

Acute myocardial ischemia monitoring before and during angioplasty by a novel vectorcardiographic parameter set

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Abstract

Background: This work evaluates the vectorcardiographic dynamic changes in ischemic patients before and during Percutaneous Transluminal Coronary Angioplasty (PTCA).

Methods: Four QRS-loop parameters were computed in 51 ischemic and 52 healthy subjects with the objective of assessing the vectorcardiographic differences between both groups: maximum vector magnitude (QRS_{mVM}), planar area (QRS_{PA}), maximum distance between centroid and loop (QRS_{mDCL}) and perimeter (QRS_P). The conventional ST-change vector magnitude (STC_{VM}), QRS-vector difference (QRS_{VD}) and spatial ventricular gradient (SVG) were also calculated.

Results: Statistical minute-by-minute PTCA comparison against a healthy population showed that ischemic patients monitoring is greatly enhanced when all the QRS-loop parameters, in combination with the standard STC_{VM} , QRS_{VD} and SVG indexes, are used in the classification. Sensitivity and Specificity, in turn, reached rather high values, 95.4% and 95.2%, respectively.

Conclusions: These new vectorcardiographic set of complementary QRS-loop parameters, when combined with the classics STC_{VM} , QRS_{VD} and SVG indexes, increase sensitivity and specificity for acute ischemia monitoring.

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Keywords:

Cardiac ischemia; QRS-loop parameters; Coronary Angioplasty

Background

Myocardial ischemia is caused by a decompensation between the oxygen supply and demand; it is frequently associated with coronary atherosclerosis. The temporary occlusion of a coronary artery derives in a reversible ischemia, while a prolonged obstruction leads to myocardial infarction with serious consequences, such as malignant arrhythmias, heart failure and/or sudden cardiac death. Percutaneous Transluminal Coronary Angioplasty (PTCA) is a therapeutic procedure used to reestablish blood flow in narrowed arteries. During PTCA, a balloon located at the tip of a catheter is inflated at the atheroma site to compress it causing simultaneously a full and controlled short-term total occlusion,

which obviously also resembles an acute myocardial ischemia. Such occlusion provides an attractive opportunity to study myocardial changes due to lack of coronary patency during its initial minutes.¹

Shortly after the beginning of balloon inflation, some changes can be detected in the electrocardiogram (ECG), such as ST-segment deviation and T-wave modifications, due to alterations in the ventricular repolarization process.² Several studies have demonstrated that ventricular depolarization is also modified during acute myocardial ischemia induced by PTCA. In this context, Surawicz et al. have shown, using 12-lead ECG records, that the QRS-complex terminal deflection is distorted during PTCA proportionally to the magnitude of the ST-segment shift.³ Moreover, that high frequency QRS analysis could provide valuable information to detect acute ischemia and to quantify myocardial area at risk was suggested by Ringborn et al.⁴ Recently, Romero et al. demonstrated that the upward and downward slopes of the QRS-complex change during coronary artery occlusion.⁵ Those are spatially related to the ischemic area and they might physiologically be traced back to conduction

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disturbances in the ischemic segment.^{2,4} Another conventional index that provides information on the cardiac conduction system operation and on the ventricular action potential duration heterogeneity is the Spatial Ventricular Gradient (SVG).⁶ Haar et al. have reported that this gradient, in addition to ST analysis, has a potential role in detecting ischemia.⁷

Within the vectorcardiography framework, the momentary cardiac electrical activity is representable by a single vector in the Euclidian space, i.e., the heart vector, and the VCG precisely describes both components, magnitude and direction, as time proceeds. Several studies have proposed its use for evaluating cardiac changes during myocardial ischemia or infarction. In a recent work, Hasan et al. concluded that vectorcardiographic analysis of beat-to-beat variability in ventricular depolarization and repolarization may provide markers of electrical instability in patients with myocardial infarction.⁸ Eriksson used ST_{VM} , ST-change-vector magnitude (STC_{VM}) and QRS_{VD} monitoring to give valuable prognostic information in cases of unstable angina and acute myocardial infarction, and concluded that vectorcardiography monitoring may identify myocardial reperfusion at an early stage.⁹ Jensen et al. proposed $STC_{VM} = 0.05\text{mV}$ as the best criterion for the detection of myocardial ischemia in VCG studies that monitor coronary angioplasty.¹⁰

Maximum ST-depression (in vector lead X) and STC_{VM} were the best determinants found by Lundin et al.,¹¹ obtained by multivariate analysis during exercise test in patients showing acute heart disease. Dellborg et al. demonstrated that monitoring myocardial ischemia with dynamic computerized continuous vectorcardiography (c-VCG) seems to be more efficient than Holter monitoring and may have a higher sensitivity.¹² Additionally, c-VCG has a full real-time capacity, so allowing monitoring over prolonged periods, while the results are immediately available without time-consuming analysis. Besides, Perez Riera et al. showed better specificity, sensitivity and accuracy of the computerized VCG when compared with conventional ECG in several cardiac pathologies.¹³ Often, the advantage of the VCG is due to the constancy of the time relations between leads, while conversely, such relationships are lost in separate scalar lead analysis.

We have recently proposed a set of vectorcardiographic QRS-loop parameters computed in resting conditions records in order to distinguish ischemic patients before undergoing PTCA from healthy subjects.¹⁴ After a classification process via discriminant analysis, it was concluded that QRS-loop parameters combined with ST_{VM} improved the sensitivity and specificity values with respect to those obtained using only the ST_{VM} index.

Herein, and as one step further, we analyze the vectorcardiographic dynamic changes of the QRS-loop parameters in acute myocardial ischemic patients before and during the PTCA procedure. For this matter, we statistically compared, minute by minute, the PTCA against a healthy population. We hypothesize that the balloon occlusion modifies the morphology of the QRS-loop and, thereafter, its parameters can be used to characterize and monitoring the acute myocardial ischemia. To prove this, we evaluated

the proposed and the conventional parameters in the classification scheme.

Methods

Database

Raw clinical records were extracted from the PTB diagnostic ECG and STAFF-III databases.

The first one contains the ECG records of 52 healthy subjects (39 men, mean age 42 ± 14 years, and 13 women, mean age 48 ± 19 years). The ECGs in this collection were obtained by Physikalisch-Technische Bundesanstalt (PTB); the National Metrology Institute of Germany. Each record includes 15 simultaneously measured signals: the conventional 12 leads (I, II, III, aVR, aVL, aVF, V1–V6) together with the 3-Frank lead-ECGs (X, Y, Z). Each signal was digitized at 1000 Hz, with 16 bits of amplitude resolution.¹⁵

The second database consists of 51 ischemic patients (33 males, mean age 61 ± 13 years and 18 women, mean age 60 ± 10 years) admitted to the Charleston Area Medical Center in West Virginia, receiving elective PTCA in one of the major coronary arteries (STAFF-III study). The study was approved by the local investigation review board, and informed consent was obtained from each patient before enrollment.⁵ The mean occlusion period was 5 min 7 s. The locations of the 51 dilations were: Left Anterior Descending Artery in 11 patients, Right Coronary Artery in 14 patients and Left Circumflex Artery in 26 patients. The following inclusion criteria had to be met for the study population: no clinical or ECG evidence of an acute or recent myocardial infarction, no intraventricular conduction delay with QRS duration ≥ 120 ms [including left bundle branch block (LBBB) and right bundle branch block (RBBB)], no pacemaker rhythm, low voltage, atrial fibrillation/flutter, or any ventricular rhythm at inclusion (or during the PTCA). We also excluded patients with ECG signal loss during acquisition or with occlusion period less than 4 min 30 s.

Nine standard leads (V1–V6, I, II, III) were recorded in the study using equipment by Siemens-Elena AB (Solna, Sweden), digitized at sampling rate of 1000 Hz and $0.6 \mu\text{V}$ amplitude resolution. Synthesized orthogonal X, Y and Z leads were obtained by the Kors transform.¹⁶ A recent study has demonstrated that Kors synthesis matrix provides a better estimation of Frank leads than the Inverse Dower transform in ischemic patients.¹⁷

For each patient, two ECG records were obtained. One of them (denoted as before-PTCA Record) was acquired continuously at rest in the supine position prior to angioplasty, and the other (denoted as during-PTCA Record) was obtained during the PTCA procedure. Fig. 1 illustrates a block diagram of the different stages of the analysis.

Pre-processing

First, all ECG records were pre-processed with a band-pass filter (Butterworth, 4th order, 0.2–100 Hz, bidirectional) to reduce low and high frequency noise and a notch filter (Butterworth, 2nd order, 50/60 Hz, bidirectional) to minimize the power-line interference. A cubic spline interpolation filter

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