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Beat-to-Beat Spatial and Temporal Analysis for QRS-T Morphology

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***Abstract*—The aim of this study was to investigate beat-to-beat variations of spatial and temporal QRS and T loop morphology for identifying myocardial infarction (MI) patients. We investigated short-term 12-lead ECG recordings of 84 MI patients (22 female, mean age 63 ± 12 years and 62 male, mean age 56 ± 10 years) and 69 healthy control subjects (17 female, mean age 42 ± 18 years and 52 male, mean age 40 ± 13 years). To quantify spatial and temporal variations in QRS complex and T-wave morphology, we defined two descriptor parameters: point-to-point distance variability (*DV*) and mean loop length (*MLL*). These parameters were extracted from the reconstructed vector ECG, using singular value decomposition. The results showed that the beat-to-beat spatiotemporal point-to-point distance variability for QRS and T loops (DV_{QRS}; 0.13±0.04 vs. 0.10±0.04, $p < 0.0001$ and DV_T; 0.16±0.07 vs. 0.13±0.06, $p < 0.05$), were significantly higher in MI subjects compared to control subjects. In addition, the mean loop length of QRS and T loops were significantly higher in control subjects than MI ($p < 0.001$), respectively. In conclusion, the beat-to-beat spatiotemporal *DV* and *MLL* may be useful for characterizing conduction and repolarization characteristics in patients with MI.**

I. Introduction

The quantification of beat-to-beat QT interval variability (QTV) from standard 12-lead ECGs has received significant interest for analysing various types of heart diseases and autonomic nervous system function [1, 2]. However, the ECG represents the magnitude of the heart signal but not the orientation of the heart vector direction. In addition, recent research proposed that increased beat-to-beat QTV could occur due to lower T-wave amplitudes in the ECGs [3]. The Vectorcardiogram (VCG) is another technique (an orthogonal representation that reflects the electrical activity in the three perpendicular directions), which is the methodological extension of standard ECG. Consequently, VCG provides 3D representation of the cardiac electrical field with magnitude and vector direction. It has been suggested that the VCG may be a promising tool for analysing the heart diseases [4, 5].

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Nevertheless, in present days, the VCG is not directly recorded from the body surface for clinical studies, which was proposed by Frank [6]. Hence, currently, it is crucial to synthesize VCG from standard 12-lead ECG for obtaining orthogonal electrical activity. Different techniques have been proposed for synthesizing VCG from standard 12-lead ECG to analyze the cardiac signal [7, 8]. Previously, QRS and T loop parameters of VCG have been primarily studied for a single heartbeat [9, 10].

The beat-to-beat characteristics of spatial and temporal VCG features of QRS and T loop morphology are incompletely understood. Therefore, we introduce two VCG variables obtained from QRS and T loops for beat-to-beat VCG analysis. We hypothesized that the new variables may provide useful information for characterizing MI patients.

II. Methods and Methodology

A. Study Population

In this study, standard 12-lead ECGs (approximately 2 minutes duration with sampling frequency 1000 Hz) of 153 subjects were investigated, where 84 subjects had MI (22 females, mean age 63 ± 12 years and 62 males, mean age 56 ± 10 years) and 69 subjects were healthy (17 females, mean age 42 ± 18 years and 52 males, mean age 40 ± 13 years). In MI, patients ECG were recorded approximately 1-2 weeks after infarction. The data were obtained from the PTB diagnostic database (http://www.physionet.org).

B. Spatial VCG Analysis

For finding the beat-to-beat QT interval, we have used the algorithm proposed by Berger and co-workers [11]. The beat-to-beat QT interval was computed for each individual lead of the 12-lead ECG by following the same approach that has been described in our previous work [3]. A robust real-time QRS detection algorithm has been used which was proposed by Pan and co-workers[12]. A dual-threshold method has been applied in this algorithm to find missed beats and thus reduced the rate of false negative beats. If any beat is missed in one lead then a custom designed program automatically rejects the same beat for the rest of the leads. The beat-to-beat time interval for both QRS wave and T wave were determined from QT and R-peak detection time intervals. The offset of QRS wave was obtained by adding 48 ms from the R-peak detection time instant, which was proposed by Acar and co-workers [9]. The onset of T-wave also was computed by following the approach that has been described previously [9].

To derive VCG from 12-lead ECGs, we applied the mathematical transform method called SVD (singular value decomposition) on eight leads (I, II, V_1-V_6) which define a minimum dimensional subspace and ECG energy can be captured proposed by Acar and co-workers [9]. It is assumed that *M* is an input matrix (8×n), where 8 represents the number of corresponding rows of ECG leads and n is the number of samples of the QT interval (I, II, V_1-V_6). The SVD was then applied on *M* to create three matrixes *U, V* and *S* [9]. The columns of *U* denote the left singular vector, *V* denotes the right singular vectors, *S* denotes the decomposed vectors of the ECG signals.

The first three decomposed signals have been used in this study to reconstruct the orthogonal signal. The beat-to-beat descriptor point-to-point distance variability (*DV*) has been computed for QRS and T loops based on the coefficient of variance of the distance from each point of individual loop to the point of mean loop. The point-to-point distance has been computed by using an approach called K-nearest neighbour (kNN) algorithm where the Euclidean distance was computed between individual loops to mean loop. Furthermore, the beat-to-beat mean loop length was also computed for both QRS and T loops.

C. Statistical Analysis

We used commercial software GraphPad Prism 5® (GraphPad Software, Inc., La Jolla, CA, USA), PASW Statistics 18® (IBM SPSS, Inc., Somers, NY, USA) and Microsoft Excel version 2007 (Microsoft Corp., Redmond, WA, USA) for the statistical analysis. All values were expressed as mean ± standard deviation and considered statistical significant when $p < 0.05$. The unpaired Student t-test was used to investigate the descriptors characteristics in both studied subjects. Beat-to-beat variability of VCG descriptors was determined as standard deviation of the parameters.

III. RESULT

The mean beat-to-beat point-to-point distance for QRS loop (mean of DV_{QRS}) was not found significantly different between control group and MI group as shown in (Figure 1(A)). However, the point-to-point distance variability (DV_{QRS}) in QRS loop showed a significant increase in MI patients compared to control subjects (0.13±0.04 vs. 0.10±0.04, $p < 0.0001$) as shown in Figure 1 (B).

Similarly, the mean beat-to-beat point-to-point distance for T-loop (mean of DV_T) was not significantly different between groups as shown in Figure 2(A). However, the point-to-point distance variability (DV_T) showed significant increase in MI subjects (0.16±0.07 vs. 0.13±0.06, $p < 0.05$) compared to control subjects (see Figure 2 (B)).

Another descriptor parameter, the mean loop length (MLL_{QRS}) of QRS loop was found significantly higher in control than MI subjects were as shown in Figure 3.

Similarly, the mean T loop length (MLL_T) was found significantly longer in control subjects compared to MI patients as shown in Figure 4.

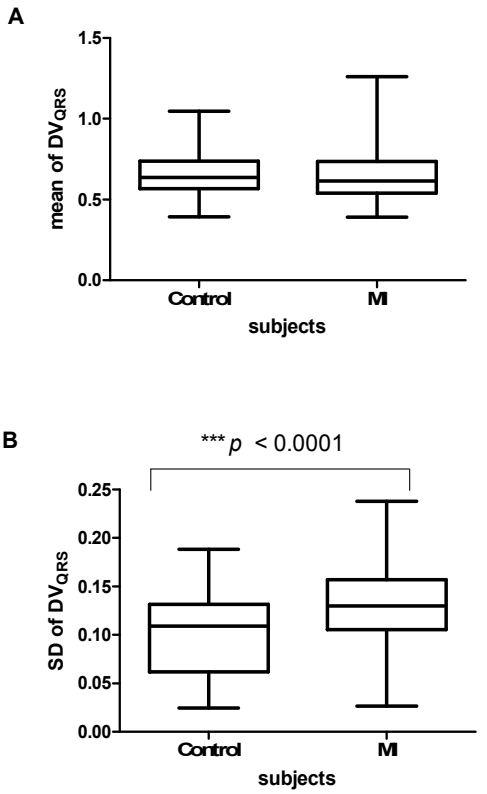

Figure 1. Mean (A) and SD (B) of point-to-point distance for QRS loop. Here, *** ($p < 0.0001$) indicate the significance in the differences between both groups.

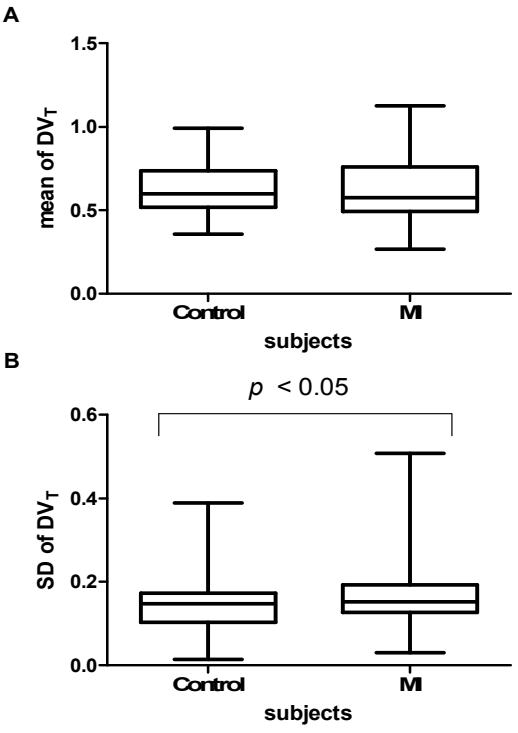

Figure 2. Mean (A) and SD (B) of point-to-point distance for T loop. Here, $p < 0.05$ indicate the significance in the differences between both groups.

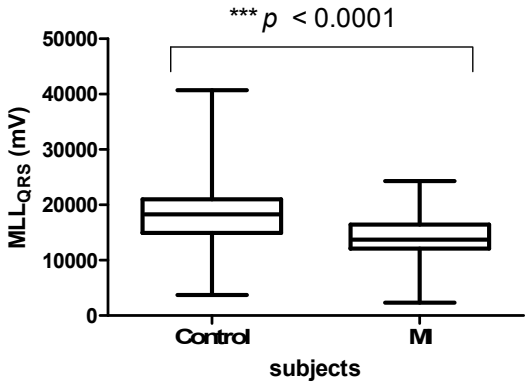

Figure 3. Mean loop length for QRS loop in control and MI subjects. Here, *** ($p < 0.0001$) indicate the significance in the differences between both groups.

IV. Discussion

This study introduces two new parameters for analyzing beat-to-beat spatiotemporal variations of ventricular depolarization and repolarization.

We found a significant difference between MI patients and control subjects in point-to-point distance variability (DV_{QRS}) in QRS loop where it was higher in MI than control subjects. The reason for higher DV_{QRS} in MI subjects was probably due to the irregular QRS loops compared to the healthy control subjects. Previous studies also demonstrated the prognostic capabilities of other VCG based indices for risk stratification in acute MI patients [13, 14].

Furthermore, the mean loop length was observed higher in healthy subjects in both QRS and T loop than in MI subjects. The reason behind this result might be the ST-elevation in MI subjects.

V. Conclusion

Our results indicate that beat-to-beat VCG analysis may be useful for characterising abnormalities in ventricular conduction and repolarization in MI patients.

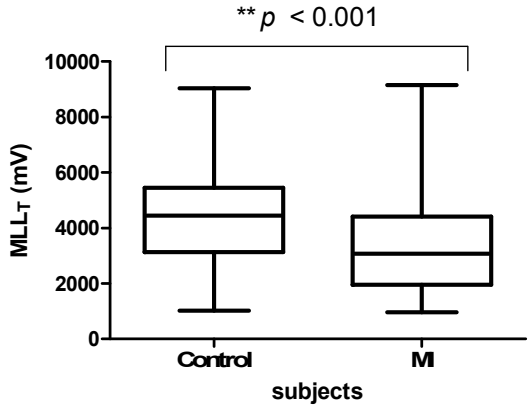

Figure 4. Mean loop length for T loop in control and MI subjects. Here, ** ($p < 0.001$) indicate the significance in the differences between both groups.

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