An algorithm for the detection of ST segment elevation relating to induced ischemia in body surface potential maps

Dewar D Finlay[1], D Guldenring[1], Raymond R Bond[1], Michael J Daly[2]

[1]University of Ulster, Belfast, UK
[2]Royal Victoria Hospital, Belfast, UK

Abstract

Criteria have been developed and published for the detection of ST segment elevation myocardial infarction (STEMI) in the 12-lead electrocardiogram (ECG). In this study we report on an algorithm for the detection of ST segment elevation in body surface potential maps (BSPM). The algorithm seeks ST segment elevation, exceeding predefined thresholds, in two contiguous/adjacent leads. Thresholds are based upon the extension of existing 12-lead ECG criteria. The algorithm was applied to 45 subjects who had 120-lead BSPMs recorded during percutaneous transluminal coronary angioplasty (PTCA). The algorithm was capable of distinguishing between baseline ECGs and peak balloon inflation ECGs with a sensitivity of 84.4% and specificity of 86.7%. Standard STEMI criteria, applied to 12-lead ECGs extracted from the same BSPMs, resulted in a sensitivity of 53.3% and a specificity of 100%. The BSPM algorithm has the potential to increase sensitivity but specificity is reduced.

1. Introduction

Coronary artery occlusion is primarily detected through analysis of the ST-segment of the electrocardiogram (ECG). Criteria have been developed, and refined, to allow identification of ST-segment elevation Myocardial Infarction (STEMI) from the 12-lead ECG [1]. The 12-lead ECG has been reported as exhibiting high specificity in the detection of STEMI but sensitivity is mediocre [2]. The low sensitivity is often attributed to the fact that the 12-lead ECG does not interrogate all areas of the myocardium (e.g. right ventricle). This in turn means that ST-segment elevation projected onto regions of the body that are not sampled by the 12-lead ECG may be missed.

Studies have shown how additional leads can improve sensitivity in the detection of STEMI [3],[4]. Additional leads can range from a handful of leads (e.g. right sided and posterior leads) that supplement the 12-lead ECG, to Body Surface Potential Maps (BSPMs), that can use as many as 200 thoracic recording sites.

Whilst the benefits of the additional BSPM leads have been reported there has been limited reporting of the diagnostic criteria applied to these additional leads. In this study we report on an algorithm for the detection of ST segment elevation in BSPMs recorded from subjects during percutaneous transluminal coronary angioplasty (PTCA).

2. Method

The proposed algorithm is based upon the extension of the current criteria for the detection of STEMI in 12-lead ECGs [1]. We extended this criteria, as described in the following paragraphs, for application to the 120-lead BSPM array illustrated in Figure 1.

2.1 Algorithm

Current guidelines for the identification of STEMI in 12-lead ECGs state that subjects with STEMI will exhibit ST-segment elevation in at least two contiguous leads [1]. ST-segment elevation is defined as a j-point potential in excess of 100 μV. This is in any lead with the exception of V_2 and V_3 where a threshold of 200 µV should be observed in men of 40 years and older. The threshold for leads V_2 and V_3 should be increased to 250 µV in men younger than 40 years, and, should be reduced to 150 µV in women.

The guidelines also state thresholds for leads supplementary to those recorded in the 12-lead ECG format. Specifically, if posterior leads V_7-V_9 are recorded, a threshold of 50 µV should be exceeded except in men under 40 years where a threshold of 100µV should be exceeded. When recorded, right-sided leads (e.g. V_3R and V_4R) should exhibit ST-segment elevation of 50µV. This is with the exception of males under 30 years of age where a threshold of 100µV should be observed.

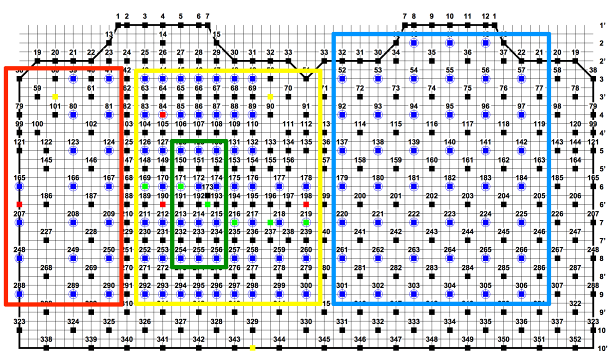

Figure 1. 120 lead BSPM electrode array.

The proposed BSPM algorithm extends the existing criteria for right-sided (e.g. V_3R and V_4R) leads to all right side BSPM leads as highlighted in Figure 1 (red box). We adopted the same approach for posterior leads by extending current criteria for leads V_7-V_9 to all posterior BSPM leads (blue box Figure 1). We applied the criteria for V_1 and V_4-V_6 to all anterior BSPM leads (yellow box) and we applied the V_2 and V_3 criteria to leads in close proximity to that region (green box). The various thresholds for the different regions highlighted in Figure 1 are summarized in Table 1. We maintained the concept of contiguous leads as defined for the 12-lead ECG and we also required that two adjacent BSPM leads exceeded the required threshold in both leads for ST segment elevation to be confirmed. In the 120-lead BSPM configuration some leads are in close proximity to each other so we stipulated that only leads with similar spacing to that between precordial leads in the 12-lead ECG could be considered as adjacent.

Table 1. Summary of thresholds for identification of ST-segment elevation in BSPM territories identified in Figure 1.

Territory	Threshold
Right Ventricle (red box)	50 µV (age >=30) 100 µV (age < 30)
Anterior (yellow box)	100 µV
V_2 and V_3 (green box)	250 µV (male age < 40) 200 µV (male age => 40) 150 µV (female)
Posterior (blue box)	50 µV 100 µV (male age <40)

2.2 Data

We tested our algorithm on 120-lead BSPMs recorded from subjects during PTCA. The data and recording procedure have been previously described [5]. The study dataset consisted of 90 BSPM recordings taken from 45 subjects. Two BSPMs, each representing one averaged cardiac cycle, were included for each subject. The first BSPM represented the subject's ECG at baseline and the second BSPM represented the subject's BSPM during peak balloon inflation (inflation time = 60-90 seconds). The population is further summarized in Table 2.

Twelve lead ECGs, along with additional supplementary leads (V_3R-V_6R and V_7-V_9), were also extracted from the BSPMs. This allowed us to create two further datasets. The first consisted of all 90 12-lead ECGs (45 baseline and 45 peak balloon inflation). The second consisted of the same 90 12-lead ECGs plus the supplementary leads listed above (V_3R-V_6R and V_7-V_9).

Table 2. Study population

Male	n =28
Mean age (std dev)	57.3 (9.7)
Occlusion site	
LAD	n=7
LCX	n=10
RCA	n=11
Female	n = 17
Mean age (std dev)	59.0 (8.7)
Occlusion site	
LAD	n=8
LCX	n=4
RCA	n=5

During evaluation our proposed algorithm was applied to the BSPM dataset in order to determine its ability to distinguish between subject's ECGs at baseline and peak balloon inflation. We also applied an implementation of the existing 12-lead ECG STEMI criteria to the 12-lead ECG dataset. We extended this algorithm, in accordance with the guidelines, and applied this to the 12-lead ECGs that also contained supplementary leads.

3. Results

Table 3 lists the performance of each lead set/algorithm studied. Performance is defined in terms of sensitivity and specificity. Also noted is number of correctly identified instances of peak balloon inflations for each occlusion site.

The pattern of performance reflected in table 3 is as one would expect. Specifically, sensitivity is increased, while specificity is reduced, as information from more ECG leads is added. Furthermore, cases that are known to be problematic for the 12-lead ECG (e.g. LCX and RCA occlusions) see improved detection using the additional leads.

4. Discussion

A challenge in the interpretation of results such as that presented here is how to make a direct comparison between the various lead set/algorithm combinations when performance is expressed in terms of both sensitivity and specificity. And, the impact of the trade-off between sensitivity and specificity is ultimately based upon clinical need. Even though the BSPM based approach increases sensitivity by over 30% the associated reduction in specificity may not be acceptable in some clinical applications.

Table 3. Performance of each lead set/algorithm.

	12-Lead	12-Lead+	BSPM
Sensitivity (%)	53.3	68.9	84.4
Specificity (%)	100	95.6	86.7
No. correctly identified			
Baseline	45	43	36
LAD (15)	10	10	12
LCX (15)	8	11	13
RCA (15)	6	10	13

The reduced specificity is likely to be an inherent problem with the approach adopted in this study (i.e. extension of existing criteria). This is due to the fact that BSPMs, such as that studied here, include large numbers leads in regions where thresholds for ST segment elevation are low (e.g. 50 µV in posterior and right sided leads). This in turn means that small increases in voltage levels in these leads, that may not be due to ischemic type changes, can result in a false positive result.

Further work could assess the performance of the BSPM algorithm across a range of ST segment thresholds and this would allow tuning for higher specificity and more direct comparison with the performance of other lead systems.

5. Conclusion

Extension of existing 12-lead ECG STEMI criteria to BSPM leads has the potential to improve sensitivity. This will however result in a reduction in specificity.

When considering the results presented in this paper a number of limitations should be highlighted. Most significantly, results are based on analysis of a very small population that may not be fully representative. Our dataset is only representative of subjects with single vessel disease and results do not provide an indication of performance when more complex cases are present. A further limitation is the fact that, although implemented, some aspects of the algorithm are not well evaluated with the current data. This is the case for the age related criteria as there are few subjects falling below the lower age limits (e.g. <30-40 years).

Acknowledgements

The authors would like to thanks Professor Milan B. Horacek for providing the data used in this study.

References

[1] K. Thygesen, J. S. Alpert, A. S. Jaffe, M. L. Simoons, B. R. Chaitman and H. D. White, "ESC/ACCF/AHA/WHF Expert Consensus Document Third Universal Definition of Myocardial Infarction," *Circulation,* vol. 126, pp. 2020-2035, October 16, 2012.

[2] E. Trägårdh, M. Claesson, G. S. Wagner, S. Zhou, O. Pahlm, "Detection of acute myocardial infarction using the 12-lead ECG plus inverted leads versus the 16-lead ECG (with additional posterior and right-sided chest electrodes)," *Clin Physiol Funct Imaging,* vol. 27, pp. 368–374, 2007.

[3] Casas RE, Marriott HJ, Glancy DL. "Value of leads V7–V9 in diagnosing posterior wall acute myocardial infarction and other causes of tall R waves in V1–V2," *Am J Cardiol* vol. 80 pp. 508–509, 1997.

[4] A. J. J. McClelland, C. G. Owens, I. B. A. Menown, M. Lown, and A. A. J. Adgey, "Comparison of the 80-lead body surface map to physician and to 12-lead electrocardiogram in detection of acute myocardial infarction," *The American Journal of Cardiology,* vol. 92, no. 3, pp. 252-257, 2003.

[5] B.M. Horacek, J.W. Warren, C.J. Penney, R.S. MacLeod, L.M. Title, M.J. Gardener, C.L. Feldman, "Optimal electrocardiographic leads for detecting acute myocardial ischemia," *Journal of Electrocardiology*, vol. 34, suppl. pp. 97-111, 2001.

Address for correspondence.

Dr Dewar Finlay
School of Engineering
University of Ulster
Shore Road
Belfast
BT37 0TQ
d.finlay@ulster.ac.uk