Detection of Acute Myocardial Ischemia by Vessel-Specific Leads Derived from Reduced Lead Sets

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Abstract

The aim of this study was to evaluate whether detection performance of ACC/ESC STEMI criteria based on 12-lead ECG can be improved by using criteria from 3 vessel-specific leads (VSLs) derived from reduced lead sets of 12-lead ECG using 3 limb electrodes at Masson-Likar torso sites and 2 chest electrodes at precordial sites V1 to V6. There are a total of 15 such lead sets and each can be recorded using a 6-wire ECG cable. The VSLs were derived from a large 120-lead mapping database (n = 892). Study data consisted of 12-lead ECGs acquired during 99 angioplasty-induced ischemic episodes with prolonged balloon inflation (mean inflation time 4'37") in 35 LAD, 47 RCA, and 17 LCx coronary arteries. The results, which will need validation on larger patient population, suggest that VSLs derived from several reduced lead sets of standard 12-lead ECG can perform better in acute myocardial ischemia identification. For the highest ranked subset (leads II, III, V3, and V6) for all occlusion subgroups the increase in sensitivity was 15.5% for the total population and 17.4%, 6.1%, and 34.7% for LAD, RCA, and LCx subgroups, respectively without any decrease in specificity. Thus it appears that VSLs derived from reduced leads of 12-lead ECG can be used to improve detection of ischemia, especially those caused by the LCx artery occlusion.

1. Introduction

In patients presenting with symptoms of acute coronary syndromes, currently used clinical diagnostic criteria [1-3], based on ST-segment elevation in the 12-lead ECG, identify patients suffering from ST-elevation myocardial infarction (STEMI) with high specificity, but low sensitivity. Consequently, many false-negative patients may not receive the appropriate therapy. We hypothesized that the sensitivity of acute MI detection can be improved by using criteria based on 3 derived vessel-specific leads (VSLs) developed previously from the Dalhousie database of ECGs obtained during controlled acute ischemia [4]. Using an independent *STAFF3 PTCA* database from Duke University [5] we have shown that detection sensitivity can be improved by using three VSLs derived from the 12-lead ECG [6]. While 12-lead ECG monitoring is technically feasible, it may not always be practical for continuous monitoring. Hence the aim of the present study was to use the same *STAFF3* database to evaluate the diagnostic capabilities of the VSLs derived from 4 independent leads (consisting of 2 limb leads and 2 precordial leads at sites V1 to V6) of the 12-lead ECG, and compare them with those that can be achieved by applying STEMI criteria currently used in clinical practice [3], and those achieved using the VSLs derived from the full 12-lead ECG.

2. Methods

2.1. Patient population

The *STAFF3* database consists of ECG data for 108 patients originally studied at the Charleston Area Medical Center in West Virginia, who underwent elective balloon-inflation percutaneous transluminal coronary angioplasty (PTCA) in one of their main coronary arteries [5]. All of these patients had continuous 12-lead ECG recorded before and throughout the PTCA procedure. Upon initial inspection of plotted ECG tracings, data from 11 patients with ECGs of substandard quality (i.e., containing artifacts that could not be eliminated or reduced by the usual ECG processing techniques) were rejected. Therefore, the test-set population consists of 97 patients. The balloon-inflation periods for these patients ranged from 1'30" to 7'17", with a mean of 4'37"; these occlusion periods were considerably longer than those used in current clinical practice. For each patient balloon-inflation PTCA recording began just before the balloon inflation and continued for the entire occlusion-reperfusion period.

2.2. ECG acquisition and processing

The standard 12-lead ECG was recorded digitally for each participant of the study by the Siemens-Elema AB

(Solna, Sweden) ECG cart at 1,000 Hz sampling rate with an amplitude resolution of 0.6 μV for the least-significant bit [5]. For each patient only one recording was selected for analysis (if there were indeed multiple inflations in the same artery for that patient), except in 2 patients with double-artery treatment for whom one recording for each occluded artery was used; thus the total number of ischemic episodes documented by 12-lead ECG was 99; 35 of these episodes were due to left anterior descending (LAD) coronary artery occlusion, 47 due to right coronary artery (RCA) occlusion, and 17 due to left circumflex (LCx) coronary artery occlusion. Subsequent ECG processing was done on an RS/6000 computer (IBM Corp, Armonk, NY). For an entire duration of each recording 3 VSLs were calculated from 4 independent leads (consisting of 2 limb leads and 2 precordial leads) of 12-lead ECG. The analysis was limited to precordial sites of V1 to V6 only. There are a total of 15 such dual precordial lead sets to be evaluated. For each recording a 10-second interval was identified as a "baseline state" and another 10-second interval (just before the end of balloon inflation) as an "ischemic state." After signal smoothing (a running median filter of 3 points) on each lead, QRS onset was determined for each beat to establish the local baseline, and the local QRS offset was designated as J point. Local baseline was defined as mean amplitude of 10 samples centered at 10 ms before the local QRS onset. To measure ST deviation of each beat, the difference between amplitude at J point and that at the local baseline was taken.

A large (n=892) 120-lead ECG mapping dataset (Dalhousie Superset) was used to perform the VSLs derivation. The objective was to fit a regression model to the dataset, in order to obtain a statistical estimate V' of the instantaneous voltage V at a given VSL by fitting the linear regression equation without intercept to the recorded voltages V_i in k predictor leads.

$$V' = \sum_{i=1}^{k} \beta_i V_i$$

The problem is to find the best-fitting coefficients β_i for predictor leads $i = 1, \ldots, k$ ($k = 4$ in the present study). The estimates of β_i were chosen to minimize the error sum of squares over all available data samples of the QT interval for all subjects of the dataset; to do so a general-purpose procedure for regression as described in [7] was used. The transformation coefficients that best fitted the dataset were then applied in the present study to the time-varying ECG signals of predictor leads (4 predictor leads for the reduced 12-lead ECG) to obtain the estimated time-varying ECG signals in 3 VSLs. The transformations were then assessed and ranked by using diagnostic performance of the resulting VSLs, i.e., by their ability to detect ischemia.

2.3. ACC/ESC criteria for STEMI

We implemented ACC/ESC STEMI criteria as follows: If the amplitude at the J point in both leads of the contiguous pairs (V1, V2), (V2, V3) was ≥ 200 μV or in the pair (V3, V4) in lead V3 ≥ 200 μV and in lead V4 ≥ 100 μV or in any of the contiguous lead pairs (V4, V5), (V5, V6), (aVL, I), (I, –aVR), (–aVR, II), (II, aVF), (aVF, III), (III, –aVL) both J-point amplitudes were ≥ 100 μV, then the STEMI criteria were met. Otherwise the STEMI criteria were not met. The leads –aVR and –aVL denote the negated leads aVR and aVL, respectively.

2.4. Assessment of diagnostic performance

The ability of diagnostic criteria to detect acute ischemia was assessed by diagnostic classification that separated the "ischemic" from the "non-ischemic" state using, in turn, the ACC/ESC and VSL criteria (for the latter, threshold was incremented in 1-μV steps within the range of 0–500 μV). Using a bootstrap method with replacement, we generated detection sensitivity and specificity values for 1,000 bootstrap trials [8] and the mean value ± 95% confidence limits of both sensitivity and specificity were computed and compared.

3. Results

Results in terms of detection sensitivity and specificity for VSLs derived from 4-predictor subsets of the 12-lead ECG are shown in Figures 1-2, and Tables 1–4. Two examples of sensitivity and specificity plots as a function of the detection threshold for VSLs derived from leads II, III, V3, and V6 are shown in Figure 1 for the total set of ischemic episodes (n = 99) and in Figure 2 for the LCx occlusion subgroup (n = 17). For comparison, the sensitivity and specificity values achieved from the existing ACC/ESC STEMI criteria are plotted on the Y-axis. In Tables 1-4, using VSLs threshold at 150 μV, all 15 possible subsets of dual precordial leads combined with 2 limb leads are ranked according to their diagnostic performance, computed as the average value of the sensitivity and specificity in detecting acute ischemia. For reference, the values of performance measures achieved from the existing ACC/ESC STEMI criteria are shown in the first row of each table, and the mean values of performance measures of VSLs derived from 8 independent leads of 12-lead ECG are shown in the second row of each table. Table 1 presents results for the total set of ischemic episodes; Tables 2, 3, and 4 show results for the subsets of ischemic episodes caused by occlusions of LAD, RCA, and LCx arteries, respectively.

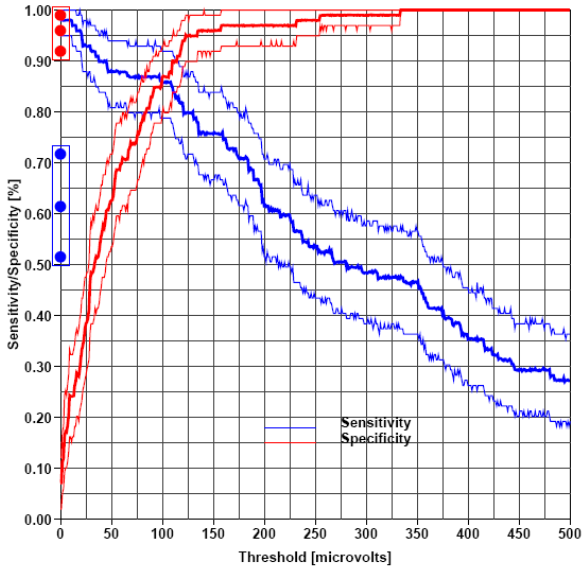

Figure 1. Acute ischemia detection by ACC/ESC criteria vs. VSLs derived from leads II, III, V3, and V6 for total population (n = 99). Mean values and 95% confidence limits of sensitivity and specificity obtained by bootstrap method are plotted for VSLs as a function of threshold and for ACC/ESC STEMI as solid circles on the Y-axis.

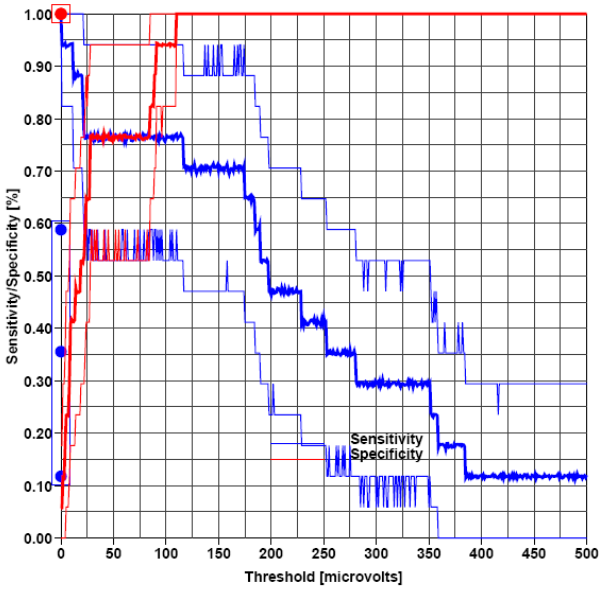

Figure 2. Detection of acute ischemia by ACC/ESC criteria vs. VSLs derived from leads II, III, V3, and V6 for the LCx subgroup (n = 17). Same layout as in Fig. 1.

4. Discussion

The results, which will need further validation on larger patient population, suggest that VSLs derived from several subsets of standard 12-lead ECG, namely 2 limb leads and 2 precordial leads, can identify acute myocardial ischemia in any vessel with better performance than existing ACC/ESC criteria applied to the standard 12 leads. Several top ranked subsets also performed as well as VSLs derived from the full 12-lead ECG. For the highest ranked subsets consisting leads II,

Table 1. Ranking of reduced lead sets using four predictor leads to derive three VSLs in the total set of ischemic episodes (n = 99). SE = Sensitivity, SP = Specificity, DP = (SE + SP)/2.

Rank	Predictor leads	*SE*	*SP*	*DP*
ACC/ESC Criteria		**60.0**	**96.0**	**78.0**
VSLs from I, II, V1–6		**72.5**	**96.0**	**84.2**
1	I, II, V3, V6	75.5	95.9	85.7
2	I, II, V3, V5	73.6	95.9	84.8
3	I, II, V4, V6	71.6	97.1	84.3
4	I, II, V3, V4	70.7	96.9	83.8
5	I, II, V4, V5	70.8	96.0	83.4
6	I, II, V2, V3	70.8	95.9	83.4
7	I, II, V1, V3	67.7	96.0	81.8
8	I, II, V2, V4	66.5	95.9	81.2
9	I, II, V1, V2	65.7	96.0	80.9
10	I, II, V2, V5	65.7	96.0	80.8
11	I, II, V2, V6	64.7	96.0	80.3
12	I, II, V1, V5	61.9	96.9	79.4
13	I, II, V1, V4	61.6	95.0	78.3
14	I, II, V5, V6	56.6	98.0	77.3
15	I, II, V1, V6	57.7	97.0	77.3

Table 2. Ranking of reduced lead sets using four predictor leads to derive three VSLs in the LAD subset of ischemic episodes (n = 35).

Rank	Predictor leads	*SE*	*SP*	*DP*
ACC/ESC Criteria		**74.0**	**97.0**	**85.5**
VSLs from I, II, V1–V6		**88.2**	**97.3**	**92.7**
1	I, II, V3, V4	91.4	97.2	94.3
2	I, II, V3, V6	91.4	97.1	94.3
3	I, II, V3, V5	91.3	97.0	94.2
4	I, II, V2, V3	85.3	97.2	91.3
5	I, II, V1, V3	85.7	97.0	91.3
6	I, II, V4, V5	83.0	97.1	90.0
7	I, II, V4, V6	82.6	97.2	89.9
8	I, II, V2, V5	74.8	100.0	87.4
9	I, II, V1, V2	74.2	100.0	87.1
10	I, II, V2, V4	77.0	97.1	87.1
11	I, II, V1, V5	71.9	100.0	86.0
12	I, II, V1, V4	74.4	97.1	85.7
13	I, II, V2, V6	70.9	100.0	85.4
14	I, II, V1, V6	62.6	100.0	81.3
15	I, II, V5, V6	59.9	100.0	79.9

III, V3, and V6, the increase in sensitivity was 15.5% for the total population and 17.4%, 6.1%, and 34.7% for LAD, RCA, and LCx subgroups, respectively without any decrease in specificity. Thus, we conclude that vessel-specific leads derived from reduced 12-lead using 2 limb leads and 2 precordial leads may be used to improve acute ischemia detection. In particular, vessel-specific leads can improve the detection of acute ischemia caused by the occlusion of the LCx artery, which is more frequently missed by the conventional 12-lead ECG criteria [9].

Table 3. Ranking of reduced lead sets using four predictor leads to derive three VSLs in the RCA subset of ischemic episodes (n = 47).

Rank	Predictor leads	*SE*	*SP*	*DP*
ACC/ESC Criteria		**60.0**	**94.0**	**77.0**
VSLs from I, II, V1–6		**64.1**	**93.7**	**78.9**
1	I, II, V2, V3	66.2	93.7	79.9
2	I, II, V3, V6	66.1	93.6	79.9
3	I, II, V3, V5	65.9	93.6	79.7
4	I, II, V3, V4	61.8	95.9	78.8
5	I, II, V4, V6	61.7	95.8	78.8
6	I, II, V2, V4	63.9	93.7	78.8
7	I, II, V4, V5	63.8	93.4	78.6
8	I, II, V1, V2	64.1	91.5	77.8
9	I, II, V2, V5	63.9	91.4	77.7
10	I, II, V2, V6	63.5	91.5	77.5
11	I, II, V1, V3	57.3	93.5	75.4
12	I, II, V1, V5	57.3	93.5	75.4
13	I, II, V1, V6	55.3	93.6	74.5
14	I, II, V1, V4	55.1	91.6	73.4
15	I, II, V5, V6	51.0	95.6	73.3

Table 4. Ranking of reduced lead sets using four predictor leads to derive three VSLs in the LCx subset of ischemic episodes (n = 17).

Rank	Predictor leads	*SE*	*SP*	*DP*
ACC/ESC Criteria		**36.0**	**100.0**	**68.0**
VSLs from I, II, V1–6		**65.1**	**100.0**	**82.5**
1	I, II, V4, V6	76.5	100.0	88.3
2	I, II, V3, V6	70.7	100.0	85.3
3	I, II, V5, V6	65.3	100.0	82.6
4	I, II, V4, V5	65.0	100.0	82.5
5	I, II, V1, V3	59.2	100.0	79.6
6	I, II, V3, V5	58.0	100.0	79.0
7	I, II, V2, V6	53.6	100.0	76.8
8	I, II, V3, V4	53.5	100.0	76.7
9	I, II, V1, V4	53.4	100.0	76.7
10	I, II, V2, V3	53.4	100.0	76.7
11	I, II, V1, V6	53.2	100.0	76.6
12	I, II, V1, V5	53.0	100.0	76.5
13	I, II, V2, V4	52.9	100.0	76.4
14	I, II, V2, V5	52.6	100.0	76.4
15	I, II, V1, V2	52.4	100.0	76.2

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