Low Level and High Frequency Fragmentation of the QRS Changes during Acute Myocardial Ischemia in Patients with and without Prior Myocardial Infarction

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Abstract

High frequency (HF) QRS fragmentation and very-low amplitude abnormal intra-QRS potential (uAIQP) analyses have been used to track ischemic changes during coronary artery occlusions. The aim of this study was to assess the relationship between these two techniques in detecting acute myocardial ischemia and the effects of a previous myocardial infarction (MI).

Fifty-six patients who underwent elective percutaneous coronary intervention (PCI) procedures were selected and classified into 2 groups according to the presence of prior healed MI (old-MI) (n=18) or not (no_MI) (n=38). Continuous ECG before and during the PCI were recorded and signal-averaged. uAIQPs were obtained using a signal modelling approach. $HFQRS_{RMS}$ was obtained by band pass filtering the ECGs at 150 to 250 Hz. QRS-HFpower was estimated from a modelling power spectral technique. uAIQP and HF indices were obtained from a baseline and an occlusion-PCI ECG episode.

uAIQP and HF values decreased ($p<0.05$) for each of the 12 leads at the PCI event respect to baseline in all patients and the no-MI group. Changes in uAIQP or HF did not separate the groups. uAIQP and QRS-HFpower values at baseline were lower in all leads, except V1-V2, in the old-MI groups compared to no-MI ($p<0.05$). Pearson's correlation showed moderate relationship among the indices in most of leads.

High-frequency QRS fragmentation indices could add diagnostic value to ST analysis for diagnosing ischemia when a baseline ECG information is available. Patients with old-MI presented lower uAIQP amplitudes compared to no-MI, however further studies are needed to elucidate the effects of old MI on very-low level fragmentation of the QRS.

1. Introduction

Noninvasive detection and monitoring of myocardial ischemia is usually performed by evaluating changes during the repolarization phase (ST segment, T-wave) in the standard 12-lead ECG. Depolarization changes (QRS complex) have been traditionally associated with infarction. However, using higher amplitude and time resolutions, numerous studies have shown that high-frequency (HF) QRS fragmentation measures provide valuable information to detect acute myocardial ischemia [1-3]. Very-low amplitude and high-frequency fragmentation of the QRS complex has been associated with the electrical activation wavefront from the myocardium produced by the branching nature of the conduction system. During myocardial ischemia decreased HF and fragmentation of the QRS has been observed, probably linked to slowed conduction velocity in the myocardial cells or the conduction fibers [4].

High-frequency QRS components have been usually characterized from signal-averaged beats using band-pass filtering at the frequency band of 150 to 250 Hz and computing the RMS value of the filtered QRS.

Microvolt amplitude intra-QRS potentials, or very low-level QRS notches and slurs, can also be characterized in the time domain using a parametric modelling technique applied to the QRS [5]. Abnormal intra-QRS potentials (AIQP) at μV level have been applied to evaluate changes in low level QRS fragmentations due to acute myocardial ischemia [6]. The purpose of this work was to assess the relationship between high-frequency QRS components and μV level AIQP during acute myocardial ischemia and the presence or not of previous myocardial infarction.

2. Methods

2.1. Population and data acquisition

The study included 56 patients from the STAFF III database [7,8], a collection of continuous ECG recordings from 104 patients receiving elective percutaneous coronary interventions (PCI) at the Charleston Area Medical Center, WV. The database was obtained before coronary stents were widely available and the occlusion periods were considerably longer than those in usual coronary angioplasty procedures. Therefore, these PCI

procedures were a good model of hyper acute transmural ischemia. Inclusion criterion was occlusion duration of at least 3-min and strict criteria concerning the noise level in each of 12 leads of the ECG signal (see details in [6]). Balloon inflation periods ranged from 3.1 to 7.3 minutes (mean ± SD = 5.0 ± 0.6 min). Patients were classified into two groups: (i) presence of prior healed myocardial infarction (old-MI) (n = 18) or (ii) not (No-MI) (n = 38).

Continuous 9-leads ECG's (I, II, III (Mason-Likar electrode positions), V1-V6) were acquired at 1 kHz, with 0.6μV of amplitude resolution with equipment provided by Siemens-Elena (Solna-Sweden). The three augmented aVL, -aVR and aVF were calculated from the limb leads. For each patient, two ECG recordings were analysed: (i) a pre-inflation ECG that was acquired during 5 minute before any catheter insertion, and (ii) the occlusion ECG recording which commenced about 1 minute before balloon inflation and continued during the inflation period and ended at least 3 minutes after deflation.

2.2. Preprocessing and data selection

ECG recordings were signal averaged to ensure low noise level using two approaches. In pre-inflation ECGs conventional ensemble averaging was used, whereas, for occlusion ECG recordings an exponential averaging recursive technique was employed to track changes in QRS morphology [9,10]. Noise level was estimated in each lead of the signal-averaged beat as the RMS value during 100 ms, starting 100 ms after QRS end. The inclusion noise criteria were a noise level 0.75 μV of lower for each of the 12 individual leads and similarity of noise level, within 0.35 μV, between the baseline beat and the end of the occlusion (PCI) beat.

A pair of ECG beats was chosen for each patient to assess the effect of acute myocardial ischemia provoked at the end of the occlusion period respect to baseline. The baseline beat was selected using the following condition. Firstly, if the occlusion ECG recording contains enough period before the inflation of the balloon to obtain an averaged beat within the noise criterion then the baseline beat is chosen from the pre-inflation portion of this recording. Otherwise, an averaged beat from the pre-inflation ECG recording within the noise criteria was selected. As occlusion-ischemic (PCI) ECG beat, we selected the averaged beat at the end of balloon inflation.

QRS onset and offset of the averaged beats were obtained using a multi-lead approach [11].

2.3. QRS high frequency characterization

Two techniques were used to characterize high-frequency fragmentation of the depolarization wavefront from the 12-lead signal-averaged selected beats.

Firstly, high-frequency QRS (HFQRS) components were extracted through band-pass filtering at the band of 150 to 250 Hz, using a Butterworth filter in a forward-backward fashion; then, $HFQRS_{RMS}$ indices were obtained from the RMS value of the filtered QRS [1-3].

Secondly, a power spectral density (PSD) estimation of the QRS complex was computed fitting an auto-regressive (AR) model to the each QRS complex.

$$y(n) = -\sum_{k=1}^{na} a_i y(n-k) + e(n) \qquad (1)$$

where *y(n)* is the QRS complex, a_i are the model parameters, *e(n)* is the model residual and *na* is the model order. The latter was automatically chosen for each lead using the Broersen's combined information criterion (CIC) [12]. The model parameters and the variance of the driving noise were estimated using the Burg method [13]. From the theoretical spectrum of the model:

$$P_{xx}^{AR}(f) = \frac{\sigma_e^2}{f_s \left| 1 + \sum_{k=1}^{na} a_k e^{-j2\pi kf/f_s} \right|^2} \qquad (2)$$

the estimated spectrum of the QRS is computed, where f_s is the sampling frequency. The average power of the QRS (QRS-HFpower) was obtained as

$$P_{avg} = \int_{fL}^{fH} P_{xx}^{AR} df = \frac{f_s}{N} \sum_{f=fL}^{fH} P_{xx}^{AR}(f) \qquad (3)$$

between *fL* = 150 Hz and *fH* = 250 Hz, where *N* = number of QRS samples.

2.4. Micro-Volt level AIQP

AIQP at μV level were obtained from each individual lead using a system modelling approach to estimate the smooth QRS complex. The method, fully described in [5], estimates an ideally normal smooth QRS waveform based on an auto-regressive with exogenous input (ARX) model of each preprocessed QRS. The QRS complex can be considered as the response of the cardiac system to an impulse stimulus at the atrioventricular node. The impulse response can represent the smooth regular part of the QRS complex, leaving possible very-low level AIQP or micro-level fragmentation in the residual. The time-domain QRS signal is preprocessed with the discrete cosine transform (DCT) in order to produce an energy-compacted form of the QRS. The ARX model given by

$$y(n) = -\sum_{i=1}^{na} a_i y(n-i) + \sum_{j=0}^{nb} b_j u(n-j) + e(n) \qquad (4)$$

where y(n) is the DCT of the QRS, u(n) is an impulse, *e(n)* is the model residual and the set of coefficients a_i and b_j comprise the model with order (*na*, *nb*). The modelled signal is expressed as a linear regression, where the model parameters are included and they were analytically estimated by the least-squares estimation method [5]. A model order of *na* = 7 and *nb* = 8 was chosen. The inverse

DCT was applied to produce the modelled QRS in the time-domain and subtracted from the original QRS signal. The difference, representing the unpredictable part of the QRS, is the abnormal intra-QRS signal or μV level fragmented part of the QRS, and was quantified by calculation of the RMS amplitude between the QRS limits (μAIQP).

To quantify the amount of changes due to the ischemia variation of the HFQRS, QRS-power and μAIQP were also calculated for each lead, subtracting the baseline measures from the PCI ones ($\Delta HFQRS_{RMS}$, ΔQRS-HFpower and ΔμAIQP, respectively).

3. Results

There were no significant differences in age, sex or occlusion time between the no MI and the old MI groups.

Figure 1 shows μAIQP mean ± standard error of the mean (SEM) values at the baseline and PCI (panel A) and its changes, ΔμAIQP, (panel B) for the No-MI and old-MI groups. μAIQP values decreased significantly in the entire study population and in the No-MI group at the PCI event respect to baseline ($p < 0.05$ in precordial leads, $p < 0.01$ in limb and augmented leads). Old-MI group presented decreased μAIQP values during ischemia in V1, V5, V6 and the limb and augmented leads ($p < 0.05$).

The group of patients with previous MI showed baseline μAIQP values significantly smaller than the baseline No-MI group in all leads except V1 and V2 ($p < 0.05$).

Figure 2 displays the mean ± SEM values of HF characterization of the QRS complex from the 12-lead signal-averaged selected beats, obtained from two different approaches. Panel A shows a markedly decrease of $HFQRS_{RMS}$ values due to PCI respect to baseline in V1-3, V6 ($p < 0.05$) and limb and augmented leads ($p < 0.01$) in the No-MI group. Decrease of this index was also observed in the old-MI group at all leads, excepting V3 and V4 ($p < 0.05$). However, baseline $HFQRS_{RMS}$ values were similar in both MI history groups.

Changes in the average power spectrum of the QRS at the 150-250 Hz band (QRS-HFpower, in dB) are shown in Panel B of figure 2. As $HFQRS_{RMS}$ measures, QRS-HFpower values were significantly reduced with a marked reduction in all leads ($p < 0.01$) in the No-Mi group. The old-Mi group showed reduced QRS-HFpower in all leads excepting V2 and V3 ($p < 0.05$).

In the same trend as AIQP values and contrary to $HFQRS_{RMS}$, QRS-HFpower at baseline was markedly lower in the group with prior MI respect to No-MI ($p < 0.05$ in V1-6, $p < 0.01$ in limb and augmented leads).

The effect of acute myocardial ischemia (PCI episode) showed no significant differences in changing indices ΔμAIQP, $\Delta HFQRS_{RMS}$ and ΔQRS-HFpower between the groups with old-MI and non-MI.

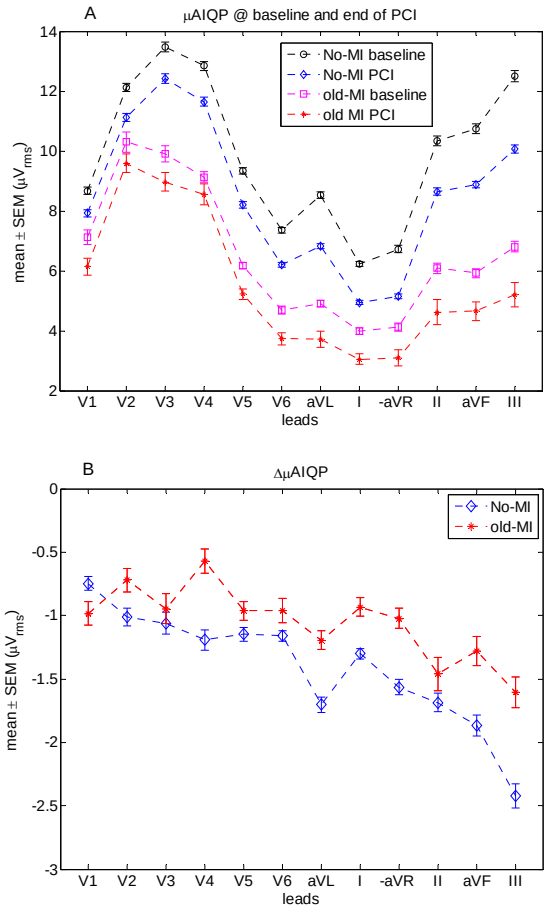

Figure 1. μAIQP mean ± SEM values at baseline and the end of PCI in No-MI and old-MI groups (panel A). μAIQP changes (ΔμAIQP) in both groups (panel B).

Pearson's correlation showed a moderate correlation among the changing indices due to ischemia. Significant correlations were found between μAIQP and $HFQRS_{RMS}$ in leads V3, V4, I, III aVL and aVF and between $HFQRS_{RMS}$ and QRS-HFPower in leads V3 and V4 only ($p < 0.05$).

4. Discussion and conclusion

High-frequency QRS fragmentation indices assessed in this work have provided important value to detect acute myocardial ischemia when a baseline ECG information is available. Both high-frequency measures ($HFQRS_{RMS}$ and QRS-HFpower) and μAIQP have shown reduced values at the end of the occlusion periods (PCI) respect baseline in both MI groups. Results were less significant in the old-MI group, but probably due to small cohort.

Patients with a prior MI present lower baseline high-frequency fragmentation revealed by μAIQP and QRS-HFpower measures but not by $HFQRS_{RMS}$ index. The $HFQRS_{RMS}$ index, based in bandpass linear filtering

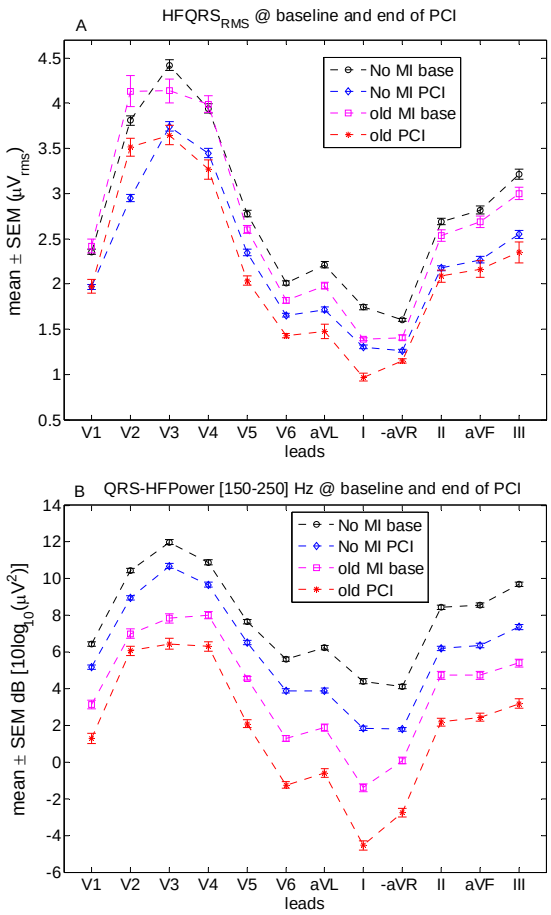

Figure 2. High-frequency components at baseline and the end of PCI in No-MI and old-MI groups. HFQRS$_{RMS}$ (panel A) and QRS-HFpower (panel B).

suffers from phase distortion and filter ringing, smearing the QRS high-frequency components. Power spectral estimation based on AR modelling, using the Burg's method, improves high-frequency components estimation since it provides high-resolution spectral estimation of short-term signals as the QRS complex and does not require pre-windowing. This technique, although requires more computing power, looks more reliable to estimate HF components. Nowadays it could be easily implemented in portable devices.

The lack of strong correlation among the indices indicates that they can contribute and add value to conventional ST analysis in detection myocardial ischemia. But, high-resolution baseline-reference ECGs in the patients' electronic database is very important for including these and other proposed new indices.

Acknowledgements

This study was supported in part by the project TEC2010-20886-C02-01 from the Spanish Ministry of Science and Innovation.

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