

Dynamical Behavior of Intra-QRS Potentials During Induced Myocardial Ischemia

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Abstract

The objective of this study is to assess the prevalence and natural progression of abnormal intra-QRS potentials (AIQP) in the HRECG during percutaneous transluminal coronary angioplasty (PTCA). 25 patients were studied: 7 had occlusion of the left anterior descending (LAD), 9 of the left circumflex (LCX), and 9 of the right coronary artery (RCA). HRECG with enhanced signal-to-noise ratio were obtained every 60 seconds from a subensemble of beats using a time-frequency plane Wiener filter. AIQP, QRS high frequency components and ST segment deviation were estimated every 60 seconds. AIQP amplitudes mean values increased rapidly during the first minute of balloon inflation compared to the pre-inflation recording. The increase is maintained throughout the inflation period decreasing after the inflation period. An analysis of variance showed very significant changes in AIQP values between pre-inflation and inflation epochs ($p < 0.001$). A relationship between AIQP timing, measured as the 'center of mass' of AIQP signal, and location within the artery (LAD, LCX and RCA) was found during the 1st minute of inflation ($p = 0.02$): AIQP timing occurs later in RCA occlusion. These observations suggest that AIQP show promise as a time-localized sensitive marker of ischemically altered ventricular activation.

1. Introduction

Detection of myocardial ischemia in the acute or long-term monitoring settings is presently limited by the predictive power of ST segment deviations in the standard 12-lead ECG. Reversible ischemia was generally measured only during the repolarization process. However, previous studies by Abboud et al. [1] has demonstrated changes in the high frequency content of the QRS complex as a function of ischemia, during periods of complete coronary occlusion, that were reversed when blood flow to the myocardium was reestablished. Significant QRS changes have also been documented on the standard ECG during the transient acute transmural ischemia produced by angioplasty balloon occlusion [2].

Recently, we have proposed the concept of abnormal intra-QRS potentials (AIQP), as low amplitude notches and slurs in the QRS complex of the high resolution ECG (HRECG), which may represent pathophysiological signal representation of a reentrant mechanism for ventricular tachycardia [3]. In ischemia, AIQP would result from altered activation due to localized changes in conduction, occurring around a region of functional block. The objective of this study is to assess the prevalence and natural progression of AIQP and QRS high frequency components in the HRECG during percutaneous transluminal coronary angioplasty (PTCA). PTCA provides a very good model to evaluate electrophysiological changes of transmural ischemia resulting from the thrombotic occlusion responsible for acute myocardial infarction. The coronary angioplasty laboratory selected for the present study is unique in employing single prolonged balloon inflation. This provides a several minute period for comparison of the serial changes observed on both standard and high resolution ECG.

2. Methods

2.1. Data acquisition

In collaboration with Duke University Medical Center, continuous HRECG were recorded in 25 patients undergoing elective PTCA. Recording commenced at least 1 minute before balloon inflation. Balloon inflation periods ranged from 3 to 5 minutes. Up to 4 minutes of post-inflation period was also registered. HRECG data were recorded continuously using the Predictor system (Corazonix Corp., Oklahoma City, OK), at a sampling rate of 1,000 Hz. Of the 25 patients studied, 7 had occlusion of the left anterior descending (LAD), 9 of the left circumflex (LCX), and 9 of the right coronary artery (RCA). No subject had a prior myocardial infarction.

The signal-averaged ECG (SAECG) typically requires on the order of 300 averaged beats for a hi-fidelity, low-noise study. The environment of the catheter laboratory produces significant initial noise levels in the HRECG, due to the presence of electromagnetic and electrostatic

fields from other equipment, notably fluoroscopy devices. This difficulty was overcome with the optimally filtered SAECG, a technique based on an *a posteriori* implementation of Wiener's theory of filtering [4]. This technique employs spectro-temporal representations of every beat in the sub-ensemble to accelerate noise reduction and enhance the signal-to-noise ratio of the SAECG.

The continuous high resolution ECG recording was analyzed off-line, after the PTCA procedure. A typical, normal sinus rhythm QRS complex was first selected in the pre-inflation period. This was used as a template for subsequent signal averaging of the entire ensemble of beats. Up to 10 sequential optimally filtered sub-ensemble averages was computed as follows: 1: A pre-inflation subensemble average, comprised of up to 128 beats available immediately prior to balloon inflation. 2-6: Between 3 and 5 subensemble averages, each of 60 seconds duration, computed sequentially during the balloon inflation period. All available beats, within each 1-minute epoch, that passed the alignment, classification and noise criteria, were included. 7-10: Up to 4 sequential, post-deflation subensemble averages, each of 60 seconds duration.

2.2. HRECG subensemble analysis

Each subensemble epoch during pre-inflation, inflation and post-inflation periods was processed for calculating ST segment deviation, AIQP's and high frequency QRS components.

ST segment deviation was measured in mV for each lead at the J point as the level above or below the PR segment baseline and the lead with the largest ST segment deviation during inflation was identified.

Abnormal intra-QRS potentials were calculated by the residual of a parametric modeling process [5]. Each individual-lead HRECG QRS complex is presented unfiltered to be mathematically modeled. The time domain HRECG signal is pre-processed with the discrete cosine transform and then it is modeled as the impulse response of an autoregressive model with an exogenous input (ARX). This is given by

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

where, $y(n)$ is the DCT of the original QRS, $u(n)$ is an impulse function, $e(n)$ is the residual or unpredictable part of $y(n)$, $\tilde{x}(t)$ is the modeled signal DCT, and the set of coefficients a_i and b_j comprise the model with order $[na \ nb]$. The model order was selected on the basis of previous experience of SAECG waveforms [3],[5]. The modeling signal is subtracted from the original QRS complex. The difference is the AIQP waveform (AIQP(t)). AIQP's

indexes were quantified by computation of the RMS amplitude between the QRS limits.

AIQP timing was also computed as the 'center of mass' of the residual waveform, defined as $AIQP_{t_0}$ by

$$\frac{\sum_{t=QRS_{on}}^{AIQP_{t_0}} AIQP^2(t)}{\sum_{t=QRS_{on}}^{QRS_{off}} AIQP^2(t)} \approx 0,5 \quad (2)$$

Aboud et al [1] analyzed the bandwidth 150-250 Hz to detect transient myocardial ischemia. Changes in high frequency QRS components during PTCA procedure in each subensemble epoch were measured estimating the spectral components of the QRS interval using a 4-term Blackman-Harris window. We measured the high frequency components for each individual lead in the bandwidth 150-250 Hz.

3. Results

3.1. AIQP amplitudes during PTCA

Figure 1 describes the AIQP amplitude mean values (mean of the 3 XYZ leads) during PTCA procedure for each of the 25 subjects and the mean values considering individual arteries occlusion. The values were obtained for each of the optimally filtered SAECG subensembles. Analyzing either all patients or each individual artery occlusion, AIQP mean amplitudes rises significantly during inflation related to pre-inflation. After deflation of the balloon AIQP amplitude values decreased showing a QRS waveform similar to the pre-inflation one. Figure 2 shows the HRECG (lead Y) during the PTCA procedure from a LAD patient depicting QRS changes throughout the inflation. An analysis of variance showed that in all cases changes in mean AIQP amplitudes between pre-inflation and inflation epochs were very significant ($p < 0.001$). Including all patients, AIQP amplitude values between 3rd minute of inflation and 2nd minute of post-inflation decrease significantly ($F=9.16$, $p=0.003$). For individual arteries, AIQP amplitude values decrease during post-deflation is observed significant in LAD and RCA ($p < 0.05$). Table I summarized AIQP mean values for all patients and classified by arteries occlusion. AIQP measurements were made relative to the model of the pre-inflation SAECG with model order $[na=7, nb=8]$.

Modeling each SAECG subensemble with the same model order, AIQP amplitude values increased significantly during the inflation period related to pre-inflation and post-deflation minutes only in lead X of LAD occlusion. In other arteries the changes were not statistically significant.

Table I. AIQP mean Amplitude RMS values during PTCA procedure.

Artery	AIQP Pre-inflat (μV)	AIQP Inflat -1min (μV)	AIQP Inflat -2min (μV)	AIQP Inflat -3min (μV)	ANOVA	AIQP Postinflat-2min (μV)	ANOVA Inf-3min & post-inf2
All (N=25)	8.66 \pm 3.9	73.28 \pm 63.5	98.22 \pm 91.9	117.4 \pm 128	p<0.0001	69.47 \pm 43.5	p=0.003
LAD (N=7)	8.70 \pm 4.0	86.43 \pm 50.3	120.36 \pm 122	168.0 \pm 201	p<0.001	75.40 \pm 30.6	p=0.04
LCX (N=9)	9.42 \pm 4.1	55.45 \pm 37.2	78.87 \pm 58.2	94.47 \pm 71.1	p<0.001	72.28 \pm 48.3	p=0.1
RCA (N=9)	7.86 \pm 3.7	80.88 \pm 87.3	100.3 \pm 91.7	101.9 \pm 87.9	p<0.001	61.14 \pm 47.7	p<0.5

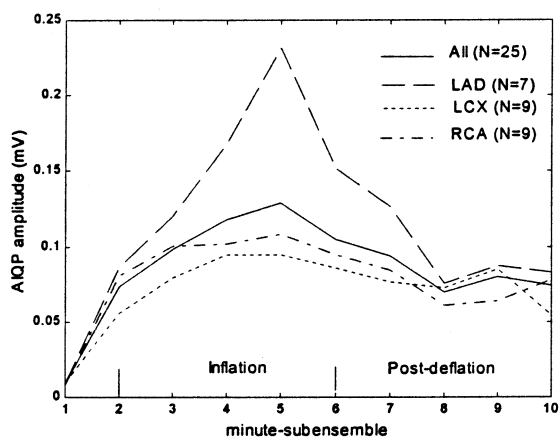


Figure 1. AIQP mean RMS amplitude values for each minute-subensemble during PTCA of all patients and classified by artery occlusion LAD, LCX and RCA.

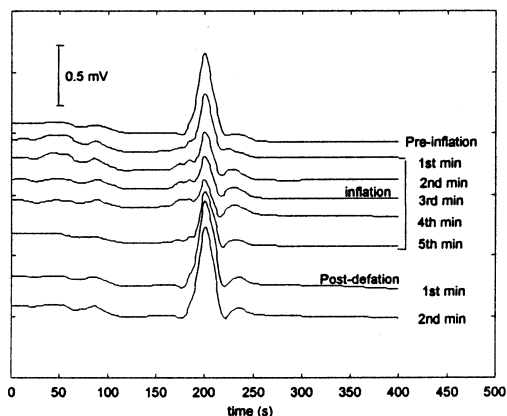


Figure 2. SAECG subensembles from a patient with LAD occlusion during PTCA procedure.

3.2. AIQP timing

AIQP timing (AIQP_{t0}) considering the mean values obtained from 3 leads X-Y-Z in patients with different artery occlusions LAD, LCX and RCA is shown in figure 3. The time indicates the 'center of mass' of the AIQP signal and it is expressed in % of QRS duration. During

the first minute of inflation a relationship between AIQP timing and location artery is observed ($p=0.02$). AIQP_{t0} mean values, as shown in table II, predict an early ischaemically altered activation of the myocardium observed in the QRS for LAD occlusions, compared with RCA occlusions.

Table 2. AIQP timing considering the 3 leads X-Y-Z

Artery	AIQP _{t0} Pre-inflation (%)	AIQP _{t0} 1 st min inf (%)
LAD (N=7)	0.42 \pm 0.08	0.47 \pm 0.09
LCX (N=9)	0.41 \pm 0.09	0.48 \pm 0.08
RCA (N=9)	0.42 \pm 0.14	0.54 \pm 0.11
ANOVA among 3 groups - min	p = 0.97	p= 0.02 (F=4.1)

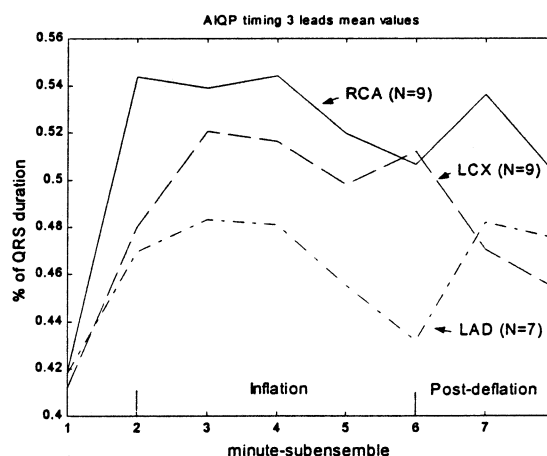


Figure 3. Mean values of AIQP timing related to QRS duration during PTCA procedure.

3.3. ST segment deviation

In 15 of the 25 patients studied (60%) there was ST

deviation greater than 0.1 mV in any lead during the inflation period: 3 in LAD occlusion (57%), in 6 of the 9 LCX (67%) and 5 out of the 9 RCA (55.5%).

3.4. High frequency QRS components

Figure 4 shows boxplots describing how high frequency energy in the bandwidth 150-250 Hz decrease significantly in LAD occlusion leads X and Y during PTCA (panels a and b), increasing the values after deflation. The lowest values during inflation were reached at the 4th and 5th minutes. In LCX PTCA, values of high frequency decreased during inflation in leads X and Z; the values increased in lead Y (panel c), although the changes were not statistically significant. In RCA occlusion, high frequency components decreased during inflation in all leads but not significantly; panel d shows high frequency components in lead Y of RCA occlusion.

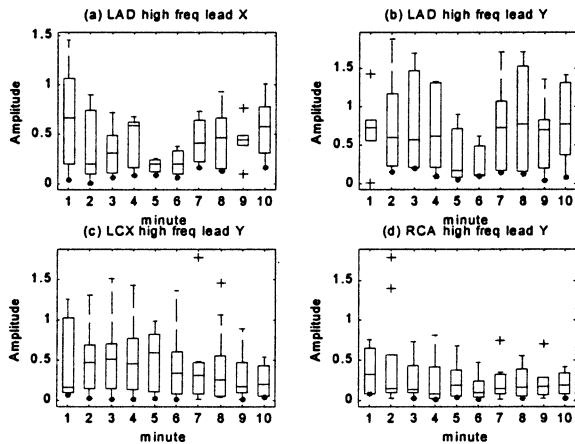


Figure 4. QRS High Frequency components from 150 to 250 Hz (boxplot) during PTCA in (a) LAD occlusion, lead X, (b) LAD lead Y, (c) LCX PTCA lead Y and (d) RCA occlusion lead Y. Minute 1: Pre-inflation, Minute 2, to 6: 2nd, to 5th minutes of inflation, minutes 7 to 10: 1st, to 4rd minutes of post-deflation.

4. Discussion and conclusions

In all patients, AIQP amplitude showed a significant increase during inflation related to pre-inflation and post-deflation. In several subjects, like the example in figure 2, AIQP represent gross changes in QRS morphology. However, small notches and slurs are also identified during the occlusion of arteries. Modeling each individual SAECG beat, AIQP amplitudes related to small notches and slurs were identified significantly in LAD occlusion.

The 'center of mass' of the AIQP waveform shows a promise index of location of ischemically-altered

activation. Figure 3 depicts differences among arteries occlusion in AIQP₁₀ index during the inflation epochs. LAD and LCX occlusions produce earlier abnormal activation than RCA occlusion. However, during pre-inflation the values were very similar.

High frequency components within the QRS in the bandwidth 150-250 decreased significantly in LAD occlusion in all leads. In LCX and RCA PTCA high frequency energy decreased not significantly during inflation, although in LCX lead Y the high frequency values increased during PTCA.

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