reading. That age, gender and body build affects ECG interpretation is common knowledge. Impacts of modern perfusion therapies and medications on ECG are different today than the traditional therapy and may introduce rapid ECG regression. In the test dataset, patients have already received perfusion therapies or medications when follow up ECGs were acquired. The AMI evolution design approach in the current program may expect a more classical infarct evolution pattern and may have difficulty in handling rapid regression properly. The evolution criteria in the current program may need further modification to reflect today’s cardiology practice.

The algorithm design approach of examining changes within a category provides a very useful structure for the algorithm, but it also created some difficulties. This design requires a very close link between the comparison algorithm and the Philips 12-lead analysis program by category and severity of each diagnostic statement. Each new revision of the ECG analysis program demands careful review of the serial comparison algorithm. Recent introduction of a new Philips 12-lead analysis program may have induced some inappropriate alignments and caused the disagreements. One advantage in the current algorithm design is that the requirements for waveform changes by category are relatively simple, usually based on waveform amplitude and duration in one or more of the pertinent leads. The structure of the algorithm makes it possible for categorized serial comparison criteria enhancement without affecting the rest of the algorithm.

In conclusion, the serial ECG comparison program

tested in this study has shown high agreement with an expert cardiologist ECG reader in AMI diagnosis. The serial comparison program tested has also shown high agreement with an expert cardiologist in identifying AMI evolution status. We strongly believe the serial ECG comparisons performed by an automated program are of great assistance to routine ECG readers in clinical practice.

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