Temporal Evolution of ECG-based Indexes in Patients with Myocardial Ischemia Induced by Prolonged Balloon Occlusion

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Abstract

The time course of ischemic ECG changes induced by prolonged occlusion have been studied. We have analyzed the evolution along angioplasty of an Ischemic Changes Sensor *(ICS) parameter estimated for different ECG-based indexes in 83 patients. We compared traditional indexes (e.g. ST level, QT interval, T wave measurements, etc.) and global measurements derived using the Karhunen-Loève transform applied on different ECG intervals. The KLT-based indexes showed a better sensitivity to ischemic changes than did the traditional indexes (89% in KLT index for ST-T complex, vs. 61% in ST level index). Further, it was found that changes in the ST-T complex usually appeared earlier than in the QRS complex (77% of patients vs. 23%). A similar percentage occurred earlier in the T wave (41%) and in the ST segment (36%). It was also found that the largest changes occurred during the first minute of occlusion.*

1. Introduction

Different ECG-based indexes have been used to diagnose myocardial ischemia and several grades of ischemia have been established as an estimate of its severity [1]. Many studies related to myocardial ischemia detection have been written, but the prognostic significance for the different indexes of the ventricular repolarization period is still unclear. Ischemic ECG changes precede angina in the ischemic cascade and they may be the only sign of "silent myocardial ischemia". Thus, it is needed to find indexes that can detect early changes on the ECG which may evolve to ischemic disease. Most indexes related to ischemia are based on measurements at specific points of the ECG: ST segment deviations, QT variability, repolarization alternans, etc. We call them local indexes. On the other hand we refer to as global indexes, those which take into account the information contained in an ECG interval. We developed such global indexes using the Karhunen-Loève transform (KLT) [2, 3].

Percutaneous Transluminal Coronary Angioplasty (PTCA) provides an excellent model to investigate the changes of transmural ischemia [4]. Several studies have reported different ECG changes evoked by PTCA [4, 5].

The aim of this work is to describe the time course of the PTCA-induced ischemic changes studying the incidences of ischemia in different ECG segments.

2. Materials and methods

2.1. Study group

A set of 83 patients from the **STAFF3 database** undergoing elective PTCA was analyzed. The inflation duration ranged from 1' 30" to 7' 17" (mean, 4' 26"). Notice the long mean period of occlusion compared to a normal PTCA procedure. Nine standard leads were recorded and digitized at a sampling rate of 1 KHz and amplitude resolution of 0.6 μV.

2.2. Traditional indexes

We automatically measured on the continuously averaged ECG some indexes traditionally used in clinical diagnosis. The values for STJ+60 level, T wave amplitude and position respect to the QRS fiducial point, and durations of QRS complex and QT interval were estimated in each beat n, obtaining, respectively, the series $ST(n)$, $T_a(n)$, $T_p(n)$, $QRS_d(n)$ and $QT(n)$.

2.3. Global KLT-based indexes

We used the KLT to describe ischemic changes considering the information in entire ECG segments.

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This is a mathematical tool that represents the signal information in a few coefficients. The beat-to-beat dynamic evolution of the signal can be characterized by the study of the KLT coefficients series.

The KLT basis functions were derived using a database which contains a large variety of repolarization patterns [6]. Signal pre-processing (including selection of beats, cubic splines baseline wander rejection, and correction for the effects of the HR in the repolarization period using Bazett's formula) was applied in the derivation of the basis functions and later in the coefficients series estimation.

In this work we have considered four ECG intervals (QRS complex, ST segment, T wave and the entire ST-T complex). In previous studies [2, 3] it was demonstrated that with a few KLT coefficients it is possible to track the ECG evolution. We used four KLT coefficients for each analyzed segment and then selected that one which exhibited the largest changes.

An example of global indexes trends during an angioplasty procedure is shown in Fig. 1 (occlusion period between dash-dotted lines). The first order KLT coefficients series for the ST-T and QRS complexes ($\alpha_0^{STT}(n)$ and $\alpha_0^{QRS}(n)$, respectively) are plotted. They represent the morphological changes of the ECG in both complexes showing that the $\alpha_0^{STT}(n)$ series exhibits a clear tendency of change after the first 30 seconds of occlusion, while the $\alpha_0^{QRS}(n)$ series only presents smaller variations which occur later in time. Representative ECG morphologies of the different stages are also shown.

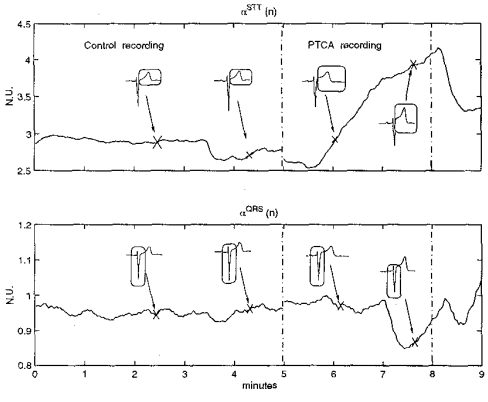


Figure 1: *The $\alpha_0^{STT}(n)$ and $\alpha_0^{QRS}(n)$ series during a complete PTCA procedure.*

2.4. The *ICS* parameter

An *Ischemic Changes Sensor* (*ICS*) parameter was defined and estimated for every index (including local and KLT-based) to measure their capability for detection of ischemic changes [3]. The ICS parameter provides information of the change magnitude that a certain index reflects and is defined by

$$ICS_{index} = \frac{\Delta index}{\sigma_{index}} \quad (1)$$

where $\Delta index$ is the amplitude of change in an index during the occlusion (estimated by fitting a linear polynomial), σ_{index} is the standard deviation of the index as measured in the control ECG, and *index* is any of ST, T_a, T_p, QRS_d, QT, α^{QRS}, α^{STT}, α^{ST} and α^{T}. In Fig. 2 an example which describes how this ICS parameter was developed is shown.

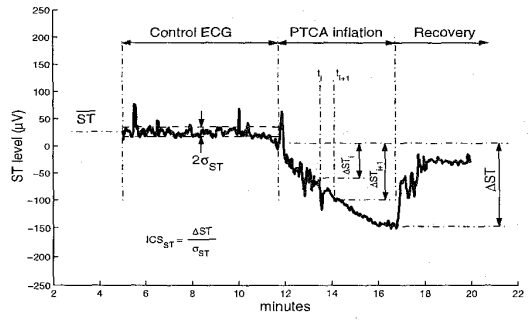


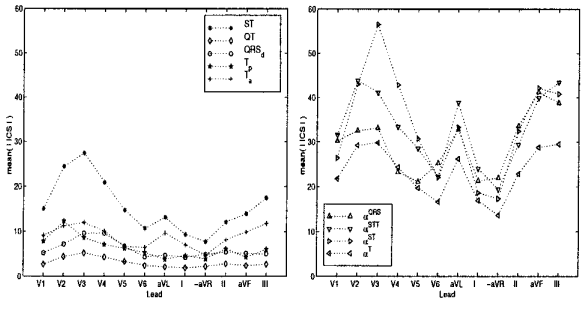
Figure 2: *Example of series evolution (ST(n)) for ICS parameter derivation (ICS_{ST}).*

The ICS parameter was estimated every ten seconds (instant t_j) from the beginning of occlusion to study the ECG changes evolution reflected in the different indexes. A decision rule ($|ICS| > \eta$, with $\eta = 8$) was used to consider a change large enough to be detected. By means of the ICS parameter we compared the described local and KLT-based measurements to determine which presents an earlier response to the ischemic changes.

3. Results

Changes at the end of the occlusion. The KLT-based indexes were more sensitive to ischemia than the traditional indexes showing the largest ICS values at the end of the occlusion. This is shown in Figs. 3(a) and 3(b), where the averaged results ($\overline{|ICS|}$) are represented. Only the values of ICS_{ST} approached to the range of the KLT-based indexes. QRS_d, T_p and QT indexes showed smaller ICS values. With respect to the KLT-based indexes α^{STT} and α^{ST} were the most sensitive. The largest $\overline{|ICS_{index}|}$ values were

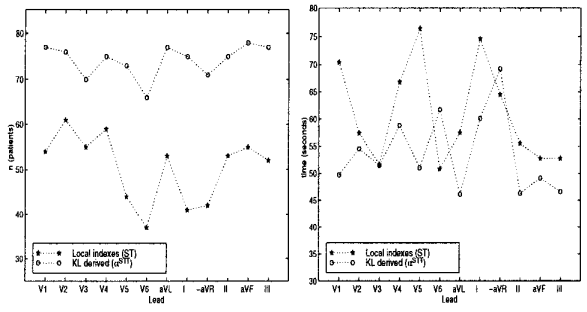
found in leads V2, V3 and V4, appearing as the most sensitive leads to the induced changes.



(a) $\overline{|ICS|}$ in local indexes. (b) $\overline{|ICS|}$ in KLT indexes.

Figure 3: $\overline{|ICS_{index}|}$ *for the different indexes.*

Time courses of changes. The KLT-based indexes reached higher level of sensitivity than local indexes did and they also presented an earlier manifestation of the changes. We averaged among patients the ICS parameters of the most sensitive indexes in the traditional indexes group (ST) and KLT-based indexes group (α^{STT}); they exceeded the threshold ($\overline{|ICS|} > 8$) in 89% and 61% of patients, respectively (see Fig. 4(a)). The threshold was crossed in mean 54 and 61 seconds, respectively, after the beginning of the occlusion (see Fig. 4(b)).



(a) Changes detected. (b) Detection times.

Figure 4: *Detected changes and times of detection.*

From the first seconds of occlusion the KLT-based indexes showed larger ICS values corresponding to a faster response to the induced ischemia. The evolution of ICS parameters averaged among patients along five minutes of occlusion is represented in Fig. 5 for the leads V2 (above) and V6 (below) (note that along the time axis there are different number of patients to average due to the differences in occlusion times). Only the ICS parameter corresponding to the

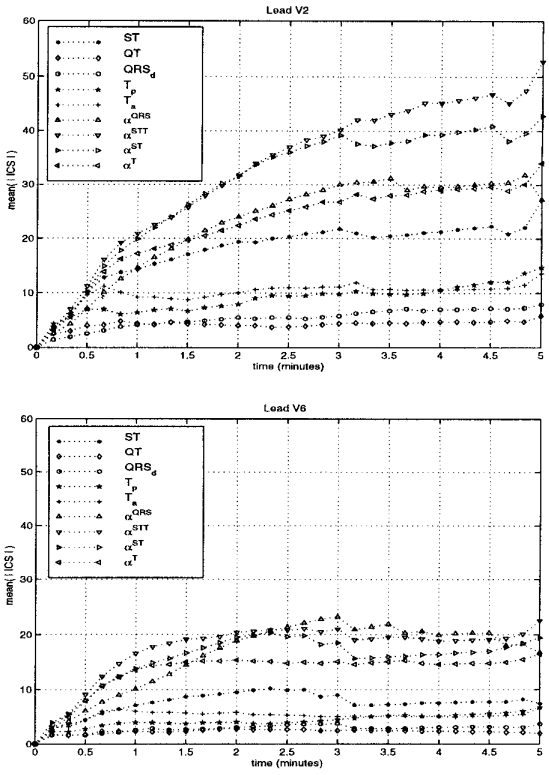


Figure 5: *Mean among patients of the different ICS parameters evolution in leads V2 (above) and V6 (below) along five minutes of occlusion.*

traditional ST index approached to the values of the global KLT-based indexes. In leads with usual low projection of the cardiac vector on the ST-T complex as V1 or V6 the ICS parameters of α^{STT} and α^{ST} indexes considerably decreased their values in relation with those of leads with more projection as V2 or V3. In those cases α^{QRS} and α^{STT} had similar ICS values (see lower panel in Fig. 5).

It is remarkable to note that the largest changes in the ECG seemed to appear during the first minute of occlusion: during this period more than 66% of the final ICS_{index} value reached at the end of occlusion is found. During the second minute only 17% of the maximum ICS_{index} (in mean) is accounted for, and during the third minute the contribution to the final ICS value is even smaller (6%). It was only in the $ICS_{\alpha^{QRS}}$ parameter that relatively large changes occurred during the second and following minutes of occlusion. The percentages accounted for the final $ICS_{\alpha^{QRS}}$ value along the first three minutes were 45%, 36% and 17%, respectively. This result supports the observation of a delayed response of the QRS with

respect to the ST-T complex during induced ischemia.

Incidence of ischemia on the different ECG segments. The indexes related to the ventricular repolarization period were activated earlier than those related to the ventricular activation: in 77% of patients the changes were first detected on the ST-T complex whereas in 23% were on the QRS complex (see Fig. 6). Analyzing in more detail the repolarization period we found that around the same percentage of patients showed the earliest ischemic changes in T wave (41%) and in ST segment (36%).

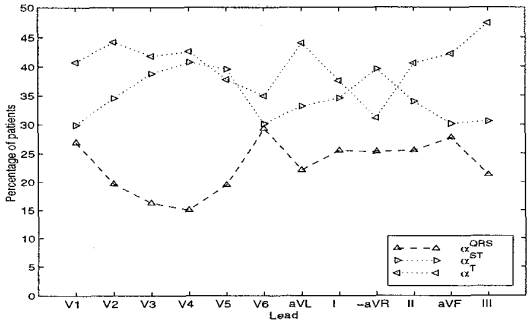


Figure 6: *Percentage of patients in which the KLT-based indexes detected the earliest changes.*

4. Discussion and conclusions

The KLT-based indexes showed better sensitivity to ECG changes than traditional indexes did (89% vs. 61%) showing that ischemic changes appear not only in a single fixed point of the ECG but in ECG regions related to the myocardium area where the lack of oxygen is present. The use of the ST level index is insufficient for characterizing a wide variety of ischemic patterns that can nevertheless be better represented by using global indexes.

It was also found that ECG changes appear significantly earlier in the repolarization period than in the activation period. Changes in T wave can precede changes in ST segment at about the same percentage as for the reverse case. These results are not enough to support the "ischemic cascade" hypothesis in which T wave changes precede ST segment deviations.

The evolution of the ICS parameters also showed that the largest changes appeared during the first minute of occlusion (with a roughly linearly increase).

The results suggest that a high percentage of patients showed QRS complex changes. It should be noted that changes detected in the QRS by the KLT-derived index (α^{QRS}) in some cases could be secondary changes, i.e. deformations induced by ST changes on the terminal part of the QRS (included in the KLT window for the QRS). Such changes were easier to find in the advanced stages of the occlusion and should be interpreted with care.

The measure of α^{STT} in leads as V2 or V3 has been shown as the most sensitive index in detecting the induced changes and should be considered in the development of an ischemia detector.

Acknowledgements

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