

Validation of New Enhanced ACC/ESC STEMI Criteria on the Population of Patients with Suspected Myocardial Infarction

JY Wang¹, GS Wagner², TN Martin³, JW Warren⁴, M Mirmoghisi⁴, BM Horáček⁴

¹Philips Healthcare, Andover, MA, USA; ²Duke University Medical Center, Durham, NC, USA; ³Cardiac Magnetic Resonance Unit, Glasgow University, Glasgow, UK; ⁴Dalhousie University, Halifax, NS, Canada

Abstract

Current electrocardiographic criteria for identifying patients with ST-segment elevation myocardial infarction (STEMI) perform with high specificity (SP), but low sensitivity (SE). Based on data acquired during balloon-inflation angioplasty, we found that the SE of ACC/ESC STEMI criteria can be improved without any loss of SP by considering ST elevation in 3 added pairs of contiguous leads (aVL, -III; III, -aVL; and -V2, -V3). The aim of the present study was to validate these findings on an independent dataset consisting of 12-lead ECGs of patients with (n = 58) and without (n = 58) acute myocardial infarction. ST deviation was measured at J point in 12 standard leads by a cardiologist from paper tracings, with resolution of 50 μ V; these tracings were then scanned and high-resolution ST measurements were made from computer monitor. By using manual measurements from paper, the detection of ischemic state using the existing STEMI criteria achieved SE/SP of 50/97%, whereas with enhanced STEMI criteria SE/SP were 66/97%. Computer-assisted measurements yielded SE/SP of 43/98% for the existing and 55/98% for enhanced STEMI criteria; however, at thresholds for ST elevation lowered by 30 μ V (i.e., by emulating "rounding" in readings from paper) SE/SP values for computer-assisted measurements equaled those for manual ones. Thus this study confirmed that existing ACC/ESC STEMI criteria enhanced by 3 additional features yield improved SE of ischemia detection without lowering SP.

1. Introduction

Currently used electrocardiographic criteria [1] recommended by the American College of Cardiology / European Society of Cardiology (ACC/ESC) for identifying patients with ST-segment-elevation myocardial infarction (STEMI) perform with high specificity, but low sensitivity. Consequently, many false-negative patients may not receive the appropriate therapy.

Several previous studies, such as [2, 3], addressed this deficiency—within the framework of conventional 12-lead ECG—by considering both ST elevation and ST depression (a 24-lead ECG concept illustrated in Fig. 1) in contiguous leads and found that sensitivity can be vastly improved at the cost of what appears to be a small decrease in specificity. Our aim was to seek additional features extracted from 12-lead ECG that improve sensitivity of ischemia detection without decreasing high specificity of ACC/ESC criteria, which is undesirable [4]. We also avoided using ST depression in leads V4–V6, which is known to be associated with subendocardial ischemia [4].

2. Methods

2.1. Patient population

Design set consisted of 12-lead ECGs from *STAFF3* database from Duke University [7] of controlled ischemic episodes caused by balloon inflation during elective 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. Test set, from University of Glasgow, comprised 12-lead ECGs of 58 patients with myocardial infarction (MI) and 58 patients without MI [3], as confirmed by MRI.

2.2. ECG acquisition and processing

In the design 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 1,000 Hz sampling rate with an amplitude resolution of 0.6 μ V for the least-significant bit [5]. Subsequent ECG processing was done 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 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; this measurement was done automatically by computer algorithm, with 1- μ V resolution.

In the test set, the standard 12-lead ECG was recorded traditionally on paper for each participant of the study. ST deviation was then measured at J point in all 12 standard leads by a cardiologist (GSW) from paper tracings, with resolution of 50 μ V. Paper tracings were subsequently scanned (472 pixels per 1 mV) and high-resolution ST measurements were independently made from computer monitor by 2 readers (JWW, MM); an average of these 2 readings was used in comparison with cardiologist’s measurements.

2.3. Criteria for STEMI

We implemented ACC/ESC STEMI criteria [1] as follows: If the amplitude at the J point in both leads of the contiguous pair (V2, V3) was $\geq 200 \mu$ V or in the pair (V1, V2) in lead V1 $\geq 100 \mu$ V and in lead V2 $\geq 200 \mu$ V or in the pair (V3, V4) in lead V3 $\geq 200 \mu$ V and in lead V4 $\geq 100 \mu$ V or in any of the contiguous lead pairs (V4, V5), (V5, V6), (aVL, I), (I, -aVR), (-aVR, II), (II, aVF), (aVF, III) both J-point amplitudes were $\geq 100 \mu$ V, then the STEMI criteria were met. The lead -aVR denotes the negated lead aVR.

New enhanced ACC/ESC STEMI criteria assessed in the present study included in addition to contiguous lead pairs recommended by ACC/ESC 3 additional features: ST elevation in lead pairs (aVL, -III), (III, -aVL), and (-V2, -V3). If the amplitude at the J point in both leads of any of the additional lead pairs was $\geq 100 \mu$ V then the new enhanced STEMI criteria were met. The negated leads are denoted -III, -aVL, -V2, -V3.

2.4. Assessment of diagnostic performance

The ability of both existing ACC/ESC criteria [1] and new enhanced ACC/ESC criteria to detect acute ischemia was assessed by diagnostic classification that separated the “ischemic” from the “non-ischemic” state. Using a bootstrap method with replacement, we generated the mean values of sensitivity and specificity for ischemia detection by performing 1,000 bootstrap trials [8]; these bootstrap-generated mean values were then compared.

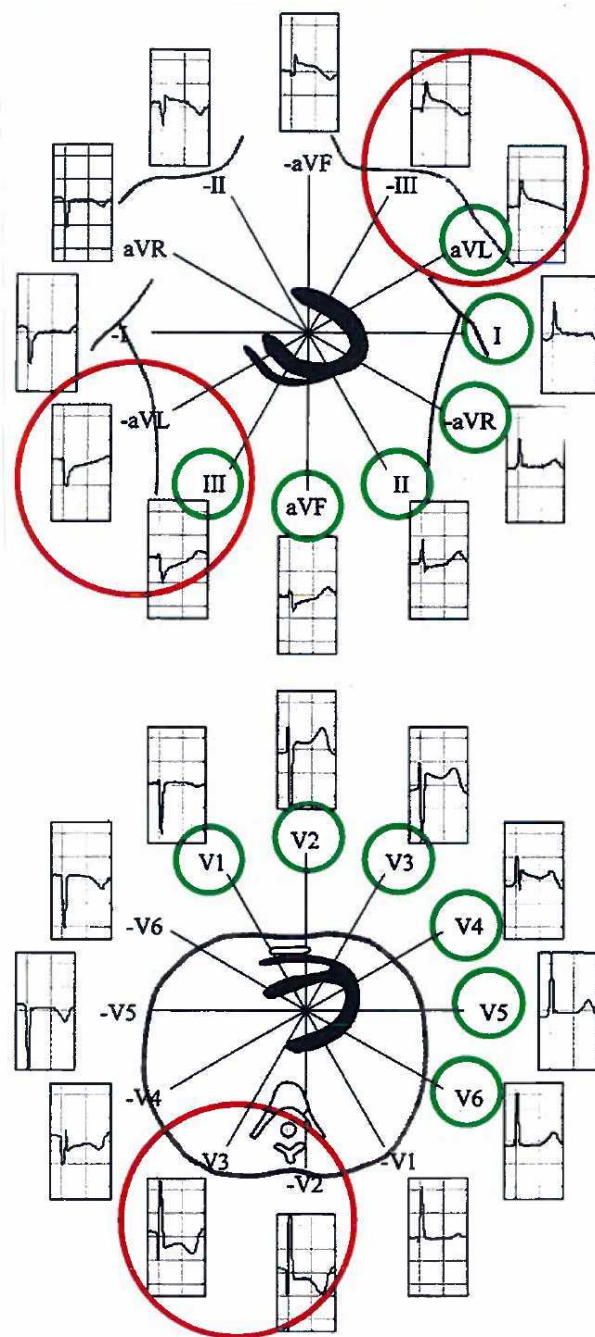


Figure 1. Wagner’s 24-lead view of the standard 12-lead ECG in frontal (top) and transverse (bottom) planes [3]. ACC/ESC STEMI criteria use contiguous lead pairs of leads in small green circles: (aVL, I), (I, -aVR), (-aVR, II), (II, aVF), (aVF, III), (III, -aVL), (V1, V2), (V2, V3), (V3, V4), (V4, V5), (V5, V6); enhanced ACC/ESC STEMI criteria use additional lead pairs that are marked by red circles: (aVL, -III), (III, -aVL), and (-V2, -V3).

3. Results

For the design set, the detection of ischemia by means of the ACC/ESC STEMI criteria [1] achieved mean *SE/SP* of 59/96% in the entire dataset, 74/97% in the LAD group, 56/94% in the RCA group, and 36/100% in the LCx group. In comparison, the *SE/SP* values of STEMI criteria enhanced by 3 added features (defined in Section 2.3) were 74/95% overall, 83/97% in the LAD group, 70/94% in the RCA group, and 64/94% in the LCx group. Adding more than 3 features was detrimental to specificity.

For the test set, results are summarized in Table 1. It is apparent from this table that sensitivity of ischemia detection is not as good for high-resolution measurements made from the computer monitor as for measurements from paper tracings, which were made with low resolution of 50 μV . To understand this paradox, we gradually lowered threshold for computer-assisted measurements of ST elevation in 5- μV steps. With thresholds lowered by 30 μV , sensitivity and specificity values exactly equaled those achieved by measurements from paper tracings.

Table 1. Test-set performance of new enhanced criteria on the population with suspected myocardial infarction

Method of ST measurement	Testing Criteria	Sensitivity (%)	Specificity (%)
Cardiologist's measurement from paper tracings	ACC/ESC STEMI	50 (29/58)	97 (56/58)
	Enhanced STEMI	66 (38/58)	97 (56/58)
Computer-assisted measurement from screen	ACC/ESC STEMI	43 (25/58)	98 (57/58)
	Enhanced STEMI	55 (32/58)	98 (57/58)

4. Discussion

Test-set results (Table 1) confirm that the sensitivity of detecting acute MI achieved by ACC/ESC criteria can be increased by adding 3 features without *any* decrease in specificity. Three pairs of contiguous leads that we added to the set of 10 contiguous pairs of the 12-lead ECG recommended by ACC/ESC [1] were selected by statistical means, considering the constraints that leads -V4 to -V6 should be avoided and high specificity should be maintained. When the statistical selection was done, we found it instructive to consult body-surface potential mapping data that show ST distributions during supply [5] and demand ischemia [6].

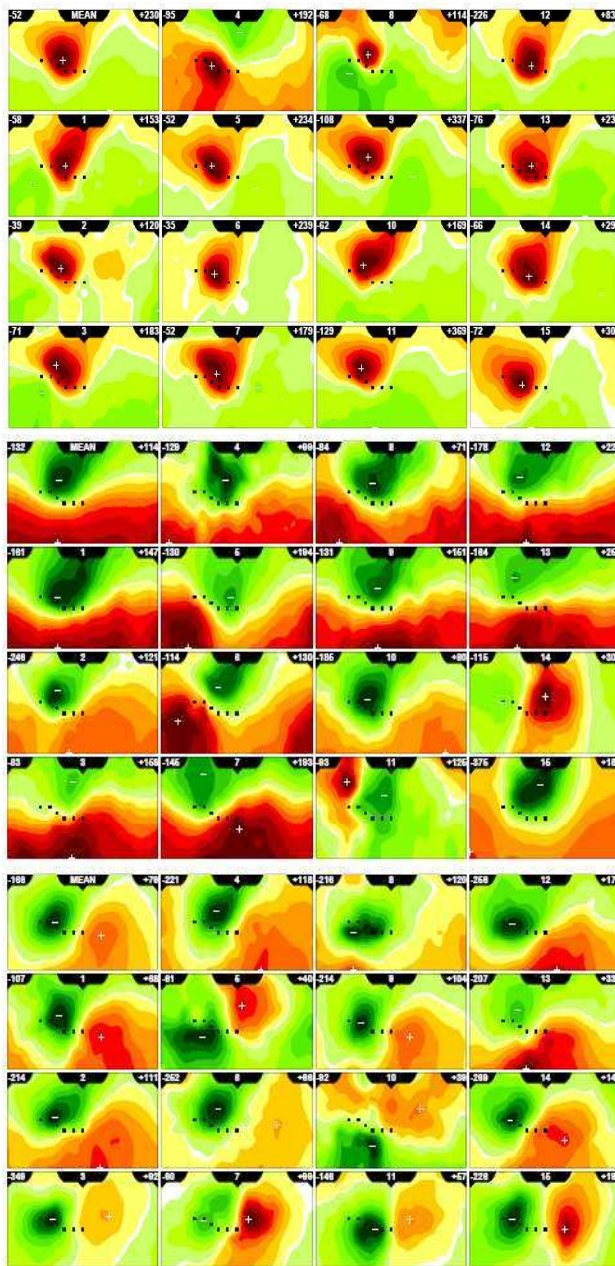


Figure 2. Body-surface potential distributions of ST-segment changes for supply ischemia during PTCA. Upper panel: maps corresponding to ischemia caused by occlusion of the LAD; middle panel: maps corresponding to ischemia caused by occlusion of the RCA; bottom panel: maps corresponding to ischemia caused by occlusion of the LCx. Each panel shows mean map for the group (left upper map) and 15 maps for individual patients who belonged to that group.

Body-surface potential maps corresponding to supply ischemia [5] are reproduced in Fig. 2. By inspecting this figure, two observations can be made: First, body-surface potential maps associated with supply ischemia due to RCA occlusion illustrate why the additional contiguous pair comprising leads $-aVL$ and III might detect cases where the vector representing injury current is oriented toward the lower-right torso. Second, some body-surface potential maps associated with supply ischemia due to LCx occlusion illustrate why some LCx cases can be detected by the additional contiguous pair comprising aVL and $-III$. In addition, inspection of results reported by Hänninen and co-workers [6]—which show body-surface potential distributions for ST segment during demand ischemia—explains why patients with ST elevation in aVR and ST depression in leads $V4-V6$ cannot be considered STEMI patients [4].

Regarding the paradox in Table 1, we attribute it to “rounding up” in cardiologist’s readings.

5. Conclusion

Based on results of this study, we conclude that existing ACC/ESC STEMI criteria enhanced by just 3 additional features yielded much improved sensitivity of ischemia detection without any detrimental effect on specificity. This finding—which needs to be corroborated on a larger study population—indicates that the current ACC/ESC criteria can still be further improved.

Acknowledgements

Support for studies at Dalhousie University was provided by the Heart & Stroke Foundation of Nova Scotia and by the Canadian Institutes of Health Research.

References

- [1] Thygesen, K *et al.* Universal definition of myocardial infarction: ESC/ACCF/ AHA/WHF expert consensus document. *JACC* 2007;50:2173–95.
- [2] Perron, A *et al.* Maximal increase in sensitivity with minimal loss of specificity for diagnosis of acute coronary occlusion. *J Electrocardiol* 2007;40:463–9.
- [3] Martin, TN *et al.* ST-segment deviation analysis of the admission 12-lead electrocardiogram as an aid to early diagnosis of MI. *JACC* 2007;50:1021–8.
- [4] Kligfield, P. How many leads are in the 12-lead ECG, and what does that mean for the diagnosis of acute STEMI? *J Electrocardiol* 2007;40:472–4.
- [5] Horáček, BM *et al.* Optimal electrocardiographic leads for detecting acute myocardial ischemia. *J Electrocardiol* 2001;34(Suppl):97–111.
- [6] Hänninen H *et al.* ST-segment level and slope in exercise-induced myocardial ischemia. *Am J Cardiol* 2001;88:1152–6.
- [7] Garcia J, Wagner G, Sörnmo L, Lander P, Laguna P. Identification of the occluded artery in patients with myocardial ischemia induced by prolonged percutaneous transluminal coronary angioplasty using traditional vs transformed ECG-based indexes. *Compute Biomed Res.* 1999;32:470–82.
- [8] Efron B, Tibshirani RJ. An introduction to the bootstrap. Chapman and Hall, New York, 1993.
- [9] Wang JY, Mirmoghisi M, Warren JW, Wagner GS, Horáček BM. Detection of acute myocardial ischemia by vessel-specific leads derived from the 12-lead electrocardiogram. *Computers in Cardiology.* 2007;34:301–304.

Address for correspondence:

John Wang
 Philips Healthcare
 3000 Minuteman Road, MS-0455
 Andover, MA 01810-1099
 USA
 E-mail: john.j.wang@philips.com