Evolution of T Wave Width During Severe Ischemia Generated by Percutaneous Transluminal Coronary Angioplasty

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Abstract

In this work we studied the evolution of ventricular repolarization dispersion (VRD) in the ECG during ischemia induced by Percutaneous Transluminal Coronary Angioplasty (PTCA). We hypothesized that at early ischemia stages the endocardium action potential duration (APD) is slightly reduced or unchanged while the epicardium one is reduced in a larger proportion and afterwards the APD at the epicardium returns to the normal values as ischemia evolves. This has been previously reported in isolated cat cardiac tissue studies. T-wave width (T_w) is measured by an automatic delineator and proposed as indicator of this repolarization dispersion increase. Results showed a significant widening of 11.5 ms of the T-wave during the first minute of occlusion at RCA occluded patients, with recovery to non-significant widening values after the second minute. No significant changes were observed for LAD or LCX patients. These results are in accordance with APD reported at cellular level on animal experiments.

1. Introduction

Myocardial ischemia occurs from decompensation of myocardial oxygen supply and demand. It is frequently associated to coronary atherosclerosis. The temporary occlusion of a coronary artery can derive in reversible ischemia, while a prolonged obstruction gets as result myocardial infarction with consequences such as arrhythmias, heart failure and/or sudden death. During myocardial ischemia the effects onto the ionic fluxes in the cell membrane produces changes in the action potential (AP) morphology which are reflected in the ECG. The ST-T complex of the ECG reflects the time period from the end of active ventricular depolarization to the end of repolarization in the electrical cardiac cycle. Myocardial ischemia modifies AP in amplitude and duration which may alter normal ventricular repolarization dispersion (VRD). VRD is associated with variation of recovery times throughout ventricular myocardial cells as a result of differences in activation times, AP duration and morphology of the APs. An increased VRD (IVRD) implies a modification of the T-wave morphology. New experimental studies have shown that T-wave widening could be a marker of IVRD [1]. We hypothesized that at early ischemia stages the endocardium action potential duration (APD) is slightly reduced or unchanged while the epicardium one is reduced in a larger proportion and afterwards the APD at the epicardium returns to the normal values as ischemia evolves. This has been previously reported in isolated cat cardiac tissue studies [2]. T-wave width (T_w) could be an indicator of this repolarization dispersion increase, (Fig. 1).

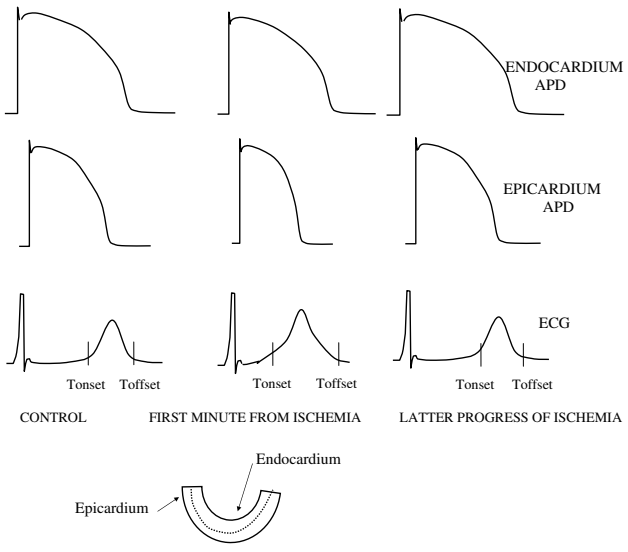

Figure 1. Schematic view of ECG, epicardium and endocardium action potential during control, early ischemia and after several minutes of ischemia. Based on results from[8].

In this work, we analyzed the electrophysiological changes of transmural ischemia using a Percutaneous Transluminal Coronary Angioplasty (PTCA) model. The sudden complete coronary occlusion produced by balloon inflation allows study of the initial minutes of the ischemic event. The aim of this work is to study the VRD evolution

on the ECG during PTCA induced ischemia. We analyzed the T_w duration as a marker of VRD evolution during the time course of the ischemic process.

2. Methods

2.1. Database

The study group consisted of 50 ECG records from patients at the Charleston Area Medical Center in West Virginia undergoing elective prolonged balloon occlusion during PTCA in one of the major coronary arteries (STAFF-III study) [3]. This study group was selected from a total of 108 patients, with the condition that T-wave could to be delineated during the complete time course of ischemia. The mean inflation duration was 4' 28" with a standard deviation of 74". Nine leads (V1-V6, I, II and III) were recorded using equipment by Siemens-Elena AB (Solna, Sweden) and digitized at sampling rate of 1000 Hz and amplitude resolution of 0.6 μV. Leads aVR, aVL and aVF were derived from leads I, II and III. Synthesized orthogonal X, Y and Z leads were also obtained from the Inverse Dower transform [4]. Two ECG were acquired for each patient in supine position. The first ECG was recorded during control (5 min. before the PTCA procedure) and the second ECG was recorded during PTCA procedure. Moreover, we considered separately the study according to the different occlusion sites: left anterior descending artery (LAD) in 14 patients, right coronary artery (RCA) in 26 patients and left circumflex artery (LCX), in 10 patients.

2.2. T wave delineation

First, QRS fiducial point was detected by an automatic QRS detector. Then, an ECG delineation system based on the wavelet transform (WT) has been used for T-wave location and delineation. This delineator has been previously described and evaluated in standard databases [5]. The multiscale approach permits to attenuate noise at rough scales, and then to refine the precision of the positions with the help of finer scales. Multiscale T-wave detection and delineation consists of first defining a T-wave search region window for each beat, relative to the QRS position and function of the recursively computed RR interval. Within this window, at least two local maxima in the 4th scale, exceeding a threshold, need to be found in order to asses the presence of a T-wave. The zero crossing between them are considered as T-wave peaks. Depending on the number and the polarity of the found extreme there are 6 different possible T-waves: positive (+), negative (-), biphasic (+/- or -/+), only upwards and only downwards . If the T-wave is not found in the 4th scale the process is repeated over the 5th scale. The onset (offset) of the T-wave is identified by finding the crossing point of the WT signal with a threshold defined by a fraction Kon (Koff) of the first (last) significant maximum of the WT modulus. If a local minimum is found before the threshold is crossed, the local minimum is considered as the onset (offset). Examples of this delineation can be seem at Fig.2

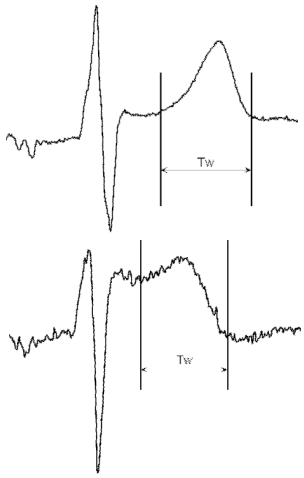

Figure 2. Example of ECG delineations at a control beat (top) and during ischemia (elevated ST segment), (bottom).

2.3. ST segment measurement

With the aim to verify the extent of the transmural ischemia we computed the ST-segment evolution during the PTCA procedure. Cubic splines baseline algorithm was applied to the ECG before direct ST-segment computation at those beat selected as normals. The ST-segment level was measured at a fixed distance from the J fiducial point (J + 60 ms). A median filter (windows size of 7.5 sec) on the series from each lead and patient was compute to avoid outliers.

The occlusion evolution was quantified with an ischemic changes sensor (ICS) index. This index was used previously with the aim to characterize ischemic changes from ST-segment, T-wave peak, T-wave amplitude and others indexes in PTCA recording containing control records [3]. It is defined as:

$$\mathrm{ICS}_{\mathrm{ST}} = \frac{\Delta_{\mathrm{ST}}}{\sigma_{\mathrm{ST}}} \tag{1}$$

where Δ_{ST} is the magnitude of change of ST-segment during PTCA occlusion and σ_{ST} is the standard deviation of the ST-segment evaluated in the control ECG. The standard deviation changes during control ECG (prior to the inflation) would reflect normal changes of ventricular repolarization. Therefore changes during PTCA of the same order as σ_{ST} should not be considered significant. For the occlusion period the magnitude of change in Δ_{ST} was calculated with a linear fitting model [3]. The bigger the ICS

(>1) the bigger the capacity of the index to detect the ischemic change.

2.4. Evaluation index

To quantify and analyze the VRD, the index T-wave width duration (T_W) was calculated as: $T_W = T_{OFF} - T_{ON}$ from a multilead delineation rule [6]. This rule selects between the 15 leads a unique T_{ON} (the earliest reliable T-wave onset at any lead) and a unique T_{OFF} (the latest reliable T-wave offset) with an outlier protection rule.

3. Results

We perform a median filtering with a windows size of 7.5 sec on the T_W series and characterize 7 different time instants: the control situation (C) associated to the median value of the 7,5 sec just before the start of occlusion, the occlusion start (O_S) associated to the median value of the first 7,5 sec of occlusion, the first minute (O_1) associated to the median of 7,5 sec centered around the first minute, the second (O_2), the third (O_3) and the fourth (O_4), for their respective minutes, and finally the occlusion end (O_E) associated to the 7,5 sec just before the end. Two kind of comparison statistics were applied. The first one we compared C with O_S, O_1, O_2, O_3, O_4 and O_E respectively. In the second one, we compared O_S with O_1, O_2, O_3, O_4 and O_E respectively.

Bonferroni tests have been used in order to asses whether the means of T_W are statistically different in both comparisons. The results are presented in Table 1 and Fig.3. Results show statistically significant lengthening in T_W during O_S and O_1 when compared with control, C. Moreover, statistically significant shortening of T_W at O_4 and O_E compared with O_S is obtained.

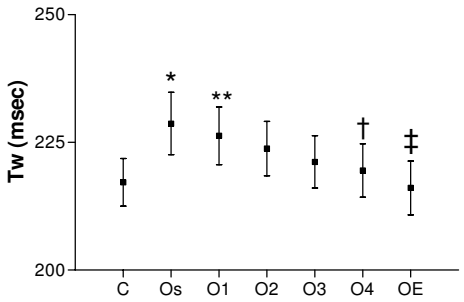

Figure 3. T_W at different stages in RCA records, expressed as mean±SEM.

The magnitude of changes Δ_{ST} (Fig. 4) and ICS_{ST} (Fig.5) parameter were estimated for each lead in each patient. During PTCA procedure significant ischemic induced changes were observed (Fig. 4 and 5). In Fig.5, the

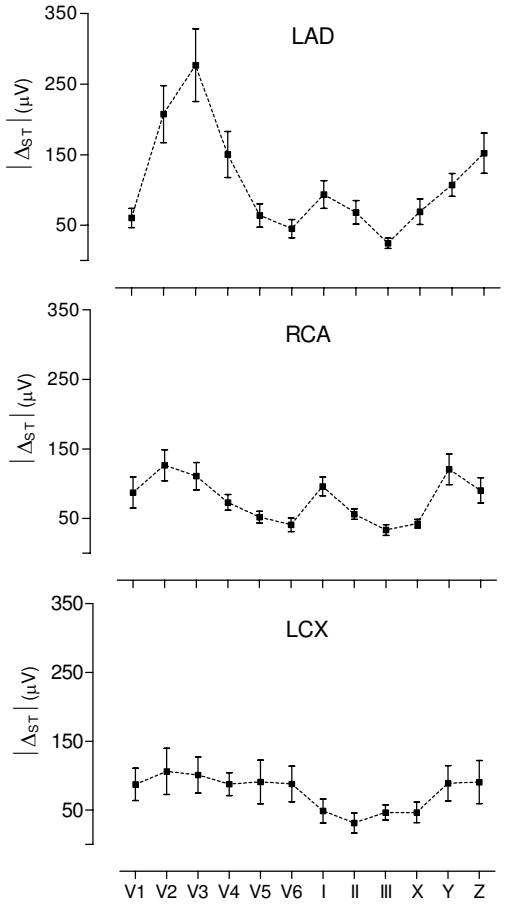

Figure 4. $|\Delta_{ST}|$ of differents leads in the three coronary occluded group.

largest values of $|ICS_{ST}|$, in mean, were found in leads V2, V3 and V4. We can see in Fig.4 the mean ± SEM of $|\Delta_{ST}|$

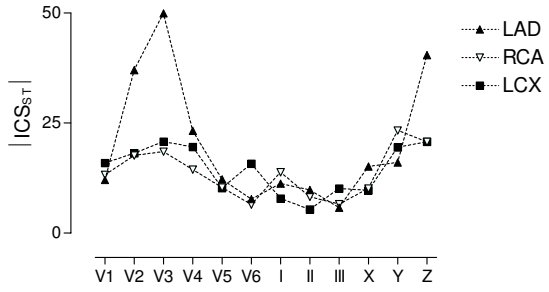

Figure 5. $|ICS_{ST}|$ of differents leads for the three occluded artery.

index. We considered variations in absolute value with the objective to avoid the cancellation of positive and negative ST elevation/depression among different patients. Besides, it can be seen in top panel of Fig. 4 (LAD), middle (RCA) and bottom (LCX) that leads V2, V3 and V4 showed the largest changes in $|\Delta_{ST}|$ series.

Table 1. Evolution of T-wave width at different stages of the PTCA procedure. *p<0.01, **p<0.05 (C vs. O); †p<0.05, ‡p<0.001 (O_s vs. O); § not significant.

	Occluded artery	C	O_S	O_1	O_2	O_3	O_4	O_E	n
$T_{\mathrm{W}}(ms)$	**LAD**	231.9±7.0	233.9±6.6 §	232.1±5.4 §	230.1±4.5 §	225.8±4.6 §	–	228.5±4.6 §	14
$T_{\mathrm{W}}(ms)$	**RCA**	217.2±4.6	228.7±6.1 *	226.3±5.6 **	223.8±5.3 §	221.2±5.1 §	219.5±5.2 †	216.1±5.2 ‡	26
$T_{\mathrm{W}}(ms)$	**LCX**	222.9±8.6	220.6±7.5 §	221.3±7.2 §	222.1±7.6 §	222.7±8.6 §	223.4±10.0 §	224.0±11.6 §	10

4. Discussion and conclusions

Several reports have shown morphology changes or pronounced changes in epicardial APD during ischemia [7][8]. Other work reported that the development of arrhythmias during the early stages of ischemia could be related to the VRD between endocardial and epicardial muscle cells [2]. Here, the authors studied the effects of ischemia on trasmembrane APs of both endocardial and epicardial muscle cells of coronary perfused cat left ventricles. They demonstrated that the effects of ischemia showed to be quantitatively and qualitatively different at epicardial and endocardium cells. Moreover, they showed that the APD of endocardial cell decreased progressively during ischemia, whereas the APD of epicardial cells reduced abruptly and then partially recovered.

In our work, we hypothesized that this cellular phenomenon can be extrapolated to humans and that it can be quantified at the ECG surface as a transient T-wave widening. We can observe in Table1 that the T_{W} during RCA occlusion is increased from the very beginning of the occlusion. Nevertheless, a decreased of the T_{W} was latter observed during O_2, O_3, O_4 and O_{E} related to the initial time occlusion time O_s. This observations are concordant with [2] and do support our hypothesis in this work. LAD and LCX occlusion did not present statistic differences at any stage. Further investigation on this apparent occluded lead dependent phenomena should be done prior to made any further expeculation, even more at the light of the reduced number of cases for those leads.

The evolution of T_{W} during the course of occlusion encourages the undertaking of deeper studies to correlate the APD evolution with ischemia process.

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References

[1] Arini PD, Valverde ER, Bertrán GC, Laguna P. Quantification of ventricular repolarization dispersion on the electrocardiogram by means of T wave duration. XXXI International Conference in Computers in Cardiology IEEE Computer Society september 2004;31:757–760.

[2] Kimura S, Bassett AL, Kohya T, Kozolovskis PL, Myerburg RJ. Simultameous recording of action potential from endocardium and epicardium during ischemia in the isolated cat ventricle: relation of temporal electrophysiologic heterogeneites to arrhytmias. Circulation 1986;2:401–409.

[3] García J, Lander P, Sornmo L, Olmos S. Wagner GLP. Comparative study of local and Karhunen-Loeve-Based ST-T indexes in recording from human subjects with induced myocardial ischemia. Computer and Biomedical Research 1998;31:271–292.

[4] Edenbrandt L, Pahlm O. Vectocardiogram synthesized from 12-lead ECG: superioty of the inverse Dower matrix. J Electrocardiol 1988;21:361–367.

[5] Martinez J, Almeida R. Olmos S, Rocha A, Laguna P. A wavelet-based ECG delineatior: Evaluation on standard databases. IEEE Transactions on Biomedical Engineering 2004;51(4):570–581.

[6] Laguna P, Jané R, Caminal P. Automatic detection of wave boundaries in multilead ECG signals: Validation with the CSE. Comp Biomed Res 1994;27:45–60.

[7] Kleber A, Janse M, Capelle F, Durrer D. Mechanism and time course of S-T and T-Q segment changes during acute regional myocardial ischemia in the pig heart determined by extracellular and intracellular recording. Circulation Research 1978;42:603.

[8] Downar E, Janse M, Durrer D. The effect of acute coronary artery occlusion on subepicardial transmembrana potentials in the intact porcine heart. Circulation 1977;56:217.

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