Detection of Electrode Interchange in Right Precordial and Posterior ECG Leads

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Abstract

This study presents a method for automated detection of misplaced supplementary precordial leads, including the right-sided V3R, V4R and the posterior V8, V9 leads. Considering their uncommon use in clinical routine, a lead reversal is quite probable and could result in erroneous diagnosis and treatment. The method allows real-time implementation by scoring inter-lead cross-correlations over continuous 4s episodes, scanning the normal progression of PQRST waveforms within leads [V4R, V3R, V3, V4] and [V4, V5, V6, V8, V9]. A large 16-lead ECG database with 1333 chest pain patients is used to test the performance of the method for all possible 23 swaps between the supplementary leads V4R, V3R, V8, V9, assuming correct positions of the standard V1-V6. The sensitivity (Se) for lead reversals is Se=94.1±4.6%, ranged between 78.5% and 97.8%, with the most difficult detection of V3R/V4R swap (Se=78.5%), V4R/V9 swap (Se=83.7%), V8/V9 swap (Se=91.8%). The achieved specificity for the correct lead positions is Sp=83.4%.

1. Introduction

Lead reversal has been reported to occur in 0.4-4% of all standard 12-lead ECGs [1]. This proportion might be much higher for 16-lead ECGs, including the uncommon used right-sided precordial and posterior leads.

The automated detection of ECG electrode interchange is a challenging task that has been extensively studied for limb leads, e.g. recognition of left arm (LA) and left leg (LL) reversal by analysis of P wave amplitude [2] and QRS, P wave axes [3]; right arm (RA) and right leg (RL) swap alarm by search for flat line ECG in lead II [4]; detection of different LA/LL/RA reversals by direction of inscription of the P loop and/or the frontal P axis [5], analysis of the frontal QRS axis [6], comparison between a composite lead aVF/I and V6 [7], reconstruction of a lead using redundancy of information in the eight independent leads [8], application of morphology measurements, including QRS and P wave amplitudes, frontal axis and clockwise vector loop rotation combined with redundancy features [9], gathering the features in [3] and [8] for a more robust and accurate performance [10].

The detection of precordial lead reversals is elaborated in fewer studies. Among above referred methods for limb electrode interchange, only three analyse precordial leads: [3] address reversals of 5 adjacent leads (V1/V2, V2/V3, V3/V4, V4/V5, V5/V6), [8] evaluates reversals of 9 leads (5 adjacent leads, V1/V3, V4/V6, V4/V5/V6/V1/V2/V3, V6/V5/V4/V3/V2/V1), [9] handles reversals of 7 leads (5 adjacent leads, V1/V3, V4/V6). Twenty three reversals of precordial leads (V1-V6) are tested in a previous study of our team [11], showing that a method based on inter-lead correlation analysis and time-alignment of R and S peaks could provide a mean accuracy of up to 95.7%/93.5% on 77 healthy subjects with swapped/correct lead set.

Considering that supplementary precordial electrodes are placed for specific diagnostic purposes (improved study of right ventricle pathologies, scanning for presence of posterior myocardial infarction, etc.) and therefore are infrequently acquired, no methods regarding the correct placement of right precordial (V3R, V4R) and posterior (V8, V9) leads are found in the literature. However, their incorrect placement can simulate or mask ECG abnormalities and might lead to wrong therapy decisions.

The aim of this study is to present a method for automated detection of misplaced right precordial and posterior leads, based on the assessment of the cross-correlation between lead pairs.

2. ECG database

The database used in this study contains resting 16-lead ECG recordings (standard 12 leads, 2 right-sided precordial leads (V3R, V4R), 2 posterior leads (V8, V9)), collected from 1333 chest pain patients at the Emergency Department of the Basel University Hospital. The signals are acquired via a Schiller CS-200 Excellence device, with 1kHz sampling rate, 1μV resolution, in a bandwidth of 0.05 to 300Hz. The device does not give any feedback to the user with respect to any lead reversal. The precordial electrode positions are shown in figure 1.

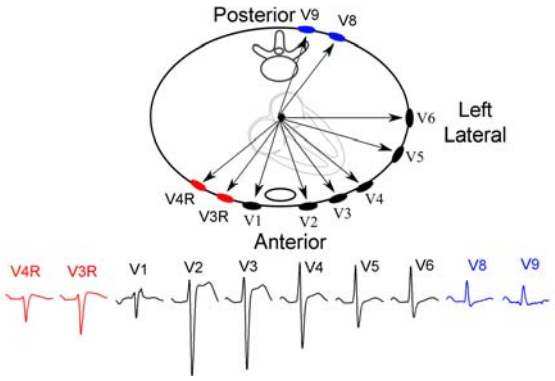

Figure 1. Positions of 10 precordial leads in the horizontal plane and the inter-lead normal PQRST progression.

3. Method

The method for automated detection of misplaced right precordial (V3R, V4R) and posterior (V8, V9) leads is based on inter-lead correlation analysis – an approach that follows our previous studies on lead reversals within the standard precordial set (V1-V6) [7, 11], however, extends the scope of the cross-correlated leads.

The algorithm works on continuous 4s episodes of pre-filtered ECG in a bandwidth 1 to 30 Hz. No special requirements for P-QRS-T patterns delineation are applied, considering that the high-amplitude components of the ECG signal (i.e. QRS complexes, T-waves) would have the greatest impact on the estimated cross-correlation coefficients between leads:

$$r(Vn,Vm)=\frac{\sum_{t=0}^{4\,seconds} Vn_t\,Vm_t}{\sqrt{\sum_{t=0}^{4\,seconds} Vn_t^2\ \sum_{t=0}^{4\,seconds} Vm_t^2}},$$

where *t* represents the time series of leads *Vn*, *Vm*.

3.1. Detection of V4R, V3R interchange

The incorrect placement of the right precordial leads V3R, V4R is detected by analysis of cross-correlations within the lead set: [V4R, V3R, V3, V4]. All inter-lead correlation coefficients are arranged in a matrix *R1(4x4)*.

$$R1=\begin{bmatrix} r(V4R,V4R)=1 & >r(V4R,V3R) & >r(V4R,V3) & >r(V4R,V4) \\ r(V3R,V4R)< & r(V3R,V3R)=1 & >r(V3R,V3) & >r(V3R,V4) \\ r(V3,V4R)< & r(V3,V3R)< & r(V3,V3)=1 & >r(V3,V4) \\ r(V4,V4R)< & r(V4,V3R)< & r(V4,V3)< & r(V4,V4)=1 \end{bmatrix}$$

The correlation coefficients within every row in *R1(4x4)* are compared and any deviation from the trend for gradual increase towards the diagonal entries, where a lead is compared to itself, is considered as a lead reversal. This assumption is illustrated in figure 2, showing a typical example where a gradual increase of the amplitude ratio R-wave/S-wave is observed from V4R to V4.

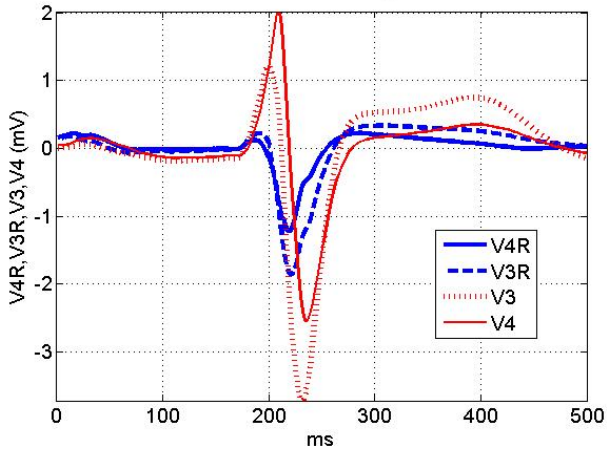

Figure 2. Typical alignment of P-QRS-T waveforms when V4R, V3R, V3, V4 are at their correct positions.

3.2. Detection of V8, V9 interchange

The incorrect placement of the posterior leads V8, V9 is detected by analyzing a matrix *R2(5x5)*, containing the cross-correlation coefficients of the lead set: [V4, V5, V6, V8, V9].

$$R2=\begin{bmatrix} r(V4,V4)=1 & >r(V4,V5) & >r(V4,V6) & >r(V4,V8) & >r(V4,V9) \\ r(V5,V4)< & r(V5,V5)=1 & >r(V5,V6) & >r(V5,V8) & >r(V5,V9) \\ r(V6,V4)< & r(V6,V5)< & r(V6,V6)=1 & >r(V6,V8) & >r(V6,V9) \\ r(V8,V4)< & r(V8,V5)< & r(V8,V6)< & r(V8,V8)=1 & >r(V8,V9) \\ r(V9,V4)< & r(V9,V5)< & r(V9,V6)< & r(V9,V8)< & r(V9,V9)=1 \end{bmatrix}$$

The trend for gradual decrease of the correlation coefficients outward from the main diagonal is used to detect a lead reversal. Figure 3 is an example of the typical distribution of the lead waveforms within one cardiac cycle, showing a gradual decrease of the S-wave amplitude from V4 to V9 and appearance of Q-wave in V8, increasing in V9.

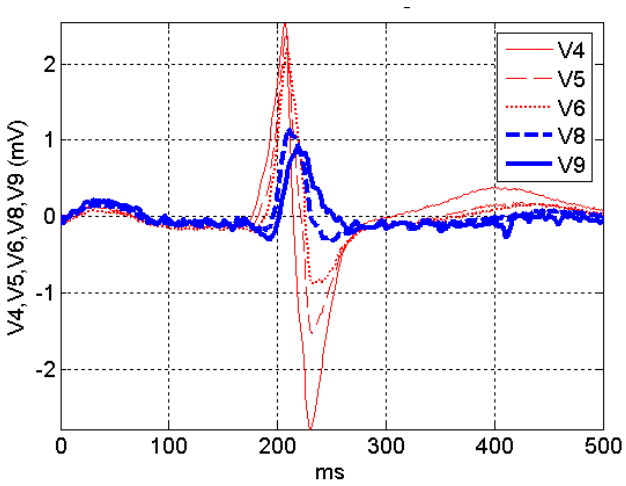

Figure 3. Typical alignment of P-QRS-T waveforms when V4, V5, V6, V8, V9 are at their correct positions.

4. Results and discussion

The performance of the method for detection of right precordial and posterior leads interchange is tested, considering that all ECG leads in the database are correctly acquired in the clinical environment. Given that the number of all possible placements of V3R, V4R, V8, V9 within the full set of 10 precordial leads (V1-V8, V3R, V4R) is immense (10*9*7*8=5040), we simulate a reduced number of 23 swapped positions only between these additional leads which are not acquired in the standard ECG and their interchange is quite probable (due to inexperience). We do not simulate reversals between standard precordial leads (V1-V6), which is beyond the scope of this study and shall be detected by another correlation matrix [11]. The full set of simulated swaps and their detection performance are presented in Table 1.

Table 1. Accuracy for detection of V4R, V3R, V8, V9 lead reversal. The first row (Test 0) shows the specificity (Sp) for the correct positions. The next rows show the sensitivity (Se) for 23 different swaps (grey cells).

Test No	Precordial Leads					Detection Accuracy (%)
	V4R	V3R	V1-V6	V8	V9	
	Grey cells show the swapped electrodes					
0	V4R	V3R	V1-V6	V8	V9	83.4
1	V3R	V4R	V1-V6	V8	V9	78.5
2	V4R	V3R	V1-V6	V9	V8	91.8
3	V4R	V9	V1-V6	V8	V3R	95.9
4	V9	V3R	V1-V6	V8	V4R	83.7
5	V4R	V8	V1-V6	V3R	V9	96.3
6	V8	V3R	V1-V6	V4R	V9	95.6
7	V9	V4R	V1-V6	V8	V3R	91.7
8	V3R	V9	V1-V6	V8	V4R	96.2
9	V4R	V8	V1-V6	V9	V3R	96.3
10	V8	V3R	V1-V6	V9	V4R	94.1
11	V4R	V9	V1-V6	V3R	V8	97.8
12	V8	V4R	V1-V6	V3R	V9	96.1
13	V9	V3R	V1-V6	V4R	V8	97.6
14	V3R	V8	V1-V6	V4R	V9	96.8
15	V3R	V4R	V1-V6	V9	V8	91.8
16	V8	V4R	V1-V6	V9	V3R	93.5
17	V3R	V8	V1-V6	V9	V4R	96.8
18	V9	V4R	V1-V6	V3R	V8	97.8
19	V9	V8	V1-V6	V3R	V4R	93.3
20	V8	V9	V1-V6	V3R	V4R	96.0
21	V3R	V9	V1-V6	V4R	V8	97.6
22	V9	V8	V1-V6	V4R	V3R	92.0
23	V8	V9	V1-V6	V4R	V3R	96.0
Test No 1 to 23: mean±standard deviation						**94.1±4.6**

The cases in figures 4-7 show different performances of the method run on 4s ECG without simulated lead reversal. Figures 4 and 6 present the normal progression of the waveforms within leads [V4R, V3R, V3, V4] and [V4, V5, V6, V8, V9] that is detected in 83.4% of the correct lead positions. This specificity limitation is suggested to be due to: unexpected differences between V4R, V3R (figure 5) that is confirmed by the low sensitivity for detection of V4R, V3R reversals (78.5%); presence of cardiac arrhythmia that alters the expected deflections of the ECG waves within leads (figure 7).

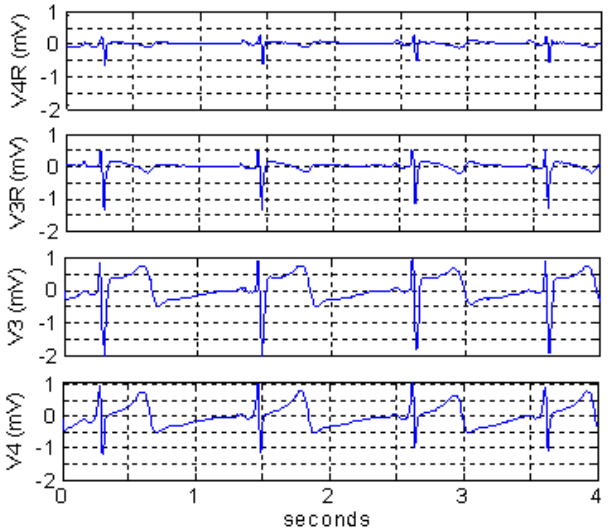

Figure 4. Leads correlated in matrix R1. The behavior of the waveforms across leads is typical – increasing R-wave and decreasing S-wave from V4R to V4. The method correctly reports: 'Correct Lead Position'.

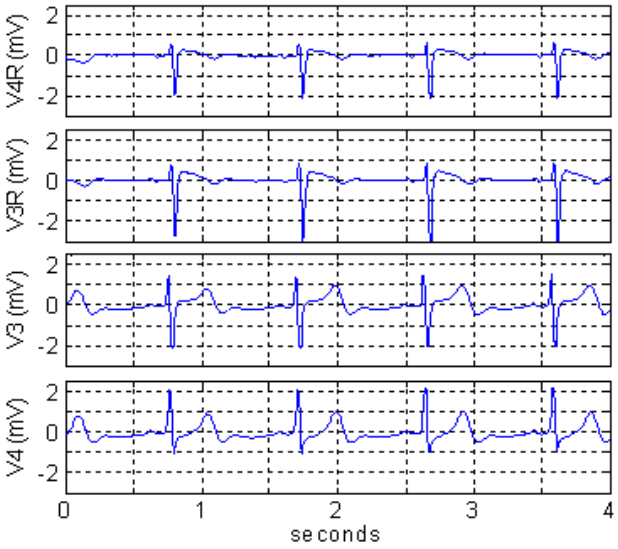

Figure 5. Leads correlated in matrix R1. The ratio R-wave/S-wave increases from V3R, V4R, V3, V4 that leads to higher correlation between V4R/V3 compared to V3R/V3 and erroneous alarm for 'Reversed V4R↔V3R'.

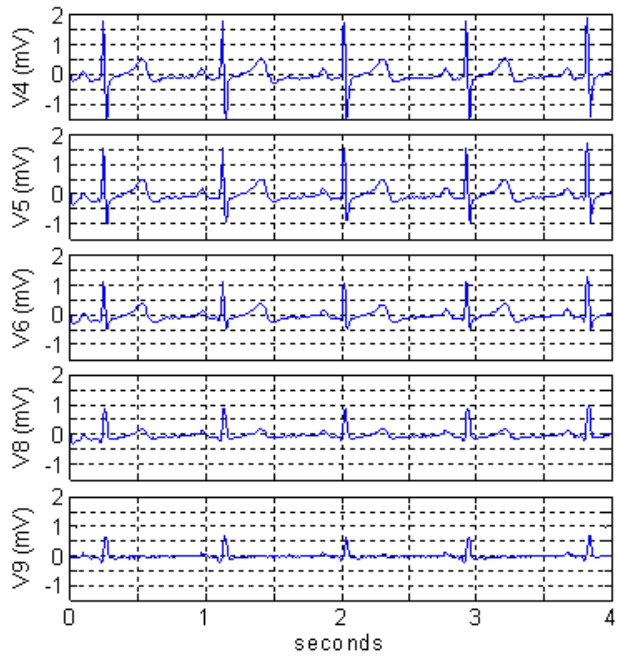

Figure 6. Leads correlated in matrix R2. The behavior of the waveforms across leads is typical – decreasing S-wave and appearing Q-wave from V4 to V9. The method correctly reports: 'Correct Lead Position'.

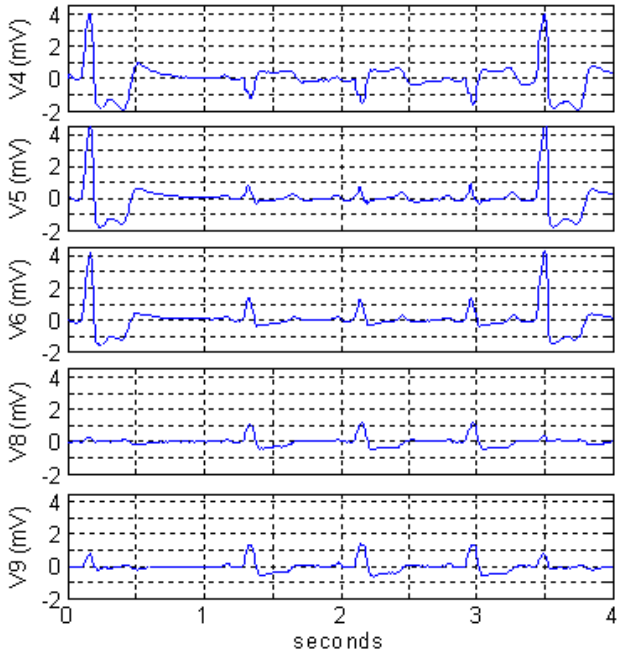

Figure 7. Leads correlated in matrix R2. The ectopic beats within the analyzed ECG interval alter the inter-lead correlations, found to be stronger between V6/V9 compared to V6/V8. This results in an erroneous alarm for 'Reversed V8↔V9'. Although we note the similarity of V8, V9 waveforms, usually with low signal amplitude, the accuracy for detection of simulated V8↔V9 reversal is as high as 91.8%.

5. Conclusions

This is the first study that presents a method for interchange detection of supplementary precordial leads (V3R, V4R, V8, V9), which is quite probable due to lack of experience in the clinical routine. The method scores inter-lead correlations over continuous 4s ECG episodes. A large 16-lead ECG database with 1333 chest pain patients is used to test 23 lead swaps with Se=94.1±4.6%, the most difficult are: V3R/V4R swap (78.5%), V4R/V9 swap (83.7%). Correct lead positions have Sp=83.4%.

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