# The effects of electrode placement on an automated algorithm for detecting ST segment changes on the 12-lead ECG

Dewar D Finlay[1], Raymond R Bond[1], Alan Kennedy[1], Daniel Guldenring[1], Kieran Moran[2], James McLaughlin[1]

[1]University of Ulster, Belfast, UK
[2]Dublin City University, Dublin, Ireland

## Abstract

*In this study we investigate the effect that ECG electrode placement can have on the detection of ST segment changes. BSPMs from 45 subjects undergoing PTCA were analysed (15 left anterior descending, 15 left circumflex and 15 right coronary artery). 12-lead ECG were extracted from BSPMs corresponding with correct precordial electrode positioning and corresponding with simultaneous vertical movement of all of the precordial leads in 5mm increments up to +/-50mm away from the correct position. A computer algorithm was developed based on current guidelines for the detection of STEMI and Non-STEMI. This algorithm was applied to all of the extracted 12-lead ECGs. Median sensitivity and specificity, based upon all baseline versus all peak balloon inflation cases, were calculated for results generated at each electrode position. With the precordial leads positioned correctly the sensitivity and specificity were 51.1% and 91.1% respectively. When all precordial leads were placed 50mm superior to their correct position the sensitivity increased to 57.8% whilst specificity remained unchanged. At 50mm inferior to the correct position the sensitivity and specificity were 46.7% and 88.9% respectively. The results show a variation of more than 10% in sensitivity when the electrodes are moved up to 100mm vertically.*

## 1. Introduction

The 12-lead electrocardiogram (ECG) remains the most important tool for screening patients with suspected acute coronary syndromes. In particular, it plays a vital role in the early diagnosis of patients with suspected acute myocardial infarction (MI). In this context much effort has been devoted to developing and refining recommendations and guidelines on diagnostic criteria for application to the 12-lead ECG [1-3]. These guidelines serve as a reference for human interpreters in clinical practice and can form the basis for decision rules during the development of computerised diagnostic algorithms.

The development of criteria to allow the detection of acute coronary syndromes is challenging and the sensitivity of the 12-lead ECG is poor [4]. A particular issue is that the 12-lead ECG may not always provide sufficient spatial sampling to detect all ECG information that is projected onto the body surface [5]. Methods that use larger numbers of electrodes, however, have not seen significant uptake in routine clinical practice and are unlikely to supersede the 12-lead ECG in the near further.

A further issue with the 12-lead ECG is its often significant intra and inter individual variability. The sources of variability in the electrocardiogram have been widely studied [6]. These have been broadly grouped under technical issues relating to how the ECG is acquired and biological issues relating more to changes in the subject between recordings.

A technical issue that is well documented is the issue of electrode placement [7]. It has been shown that variations in electrode placement can result in significant variability in the recorded ECG waveforms. This is of particular relevance in the acquisition of the 12-lead ECG, which relies on very accurate electrode placement [8].

Guidelines typically suggest the application of electrodes with reference to anatomical landmarks and for the chest electrodes these landmarks are largely based on identification of intercostal spaces. Previous clinical studies have shown that this can be problematic for a number of reasons [9]. The failure to position electrodes correctly can be due to the unfamiliarity of the operator with the guidelines or can be due to the fact that the correct anatomical landmarks are difficult to identify in some subjects.

In this study we investigate the performance of diagnostic criteria on 12-lead ECGs where the precordial electrodes are moved from their recommended positions. The aim of the study is to illustrate how the accuracy of detecting coronary artery occlusion can be affected when electrode positions are altered.

## 2. Methods

Studies on the effects of electrode placement are often

based on the analysis of body surface potential maps (BSPMs). BSPMs are suitable as they provide ECGs simultaneously recorded from large numbers of recording sites on the thorax. This in turn eliminates the effect of variability that may be introduced through recording of serial 12-lead ECGs at different sites on the body.

## 2.1. Data

Analysis was based on a set of body surface potential maps recorded from 45 subjects undergoing PTCA. The data have been previously described in [10] and are summarized as follows. All subjects were elective PTCA candidates with single vessel coronary artery disease who had 120 lead BSPMs recorded during their procedure. The electrode array, illustrated in Figure 1, was used to record BSPMs with respect to the Wilson central terminal at a frequency of 500Hz. Subsequent to recording the ECG data were processed to produce a set BSPMs representing one averaged complex for each subject at baseline and a set of BSPMs representing one average complex for each subject during peak balloon inflation. This resulted in a total of 90 BSPMs (45 BSPMs at baseline and 45 BSPMs at peak balloon inflation). For the purpose of our study we treat the 45 baseline ECGs as characteristic of subjects absent of any vessel occlusion. We treat the 45 peak balloon ECGs as characteristic of subjects with a complete occlusion of a single vessel. The peak balloon group had an equal representation of subjects with occlusion of the left anterior descending artery (LAD, n=15), left circumflex artery (LCX, n=15) and right coronary artery (RCA, n=15). The population is further summarized in Table 1.

## 2.2. Electrode misplacement simulation

In this study we focused on misplacement of the six precordial leads of the 12-lead ECG. Specifically, we simulated the effects of moving all six precordial leads simultaneously, in small increments of 5mm, up to 50mm both superior and inferior of their standard locations. Whilst it is impossible to simulate the infinite number electrode misplacement scenarios that could occur in real life we felt that this approach would be reflective of situations where there is a failure to identify the correct intercostal space. This clearly would result in electrode misplacement on the vertical axis.

Electrode misplacement was simulated by up sampling the number of electrodes in the anatomical vicinity of interest. A combination of interpolation methods were used to achieve this. In the first instance data from the 120 lead BSPMs were expanded to 352 leads using the 3-dimensional interpolation method described by Oostendorp et al [11]. These 352 leads correspond with the 352 nodes in the Dalhousie torso [10]. Linear interpolation was then used to generate signals at leads placed at the 5mm steps inferior and superior to the six precordial leads.

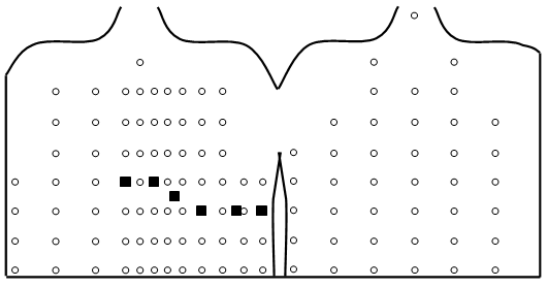


Figure 1. 120 lead BSPM electrode array with location of 6 precordial leads highlighted.

Table 1. 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 |

Once the data at all the interpolated leads were generated a total of n=21 12-lead ECGs were extracted for each case. These represented 12-lead ECGs recorded from each position as the precordial leads were moved away from their actual locations in 5mm increments up to and including 50mm superior to the actual locations and 50mm inferior to the actual locations. Also included was the 12-lead ECG as would have been recorded with the precordial leads in the correct locations. To facilitate application of diagnostic criteria the J-point potentials were extracted for each 12-lead ECG for each case. J-point location was taken as that identified in the original BSPM data.

## 2.3. Algorithm

A computer algorithm was developed based on the most recent guidelines and recommendations for the identification of ST segment elevation changes resulting from coronary occlusion [3]. These guidelines state that, for the identification of STEMI in 12-lead ECGs, subjects will exhibit ST-segment elevation in at least two

contiguous leads. ST-segment elevation is defined as a J-point potential in excess of 100μV. This is in any lead with the exception of V2 and V3 where a threshold of 200μV should be observed in men of 40 years and older. The threshold for leads V2 and V3 should be increased to 250μV in men younger than 40 years, and, should be reduced to 150μV in women.

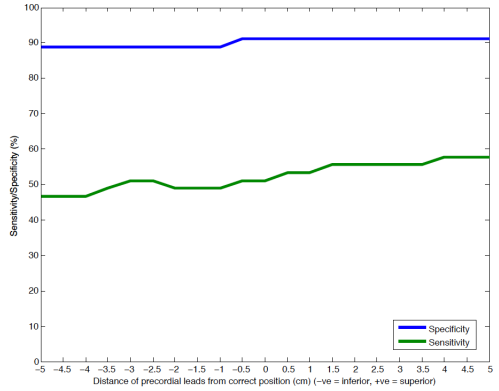
Our algorithm also considered the identification of ST segment depression changes. ST-segment depression was defined as a J-point potential less than a predefined threshold in at least two contiguous leads. As in [3] we required the depression of the ST-segment to be horizontal or down sloping. However, we elected not to use the 50μV threshold for all leads as proposed in [3]. Instead, we relied on the thresholds proposed in [12]. In this guideline a threshold for depression of 50 μV is proposed for leads V2 and V3 whereas a threshold of 100μV is proposed for all other leads. Our experience has shown that these thresholds are more specific with little cost to sensitivity. Our algorithm did not include T-wave analysis.

The algorithm was developed to identify 12-lead ECGs meeting the above criteria as being synonymous with a coronary artery occlusion. Twelve lead ECGs that did not meet these criteria were deemed not to be associated with coronary artery occlusion. The above algorithm was applied to all 12-lead ECGs that had been generated from the BSPM data. The output of the algorithm for each case was compared to the known status of that case (e.g. baseline or peak balloon ECG).

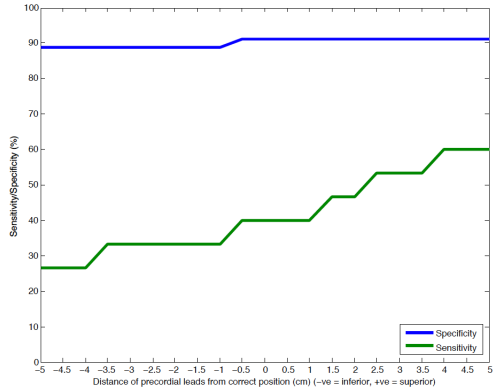
## 3. Results

Sensitivity and specificity, based upon all baseline versus all peak balloon inflation cases, were calculated for results generated at each electrode position. Figure 2a illustrates that, with the electrodes correctly positioned, our algorithm has a sensitivity of 51.1% and specificity of 91.1%. These figures are in line with previous published values for the diagnostic accuracy of the 12-lead ECG and serve to highlight the high specificity but low sensitivity of this modality. Whilst there is some variability in Figure 2a, attributed to the small numbers of subjects studied, there is a definite trend as the positioning of the precordial electrodes changes. Specifically, as the precordial leads are moved superiorly there is an increase in sensitivity whilst specificity is less affected.

Figure 2a provides an indication of the impact of electrode placement across a small population of subjects where the location of the culprit lesion is equally distributed between LAD, LCX and RCA. However, it is appreciated that the detection of LAD occlusion is likely to be more affected by precordial electrode placement than occlusion of the LCX and RAD. In order to provide more granularity on the effects of the electrode placement on the LAD group we also made a comparison between the LAD peak balloon occlusions and all subjects at baseline. This is illustrated in Figure 2b. As one would expect the implications for the LAD group only are more significant. Here a much more considerable increase in sensitivity gain can be seen as electrodes are moved from -50mm (26.7% sensitivity) to +50mm (60.0% sensitivity).




(a)




(b)

Figure 2. Variation in specificity and sensitivity when precordial leads are moved +/- 50mm (superiorly/inferiorly). a) All data included (15 LAD, 15 LCX, 15 RCA) b) LAD occlusions vs. all baseline.

## 4. Discussion

The results show that precordial lead electrode placement may have an impact on the sensitivity of the 12-lead ECG. This is particularly the case in the detection of subjects with an occluded LAD. LCX and RCA occlusions are less affected as their detection relies more on limb lead potentials.

In order to further understand the issue relating to subjects with an LAD occlusion we present data from one subject in particular. This subject's data is presented in Figure 3 as a BSPM of J-point potentials during peak balloon inflation. It can be seen that, for this subject, the area of ST-segment elevation is localised with a maxima above where leads V2-V4 are located. For this particular

subject inferior placement of the precordial leads would not detect this area of elevation and may also conceal reciprocal ST-depression. Whilst this data only represents the body surface potential distribution for just one subject we did find a similar pattern for a number of the LAD cases in our data.

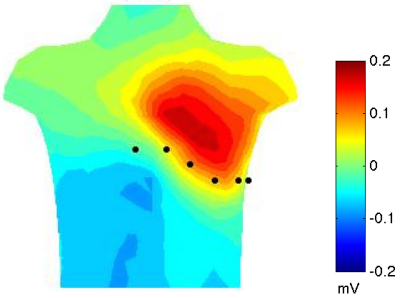



Figure 3. J-point BSPM of subject during peak balloon inflation causing complete occlusion of the LAD.

It should be noted that the 12-lead ECG from the subject whose BSPM is illustrated in Figure 3 did show some sign of ST segment depression on a number of limb leads. Whilst this ST-segment depression did not meet the thresholds specified in our algorithm it might draw the attention of a human observer. Obviously these limb lead ST segment changes remain constant regardless of precordial lead placement.

## 5. Conclusion

Our analysis has shown that precordial electrode placement may impact upon accuracy of the detection of coronary artery occlusion. This is particular the case when the LAD artery is occluded as the associated body surfaced potential changes may be localised outside the area recorded by the precordial electrodes. Whilst our current study serves to illustrate this it is limited by the small number of subjects studied and the lack of more complex multiple artery lesions.

## Acknowledgements

This project has received funding from the European Union's Horizon 2020 Framework Programme for Research and Innovation Action under Grant Agreement no. 643491. PATHway: Technology enabled behavioural change as a pathway towards better self-management of CVD (www.pathway2health.eu). The authors would also like to thank Professor Milan B. Horacek for providing the data used in this study.

## References

[1] Antman E, Bassand J, Klein W, Ohman M, Sendon JLL, Rydén L, et al. Myocardial infarction redefined—a consensus document of the Joint European Society of Cardiology/American College of Cardiology committee for the redefinition of myocardial infarction: the Joint European Society of Cardiology/American College of Cardiology Committee. J Am Coll Cardiol 2000;36(3):959-969.

[2] ESC J. ACCF/AHA/WHF Task Force for the Redefinition of Myocardial Infarction& Thygesen, K. & Alpert, JS & White, HD," Universal definition of myocardial infarction. J Am Coll Cardiol 2007;50:2173-2195.

[3] Thygesen K, Alpert JS, Jaffe AS, White HD, Simoons ML, Chaitman BR, et al. Third universal definition of myocardial infarction. J Am Coll Cardiol 2012;60(16):1581-1598.

[4] White HD. Evolution of the definition of myocardial infarction: what are the implications of a new universal definition? Heart 2008 Jun;94(6):679-684.

[5] Menown I, Patterson R, MacKenzie G, Adgey A. Body-surface map models for early diagnosis of acute myocardial infarction. J Electrocardiol 1998;31:180-188.

[6] Schijvenaars BJ, van Herpen G, Kors JA. Intraindividual variability in electrocardiograms. J Electrocardiol 2008;41(3):190-196.

[7] Schijvenaars BJ, Kors JA, van Herpen G, Kornreich F, van Bemmel JH. Effect of electrode positioning on ECG interpretation by computer. J Electrocardiol 1997;30(3):247-256.

[8] Kligfield P, Gettes LS, Bailey JJ, Childers R, Deal BJ, Hancock EW, et al. Recommendations for the Standardization and Interpretation of the ElectrocardiogramPart I: The Electrocardiogram and Its Technology A Scientific Statement. J Am Coll Cardiol 2007;49(10):1109-1127.

[9] McCann K, Holdgate A, Mahammad R, Waddington A. Accuracy of ECG electrode placement by emergency department clinicians. Emergency Medicine Australasia 2007;19(5):442-448.

[10] 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.

[11] T. F. Oostendorp, a. Van oosterom and g. Huiskamp, "interpolation on a triangulated 3d surface," *journal of computational physics,* vol. 80, pp. 331-343, 1989.

[12] Wagner GS, Macfarlane P, Wellens H, et al;. AHA/ACCF/HRS recommendations for the standardization and interpretation of the electrocardiogram: part VI: acute ischemia/infarction: a scientific statement. J Am Coll Cardiol. 53:1003–1011. 2009.

Address for correspondence.
Dr Dewar Finlay
School of Engineering
University of Ulster
Shore Road
Belfast
d.finlay@ulster.ac.uk