

# Myocardial Infarction and Ischemia Characterization from T-Loop Morphology in VCG

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## Abstract

*In the present study some particular aspects of T-wave morphology are considered for characterization and quantification of heterogeneous repolarization, using the vectorcardiogram (VCG). The orthogonal Frank leads were synthesized from the standard 12 lead ECG. For this purpose, three parameters were obtained from the VCG with two different methods of considering the zero point.*

*The population based ECG-ILSA database (Italian Longitudinal Study on Aging) was used and patients classified as healthy (328), with myocardial ischemia (123), myocardial infarction (172) or both (59) were included in this study. The modified parameters proved to yield higher discriminative power. From a statistical analysis it was found that the mean values of all the three parameters of the healthy subjects group are statistically different from those of ischemia or myocardial infarction groups.*

## 1. Introduction

Several recent publications aroused the interest in T-wave morphology. Lemire et al. [1] assert that information concerning myocardial ischemia can be obtained from the time-frequency representation of the T-wave morphology.

Kors et al. [2] investigate the QT dispersion as an attribute of the T-loop morphology, observing that small and wide T loops produce larger QT dispersion compared to large and narrow ('normal') loops.

Kallert et al. [3] assess the heterogeneous repolarization by quantitative parameters describing the T wave loop shape and subtle changes in its course.

Nowinski et al. [4] report for changes in ventricular repolarization during percutaneous transluminal coronary angioplasty in humans, observing that T loop morphology is more sensitive to coronary occlusion than QT dispersion.

Estimation of the T loop axis in relation to the QRS complex axis has long been recognized. It yields adequate information for detection of myocardial infarction and ischemia and their location in the myocardium. While the infarction is mostly connected with the QRS loop morphology and axes direction, the ischemia of the myocardium impairs its recovery process. When a portion of the ventricular wall is so affected, the normal sequence of ventricular repolarization will be disturbed and the resultant potential altered. Consequently, abnormalities are manifested in the T vectors [5].

It was shown that the T wave loop axis is a strong and independent risk indicator for fatal and non-fatal cardiac events in the elderly [6].

In addition, the vector deviation between the depolarization and repolarization waves was introduced in this context [7].

The aim of this study is to investigate the characterization of myocardial infarction and ischemia through T-loop morphology parameters. For this purpose the ECG-ILSA database has been used. Three parameters obtained from the synthesized VCG were computed with two methods, and a validation study was performed.

## 2. Material and methods

Particular aspects of T-wave morphology are considered for characterization and quantification of heterogeneous repolarization, using the vectorcardiogram (VCG). The orthogonal Frank leads were synthesized from the standard 12 lead ECG. Several methods for synthesizing Frank VCGs from simultaneously recorded 12 standard leads have been investigated and analyzed [8]. Levkov's derivation of the orthogonal leads [9-10] has been used in this study.

Three parameters were obtained from the VCG with two different computation methods:

- maximum angle between QRS and T loop axes
- T axis elevation and azimuth angle difference
- Ratio of maximum to mean T vector magnitudes

## 2.1. Maximum angle between QRS and T loop axes

The QRS and T axes are determined from the zero point of the VCG (the isoelectric point in ECG) to the most remote point of the respective loops. For example, the angle between the T and QRS axes in the frontal plane of Fig. 1, where the corresponding axes are determined from the zero point of the VCG to a point of the loop with maximum length, gives a value of  $A_n = 28^\circ$

The angles ( $A_F$ ,  $A_H$  and  $A_{LS}$ ) in the three VCG planes – frontal, horizontal and left sagittal – are computed, and the maximum value is the considered parameter MA:

$$MA = \max(A_F, A_H, A_{LS})$$

The estimation of the T loop axis in relation to the QRS complex axis provides adequate information for detection of myocardial infarction and ischemia and their location in the myocardium. The orientation of QRS and T loops are close to each other in normal case, whereas they are far from each other in some heart diseases [7].

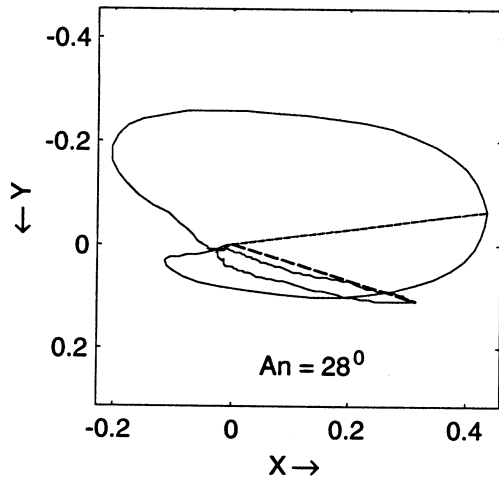


Figure 1. Angle between the QRS and T loop axes in the frontal plane.

## 2.2. T axis elevation and azimuth angles difference

The difference between frontal plane elevation and azimuth angles (DEA) is calculated along the entire segment of repolarization, providing a description of the T-wave loop morphology [3].

DEA is defined as the mean absolute value of the difference between the frontal plane Elevation ( $\alpha$ ) and Azimuth ( $\beta$ ) of all loop samples ( $n$ )

$$DEA = \text{mean}(\text{abs}(\alpha_n - \beta_n))$$

The Elevation with respect to the frontal plane is the angle between the loop axis at sample  $n$  and the Z axis in the left sagittal plane, while the Azimuth is the angle between the loop axis at the same sample and the X axis in the frontal plane (Fig. 2).

## 2.3. Ratio of maximum to mean T vector magnitudes

The ratio of maximum to mean vector magnitudes (RMMV) is adopted from the work of Kallert et al. [3]:

$$RMMV = V_{\max} / \text{mean}(V_n)$$

where  $V_n$  is the magnitude of the spatial vector of the T loop at sample  $n$  (Fig. 2).

The magnitude is calculated by the Pythagorean formula:

$$V = \sqrt{V_X^2 + V_Y^2 + V_Z^2}$$

where  $V_X$ ,  $V_Y$  and  $V_Z$  are the magnitudes of the projection of the spatial vector on the orthogonal axes.

## 2.4. Modified parameters

The ST segment elevation in the electrocardiogram leads is a recognized reliable indicator of myocardial injury, ischemia or infarction. For this reason, T loop parameter measurements with respect to the zero point of the VCG (the isoelectric point in the ECG) may lead to errors. This is especially valid when the zero point is not included in the T loop (the left sagittal plane of Fig. 2).

The size and direction of an ellipse (the form QRS and T loops mostly look like) is best characterized by its major axis. Such an approach is found in Nowinski et al. [4], where T loop Eigen values parameter is defined as a ratio of the major to the minor axis of the ellipse.

In order to capture the information of major axes, the two points of the loop with the maximum distance are detected and the point nearest to the zero point of the VCG loop is then considered (zero\*) for the following analysis. Then three modified parameters (MAM, DEAm, RMMVm) are measured with respect to the new considered zero\* point.

The difference between the two measurement techniques is illustrated in Fig. 2. The angle between the QRS and T loops of Fig. 1 changed from  $A_n = 28^\circ$  to the 'modified' value  $A_n = 3^\circ$ .

Some component of the DEAm and RMMVm parameter measurements with respect to the new reference point (zero\*) are shown in Fig. 3.

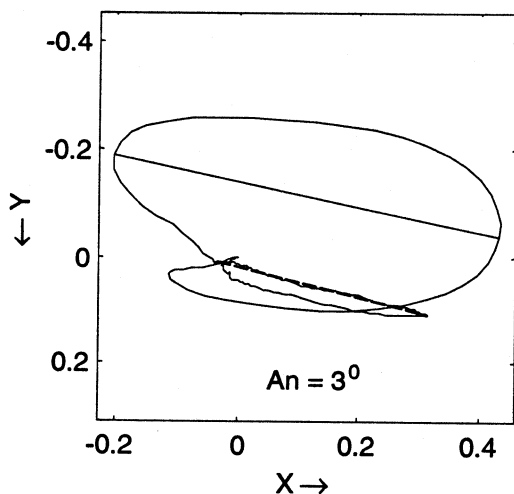


Figure 2. The QRS and T loops from Fig.1.  $An = 3^0$  between the major axes of the loops.

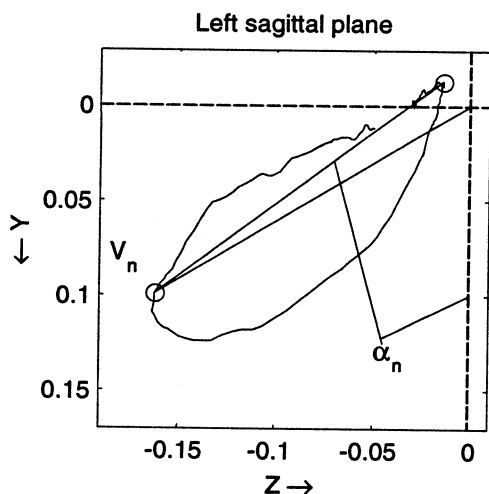


Figure 3. DEAm and RMMVm parameter measurements with respect to the point of the major axis nearest to the zero VCG point.

### 2.5. Experimental data

The population based ECG-ILSA database (Italian Longitudinal Study on Aging) has been considered. This database is composed by 2513 ECG signals of old people (1337 males and 1176 females aged from 65 to 85 years old) [11-13].

The following four groups have been selected for this study:

- 328 healthy subjects
- 123 patients with ischemia (ISCH)
- 172 patients with myocardial infarction (MI)

59 patients with ischemia & myocardial infarction (ISCH&MI)

The "healthy" group is characterized by absence of cardiovascular and chronic pulmonary diseases, by no use of drugs that can influence the electrical cardiac activity, and by no electrolyte imbalance [12]. In the remaining three groups, additional diseases (hypertension, diabetes, etc.) may be present.

### 3. Results and discussion

The 3 'original' parameters (MA, DEA, RMMV) and the 3 modified parameters (MAm, DEAm, RMMVm) have been computed in the 4 groups of patients selected from the ECG-ILSA database.

The mean values and the standard deviation of the 6 parameters in the group of healthy patients are reported in Table 1.

Table 2 reports the corresponding values in the group of patients with ischemia, myocardial infarction or both.

Table 1. Mean value  $\pm$  standard deviation of the parameters MA, DEA, RMMV and MAm, DEAm, RMMVm in the: healthy group.

Parameter	Healthy
MA	78.95 $\pm$ 52.24
DEA	59.29 $\pm$ 17.02
RMMV	2.18 $\pm$ 0.32
MAm	82.10 $\pm$ 55.02
DEAm	56.72 $\pm$ 19.31
RMMVm	2.36 $\pm$ 0.31

Table 2. Mean value  $\pm$  standard deviation of the parameters MA, DEA, RMMV and MAm, DEAm, RMMVm in the three groups: ISCH, MI, ISCH&MI.

Parameter	ISCH	MI	ISCH&MI
MA	91.67 $\pm$ 52.73	113.13 $\pm$ 50.28	118.42 $\pm$ 51.68
DEA	61.80 $\pm$ 17.94	62.28 $\pm$ 17.73	64.85 $\pm$ 18.22
RMMV	2.05 $\pm$ 0.41	2.01 $\pm$ 0.39	2.02 $\pm$ 0.42
MAm	99.89 $\pm$ 57.00	118.22 $\pm$ 50.49	125.81 $\pm$ 53.38
DEAm	64.88 $\pm$ 21.36	62.84 $\pm$ 26.31	70.78 $\pm$ 29.10
RMMVm	2.15 $\pm$ 0.46	2.11 $\pm$ 0.38	2.10 $\pm$ 0.40

Table 3. Cross-comparison (t-test) between healthy vs patients with Ischemia, Myocardial Infarction and both.

Parameter	Healthy vs ISCH	Healthy vs MI	Healthy vs ISCH&MI
MA	n.s.	p<0.0001	p<0.0001
DEA	n.s.	n.s.	n.s.
RMMV	p=0.0004	p<0.0001	p=0.0007
Mam	p=0.0026	p<0.0001	p<0.0001
DEAm	p=0.0001	p=0.0032	p<0.0001
RMMVm	p<0.0001	p<0.0001	p<0.0001

Cross-comparison between healthy and the other groups performed with t-test for all the parameters is shown in Table 3.

From this statistical analysis it come out that the mean values of the three modified parameters of the healthy subjects group are statistically different from those of ischemia or myocardial infarction groups. In addition, the modified parameters proved to yield higher discriminative power.

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