# Load Dependent Changes of Cardiac Depolarization and Repolarization during Exercise ECG Test

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## Abstract

*The trend of the morphology changes of cardiac depolarization and repolarization during exercise ECG test were examined in a group of 106 individuals. The ratio between the second and the first eigenvalues of Principal Component Analysis (PCA) was considered. The increasing and decreasing trends of PCA_QRS and PCA_T were classified as homogeneous and the rest as heterogeneous and their relationship with clinical data were studied.*

*Depolarization: an increasing percentage of heterogeneous trends were observed in the groups with cardiac risk factors. This trend was statistically significant in the dyslipidemia disease (p<0.05).*

*Repolarization: opposite to the depolarization, an increasing percentage of the homogeneous trends was obtained in the groups with cardiac risk factors, with statistically significant differences considering coronary artery disease and percutaneous coronary intervention (p<0.05).*

*The study of the load dependent behavior of PCA index during the stress test has revealed an increasing percentage of homogeneous and heterogeneous trends respectively in T and QRS wave, which can help to a better characterization of the diagnostic value of the exercise test.*

## 1. Introduction

Preliminary studies have suggested that QRS-amplitude changes due to exercise-induced alterations in ventricular volume and function can improve the diagnostic value of the exercise test.

Battler et al. [1], analyzing the QRS changes in a group of healthy and angiographically significant coronary artery disease subjects (AS-CAD), have concluded that amplitude changes during exercise testing have little diagnostic value and are not related to exercise-induced changes.

Another study of AS-CAD patients with chest pain have claimed that in subjects who have stopped exercise because of cardiac symptoms, the product of heart rate times blood pressure have been significantly lower when the QRS amplitude increases [2]. Thus, the mechanism for the QRS increase with exercise in patients with coronary artery disease appeared to be related to abnormalities in left ventricular function.

Some authors have gone even further, of predicting CAD by the exercise induced change of the composite QRS index, called 'Athens QRS' [3]

A study of healthy men and women during exercise test have been investigated the QRS changes in relation to the gender and age [4].

Load dependent changes of the T-wave have been studied in world-class athletes [5]. A decrease of electrocardiographic T-wave voltage with increasing training loads has been reported and ascribed to training-related adaptation in sympathetic activity to the ventricles.

## 2. Methods and material

### 2.1. ECG database

We studied 106 patients: age 63±10 years, 45 males, 39 with diabetes mellitus (DM), 85 with AP, 34 with positive stress test, 18 with a history of myocardial infarction (MI), 48 with angiographically significant coronary artery disease (AS-CAD). Controllable risk factors (smoke, high blood pressure, high blood cholesterol, and obesity), not controllable risk factors (gender, age and heredity) and other clinical data are presented in Table 1. Ex smokers were considered individuals who quitted from at least 6 months.

Ethics: Signing an inform consent was a prerequisite for inclusion in the study. The study protocol was approved by the local ethical committee and complied with the Declaration of Helsinki.

Table 1. Distribution of the cardiac risk factors and clinical variables for the whole group of patients. SD – standard deviation; BMI – body mass index; DM – diabetes mellitus; AH – arterial hypertension; MI – myocardial infarction; AS-CAD - angiographically significant coronary artery disease; PCI – percutaneous coronary intervention; n – number.

| Clinical variable | Distribution n = 106 |
|---|---|
| Age – mean ± SD | 62.8 ± 10.3 |
| Male – n (%) | 45 (42%) |
| BMI – mean ± SD | 28.0 ± 4.3 |
| AH – n (%) | 96 (90%) |
| DM – n (%) | 39 (36%) |
| Dyslipidemia – n (%) | 87 (81%) |
| Total cholesterol (mmol/l) – mean ± SD | 5.09 ± 1.1 |
| Triglycerides (mmol/l) – mean ± SD | 2 ± 1.8 |
| Family history of CAD – n (%) | 11 (10%) |
| Smokers (present or ex) – n (%) | 41 (39%) |
| Angina pectoris – n (%) | 85 (80%) |
| History of MI – n (%) | 18 (17%) |
| Positive stress ECG test – n (%) | 34 (32%) |
| AS-CAD – n (%) | 48 (45%) |
| PCI – n (%) | 40 (37%) |
| Coronary artery bypass grafting – n (%) | 10 (9%) |
| Stroke | 6 (6%) |

Patients were included regardless of their sex or age. Exclusion criteria were left ventricular systolic dysfunction with ejection fraction < 40%, haemodinamically significant valvular heart disease, history of ventricular tachycardia, patient unable to perform the stress ECG test or unwilling to sign the inform consent.

Digital 12-lead electrocardiograms (ECG) were acquired during stress ECG test using veloergometer (GE Marquette Stress PC ECG Application) – 2-min stages 25 W incremental workload.

The test was considered positive in the setting of ≥ 1 mm horizontal or downward-sloping ST depression 80 msec after J-point.

## 2.2. Principal component analysis

QRS detection algorithm [6] and automatic delineation of the QRS and T wave onsets and offsets [7] were performed to bound the segments for the PCA estimation.

Complexity index, the ratio between the second and the first PCA's eigenvalues has been used for this analysis:

PCA: $\lambda_2/\lambda_1$

The complexity indexes PCA_QRS and PCA_T were calculated for all QRSs and T-waves of the record. Both PCA_QRS and PCA_T were smoothed by a moving averaging procedure applied on 20 successive values.

An example of PCA_QRS of a 68 years old individual is shown in Figure 1.

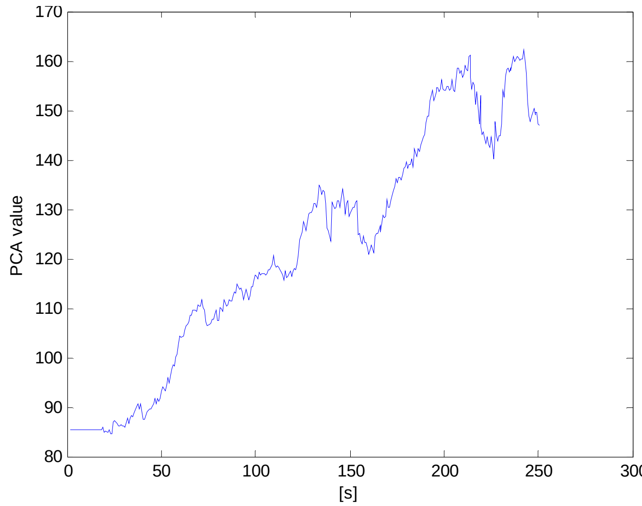


Figure 1. An example of PCA_QRS of a 68 years old individual. The case is clustered as homogeneous, with pronounced increasing trend.

The PCA_QRS and PCA_T were observed visually and the next clusters are assigned:

Homogeneous – with pronounced increasing or decreasing trends, and

Heterogeneous – all the rest, for example those of: no significant change of the baseline PCA, bidirectional (+/- or -/+) behavior of PCA, etc.

Examples of homogeneous increasing and decreasing trends are shown respectively in Figure 1 and Figure 2. Example of heterogeneous trend is illustrated in Figure 3.

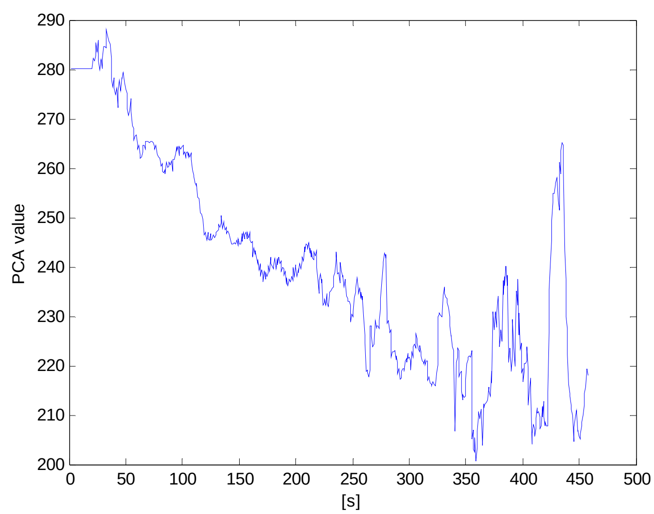


Figure 2. Example of homogeneous PCA_QRS with pronounced decreasing trend.

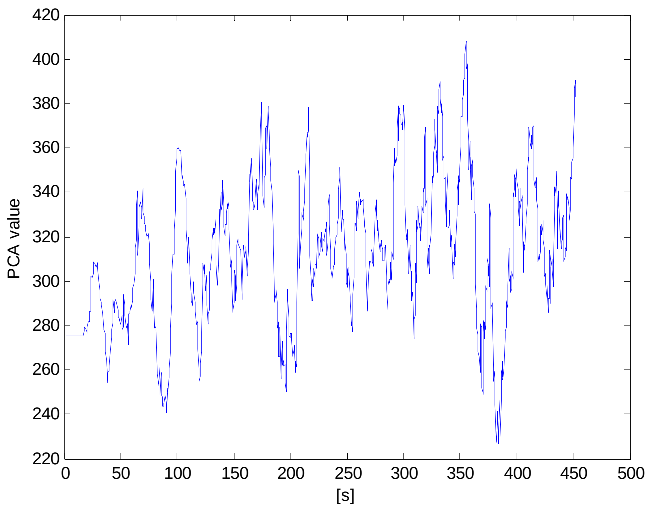

Figure 3. Example of heterogeneous PCA_QRS with no significant change of the baseline.

## 3. Results

The results of the load dependant changes of the QRS complex and T wave morphology in the groups of the controllable risk factors (smoke, high blood pressure, high blood cholesterol dyslipidemia and obesity), not controllable risk factors (gender, age and heredity) and clinical parameters (AS-CAD, Family history of CAD, PCI, Stress test, Coronary artery bypass grafting and Stroke) are presented in Table 2. Considering the entire dataset, the trends of PCA_QRS (and PCA_T) were classified as heterogeneous in 63.3% (82.1%) and homogeneous in 36.7% (21.9%) of the records.

## 4. Discussions

**Depolarization:** Statistical analysis of the classification of the trends produced a significant difference in the dyslipidemia group (p<0.05). It was interesting to note a higher percentage of PCA_QRS heterogeneous classification in groups 'with' vs. 'without' risk factors. Some examples of the classification of PCA_QRS as heterogeneous trend are:

- Age: 66.7% in the group of ≥ 65 years old, vs. 60.3% in the group of < 65 years old;
- Body mass index: 75.8% in the group of BMI >30, vs. 56.5% in the group of BMI =24÷29
- Dyslipidemia: 67.8% in patients with dyslipidemia vs. 42.2% in the no dyslipidemia group;
- Total cholesterol: 66.7% of the high and 77.4% of the borderline groups, vs. 55.1% in the normal group;
- Angiographically significant coronary artery disease: 64.6% in the group of ‘yes’, vs. 62.1% in the group of ‘no’
- Family history of coronary artery disease: 72.8% in the risk group, vs. 62.2% for patients falling out of the risk group;
- Percutaneous coronary intervention: 67.5% in intervene group, vs. 60.6% in non-intervene group;
- Angina pectoris: 72.8% in the group of ‘yes’, vs. 66.7% in the group of ‘no’;
- Coronary artery bypass grafting: 80% in the group of ‘yes’, vs. 61.5% in the group of ‘no’;
- Stroke: 66.7% in the group of ‘yes’, vs. 63% in the group of ‘no’.

**Repolarization:** Statistical analysis of the classification of the trends of PCA_T index produced a significant difference considering the AS-CAD and PCI (p<0.05).In this case, it was interesting to observe a higher percentage of PCA_T homogeneous classification in groups 'with' vs. 'without' risk factors. Some examples of the classification of PCA_T as homogeneous trend are:

- Age: 22.9% in the group of ≥ 65 years old, vs. 13.8% in the group of < 65 years old;
- Gender: 20% in men, vs. 16.4% in women;
- Smokers: 18.7 in present and 12.0 % in ex smokers, vs. 1.5% in no smokers;
- Dyslipidemia: 19.5% in patients with ‘yes’, vs. 10.5% in patients with ‘no’;
- History of myocardial infarction: 22.2% in the group of ‘yes’, vs. 17.0% in the group of ‘no’;
- Angiographically significant coronary artery disease: 27.0% in the group of ‘yes’, vs. 10.3% in the group of ‘no’;
- Family history of coronary artery disease: 27.2% for ‘yes’, vs. 16.8% for ‘no’;
- Percutaneous coronary intervention: 27.7% for ‘yes’, vs. 12.1% for no;
- Angina pectoris: 18.8% for ‘yes’, vs. 14.3% for ‘no’;
- Positive stress test: 26.5 for ‘yes’, vs. 13.9% for ‘no’
- Coronary artery bypass grafting: 30.0% in the group of ‘yes’, vs. 16,7% in the group of ‘no’;
- Stroke: 33.3% for ‘yes’, vs. 17.0% for ‘no’.

## 5. Conclusions

The study of the load dependent behavior of PCA index during stress test in relation to clinical data has revealed an increasing percentage of homogeneous and heterogeneous trends respectively in T and QRS wave, which can help to a better characterization of the exercise test in relation to cardiac risk factors.

## References

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Table 2. Load dependant changes of the QRS complex and T wave morphology. Total number of patients = 106. Total cholesterol was measured in 95 individuals. BMI – body mass index; AH – arterial hypertension; CAD - coronary artery disease; MI - myocardial infarction; AS-CAD - angiographically significant coronary artery disease; PCI – percutaneous coronary intervention; HR – heart rate

| Risk factors and clinical parameters | n | PCA_QRS | | | | PCA_T | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Homogeneous | | Heterogeneous | | Homogeneous | | Heterogeneous | |
| | | n | % | n | % | n | % | n | % |
| Age (≥ 65 years old) | 48 | 16 | 33.3% | 32 | 66.7% | 11 | 22.9% | 37 | 77.1% |
| Age (< 65 years old) | 58 | 23 | 39.7% | 35 | 60.3% | 8 | 13.8% | 50 | 86.2% |
| Males | 45 | 19 | 42.2% | 26 | 57.8% | 9 | 20.0% | 36 | 80.0% |
| Females | 61 | 20 | 32.8% | 41 | 67.2% | 10 | 16.4% | 51 | 83.6% |
| Present smokers | 16 | 6 | 37.5% | 10 | 62.5% | 3 | 18.7% | 13 | 81.3% |
| Ex smokers | 25 | 10 | 40.0% | 15 | 60.0% | 3 | 12.0% | 22 | 88.0% |
| No smokers | 65 | 23 | 35.3% | 42 | 64.7% | 1 | 1.5% | 64 | 98.5% |
| BMI (≤ 23) | 11 | 4 | 36.4% | 7 | 63.6% | 2 | 18.2% | 9 | 81.8% |
| BMI (24÷29) | 62 | 27 | 43.5% | 35 | 56.5% | 13 | 21.0% | 49 | 79.0% |
| BMI (≥ 30) | 33 | 8 | 24.2% | 25 | 75.8% | 4 | 12.1% | 29 | 87.9% |
| AH (yes) | 96 | 36 | 37.5% | 60 | 62.5% | 16 | 16.7% | 80 | 83.3% |
| AH (no) | 10 | 3 | 30.0% | 7 | 70.0% | 3 | 30.0% | 7 | 70.0% |
| Dyslipidemia (yes) | 87 | 28 | 32.2% | 59 | 67.8% | 17 | 19.5% | 70 | 80.5% |
| Dyslipidemia (no) | 19 | 11 | 57.9% | 8 | 42.1% | 2 | 10.5% | 17 | 89.5% |
| Tot. cholesterol <5.2 normal | 49 | 22 | 44.9% | 27 | 55.1% | 9 | 18.4% | 40 | 81.6% |
| Tot. cholest. 5.2÷6.2 borderline | 31 | 7 | 22.6% | 24 | 77.4% | 5 | 16.1% | 26 | 83.9% |
| Tot. cholesterol >6.2 high | 15 | 5 | 33.3% | 10 | 66.7% | 2 | 17.0% | 13 | 83.0% |
| History of MI (yes) | 18 | 9 | 50.0% | 9 | 50.0% | 4 | 22.2% | 14 | 77.8% |
| History of MI (no) | 88 | 30 | 34.0% | 58 | 66.0% | 15 | 17.0% | 73 | 83.0% |
| AS-CAD (yes) | 48 | 17 | 35.4% | 31 | 64.6% | 13 | 27.0% | 35 | 73.0% |
| AS-CAD (no) | 58 | 22 | 37.9% | 36 | 62.1% | 6 | 10.3% | 52 | 89.7% |
| Family history of CAD (yes) | 11 | 3 | 27.2% | 8 | 72.8% | 3 | 27.2% | 8 | 72.8% |
| Family history of CAD (no) | 95 | 26 | 37.8% | 59 | 62.2% | 16 | 16.8% | 79 | 83.2% |
| PCI (yes) | 40 | 13 | 32.5% | 27 | 67.5% | 11 | 27.7% | 29 | 72.3% |
| PCI (no) | 66 | 26 | 39.4% | 40 | 60.6% | 8 | 12.1% | 58 | 87.9% |
| Angina pectoris (yes) | 85 | 32 | 27.2% | 53 | 72.8% | 16 | 18.8% | 69 | 81.2% |
| Angina pectoris (no) | 21 | 7 | 33.3% | 14 | 66.7% | 3 | 14.3% | 18 | 85.7% |
| Positive stress ECG test | 34 | 13 | 38.2% | 21 | 61.8% | 9 | 26.5% | 25 | 73.5% |
| Negative stress ECG test | 72 | 26 | 36.1% | 46 | 63.9% | 10 | 13.9% | 62 | 86.1% |
| Cor. artery bypass grafting (yes) | 10 | 2 | 20.0% | 8 | 80.0% | 3 | 30.0% | 7 | 70.0% |
| Cor. artery bypass grafting (no) | 96 | 37 | 38.5% | 59 | 61.5% | 16 | 16.7% | 80 | 83.3% |
| Stroke (yes) | 6 | 2 | 33.3% | 4 | 66.7% | 2 | 33.3% | 4 | 66.7% |
| Stroke (no) | 100 | 37 | 37.0% | 63 | 63.0% | 17 | 17.0% | 83 | 83.0% |


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