Efficacy of a Reduced Lead Set for Pre-Hospital Triage of Thrombolytic Strategies

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Abstract

In emergency care situations, recording all leads of the 12-lead ECG is often not possible due to technical and organizational restrictions. The recording of a subset of leads and subsequent synthesis of the absent leads might be a solution to these problems. The goal of this study was to evaluate the efficacy of a reduced lead set, consisting of leads I, II, V2, and V5. The lead subset was derived from a data set of 12-lead ECGs recorded from patients with a suspected acute myocardial infarction prior to hospitalization. Performance was evaluated by comparing the originally recorded leads and reconstructed leads using correlation coefficients and ST-differences. Several clinically important decision rules for detection and pre-hospital treatment were evaluated on the original and reconstructed 12-lead ECGs and accuracy was determined. This study shows that high agreement, correlation coefficients and small ST-differences can be obtained between the original and reconstructed leads.

1. Introduction

Early diagnosis, risk stratification, and initiation of treatment are of importance for patients with chest pain suggestive for acute coronary syndromes and may result in reduction of mortality and final infarct size [1, 2]. The 12-lead ECG is an important non-invasive tool for diagnosing acute myocardial infarction in patients with chest pain and an increasing number of emergency medical services are being equipped with and are trained to use a 12-lead ECG recorder. Depending on local regulations, the 12-lead ECG may be evaluated by a cardiologist using facsimile transmission or by a computer program.

However, there are several practical considerations. First, a 12-lead ECG requires 10 electrodes and wires. A reduction in the number of electrodes may save time. Furthermore, there may not always be room in the ambulance for a separate 12-lead ECG recorder. An integrated solution with a defibrillator would be ideal, but not all defibrillators can record all 12 leads.

Recording of a reduced subset of leads and subsequent synthesis of a full 12-lead ECG may provide a solution to these problems. The goal of this study was to evaluate the efficacy of a reduced lead set consisting of leads I, II, V2, and V5. This lead subset has previously been shown to give excellent results in a patient monitoring setting [3].

2. Methods

2.1. Data set

The data set for this study was based on the REPAIR study [1,2,4]. REPAIR was used for the development and evaluation of a computer-assisted decision algorithm for early initiation of thrombolytic therapy in the pre-hospital setting. Between 1992 and 1994, 2641 patients in the municipality of Rotterdam with chest pain suggestive for myocardial infarction were evaluated by their general practitioner, who then asked for ambulance assistance and hospital admission. After arrival of the ambulance, a 12-lead ECG was recorded by the ambulance personnel and interpreted by a computerized analysis system.

A final diagnosis was made by the treating cardiologist, and was based on the admission and discharge ECGs, recurrence of symptoms, laboratory findings and autopsy results. These results were also provided to the general practitioner, who used the information for further patient management.

2.2. Electrocardiographic processing

In 365 patients, an ECG could not be recorded or stored due to technical failure or unsuitable circumstances on the spot. In 16 patients, the ECG was left out of the analysis because of reversed leads or pacemaker rhythms. The remaining 2260 ECGs were split into a training set (n=1435) and a test set (n=825).

All ECGs were processed by the Modular ECG Analysis System (MEANS) [5]. The program MEANS computes for each of the 12 leads a representative averaged beat from which ECG measurements are derived. MEANS has been extensively evaluated by the developers [5] and by others [6].

2.3. Reconstruction method

Leads III, aVR, aVL and aVF are mathematically dependent on leads I and II and can be calculated without

error. Lead V1 can be approximated by c_{11} * I + c_{21} * II + c_{31}* V2 + c_{41} * V5. The coefficients c_{11}- c_{41} are computed using multivariate linear regression from ECGs in the learning set. Leads V3, V4 and V6 can be reconstructed in a similar way.

2.4. Data analysis

Reconstruction accuracy of the missing leads was evaluated on three different levels. First, overall waveform similarity for each ECG was assessed by the average of the correlation coefficients between the QRS-T complexes of the original and the reconstructed leads.

Second, reconstruction accuracy was determined at the measurement level, focusing on the ST-amplitude, 60 ms after the J-point for each lead. We determined the average and the maximum of the absolute differences between the original and reconstructed ST amplitudes. Furthermore, the sum of the absolute ST deviations (SUMST) was also computed for the original and reconstructed ECGs.

Third, reconstruction accuracy was assessed at the diagnostic level. For each original and derived 12-lead ECG, we applied seven decision rules and calculated the sensitivity, specificity, and accuracy (percentage agreement) between the original and the reconstructed 12-lead ECG. Cohen's Kappa was computed to correct for chance agreement.

The first decision rule, REPAIR1988, was the original decision rule [5] for initiation of thrombolytic therapy. The ECG criteria were: ≥ 300 µV ST-elevation in ≥ 2 leads of V1-V6 or ≥ 200 µV in ≥ 2 leads in II, III, and aVF. A total ST-deviation of at least 1000 µV was also required. The exclusion criteria were: left or right bundle branch block, intraventricular conduction delays, a Wolf-Parkinson-White pattern, and pacemaker rhythms.

The REPAIR protocol was optimized in 1996 (REPAIR1996) [7] and included criteria for ST-deviation and ST-depression in the inferior and anterior leads. In 2001, primary PCI was recommended for patients with a total ST-deviation of ≥ 1500 µV (REPAIR2001) [7].

The fourth decision rule, AMI1, is a classical decision rule for determining in-hospital acute myocardial infarction. AMI1 holds true if 2 or more leads of V1-V6 show ≥ 200 µV ST-elevation or if at least 1 lead of II, III and aVF show ≥ 100 µV of ST-elevation.

The fifth decision rule, AMI2, is a rule recommended by the European Society and American College of Cardiology for the detection of myocardial ischemia and evolving myocardial infarction [8]. The rule holds true when 2 or more contiguous leads show ST elevations of ≥ 200 µV ST-elevation in leads V1, V2 or V3 and ≥ 100 µV ST-elevation in the other leads.

Lastly, we included two additional decision rules. ST depression was considered if 2 or more leads showed at least 50 µV ST depression. ST elevation was considered if ≥ 2 leads in V1-V6 had ≥ 200 µV ST-elevations or ≥ 2 limb leads (I-III, aVL, and aVF) had at least ≥ 100 µV ST elevation.

The decision rules have been designed for different purposes. For example, the REPAIR algorithms were designed with a high specificity in order to minimize the number false-positive cases, because of the elevated risk of complications when using thrombolytic therapies. For the AMI1, AMI2, and the ST-depression and ST-elevation rules, a high sensitivity and low false-negative cases are important.

Values are presented as median (interquartile range).

3. Results

The median age (interquartile range) of patients in the test set was 67 (57-74) years. A total number of 438 (53.1%) patients were male. The final discharge diagnoses were: myocardial infarction (28.6%), angina pectoris (22.9%), atypical chest pain (33.6%), severe cardiac pathologies (2.4%), other or minor cardiac pathologies (3.1%), and a group of other or non-cardiac diagnoses (9.4%).

The reconstruction technique was applied to the test set and the largest three subgroups (myocardial infarction, angina and atypical chest pain). Performance results are presented in table 1. SUMST for the myocardial infarction group is higher than for the angina pectoris and atypical chest pain groups. A similar pattern can be observed for the SUMST differences and average and maximum absolute ST differences in these groups.

Table 1. Performance results of the test set and subsets according to the discharge diagnosis.

Complete test set (n=825)	
Correlation coefficient	0.985 (0.971-0.992)
Average ST difference (µV)	25 (16-45)
Maximum ST difference (µV)	49 (29-88)
SUMST (µV)	672 (424-1360)
SUMST difference (µV)	2 (-41-55)
Myocardial infarction (n=235)	
Correlation coefficient	0.984 (0.972-0.991)
Average ST difference (µV)	41 (23-76)
Maximum ST difference (µV)	76 (42-247)
SUMST (µV)	1505 (908-2498)
SUMST difference (µV)	18 (-41-141)
Angina pectoris (n=189)	
Correlation coefficient	0.984 (0.968-0.992)
Average ST difference (µV)	24 (15-38)
Maximum ST difference (µV)	43 (28-74)
SUMST (µV)	585 (380-879)
SUMST difference (µV)	3 (-34-52)
Atypical chest pain (n=278)	
Correlation coefficient	0.987 (0.975-0.992)
Average ST difference (µV)	19 (13-33)
Maximum ST difference (µV)	38 (24-62)
SUMST (µV)	494 (355,748)
SUMST difference (µV)	-10 (-45-22)

Table 2. Median (interquartile range) correlation coefficient of each reconstructed lead in the test set.

Correlation Coefficient	V1	V3	V4	V6
Complete test set (n=825)	0.983 (0.960-0.993)	0.953 (0.877-0.980)	0.980 (0.954-0.991)	0.986 (0.967-0.994)
Myocardial infarction (n=235)	0.979 (0.957-0.992)	0.943 (0.864-0.976)	0.976 (0.948-0.988)	0.986 (0.969-0.994)
Angina Pectoris (n=189)	0.986 (0.962-0.994)	0.960 (0.897-0.982)	0.981 (0.965-0.992)	0.980 (0.958-0.993)
Atypical chest pain (n=278)	0.986 (0.966-0.993)	0.958 (0.898-0.984)	0.985 (0.959-0.993)	0.988 (0.969-0.995)

Table 3. Median (interquartile range) ST difference of each reconstructed lead in the test set.

ST difference (μV)	V1	V3	V4	V6
Complete test set (n=825)	20 (9-41)	38 (16-78)	23 (11-45)	13 (6-26)
Myocardial infarction (n=235)	25 (11-57)	63 (29-136)	39 (17-76)	20 (7-38)
Angina pectoris (n=189)	19 (8-36)	32 (16-59)	21 (12-37)	13 (6-24)
Atypical chest pain (n=278)	17 (9-34)	30 (14-55)	18 (9-32)	9 (4-17)

Table 4. Sensitivity, specificity, number of false-negative and false-positive cases, accuracy and chance-corrected accuracy based on a comparison between the original and reconstructed ECG for 7 decision rules on the test set (n=825).

Decision rule	Sensitivity (%)	Specificity (%)	False Negative	False Positive	Accuracy	Kappa
REPAIR1988	94.3	99.6	2	3	0.994	0.926
REPAIR1996	82.1	99.6	7	3	0.988	0.859
REPAIR2001	84.3	99.6	8	3	0.987	0.880
AMI1	98.1	98.3	2	12	0.983	0.931
AMI2	93.7	99.2	11	5	0.981	0.941
ST-depression	96.2	96.8	16	13	0.965	0.930
ST-elevation	97.5	98.1	6	11	0.979	0.951

Tables 2 and 3 contain the median correlations and ST differences for each reconstructed lead, respectively. Overall, lead V3 has the lowest median correlation and highest median ST difference across the complete test set and subgroups. Reconstructed lead V6 has the overall highest median performance and lowest ST difference.

For each reconstructed ECG, we determined the lead which had the largest ST-difference. The number of cases was for lead V1 202 (24%), V3 444 (53.1%), V4 115 (13%), and V6 64 (7%). Overall, lead V3 had in most cases the largest ST-difference. Similar results were found in the subgroups.

Reconstruction performance results of the myocardial infarction group were slightly lower than the angina pectoris and atypical chest pain groups. However, the myocardial infarction subgroup contains large changes in the ECG, caused by ischemia or ongoing infarction at the time of recording, resulting in high SUMST values and higher ST differences (cf. Table 1).

In table 4, performance results are presented for sensitivity, specificity and accuracy between the actual and reconstructed ECGs of the described decision rules. The number of false positive and false negative cases are also reported for each rule. The REPAIR rules had 3 false positive cases. Two of these cases were found false positive in multiple rules (REPAIR1996, REPAIR2001, AMI1 and ST-elevation) and had mediocre overall correlation and high ST-differences.

The ST-depression rule with a threshold of $\geq$ 50 μV had the highest number of false-negative and false-positive cases. After setting the depression threshold to $\geq$ 100 μV, accuracy (agreement: 0.977, kappa: 0.945) increased and the number of false negative cases (13) and false positive cases (6) decreased. These results may indicate that thresholds of $\leq$ 50 μV are more vulnerable to errors in lead reconstruction (cf. ST-differences in tables 1 and 3).

4. Discussion

The findings in this study show that high overall agreement, waveform correlation coefficients, and small ST-differences were obtained between the recorded 12-lead ECG and the reconstructed 12-lead ECG based on a reduced lead subset.

In a previous study [3], we evaluated this reconstruction technique for all lead subset combinations on a group of 236 patients who were monitored for 24 hours in the coronary care unit. The lead subset of I, II, V2, and V5 was found best in this study. We also determined the best lead subsets of varying sizes on the present training set (data not shown) and found that the best lead subset also included leads I, II, V2, and V5.

Other investigators also evaluated the use of reduced lead sets. Drew et al. [9] considered a lead subset consisting of leads I, II, V1, and V5. Lead V1 was preferred over V2, because this lead is frequently used for diagnosis of QRS morphology and atrial activity. However, lead V1 is not most efficacious for detection of myocardial ischemia [9, 10]. For this lead subset, we derived coefficients from our learning set and applied it to our test set. A slight performance loss was observed; the number of false-positive cases increased from 3 to 7 for the REPAIR rules. However, further investigation is needed to evaluate both lead set strategies.

Schreck et al. [11] evaluated the use of a lead subset consisting of leads I, aVF, and V2. This lead subset corroborates with the best lead subset (I, II, and V2) determined after a separate analysis on our training set (data not shown). However, we found an overall moderate performance loss for this lead subset. For example, the number of false-positive cases for the REPAIR rules increased from 3 to 8. These findings indicate that inclusion of a left-precordial lead, such as lead V5, increases overall reconstruction performance.

Leads V3 and V4 had the lowest reconstruction performance. A possible explanation is that these leads are often considered as transition leads between the right- and left-precordial areas on the chest. Because this transition is often specific for a patient, a reconstruction technique based on a training population does not need to be best for each individual patient. Lead V6 had the overall highest reconstruction performance, which does not come as a surprise as V6 is highly correlated with leads I and V5.

The accuracy results of the 3 REPAIR decision rules indicate that 3 out of 825 cases may receive unjustified treatment. In 2 of these false positive cases, a single, large, ST-elevation (380 µV) was found in lead V2, which propagated in the reconstructed leads and increased the reconstruction errors. Further investigation is needed to eliminate these false positive cases.

A study limitation is that we did not evaluate reconstruction accuracy of other ECG abnormalities, such as cardiac arrhythmias. However, a typical lead selected for arrhythmia monitoring is lead II [9, 10]. As this lead is part of the lead subset, arrhythmia monitoring will not be influenced by reconstruction errors.

5. Conclusion

This study shows that high accuracy, waveform correlation coefficients and small ST60 differences can be obtained from a reconstruction of a 12-lead ECG using reduced lead sets. In emergency care situations, where a 12-lead ECG cannot be recorded because of technical or organizational restrictions, a reduced lead set can be considered.

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