Development and Comparison of Single-Parameter Indices Characterizing Severity of Acute Myocardial Ischemia

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Abstract

Our aim was to assess the sensitivity/specificity of 2 indices of ischemia severity ($\Sigma|ST|$ and ST_{RMS}) for 5 triplets of leads: X, Y, Z; V2, V5, aVF; V2, V5, III; V3, V5, III; and V3, V6, III, each derived from 7 subsets of Mason-Likar 12-lead ECG with limb leads and dual precordial leads (V1, V3; V1, V4; V1, V5; V2, V4; V2, V5; V3, V5; V3, V6). Coefficients for deriving lead triplets were developed from the design set (n = 892). The test set comprised 12-lead ECGs (n = 99) acquired before and during ischemia induced by balloon-inflation angioplasty. We compared the ability of tested indices to detect ischemia by constructing their receiver operating characteristics (ROCs) and measuring a percentage area under the entire ROC curve (AUC) and in specificity range 0.8–0.9 ($AUC_{0.8\text{-}0.9}$). The mean performance for 7 predictor sets in terms of AUC (%) for $\Sigma|ST|/ST_{RMS}$ was: 88.4/88.8 for X, Y, Z; 88.6/86.5 for V2, V5, aVF; 89.4/87.5 for V2, V5, III; 90.4/90.3 for V3, V5, III; and 90.5/90.2 for V3, V6, III. Mean values of $AUC_{0.8\text{-}0.9}$ (%) for $\Sigma|ST|/ST_{RMS}$ were: 78.1/80.5 for X, Y, Z; 80.7/71.6 for V2, V5, aVF; 77.6/74.5 for V2, V5, III; 77.7/80.8 for V3, V5, III; and 85.7/82.4 for V3, V6, III. Thus we conclude that the currently used indices using "pseudo-orthogonal" leads V2, V5, aVF, and orthogonal leads X, Y, Z performed in ischemia detection nearly as the best indices based on V3, V6, III. These results should be corroborated on a larger study population.

1. Introduction

Electrocardiographic monitoring in special care units allows non-invasive detection and documentation of cardiac ischemic and arrhythmic events in patients with acute coronary syndromes, and contributes significantly to the reduction of mortality in these patients [1,2]. Although current bedside monitors allow continuous monitoring of the 12-lead electrocardiogram (ECG), it is not always practical to record all of the 12 leads, because 10 electrodes with wires may interfere with auscultation, echocardiographic examination, and resuscitation efforts. Several previous studies have assessed the feasibility of 12-lead ECG reconstruction from various subsets of leads [3-8]. The purpose of the present study was to investigate the ability of some single-parameter indices ($\Sigma|ST|$ and ST_{RMS} for 5 triplets of constituent leads), derived from reduced lead sets using Mason-Likar (M-L) limb leads and two precordial leads [9,10], to detect acute myocardial ischemia induced by balloon-inflation angioplasty.

2. Methods

2.1. Patient population

The design set used to develop coefficients for deriving desired triplets of leads from predictor leads was the Dalhousie Superset consisting of 120-lead ECGs from 892 subjects, including 290 normals, 318 patients with old myocardial infarction and 284 with inducible ventricular tachycardia [11]. The test set consisted of M-L 12-lead ECGs from *STAFF3* database from Duke University [12] of controlled ischemic episodes caused by balloon inflation during balloon-inflation percutaneous transluminal coronary angioplasty (PTCA) in one of the main coronary arteries; there were 35 episodes of left anterior descending (LAD) coronary artery occlusion, 47 episodes of right coronary artery (RCA) occlusion, and 17 episodes of left circumflex (LCx) coronary artery occlusion.

2.2. ECG acquisition and processing

The Dalhousie Superset used to develop coefficients for lead transformations consists of ECGs recorded from 120 leads for each patient (n = 892); the lead array has 3 limb leads at wrists and ankles and 117 unipolar torso leads (76 placed on the anterior and 41 on the posterior chest) [11]. Recordings were made for 15 consecutive seconds, while the subjects were supine. Analog ECGs were amplified, filtered (band pass from 0.025 to 125 Hz), multiplexed, and digitized at 500 12-bit samples per second per channel (with 2.5-μV resolution).

Table 1. Percentage area under the ROC curve (AUC/$AUC_{0.8\text{-}0.9}$) for 2 ischemia indices (Σ|ST| and ST_{RMS}) calculated for 5 lead triplets from 7 subsets of Mason-Likar 12-lead ECG consisting of limb leads and dual precordial leads

Predictor Leads	Derived X, Y, Z		Derived V2, V5, aVF		Derived V2, V5, III		Derived V3, V5, III		Derived V3, V6, III	
	Σ|ST|	ST_{RMS}	Σ|ST|	ST_{RMS}	Σ|ST|	ST_{RMS}	Σ|ST|	ST_{RMS}	Σ|ST|	ST_{RMS}
II, III, V1, V3	87.3/78.3	88.1/86.5	88.8/79.9	85.8/70.4	89.7/73.0	86.8/65.2	90.0/83.7	90.0/84.6	90.4/85.9	90.1/76.8
II, III, V1, V4	88.9/78.4	89.5/78.1	88.6/77.4	87.8/75.6	89.6/78.8	88.5/79.2	91.0/69.1	91.2/78.7	91.6/95.6	91.5/78.1
II, III, V1, V5	86.9/79.5	87.7/75.2	87.0/74.1	85.8/70.4	88.1/77.3	87.1/74.6	89.8/73.4	89.8/73.8	89.3/82.2	89.3/83.9
II, III, V2, V4	88.4/80.6	88.8/79.7	87.3/78.6	87.7/73.2	88.2/81.2	88.8/78.5	90.7/83.9	90.3/75.6	90.7/75.1	90.2/83.6
II, III, V2, V5	87.8/76.5	88.0/79.5	87.5/79.9	85.8/70.4	88.4/73.4	87.1/74.6	89.6/74.6	89.4/82.6	89.5/83.5	89.1/83.7
II, III, V3, V5	89.9/73.3	89.9/82.7	90.5/84.3	85.8/70.4	90.9/76.1	87.1/74.6	90.9/76.3	90.9/85.2	90.9/85.0	90.7/85.0
II, III, V3, V6	89.4/79.8	89.8/81.7	90.7/90.4	86.4/70.7	91.0/83.5	87.2/74.9	90.6/83.1	90.7/84.8	90.9/92.9	90.8/85.6
Mean	88.4/78.1	88.8/80.5	88.6/80.7	86.5/71.6	89.4/77.6	87.5/74.5	90.4/77.7	90.3/80.8	90.5/85.7	90.2/82.4
Maximum	89.9/80.6	89.9/86.5	90.7/90.4	87.8/75.6	91.0/83.5	88.8/79.2	91.0/83.9	91.2/85.2	91.6/95.6	91.5/85.6
Minimum	86.9/73.3	87.7/75.2	87.0/74.1	85.8/70.4	88.1/73.0	86.8/65.2	89.6/69.1	89.4/73.8	89.3/75.1	89.1/76.8
Range	3.0/7.3	2.2/11.3	3.7/16.3	2.0/5.2	2.9/10.5	2.0/14.0	1.4/14.8	1.8/11.4	2.3/20.5	2.4/8.8

In the test set, 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 kHz sampling rate with an amplitude resolution of 0.6 μV for the least-significant bit [12]. Subsequent ECG processing was done at Dalhousie University on an RS/6000 computer (IBM Corp, Armonk, NY). 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." QRS onset was determined to establish the baseline, and the QRS offset was designated as J point. Baseline was defined as mean amplitude of 10 samples centered at 10 ms before the QRS onset. To measure ST deviation of each beat, the difference between amplitude at J point and that at the baseline was taken; this measurement was done automatically by computer algorithm, with 1-μV resolution.

2.3. Assessment of ischemia indices

We assessed the sensitivity and specificity of two single-parameter indices of ischemia severity (Σ|ST| and ST_{RMS}) for 5 triplets of leads: Frank X, Y, Z [13]; V2, V5, aVF; V2, V5, III; V3, V5, III; and V3, V6, III, each derived from 7 subsets of M-L 12-lead ECG consisting of limb leads and dual precordial leads [10,11]. Coefficients for deriving lead triplets were developed from the Dalhousie Superset, as described in [11]. The test set consisted of ECG data from the *STAFF3* database [12]. We compared the ability of tested single-parameter indices to detect ischemia by varying their thresholds, constructing receiver operating characteristic (ROC) curves and measuring an area under the entire ROC (AUC) and an area under the ROC in the useful range of specificity 0.8–0.9 ($AUC_{0.8\text{-}0.9}$).

3. Results

Results summarizing performance of single-parameter indices of ischemia for various sets of leads in terms of 2 different areas under the ROC curve (an area for a full range of specificity from 0. to 1., denoted AUC, and an area for a useful range of specificity from 0.8 to 0.9, denoted $AUC_{0.8\text{-}0.9}$, are listed in Table 1. The values of performance for 5 different triplets of constituent leads, in terms of AUC (%) calculated over all 7 predictor sets, vary in a relatively narrow range: for the Σ|ST| index from the minimal value of 86.86% (for the triplet X, Y, Z) to the maximal value of 91.56% (for V3, V6, III); for the ST_{RMS} index from 85.82% (for V2, V5, aVF) to 91.47% (for V3, V6, III). On the other hand, $AUC_{0.8\text{-}0.9}$ (%) varies in a much wider range: for the Σ|ST| index from 69.1% (for V3, V5, III) to 95.6% (for V3, V6, III) and for the ST_{RMS} index from 65.2% (for V2, V5, III) to 86.5% (for X, Y, Z). Among tested triplets of constituent leads for constructing ischemia indices, the leads V3, V6, III perform the best, followed by leads V3, V5, III and Frank orthogonal leads X, Y, Z. It should be noted that ST_{RMS} index does not outperform a simple and visually verifiable Σ|ST| index. Figure 1 shows beat-to-beat ST deviations during LCx occlusion for 15 individual ECG leads and for 6 indices of ischemia (Σ|ST| and ST_{RMS} for three lead triplets). Figure 2 shows in detail how the response of these 6 indices of ischemia to LCx occlusion depends on predictor leads (for 7 sets of predictors).

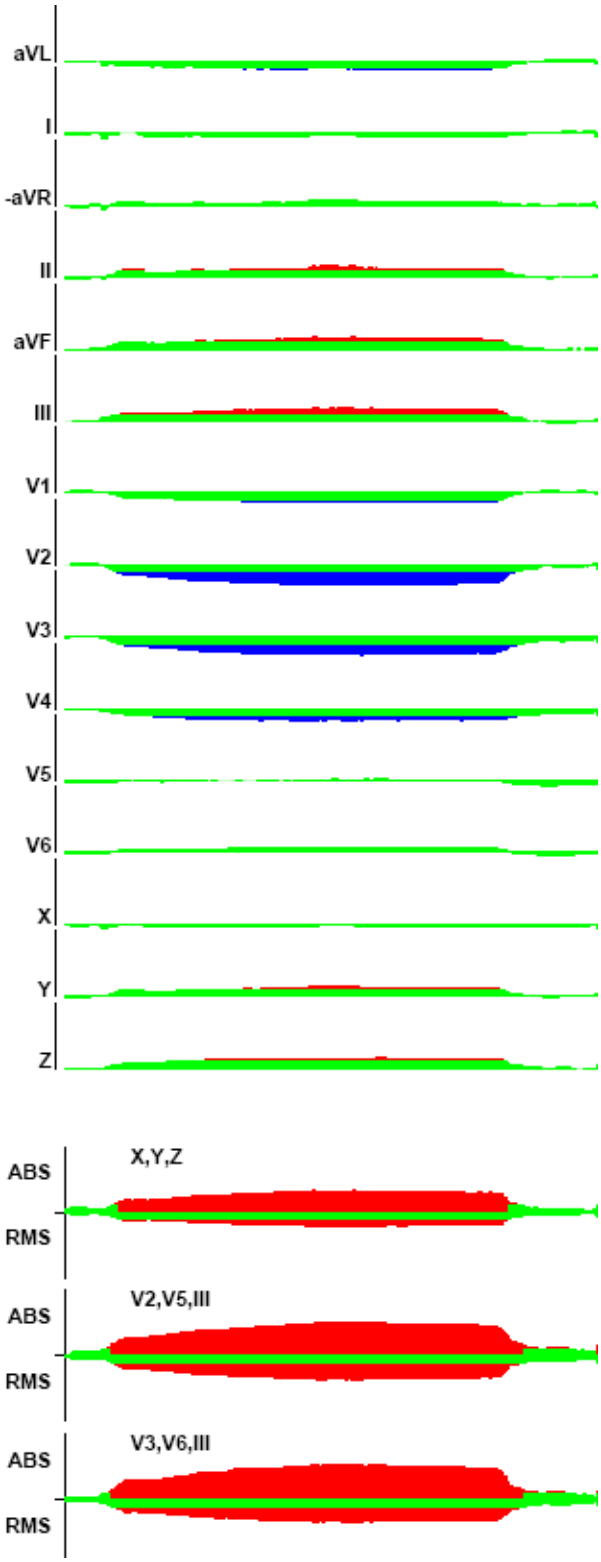

Figure 1: Beat-by-beat ST deviations during 5-min LCx occlusion as seen by 15 ECG leads and 6 indices of ischemia. Values > 100 μV red; values < −100 μV blue.

4. Discussion

As shown in Table 1, the range of mean percentage AUC for the 7 predictor sets is within 5%. This is not surprising if we consider that this table compares indices calculated for triplets of leads that were previously shown to have the best ischemia-detection performance [7] and that these triplets were derived from reduced lead sets with the best ability to reconstitute the entire 12-lead ECG [10]. This observation, based on AUC alone, would seem to imply that there are several near-equivalent choices of dual chest leads for predicting the required lead triplets and calculating single-parameter indices. However, the closer inspection of $AUC_{0.8\text{-}0.9}$ (%) values in Table 1 reveals that the choice of predictors affects the performance of corresponding indices more than AUC values based on the entire range of specificity. Nevertheless, among 5 tested triplets of constituent leads for constructing ischemia indices, the leads V3, V6, III perform the best, with currently used indices using "pseudo-orthogonal" leads V2, V5, aVF, and Frank orthogonal leads X, Y, Z not too far behind. A simple Σ|ST| index, which can be easily verified by manual reading, performs generally as well as computer-generated ST_{RMS} index.

In our early study [7], we ranked various subsets of the M-L 12-lead ECG according to their ability to detect myocardial ischemia using indices derived from ST deviation in all constituent leads of a given lead set and we found that the 3-lead sets with the best ability to detect ischemia are V3, V6, III and V3, V5, III. This result, confirmed in the present study, is not surprising, since V3 detects reliably LAD-related ischemia, III detects RCA-related ischemia, and V6 detects LCx-related ischemia. In the more detailed study [11], we found that 7 out of 15 possible pairs of M-L precordial leads used together with 2 M-L limb leads, are all almost equally capable of reconstructing the complete 12-lead/18-lead ECG, as well as the VCG. Based on these previous results, we selected 5 lead triplets and 7 predictor sets for the present study.

5. Conclusion

We conclude that the currently used indices of ischemia using "pseudo-orthogonal" leads V2, V5, aVF, and those using Frank orthogonal leads perform nearly as well as those based on the best lead triplet V3, V6, III. These results should be corroborated on a larger population.

Acknowledgements

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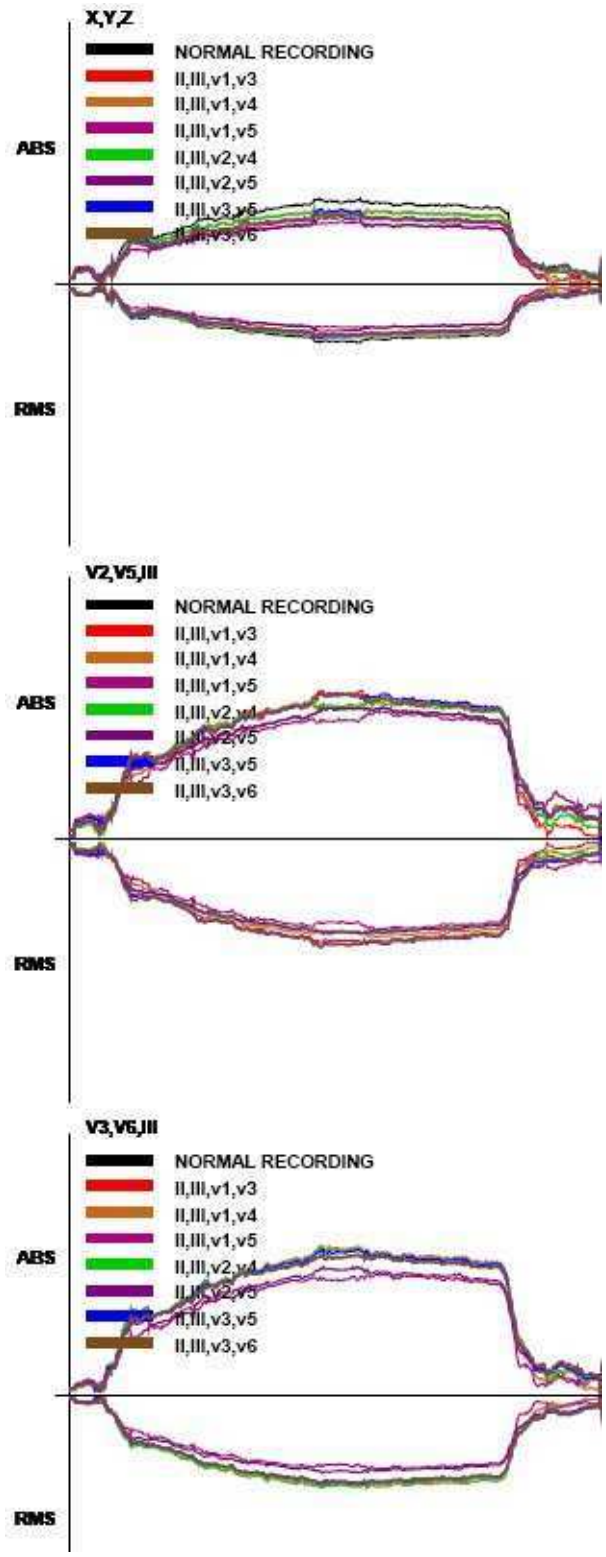

Figure 2: Envelopes of beat-by-beat ST deviations during 5-min LCx occlusion as seen by 6 indices of ischemia derived from 7 predictor sets. Same episode as in Fig. 1.

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