Time Course of ECG Depolarization and Repolarization Changes during Ischemia in PTCA Recordings

E. Pueyo[1], J. García[1], G. Wagner[2], R. Bailón[1], L. Sörnmo[3], P. Laguna[1]
[1]Department of Electronic Engineering and Communications, University of Zaragoza, Zaragoza, Spain
[2]Department of Medicine, Duke University Medical Centre, NC, USA
[3]Department of Applied Electronics, University of Lund, Sweden

Summary

Objectives: In this work we studied the temporal evolution of changes in the electrocardiogram (ECG) as a consequence of the induced ischemia during prolonged coronary angioplasty, comparing the time course of indexes reflecting depolarization and those reflecting repolarization.
Methods: We considered both local (measured at specific points of the ECG) and global (obtained from the Karhunen-Loève transform) indexes. In particular, the evolution of Q, R and S wave amplitudes during ischemia was analyzed with respect to classical indexes such as ST level. As a measurement of sensitivity we used an Ischemic Changes Sensor (ICS), which reflects the capacity of an index to detect changes in the ECG.
Results: The results showed that, in leads with low-amplitude ST-T complexes, the S wave amplitude was more sensitive in detecting ischemia than was the commonly used index ST60. It was found that in such leads the S wave amplitude initially exhibited a delayed response to ischemia when compared to ST60, but its performance was better from the second minute of occlusion. The global indexes describing the ST-T complex were, in terms of the ICS, superior to the S wave amplitude for ischemia detection.
Conclusions: Ischemic ECG changes occur both at repolarization and depolarization, with alterations in the depolarization period appearing later in time. Local indexes are less sensitive to ischemia than global ones.

Keywords
Ischemia, angioplasty, QRS amplitudes, ST value

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1. Introduction

Ischemic changes in the electrocardiogram (ECG) may precede anginal pain. Thus it is important to search for ECG-based indexes with good capability for the detection of ischemia. Percutaneous Transluminal Coronary Angioplasty (PTCA), consisting in a sudden complete coronary occlusion produced by balloon angioplasty, is a useful model to study ischemic changes that occur during the first minutes of occlusion.

Several studies have reported both ST segment and QRS complex changes evoked by PTCA even when the occlusion is not prolonged [1-5]. In other studies, indexes based on the Karhunen-Loève transform have been developed, which reflect information contained in an entire ECG segment or waveform. It has been shown that these global indexes show a higher sensitivity and an earlier response in the detection of ischemia than the local indexes [6, 7]. Other proposals have suggested the study of the ECG during ischemia by means of a new index (the Athens score) that assembles the variations of Q, R and S wave amplitudes [8].

In this study we analyzed several clinical indexes from depolarization (in particular, Q, R and S wave amplitudes) and compared them with other indexes from repolarization by measuring their capacity to reflect the ischemic changes induced during prolonged PTCA according to the methodology proposed in [7].

2. Materials and Methods

2.1 Study Population

The study group consisted of 83 patients (55 males, 28 females) from the STAFFIII database receiving elective PTCA in one of their major coronary arteries. The average duration of the occlusion period was 4’ 26”, considerably longer than that of usual PTCA procedures because the treatment protocol included a single prolonged occlusion rather than a series of brief occlusions.

The locations of the 83 dilations were: left anterior descending artery (LAD) in 27 patients, right coronary artery (RCA) in 38 patients and left circumflex artery (LCX) in 18 patients. Nine standard leads (V1-V6, I, II and III) were recorded using equipment by Siemens-Elema AB (Solna, Sweden) and digitized at a sampling rate of 1 KHz and amplitude resolution of 0.6 μV.

For each patient in the study group two recordings were considered: the control ECG recorded just before angioplasty and the PTCA recording. The control interval usually was 5 minutes long, the same order as the average inflation time.

2.2 ECG-based Indexes

ECG signal pre-processing was applied before measuring the different parameters, including the detection and selection of ‘normal beats’ labelled according to [9],

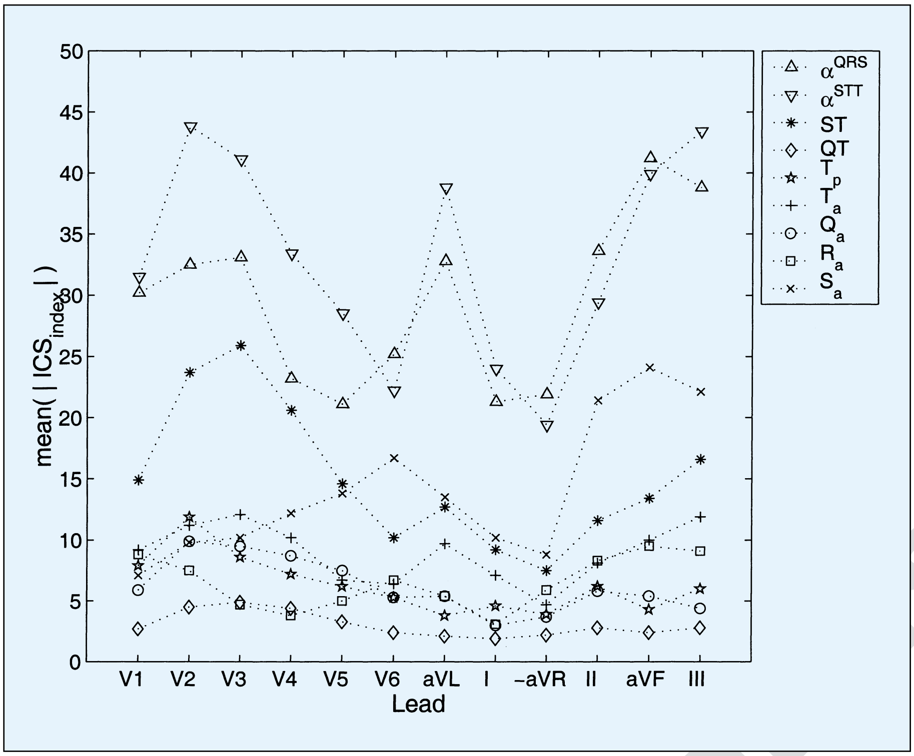

Fig. 1 Mean absolute value of ICS [mean (| ICS |)] among the 83 patients for the different indexes at the end of the occlusion in each of the twelve leads

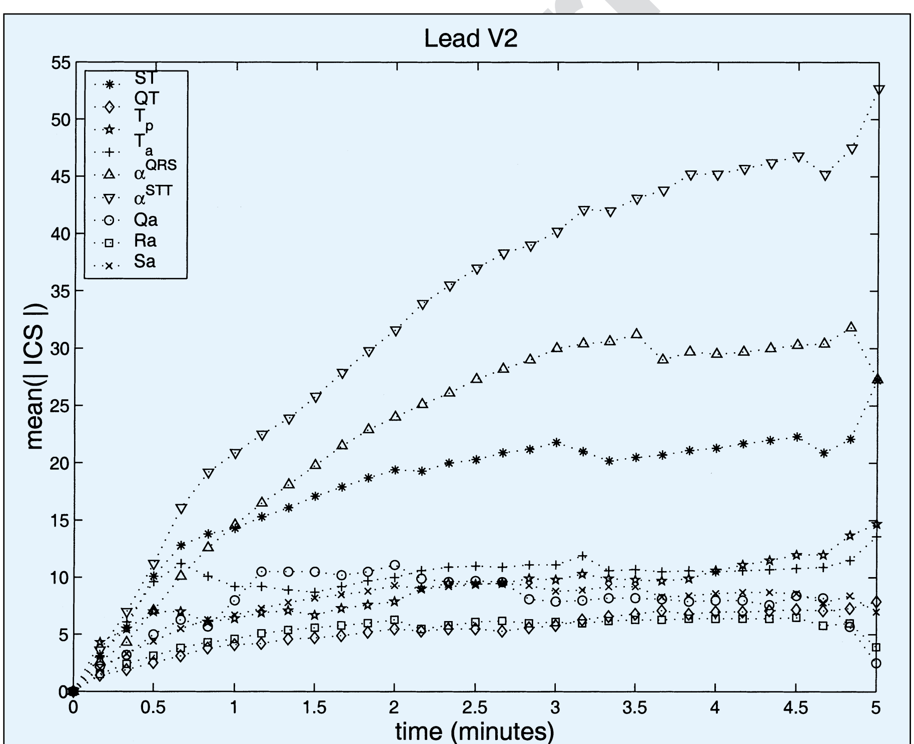

Fig. 2 Temporal evolution of the ICS for lead V2 averaged among patients. Due to the differences in the occlusion time, the number of patients included in the average changes for different times

cubic splines baseline wander attenuation, rejection of beats presenting differences in their mean isoelectric level respect to adjacent beats of more than 600 μV and signal averaging using a moving window of 10 beats (only prior to measure the local indexes) to improve the signal-to-noise ratio.

The onset and offset of the different ECG waveforms were detected by using the automated detector of waveform boundaries described in [10].

On the pre-processed signal we considered several indexes measured on specific ECG points (or derived from two ECG points in the case of interval durations): the level of the ST segment measured at 60 ms after J point (ST60), the maximum amplitude of the T wave (Ta) and its corresponding time location with respect to R wave (Tp), the QT interval length (QT) and the amplitudes of Q, R and S waves (Q_a, R_a and S_a).

These indexes were compared with other global indexes derived from the Karhunen-Loève transform (KLT). The KLT captures the information contained in an entire signal segment and concentrates it in a few coefficients. This transform was applied to the QRS complex and the entire ST-T complex. For each of these two segments the first four KLT series were considered and then the one that exhibited the largest changes (in the sense of greatest variations at the end of the occlusion averaged among the 83 patients and the 12 leads) was selected. These parameters were denoted by α^{QRS} and α^{STT}. A detailed development of the KLT and how this is applied to the ECG segments can be found in [6].

2.3 The Ischemic Changes Sensor

With the two recordings considered for each patient, before and during the angioplasty process, an Ischemic Changes Sensor (ICS) was defined. This parameter, described in [6, 7], reflects the capacity of a certain index to detect the changes induced by ischemia and is obtained according to the following formula:

$$ICS_{index}(t) = \frac{\Delta\, index\,(t)}{\sigma_{index}} \qquad (1)$$

$\Delta index(t)$ is the magnitude of a change reflected in the index during the occlusion, estimated at an instant t of the occlusion as the slope of the line obtained from linearly fitting the series values of the index from the beginning of the inflation until the instant t under consideration. Calculating $\Delta index$ in this way, we avoid outlier measures. σ_{index} is the standard deviation of the *index* in the control recording and measures the normal variations of the *index* when no occlusion is present. Finally, *index* represents any of the indexes considered in the study.

To investigate the time course of the ischemic changes, the ICS was estimated every 10 seconds from the beginning of the occlusion.

To study the significance of an index for ischemia detection, a threshold η was applied to the ICS parameter. Such a threshold was selected by considering the ICS values measured in a control population composed of 11 normal subjects without any symptoms of cardiac diseases. The ICS values for those subjects were not larger than 2.5 in any case. In order to ensure that only ischemic events were detected, a considerably larger threshold value was used ($\eta = 8$).

3. Results and Discussion

First, we studied the changes shown by the different indexes evaluated at the end of the occlusion (see Fig. 1).

When the Q_a, R_a and S_a indexes from ventricular depolarization were not included in the study, ST60 was the most sensitive of the traditional indexes in all leads [6]. However, when these three indexes were also considered in the study, it was found that in leads with usual low–amplitude ST-T complexes, such as V6, aVF, II or III, the mean final ICS (in absolute value) among the 83 patients was larger for the S_a index than for ST60 (see Fig. 1).

The leads V2, V3 and V4 were the most sensitive ones (in the sense of largest mean [| ICS |] values) for detection of induced ischemia when this matter was analyzed by means of the ST60 index. When this consid-

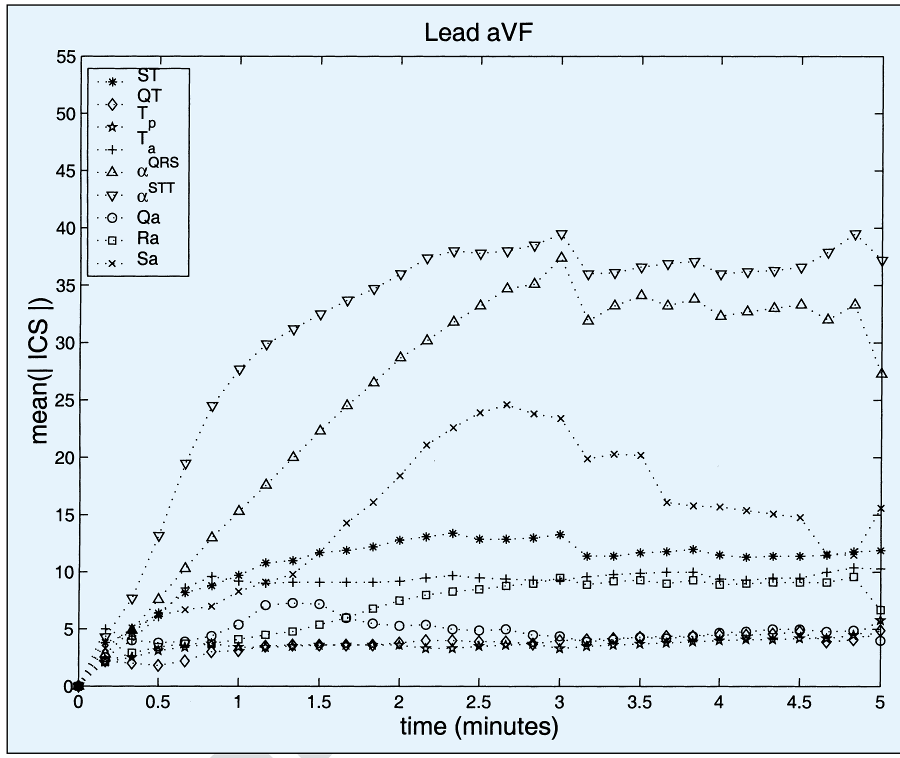

Fig. 3 Temporal evolution of ICS averaged among patients for lead aVF

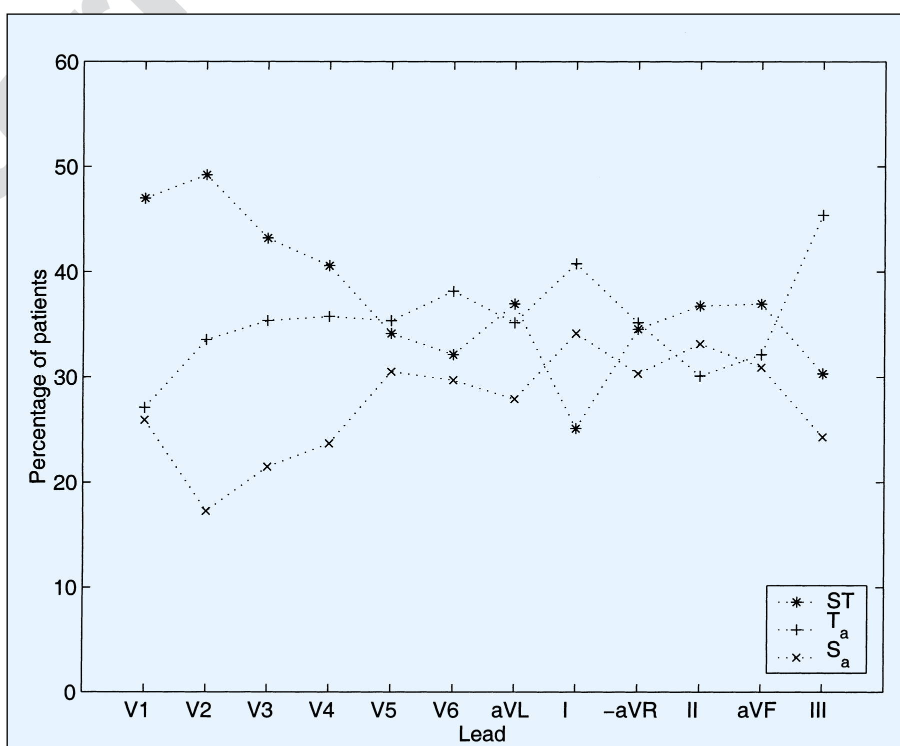

Fig. 4 Percentage of patients in whom the different indexes showed the earlier response to the ischemic induced changes, considering the following (most significant) local indexes: S_a from depolarization and ST, T_a from repolarization

eration was established in terms of the S wave amplitude, the leads aVF, II and III proved to be the most sensitive ones.

Only the ICS values corresponding to the two above-mentioned parameters, ST and S_a, approached to the range of values of the indexes derived from the KL transform. The other two depolarization indexes included in this study, Q_a and R_a, exhibited values of change considerably lower, similar to those associated with other local indexes, such as Tp.

Next, the temporal evolution of changes, registered by measuring the ICS at different times of the occlusion, was analyzed. Only the performance of S_a among the three local depolarization indexes included in the study was remarkable, since ICS_{Qa} and ICS_{Ra} did not show significant changes during the occlusion, taking similar values to the ones found for ICS_{Tp} (see Fig. 2 and Fig. 3).

The S_a index, which showed much more noticeable variations, presented different performances depending on whether the projection of the ST-T complex on the lead under consideration is large or small with respect to what occurs in the remaining leads. Thus, in leads V2, V3 and V4 the range of ICS values taken by S_a was similar to that of Ta, being these values larger than those found for the rest of local indexes such as Tp and QT, but, in any case, much smaller than the ones referred to ST (see Fig. 2).

However, in other leads such as aVF, II, V5 or V6, the changes registered by S_a were much more noticeable. In fact, although ICS_{Sa} had a slow response in comparison with ICS_{ST}, we could find an instant (2 minutes in V5, 1.5 minutes in aVF, …) in which ICS_{Sa} reached the value taken by ICS_{ST} and from then on remained higher until the end of the occlusion (see Fig. 3). Nevertheless, the local indexes always exhibited a change that was less pronounced than that of the indexes based on the KL transform [7].

The results obtained using the S_a parameter corroborate the idea that the indexes related to the depolarization (QRS complex) react to the induced ischemia later in time than the indexes referred to the repolarization (ST-T complex). In fact, evaluating the temporal contribution to the final ICS value for each of the indexes considered in the study, we could observe that for indexes associated with the ST-T complex (such as the ST60 index), the ICS grows very fast during the first minute of occlusion, but this increase is much slower during the remaining minutes. In contrast, for depolarization indexes such as S_a it is necessary to wait until the second minute to reach a large percentage of the final ICS.

Finally, we studied the percentage of patients who had their earliest ischemic changes in one of the following three intervals of the ECG: ST segment, T wave and QRS complex. The results we obtained support the idea of an earlier response of the indexes related to the repolarization with respect to the ones from depolarization, although it was noticeable that when the S wave amplitude was chosen as representative of the depolarization period, the percentage of patients with their earliest changes in QRS complex was significant (see Fig. 4).

4. Conclusion

The ECG changes induced by ischemia occur both at repolarization and depolarization. In this study we evaluated depolarization changes as compared to repolarization ones. We found that in some leads (those with usual lower projection of the ST segment) the S wave amplitude (S_a) reached rates of change superior to the ones corresponding to the ST60. The variations of this depolarization-based index S_a occurred later in time than those corresponding to indexes associated with the repolarization, which had an earlier response.

Changes given by local indexes, both at depolarization and repolarization, could not reflect by themselves all the changes induced by ischemia in the ECG. It has been shown that there are other indexes obtained from the KL transform that are more sensitive in the detection of ischemia and exhibit an earlier activation to it than the local ones.

The results we obtained in this study support the idea of the 'ischemic cascade', according to which ischemic perturbations in the QRS are preceded by changes in the T wave and in the ST segment.

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Correspondence to:
Esther Pueyo Paules
Department of Electronic Engineering and Communications, C. P.S
María de Luna 3, 50015 Zaragoza, Spain
E-mail: epueyo@unizar.es