DETECTION OF PERIPHERAL ECG ELECTRODES MISPLACEMENT

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***Summary**: A method and algorithm for detecting arbitrary peripheral ECG electrode misplacement is elaborated. Digitally recorded peripheral signals are used for generation of 5 new sets of lead reversals. A QRS complex is chosen. Its samples in I and aVF leads are taken from each of the 6 sets for module and angle calculation of the ECG vector in the frontal plane. Then its sample per sample projections over an axis coinciding with the V_6 lead direction (V_6 lies in the frontal plane also) are determined. Sums of the absolute sample differences between the projections and V_6 (which is invariant towards the peripheral lead reversals) are formed. The sums are compared and the lowest of them is assumed to belong to the true set of leads. Recordings from our own data base are processed by means of the software package MATLAB. The results of applying the algorithm on 97 recordings show a 94% correct detection.*

Introduction

Misplacements of ECG electrodes in signal acquisition result unavoidably in incorrect data interpretation, erroneous diagnosis and lack of proper therapy (GUIJARRO-MORALES *et al.*, 1991). Some of the swapped leads are extremely difficult to be detected not only by interpretation algorithms but even by experienced cardiologists. At first glance the chest electrodes seem to be most frequently subjected to reversals because of their close locations. Fortunately, the logical course of the negative-to-positive transition of the QRS complexes manifests easily eventual faults, while the peripheral electrode misplacements may cause severe diagnostic errors. HEDÉN et al. (1995b) reported 1% limb lead reversals in routine electrocardiography. They presume that around 300 million ECGs are recorded annually in the world, using computer-based interpretation programs. Therefore, up to 3 million traces may be a source of errors.

Some interpretation programs (e.g., the MARQUETTE MAC II ECG Analysis Program, 1982) offer several rules for detection of suspected arm electrode reversal. No other limb electrode misplacements are recognized by these programs. HEDÉN *et al.* (1995a) found that the sensitivity for the detection of the right/left arm electrode reversal becomes significantly higher using Neural Networks (NNs). HAISTY W.K.Jr. *et al.* (1993) proposed simple criteria for right arm/right foot electrode swapping. HEDÉN *et al.* (1995b) obtained by NNs sensitivities of 57.6% and 80.5% for left arm/left foot and right arm/left foot transpositions, respectively. However, the total number of possible peripheral electrode swappings is 5, including 2 circular rotations. Each of them could represent a rare but real case of ECG activity because the heart axis may have any spatial position. Therefore, a successful weight adjust in NNs during the training period is *a priori* highly embarrassed.

We elaborated a relatively simple algorithm for detection of any limb lead reversal.

Method

$\mathbf{V_6}$ is the only chest lead that can be considered to lie also in the frontal plane. The Einthoven triangle is presented in Fig. 1. As the other chest leads, $\mathbf{V_6}$ is invariant with respect to limb electrode misplacements because the Wilson point represents a mean sum of the three limb potentials. We assume that the angle φ between the directions of $\mathbf{V_6}$ and **I** leads is approximately $\varphi=45^0$. The **aVF** and **I** leads allow us to determine the module **M** and its angle α of the frontal component **FV** of the spatial vector. Here α is the angle between **FV** and the **X** axis. **FV** is then projected upon the $\mathbf{V_6}$ direction resulting in a computed $\mathbf{V_{6C}}$.

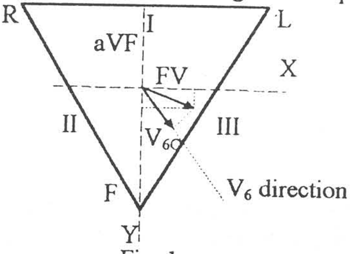

Fig. 1

Table 1

RA	LA	LL	Leads		
R	L	F	I	II	III
R	F	L	II	I	-III
L	R	F	-I	III	II
L	F	R	III	-I	-II
F	R	L	-II	-III	I
F	L	R	-III	-II	-I

The 6 sets of possible limb derivations are shown in Table 1. The limbs are designated by **RA** (right arm), **LA** (left arm) and **LL** (left leg). The generally accepted marks **R**, **L** and **F** are used for the lead banana-plugs. The first correct set forms the **I**, **II** and **III** Einthoven leads. The other swappings yield erroneous leads.

The differences between $\mathbf{V_6}$ and each of the $\mathbf{V_{6C}}$ calculated from misplaced leads are compared. The least difference is assumed to correspond to the true electrode set.

Data base and algorithm

We used our own 12-lead data base, recorded at the National Centre of Cardiovascular Diseases. The recordings were processed by the software package MATLAB. Peripheral and $\mathbf{V_6}$ leads were subjected to mains interference elimination and drift suppression. The Einthoven signals were swapped to simulate **I** and **aVF** leads from the 5 erroneous electrode locations. A QRS complex is chosen and its left and right isoelectric points **on** and **off** are detected. The recorded **j=1** samples $\mathbf{I}_{i,1}$ and $\mathbf{aVF}_{i,1}$ leads inside the surrounded complex (**i** varies from **on** through **off**) are taken for computing the modules $\mathbf{M}_{i,1}$ and the angles $\alpha_{i,1}$ enclosed between $\mathbf{FV}_{i,1}$ and the **X** axis. The sample projections $\mathbf{V_{6Ci,1}}$ over the $\mathbf{V_6}$ direction are calculated. This is then repeated for the 5 erroneous sets $\mathbf{j=2\div6}$.

$$M_{i,j}=\sqrt{I_{i,j}^2+aVF_{i,j}^2};\quad \tan\alpha_{i,j}=\frac{aVF_{i,j}}{I_{i,j}};\quad V_{6Ci,j}=M_{i,j}\cos(\alpha_{i,j}-\varphi)$$

$$\text{for}\quad i\in[on,off]\quad\text{and}\quad j=1,2,\ldots,6$$

Finally, the differences $\mathbf{d_j}$ are formed

$$d_j=\sum_{i=on}^{off}\left|V_{6i}-V_{6Ci,j}\right|\quad\text{for}\quad j=1,2,\ldots,6$$

and the minimal value is accepted as related to the true peripheral electrode set.

Results and discussion

Ninety-seven recordings with correct electrode locations were checked. Ninety-one of them were confirmed by the program, i.e., an accuracy of 94% was reached. Two of them are shown in Fig. 2 and 3. The calculated $\mathbf{V_{6C}}$ of the swapped sets are marked by $\mathbf{V_{6Csw1}}$ through $\mathbf{V_{6Csw5}}$. One of the false detected cases is presented in Fig. 4. Here the reversals of the 2nd and the 5th rows resulted in $\mathbf{d_2}=\mathbf{d_5}=7.43$, that are lower than the difference associated with the true electrode location $\mathbf{d_1}=8.24$.

These results proved the efficiency of the method and algorithm. The MATLAB program is running for about 10 s., so that an implementation in computerized electrocardiographs may offer a faster checking of the peripheral leads.

Acknowledgment

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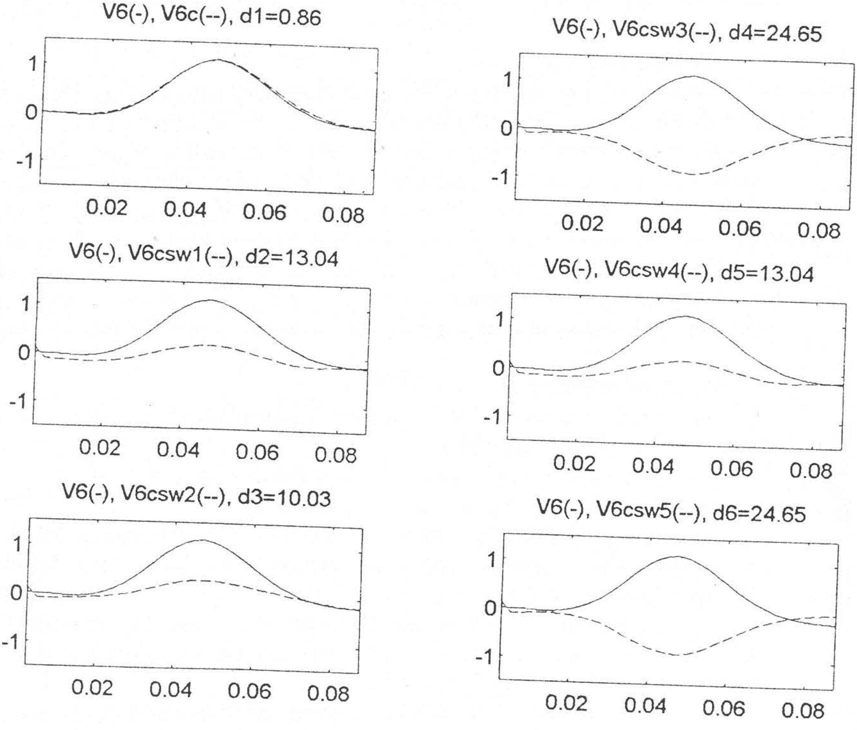

V6(-), V6c(--), d1=0.86

V6(-), V6csw3(--), d4=24.65

V6(-), V6csw1(--), d2=13.04

V6(-), V6csw4(--), d5=13.04

V6(-), V6csw2(--), d3=10.03

V6(-), V6csw5(--), d6=24.65

Fig. 2

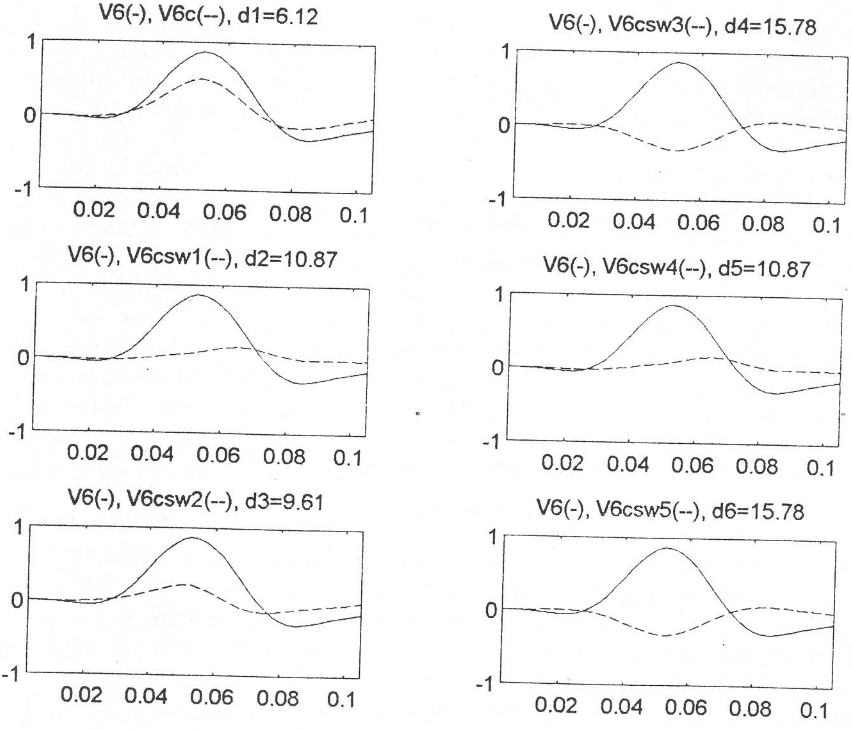
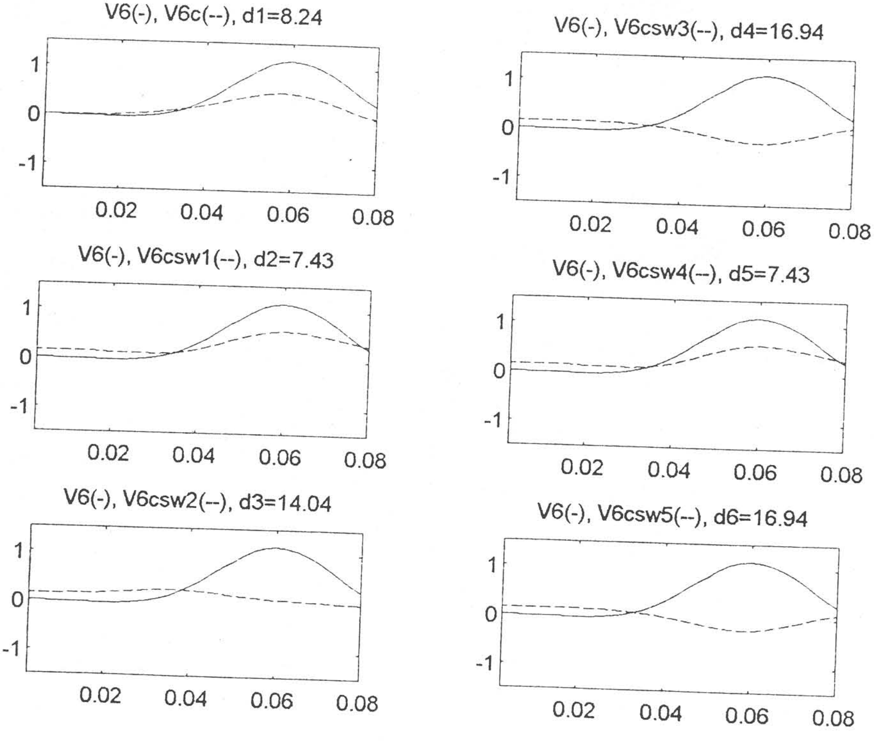

V6(-), V6c(--), d1=6.12
V6(-), V6csw3(--), d4=15.78
V6(-), V6csw1(--), d2=10.87
V6(-), V6csw4(--), d5=10.87
V6(-), V6csw2(--), d3=9.61
V6(-), V6csw5(--), d6=15.78
1
0
-1
0.02
0.04
0.06
0.08
0.1

Fig. 3



V6(-), V6c(--), d1=8.24

V6(-), V6csw3(--), d4=16.94

V6(-), V6csw1(--), d2=7.43

V6(-), V6csw4(--), d5=7.43

V6(-), V6csw2(--), d3=14.04

V6(-), V6csw5(--), d6=16.94

Fig. 4