

# Study of QRS-Loop Parameters and Conventional ST-T Indexes for Identification of Ischemic and Healthy Subjects

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## Abstract

Several studies have shown the usefulness of the vectorcardiogram (VCG) and the electrocardiogram (ECG) for the detection of cardiac ischemia. We computed a set of VCG and ECG parameters to identify ischemic patients from healthy subjects. The study groups consisted of 80 ischemic patients and 52 healthy subjects. For both populations, five VCG parameters computed on QRS-loop were analyzed, i.e.: (a) Volume, (b) Planar Area, (c) Ratio between Area and Perimeter, (d) Perimeter, and (e) Distance between Centroid and Loop. Likewise, three conventional ECG ST-T parameters were calculated, i.e.: (f) ST Vector Magnitude, (g) ST segment level and, (h) T-wave amplitude. Results indicate that VCG and ECG parameters have significant differences between healthy and ischemic subjects. The QRS-loop parameter with the best global performance was Volume, which reached a Sensitivity (Se)=64.5%, a Specificity (Sp)=74.6%, and an Area Under Relative Operating Characteristic Curve (AUC)= 0.77. The best ST-T index was STVM, which obtained Se= 73.2%, Sp=73.9%, and AUC=0.79. However, when all QRS-loop and ST-T parameters were combined, we obtained Se=90.9%, Sp=93.7% and AUC=0.97. In conclusion, the inclusion of QRS-loop parameters improves the conventional ST-T analysis in the identification of ischemic patients.

## 1. Introduction

Leave Myocardial ischemia is a cardiac pathology characterized by the lack of oxygen in the heart cells and it is caused by an obstruction or stenosis of the coronary arteries, which blocks the normal flow of blood towards the cardiac muscle. It is well-known that insufficient myocardial cell irrigation reflects in the Electrocardiogram (ECG) as ST-segment deviation [1], T-wave alterations [2] and QRS-complex slopes modifications [3]. In all cases, the amplitude and temporal changes of the QRS-complex during an

ischemic episode are spatially related to the ischemia area.

Besides, the Vectorcardiogram (VCG) has been proposed to evaluate cardiac changes during ischemia or infarction. Eriksson used VCG monitoring to identify myocardial reperfusion at an early stage in patients with acute myocardial infarction [4]. Kawahito *et al.* concluded that VCG monitoring may be useful for identifying myocardial ischemia during carotid endarterectomy [5]. More recently, Pérez Riera *et al.* exposed the advantages of the computerized VCG compared to the ECG, particularly by showing better specificity, sensitivity and accuracy as compared with conventional ECG for the diagnosis of several cardiac pathologies [6].

In a previous work, we analyzed a set of VCG parameters computed in the cardiac depolarization phase in ischemic patients [7]. The aim of this study was to differentiate a group of ischemic subjects from a population of healthy ones by means of a combined VCG and ECG analysis of the ventricular depolarization-repolarization process. For that matter, five vectorcardiographic QRS-loop parameters and three conventional ECG ST-T indexes were computed, including them afterwards within a patient classification scheme.

## 2. Materials

Raw clinical records were extracted from the PTB diagnostic ECG database obtained by the National Metrology Institute of Germany [8] and the STAFFIII database from the Charleston Area Medical Center in West Virginia, USA [9].

The first one contained the ECG records of 52 healthy subjects (39 men, age  $42 \pm 14$  yrs, and 13 women, age  $48 \pm 19$  yrs). Each record included 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 1 kHz, with 16 bits of amplitude resolution.

The second database consisted of 80 ischemic patients

(50 men, age  $60 \pm 12$  yrs, and 30 women, age  $62 \pm 11$  yrs), before angioplasty. Nine standard ECG leads (V1–V6, I, II, III) were digitized at a sampling rate of 1 kHz and an amplitude resolution of  $0.6 \mu\text{V}$ . Synthesized orthogonal X, Y and Z leads were obtained by the Kors transform [10].

### 3. Methods

Figure 1 illustrates a block diagram of the different stages of the proposed analysis.

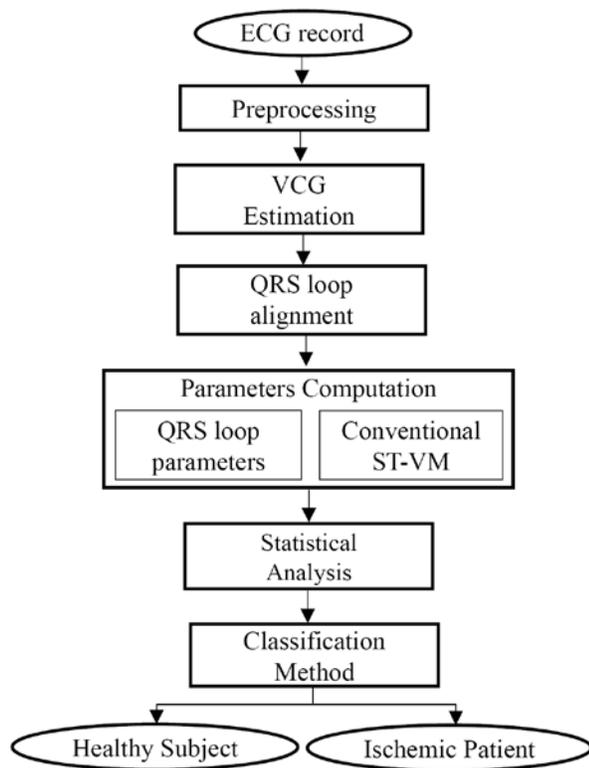


Figure 1. Proposed Analysis General Diagram.

#### 3.1. Preprocessing

First, all ECG records were preprocessed 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, 2th order, 50/60 Hz, bidirectional) to minimize the power line interference. A cubic spline interpolation filter was used to attenuate ECG baseline drifts and respiratory artifacts. Thereafter, the QRS complexes and their endpoints were detected using a modified version of Pan and Tompkins algorithm [11]. Beats with a RMS noise level  $>40 \mu\text{V}$  (measured within a 40 ms window located at  $2/3$  of the RR interval)

were excluded. Ectopic beats were also eliminated with the use of a cross-correlation technique.

#### 3.2. QRS loop Estimation and Alignment

The QRS-loop was obtained by drawing simultaneously, in a 3D plot, the instantaneous amplitudes of XYZ orthogonal leads in the temporal interval defined from the starting point of Q wave (or R if there is not Q) to the final point of S wave (or R if there is not S).

In order to analyze the beat-to-beat variations of QRS-loops, it is previously necessary to align them. The spatial alignment of QRS-loops compensates the changes in the orientation of the cardiac electrical axis caused by extracardiac factors, like the respiratory induced movements of the heart. QRS spatial alignment was resolved by computing the Rotation and Translation Matrices; that allow the beat-to-beat QRS-loop alignment against a pattern or template QRS-loop, the latter obtainable from the averaged QRS-complex [7].

#### 3.3. Parameters Computation

No Five VCG QRS-loop parameters [7] and three ECG ST-T indexes were computed for each detected beat.

1) QRS-loop Volume ( $QRS_V$ ): The volume of the 3D VCG representation was calculated from the set of points that produce the minimum convex volume (using the “Convex Hull” technique [14]), and that contains all points of the VCG loop.

2) QRS-loop Planar Area ( $QRS_{PA}$ ): It is the estimated area of the loop obtained by projecting the QRS-loop on the Optimum Plane (OP), which is the best adjusted plane computed by least mean squares. It could reflect hemodynamic abnormalities in cardiac lesions.

3) Maximum Distance between the QRS-centroid and the QRS-loop ( $QRS_{DCL}^{\max}$ ): The centroid loop is initially estimated and, thereafter, the Euclidean distance from this centroid to each point of the loop is determined searching for its maximum. This parameter measures a relative distance that is independent on the position of 3D loop.

4) QRS-loop Perimeter ( $QRS_P$ ): It is the Perimeter computed over the QRS-loop projected over the OP. It measures the loop total length and detects loop contour changes.

5) Ratio between the Area and Perimeter ( $QRS_{AP}^{\text{Ratio}}$ ): This ratio is evaluated over the QRS-loop projected on the OP. This parameter was calculated with the aim of analyzing changes in the QRS-loop morphology.

6) ST-Vector Magnitude ( $ST_{VM}$ ): It monitors (or assesses) cardiac ischemia and is defined as the vector magnitude composed of the (X, Y, Z) ST-segment deviations from the isoelectric level

( $ST_{VM} = \sqrt{ST_x^2 + ST_y^2 + ST_z^2}$ ), measured as the ECG amplitudes at the J-point. This point was estimated as  $J_k = 40 + 1/3 (RR_k)^{1/2}$  (in ms), where  $k$  denotes the  $k$ -th beat and  $RR_k$  is the RR interval between the current beat and the following one.

7) ST level in V3 ( $ST_{V3}$ ): It is the value of the ST segment level measured at the J point plus 60 ms in V3.

8) T-wave amplitude in V3 ( $T_{V3}$ ): It is the value of T-wave peak measured at V3.

### 3.4. Statistical and classification methods

All parameters were computed for each detected sinus beat in every ECG record. Comparisons between groups were made using the non-parametric Mann-Whitney test because the underlying variables distribution was non Gaussian. Thereafter, each parameter mean value across the entire record was calculated. These values were used as inputs to a classifier based on **Linear Discriminant Analysis (LDA)** to distinguish ischemic patients from healthy subjects. The LDA classifier is a linear combination of variables, as follows,

$$y = \mu_0 + \mu_1 X_1 + \mu_2 X_2 + \dots + \mu_p X_p$$

where  $y$  is the output value of the discriminant function;  $\mu_n$  (with  $n=1, \dots, p$ ) stand for the coefficients of the discriminate function;  $X_n$  are the discriminate variables (QRS-loop and/or ST-T parameters) and  $p$  is the number of variables in the analysis.

The resulting discriminant function can be used to assign each ECG record to a particular class, ischemic patient or healthy subject, based on its values of discriminate variables. The model coefficients are estimated with a subset of ECG records for which the group is known. This subset of observations is sometimes referred to as the **training subset** (we used the 70% of ECG records of both populations).

In order to validate the model, this discriminant function was used to predict the group of another different subset (referred to as **validation subset**) of the ECG records (we used the remaining 30% of the ECG records).

To evaluate the performance of the LDA classifier, we computed the **Receiver Operating Characteristic (ROC)**. It plots the Sensitivity (Se) against the 1-Specificity (Sp) values for the different possible cut-off points (cut-off values were swept between -5 and 5 in 0.01 steps) of the discriminant function.

Then, the optimal cut-off point in the ROC curve was computed as the point nearest the top left-hand corner. This selection maximizes the Se and Sp sum, when it is assumed that the 'cost' of a false negative result is the same as that of a false positive one. Finally, the global

performance of the classifier was evaluated with the Area Under the ROC Curve (AUC).

## 4. Results

Table 1 shows the Mean±SD values computed for each parameter in both populations, where the values marked with \* indicate the statistical significance ( $p < 0.0001$ ) Table 2 displays the Se, Sp and AUC values obtained in the classification process using each individual QRS-loop and ST-T parameters and the combination of them all.

Table 1. Mean±SD values for VCG QRS-loop and ECG ST-T parameters

Parameters	Healthy Subjects	Ischemic Patients
$QRS_V$ [mV <sup>3</sup> ]	0.15 ± 0.16	0.07 ± 0.06*
$QRS_{PA}$ [mV <sup>2</sup> ]	1.20 ± 0.65	0.79 ± 0.50*
$QRS_{DCL}^{max}$ [mV]	1.03 ± 0.32	0.80 ± 0.22*
$QRS_P$ [mV]	4.84 ± 1.32	3.86 ± 0.96*
$QRS_{AP}^{Ratio}$ [mV]	4.44 ± 1.94	5.45 ± 1.64*
$ST_{VM}$ [mV]	0.05 ± 0.03	0.12 ± 0.10*
$ST_{V3}$ [mV]	0.08 ± 0.09	-0.01 ± 0.10*
$T_{V3}$ [mV]	0.56 ± 0.29	0.30 ± 0.29*

\* indicates  $p < 0.0001$ , ischemic patients vs healthy subjects.

Table 2. Classification results for VCG QRS-loop and ECG ST-T parameters.

Parameters	Se (%)	Sp (%)	AUC
$QRS_V$ [mV <sup>3</sup> ]	64.5	74.6	0.77
$QRS_{PA}$ [mV <sup>2</sup> ]	70.5	72.5	0.73
$QRS_{DCL}^{max}$ [mV]	38.5	60.4	0.47
$QRS_P$ [mV]	69.9	69.5	0.70
$QRS_{AP}^{Ratio}$ [mV]	71.6	66.1	0.75
$ST_{VM}$ [mV]	73.3	73.9	0.79
$ST_{V3}$ [mV]	72.8	70.6	0.78
$T_{V3}$ [mV]	66.7	70.0	0.75
All QRS-loop	82.5	91.3	0.90
All ST-T	81.4	75.9	0.87
<b>All combined</b>	<b>90.9</b>	<b>93.7</b>	<b>0.97</b>

## 5. Discussion and Conclusions

Several papers have proposed different techniques to detect and classify changes in cardiac electrical activity recorded from the surface ECG in patients with myocardial ischemia [1-3]. This cardiopathy is usually diagnosed on the ECG by the measurement of ST deviation at the J-point. A recent review demonstrates the superiority of the VCG based techniques versus those

based on the ECG alone; vectorcardiography provides a better and more rational insight into the electrical phenomena that occur spatially [6].

The aim of this work was to evaluate the differences between a group of ischemic subjects from a population of healthy ones using a combined VCG and ECG analysis of the cardiac ventricular depolarization-repolarization phases. Five VCG QRS-loop and three conventional ECG ST-T parameters were calculated and, thereafter, they were processed with a patient classification scheme. All parameters show statistically significant differences between two populations ( $p < 0.0001$ ).

The VCG QRS-loop parameter with the best global performance was  $QRS_V$ , which reached  $Se=64.5\%$ ,  $Sp=74.6\%$ , and  $AUC=0.77$ . The best ST-T parameter was the  $ST_{VM}$ , which obtained  $Se=73.2\%$ ,  $Sp=73.9\%$ , and  $AUC=0.79$ . However, it must be underlined that, when all QRS-loop and ST-T parameters were combined, those levels improved to  $Se=90.9\%$ ,  $Sp=93.7\%$  and  $AUC=0.97$ .

In conclusion: The proposed technique based on QRS-loop study could be used in addition to the conventional ST-T analysis for a better identification of ischemic patients.

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