The Effect of Heart Orientation on High Frequency QRS Components in Multiple Bandwidths

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Abstract

Reduced power of high frequency (HF) oscillations inside the QRS complex reflects ischemic pathology in the heart. In order to show spatial and frequency dependencies, we examined the effect of heart orientation on power of high frequency components under normal and ischemia condition within various frequency bands.

Root mean square (RMS) of the signal in QRS region within frequency bands from 150 Hz to 550 Hz and heart rotation around longitudinal axes (360°) were computed from four rabbit isolated hearts. Experimental protocol included control, ischemic and reperfusion phases.

This pilot study shows that RMS level of HF signal in non-ischemic heart differs within lead orientation and its maximum lies in a region around specific angle. Relative decrease in RMS value also depends on lead position. When depicted in spatial-frequency plane with polar coordinates, these relative changes contributes to specific patterns under both normal and ischemic conditions, which should be further examined.

1. Introduction

Various approaches of cardiac ischemia evaluation exist, yet most of them are related to morphology of standard electrocardiographic (ECG) recording which is conventionally limited to frequency range below 150 Hz.

Analysis of high frequency components of the ventricular depolarization during the QRS complex (HF-QRS) has been shown to provide valuable information on ischemic heart disease in previous studies [1, 2]. Extraction of high frequency features proceeds from signal averaged QRS complex to achieve low noise level; signal is further processed by band pass filtering. Frequency band 150–250 Hz is most commonly used in HF analysis considered as gold standard.

Two methods of HF-QRS quantification are most widely used. First is the root mean square (RMS) value, which represents averaged amplitude between QRS onset and offset. Decrease in RMS value is related to pathological changes [1]. Second approach is based on estimation of signal power envelope using Hilbert transform and numerical parameterization of the envelope morphology. Evaluation of zones with reduced amplitude (RAZ) describing electric dissociation of HF components is the most frequently used approach [2].

In recent work [3], an effect of heart orientation on morphology of isolated heart electrograms (EGs) under normal and ischemic condition has been presented. The main goal was to decrease the probability of incorrect classification of ischemic changes due to differences in anatomy or electrode placement.

This follow-up study investigates an effect of heart orientation on HF-QRS components in different frequency bands under the same condition as in [3, 4] with the same goal.

2. Methods

All experiments were performed in accordance with the guidelines for animal treatment approved by local authorities and conformed to legislation of the European Union.

2.1. Data measurement

Hearts from four New Zealand rabbits were excised under general anesthesia (i.m. injection of xylazin and ketamine) and retrogradely perfused according to Langendorff [5] at constant pressure of 85 mmHg by an oxygenated (95% O_2; 5% CO_2) Krebs-Henseleit buffer (1.25 mM Ca^{2+}, 37 °C).

Measurement was performed by non-contact method [6] using three Ag-AgCl electrodes placed in an orthogonal coordinates X, Y, Z on an interior wall of buffer-filled glass chamber (Figure 1). Data were acquired by NI USB-6259 measuring card with 16-bit resolution and sampling frequency f_s =2000 Hz.

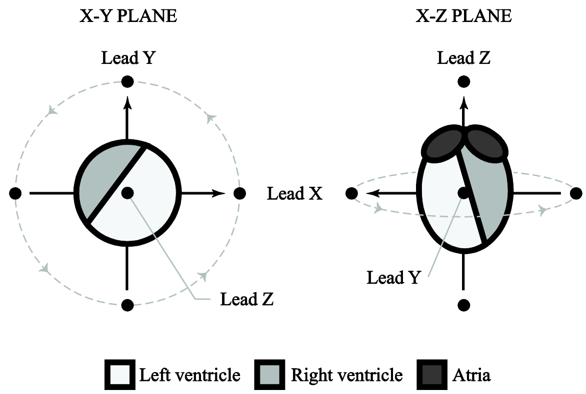

Figure 1. EG recording system with initial position of electrodes. Dashed line with arrows shows the direction of electrode rotation.

Heart function was stabilized for 20–30 minutes. Heart was then subjected to 10 min global ischemia followed by 10 min of reperfusion. In each experimental phase (including last part of the stabilization), heart was rotated along longitudinal axis within 10° step. Range of rotation was 0–90° as the electrode placement allows reconstruction of entire 360° range. In ischemia phase, rotation was done after stabilization of EG morphology (approx. 1.5 min). Length of the recording at any heart position was about 8–10 s and included 10–20 QRS complexes.

2.2. Signal processing

Segments of signal with noise or artefacts were excluded from further analysis. Baseline wander was suppressed by Lynn's filter with 0.5 Hz cut-off frequency. QRS complexes were detected and delineated by an automatic wavelet-based algorithm [7]. All delineated positions were verified and corrected manually.

EGs in the range between 100–350° corresponding to lead X were reconstructed as is shown in Figure 2. It should be noted that rotation of the electrode system instead of heart rotation is depicted in Figure 2 for better understanding. Only EGs from single full-range lead (X) underwent further processing.

HF-QRS were extracted from the signal-averaged QRS complexes using bandpass filtering. First, QRS complexes from the individual heart angles were grouped and aligned within each group to the same position using cross-correlation. Only QRS complexes with correlation coefficient exceeding 0.99 were included. Averaged QRS complex was decomposed by Butterworth bandpass filter into 7 frequency bands in range 150–550 Hz, band width of 100 Hz and 50 Hz step size. Higher frequency bands were not analyzed due to low SNR of the signal. Zero phase filtering in forward and backward direction was used to suppress phase nonlinearity. For each frequency band and each heart angle RMS voltage value from samples between QRS onset and offset was then computed.

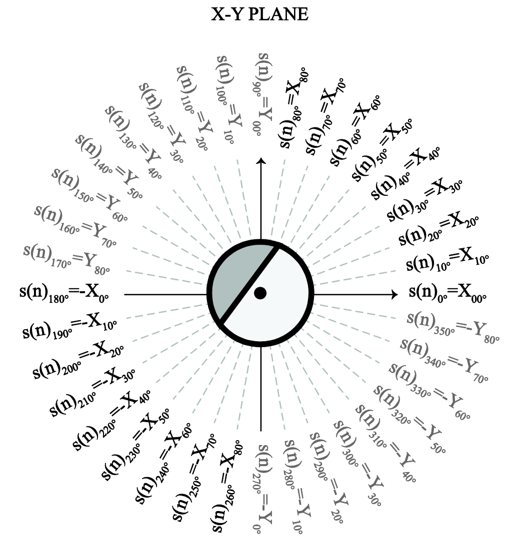

Figure 2. EG recording system with initial position of electrodes. Dashed line with arrows shows the direction of electrode rotation.

3. Results

RMS values in multiple frequency bands during control (normal condition) and ischemia phase and its dependency on heart orientation were investigated in this study. Overall results for all four isolated hearts are depicted in Figure 3. Under normal condition, zone of increased RMS values between angles 60° and 150° can be clearly seen (Figure 3, a) in bands 1–3 (150–350 Hz). Peak of the zone corresponds to the angle of 90° with magnitude about twice as large as compared to 'baseline' values. During ischemia, RMS values rapidly decrease over entire range of angles with relatively flat distribution (Figure 3, b) relatively to the normal condition. Relative voltage drop (Figure 4) is thus the highest within the elevated zone occurring under normal condition (about 30 % larger within the peak).

These relative changes between normal and ischemic conditions create specific patterns when depicted as normalized isolines in spatial-frequency plane with polar coordinates (Figure 5). Ischemic pattern (Figure 5, b) shows similar elevated zones in lower frequency bands; however, the position and quantity of the zones was highly individual in each heart and seems not to be related to the normal condition pattern.

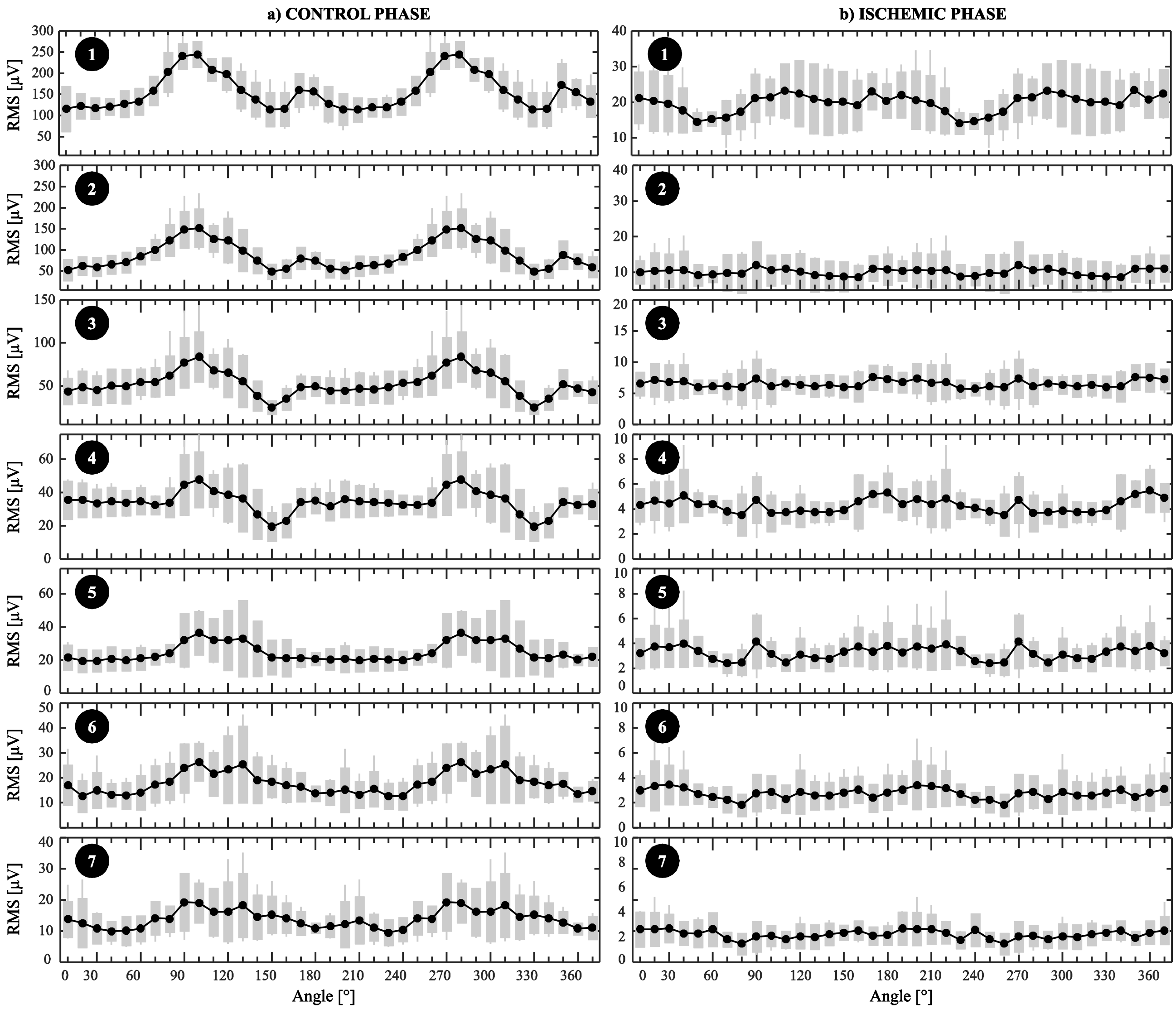

Figure 3. Relation between RMS value and heart rotation in a) control phase b) ischemic phase in different bandwidths; 1: 150–250 Hz; 2: 200–300 Hz; 3: 250–350 Hz; 4: 300–400 Hz; 5: 350–450 Hz; 6: 400–500 Hz; 7: 450–550 Hz.

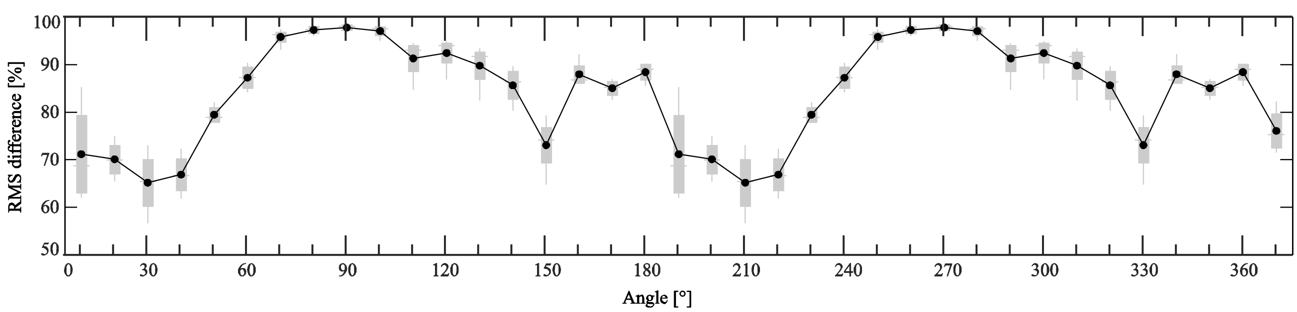

Figure 4. Relative difference in RMS values between control and ischemic phase and its relation to heart rotation (single isolated heart, box plots and median of values from frequency range 150–400 Hz).

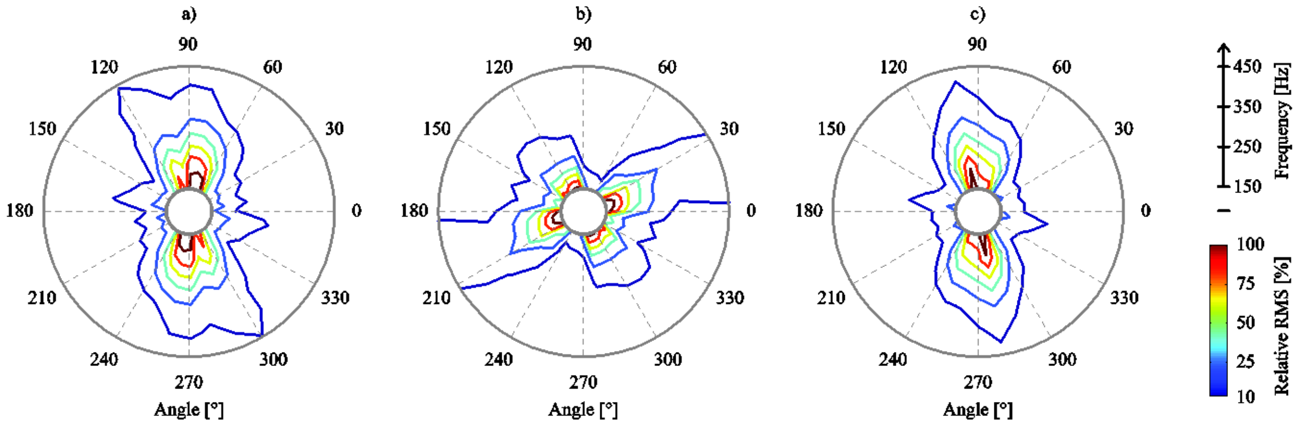

Figure 5. Contour patterns of normalized RMS values across all bands and angles in a) control, b) ischemic and c) reperfusion phase (single isolated heart). Frequencies are plotted in ascending order from the centre of the graph to the outer circle. RMS lower threshold is set to 10 %.

4. Conclusion

Decrease in RMS voltage value is related to pathological changes; however, there are no standard rules for classification of ischemic state based on the rate of decrease. There is strong dependence of relative decrease in RMS value on the position of ECG lead. Further research is needed to better understand the connection between heart structures and the level of RMS value under different conditions as well as the possibility of using individual patterns of residual RMS values during ischemia in classification process. Results of this study may help in choosing the most appropriate lead and designing experimental protocols in experimental HF-QRS analysis.

5. Study limitations

This work should be considered as preliminary study. Only four isolated hearts were investigated of which two showed slightly lowered RMS values in control phase due to very slow recovery during stabilization which may affect the results. With respect to the averaging of QRS complexes, there is a compromise between time dependent changes in HF-QRS components and increase of SNR. Therefore, only ten to twenty QRS complexes could be averaged in each heart position.

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