The Effect of Precordial Lead Displacement on P-wave Morphology in Body Surface Potential Mapping

Michał Kania[1], Hervé Rix[2], Małgorzata Fereniec[1], Dariusz Janusek[1], Roman Maniewski[1]

[1]Nalecz Institute of Biocybernetics and Biomedical Engineering, Warsaw, Poland
[2] Lab. I3S, University of Nice-Sophia Antipolis, Sophia Antipolis, France

Abstract

The aim of this study was to investigate the variability of P wave morphology recorded in a close distance to precordial ECG leads.

The study consisted of 60 cardiac patients. The ECG signals interpolated at points located at a distance up to 7 cm from the precordial lead location were compared to signals recorded from precordial leads. The 67-channel high-resolution ECG data were used.

The distortions in ECG signals was increasing with the distance from precordial lead location, were specific for particular electrode and direction of displacement. Up to 5 cm there were not significant changes in values of correlation coefficient in all studied electrode positions. The P-wave morphology changes were prominent in values of delta parameter computed using the distribution function method and in values of normalized root mean square error beyond 2 cm distance from precordial leads V_1 *and* V_2*. No significant ECG morphology changes up to 5 cm from location of leads* V_3*,* V_4*,* V_5 *and* V_6 *were observed.* V_1 *electrode is more sensitive to vertical than to horizontal displacements in contrary to* V_2 *electrode where horizontal shift in direction to* V_1 *position play a key role.*

1. Introduction

The 12-lead ECG is currently the most common used electrode layout in clinical practise. However, its diagnostic value is limited in detection of acute coronary syndromes [1].

Many independent factors related to ECG measurement procedure or physiological interindividual variability affects the ECG examination results [2]. ECG electrodes could be inaccurate positioned in suggested anatomical landmarks [3]. This problem could arise from mistakes of medical staff [4-7], as well as from the need to expose the space on the thorax surface for other diagnostic procedures [8]. V_1 and V_2 electrodes are moved superiorly to second or third intercostal space [6], resulting in displacement of remaining precordial electrodes. Electrodes V_5 and V_6 are also placed frequently in the fifth intercostal space and not in parallel position to electrode V_4 [3].

Amplitude, shape and polarity of P-waves, as well as P-Q interval are of interest of physicians. All those information are used during diagnosis process and ECG signal disturbances can influence medical decision. Duration of P wave and the depth of P-wave inversion in leads V_1 or V_2 are strong independent predictors of cardiovascular death [9]. It was also shown [10] that P-wave shape is significantly changed by a sleep apnea occurence.

The aim of the study was to examine the influence of a precordial ECG electrode misposition in the range up to 7 cm on P wave morphology changes.

2. Materials and methods

2.1. Measurements and signal preprocessing

The study was carried out in a group of 60 men (average age 62.7 ± 11.7 years). The high-resolution ECG system (*ActiveTwo, Biosemi*) were used in the study. The 64 active electrodes were positioned on the thorax surface according to modified Amsterdam lead system [4; 29] (Fig. 1).

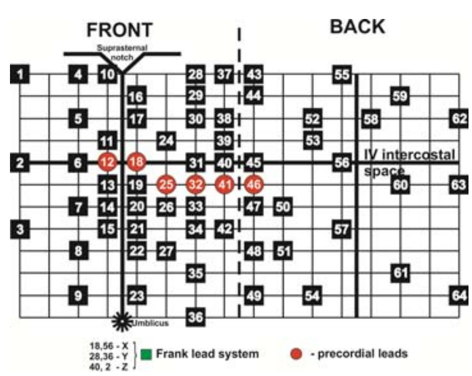

Figure 1. ECG electrode layout on the thorax surface.

The five minute ECG recordings measured at rest were band-pass filtered with cutoff frequencies 0.05, 250 Hz. Baseline wander was reduced using linear estimation and removal procedure (with U-P segment refer to isoelectric line). Signal averaging in time was performed using cross-correlation method. ECG characteristic points were automatically detected as in [11], checked and edited.

2.2. Assessment of the influence of electrode misplacement on ECG signal morphology

ECG signals were interpolated [12] in 11x11 coordinates of rectangular grid centered on selected precordial lead position. The positions of interpolation points were estimated for each subject. The distance between neighboring points was 1 cm. The shapes of reference P-waves recorded from precordial leads were compared to shapes of P waves obtained by interpolation procedure. The three markers of ECG morphology changes were used: Δ parameter computed using Distribution Function Method (DFM) [13], normalized root-mean square error (*NRMSE*) and Pearson correlation coefficient (*R*) [14].

If a reference signal $s_0(t)$ and signal to compare $s_j(t)$ are equal in shape, signal $s_j(t)$ can be derived from $s_0(t)$ through affine function:

$$s_j(t') = k_j' s_0\left(\frac{t'-t_j}{a_j}\right) \text{ where } t' = a_j t + t_j \text{ and } k_j' = \frac{1}{k_j}. \quad (1)$$

The k_j, a_j, t_j are respectively magnitude coefficient, scale coefficient, and delay. ECG signals are after baseline correction therefore offset of s_0 was not included in above equation. The difference in shape between $s_0(t)$ and $s_j(t)$ could be characterized by function φ defined by relation:

$$S_j(t) = S_0(\varphi(t)) \text{ i.e. } \varphi = S_0^{-1} \circ S_j, \quad (2)$$

where $S_j(t)$ and $S_0(t)$ are the normalized integral functions of $s_j(t)$ and $s_0(t)$ respectively, increasing from zero to one. The shape variation between $s_j(t)$ and $s_0(t)$ can be quantified by Δ parameter measuring the distance between the function φ and the least mean square line fitted on φ:

$$\Delta = \sqrt{\frac{1}{M}\sum_{i=1}^{i=M}(\varphi(i)-y(i))^2} \quad (3)$$

The Δ parameter describes the 'real' ECG morphology changes between a pair of two signals omitting the scaling effect i.e. stretching or shrinking of ECG waves either in amplitude or in time.

The analysis of P-wave shape changes in time in a given precordial lead were performed in order to distinguish the effect of ECG electrode misplacment from physiological variability of P-wave morphology in time. Five sets of ECG signals (V_1-V_6) averaged in time from consecutive one minute recordings were compared to the first set. The mean P-wave shape variability in a given ECG lead was quantified by Δ, *NRMSE* and *R*.

3. Results

The largest observed P-wave shape changes in time were 0.01 ± 0.01 (V_1), 0.01 ± 0.01 (V_4) and 0.99 ± 0.01 (V_5) for Δ, *NRMSE* and *R,* respectively. These values were used as a threshold to decide about significance of shape changes due to electrode displacement.

The mean values of computed parameters quantified the influence of ECG electrodes shift by 5 cm on P wave shape were presented in Table 1.

Table 1. Maximal observed changes of ECG morphology at 5 cm distance from precordial electrode positions. Bold font highlights the largest ($\overline{\Delta}$, $\overline{NRMSE}$) and smallest ($\overline{R}$) values ± SD of ECG shape difference descriptors..

Parameter	V_1	V_2	V_3
$\overline{\Delta}$ [ms]	0.08±0.05	**0.10±0.04**	0.06±0.02
$\overline{NRMSE}$ [%]	16±6	**20±7**	13±7
$\overline{R}$	0.90±0.08	**0.84±0.17**	0.92±0.11

The distributions of obtained mean values of Δ, *NRMSE* and *R* parameters (called Shape Difference Maps – *SDM*) around precordial electrodes positions are presented in Fig. 2. *SDM* for V_4, V_5 and V_6 leads were not shown due to not observed significant changes in $\overline{\Delta}$, $\overline{NRMSE}$ and $\overline{R}$.

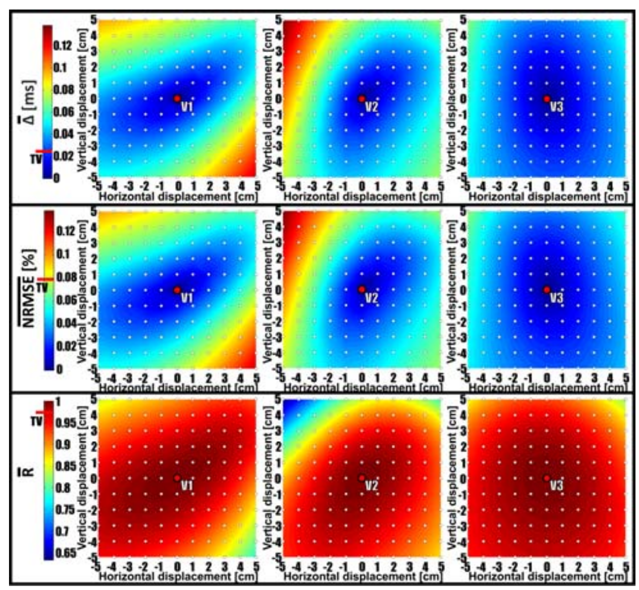

Figure 2. Body surface distributions of $\overline{\Delta}$, $\overline{NRMSE}$ and $\overline{R}$ parameters computed for P-wave in the studied patients group. Distributions of parameter values (*SDM*) quantify the shape difference between P-wave recorded in the standard position of selected precordial electrode (marked

by red dot in the center of each map) and P-wave interpolated in a given distance from correct electrode position. Maps for each parameter are presented in a separate row. The subsets of *SDM* for a given precordial electrode are shown in subsequent columns. The distance between neighboring interpolation points corresponds to 1 cm shift of the standard precordial lead. The threshold values related to the largest observed P wave shape variability in time in precordial leads are marked on colorbars by red line.

Color scales of SDM were normalized. The red (blue) color corresponds to the maximum (minimum) value for a given shape parameter. The standard deviations from mean shape difference descriptors ranged from 0 to 0.06 for $\overline{\Delta}$, from 0 to 0.09 for $\overline{NRMSE}$ and from 0 to 0.26 for $\overline{R}$. These values were increasing with the distance from precordial leads positions and its distributions follow the changes in values of $\overline{\Delta}$, $\overline{NRMSE}$ and $\overline{R}$.

4. Discussion

In performed study significant changes of P-wave morphology were observed when precordial electrodes were displaced from their correct positions.

Distributions of all evaluated parameters ($\overline{\Delta}$, $\overline{NRMSE}$ and $\overline{R}$) in relation to electrode shift in a given direction were coincident. The changes in values of $\overline{\Delta}$ followed the changes in vales of $\overline{NRMSE}$ and $\overline{R}$ with no matter in which direction electrode were shifted. This suggest that observed differences in P-wave shape relate to 'real' morphology changes i.e. to changes in the main waveform pattern, not to scaling of ECG signal either in time or in amplitude.

The dispersion of P-wave shape increased with the distance from precordial lead. That shape disparity was observed both in the mean shape difference values and its standard deviation values (Fig. 2). The $\overline{R}$ parameter was the least sensitive to changes of precordial electrode positions compared to other calculated parameters. Up to 5 cm there were not visible changes in values of correlation coefficient in all studied electrode locations.

There were not observed changes in P-wave morphology up to 2 cm from precordial leads locations (Fig. 2). Mean values of shape difference descriptors were in the range of physiological variability of ECG signal morphology in time (Table 1). Our previous results [14] suggest that this observation is valid as well for QRS and ST-T-U complexes. This is also in agreement with the results of simulation study performed by Turzova et al. [15] where the mean relative error between body surface potential maps estimated in standard and verticaly shifted electrodes positions remained less than 5% up to ± 2 cm shift. Beyond the threshold value set to 2 cm differences in BSPM steeply increased [15].

A degree of P wave morphology changes depends on ECG lead, shift magnitude, and direction of displacement. We found that leads V_1 and V_2 are the most sensitive to displacement (Fig. 2). For example a 5 cm left displacement of V_2, in direction to V_1 position, causes significant changes of P-wave shape (Table 1, Fig. 2). Besides the shift magnitude, directions of precordial lead displacement have significant impact on P-wave morphology (Fig. 2). Lead V_1 is more sensitive to vertical than horizontal displacement. In our previous study [14] we have shown that this statement is not valid for QRS and ST-T-U shape changes where horizontal displacement of V_1 plays a key.

Lead V_2, in contrast to V_1 electrode, is more sensitive to horizontal than to vertical displacement with more prominent changes of P-wave morphology while moving V_2 electrode in direction to V_1 lead position.

There were not significant changes of P-wave morphology observed in maps of all computed parameters for V_3, V_4, V_5 and V_6 leads.

Placing precordial electrodes in accordance with the existing standard does not ensure that for all subjects they are located in the same relation to the heart position. The source of ECG signal may be situated in the frontal plane at a distance up to 3 centimeters from the position of precordial electrode V_2 on the chest. This variability causes change in distribution and amplitudes of heart potentials measured on the body surface [16, 17].

The body surface potential mapping could be used to avoid problems with precise positioning of ECG leads with reference to heart location. BSPM capture information not visible in standard ECG leads [18-21]. Higher number of electrodes decreases the probability that some of diagnostic information will be missed.

5. Conclusions

This study was focused on detailed description of the influence of precordial electrodes displacement in any direction on P wave morphology. Performed study indicated V_1 and V_2 leads are the only ECG leads where P-wave morphology changes significantly as a consequence of precordial electrodes displacements up to 7 cm. The direction of electrodes displacement plays a key role. The influence of a given direction of electrode shift on ECG signal is different for each ECG lead. Performed multiparameter analysis suggests that observed changes in P-wave shape are not connected with signal scaling effect both in time and amplitude but they are real changes in the main waveform pattern. Whether observed changes have significant effect on clinical diagnosis need to be verified by clinically oriented studies.

Acknowledgements

This work was financially supported by National

Science Centre of Poland (grant no. 2011/01/N/ST7/06690 and grant no. NN 518 504 339).

References

[1] Finlay DD, Nugent CD, Kellett JG, Donnelly MP, McCullagh PJ, Black ND. Synthesising the 12-lead electrocardiogram: Trends and challenges. European Journal of Internal Medicine 2007; 18: 566-570.

[2] Schijvenaars BJ, van Herpen G, Kors JA. Intraindividual variability in electrocardiograms. Journal of Electrocardiology 2008; 41: 190-196.

[3] Kligfield P, Gettes LS, Bailey JJ, et al. Recommendations for the standardization and interpretation of the electrocardiogram. Part I: The electrocardiogram and its technology. A scientific statement from the American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; the American College of Cardiology Foundation; and the Heart Rhythm Society. Heart Rhythm 2007; 4: 394-412.

[4] Herman MV, Ingram DA, Levy JA, Cook JR, Athans RJ. Variability of electrocardiographic precordial lead placement: a method to improve accuracy and reliability. Clinical Cardiology 1991; 14: 469-476.

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

[6] Rajaganeshan R, Ludlam C, Francis D, Parasramka S, Sutton R. Accuracy in ECG lead placement among technicians, nurses, general physicians and cardiologists. International Journal of Clinical Practice 2008; 62: 65-70.

[7] Rudiger A, Hellermann JP, Mukherjee R, Follath F, Turina J. Electrocardiographic artifacts due to electrode misplacement and their frequency in different clinical settings. American Journal of Emergency Medicine 2007; 25: 174-178.

[8] Nelwan SP, Kors JA, Meij SH, van Bemmel JH, Simoons ML. Reconstruction of the 12-lead electrocardiogram from reduced lead sets. Journal of Electrocardiology 2004; 37: 11-18.

[9] Kaykha A, Myers J, Desser KB, Laufer N, Froelicher VF. The prognostic importance of isolated P-Wave abnormalities. Clinical Cardiology 2010; 33: E87-93.

[10] Boudaoud S, Rix H, Meste O, Heneghan C, O'Brien C. Corrected integral shape averaging applied to obstructive sleep apnea detection from the electrocardiogram. EURASIP Journal on Advances in Signal Processing 2007; 2007.

[11] Fereniec M, Stix G, Kania M, Mroczka T, Janusek D, Maniewski R. Risk assessment of ventricular arrhythmia using new parameters based on high resolution body surface potential mapping. Medical Science Monitor 2011; 17: MT26-MT33.

[12] Sandwell DT. Biharmonic Spline Interpolation of GEOS-3 and SEASAT Altimeter Data. Geophysical Research Letters 1987; 2: 139-142.

[13] Rix H, Malengé JP. Detecting small variations in shape. IEEE Transactions on Systems, Man and Cybernetics 1980; 10: 90-96.

[14] Kania M, Rix H, Fereniec M, et al. The effect of precordial leads displacement on ECG morphology. Medical and Biological Engineering and Computing 2013; DOI: 10.1007/s11517-013-1115-9; In Press.

[15] Turzova M, Tysler M, Kneppo P. A model study of the sensitivity of body surface potential distribution to variations of electrode placement. Journal of Electrocardiology 1994; 27: 255-262.

[16] MacLeod R, Ni Q, Punske B, Ershler P, Yilmaz B, Taccardi B. Effects of heart position on the body-surface electrocardiogram. Journal of Electrocardiology 2000; 33: 229-237.

[17] van Oosterom A, Hoekema R, Uijen GJ. Geometrical factors affecting the interindividual variability of the ECG and the VCG. Journal of Electrocardiology 2000; 33 Suppl: 219-227.

[18] Carley SD, Jenkins M, Mackway Jones K. Body surface mapping versus the standard 12 lead ECG in the detection of myocardial infarction amongst emergency department patients: a Bayesian approach. Resuscitation 2005; 64: 309-314.

[19] Kania M, Fereniec M, Janusek D, et al. Optimal ECG lead system for arrhythmia assessment with use of TCRT parameter. Biocybernetics and Biomedical Engineering 2009; 29: 75-82.

[20] Lefebvre C, Hoekstra J. Early detection and diagnosis of acute myocardial infarction: the potential for improved care with next-generation, user-friendly electrocardiographic body surface mapping. American Journal of Emergency Medicine 2007; 25: 1063-1072.

[21] Svehlíkova J, Kania M, Turzova M, Heblakova E, Tysler M, Maniewski R. Identification of ischemic lesions based on difference integral maps, comparison of several ECG intervals. Measurement Science Review 2009; 9: 117-121.

Address for correspondence.

Michal Kania
Nalecz Institute of Biocybernetics and Biomedical Engineering,
Laboratory for Bioelectromagnetical Measurements and Imaging
ul. Trojdena 4, 02-109 Warsaw, Poland