Characterization of Temporal Patterns of Transient Ischemic ST Change Episodes During Ambulatory ECG Monitoring

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Abstract

To test a hypothesis that different physiologic mechanisms might account for different temporal patterns of ST changes, we studied records from the European Society of Cardiology ST-T Database. We measured time- and frequency-domain changes of the instantaneous heart rate time series and incidence of arrhythmias associated with ischemic ST changes for two very different temporal patterns of ST change: a group of records containing salvos of ST episodes, and a group of records containing isolated ST episodes. The observations supported our hypothesis that salvo patterns reflect coronary vasoconstrictions or vasospasms, and that the isolated episodes result from sporadic physical activity.

1. Introduction

Transient ischemic changes in the ST segment (*ST episodes*) may appear in a variety of settings, including stable angina pectoris, stable coronary artery disease, variant or Prinzmetal's angina, unstable angina, syndrome X, and after myocardial infarction [1]. Myocardial ischemia occurs when the oxygen demand exceeds the supply. During ambulatory electrocardiographic (AECG) monitoring, ischemic ST changes are most often correlated with physical activity in patients with stable coronary artery disease [2], and are usually accompanied by a marked increase in heart rate as the cardiovascular control system attempts to meet increased oxygen demands. Much less often, ischemia may occur without physical exertion or increased heart rate, as a result of reduction in blood flow (hence, oxygen supply) due to vasoconstrictions associated with mental stress, vasospasms associated with Prinzmetal's angina, or thrombosis associated with unstable angina. Differentiating between demand-driven and supply-driven ischemia is important, since doing so can provide insight into physiologic mechanisms generating ischemia, and guidance in the choice of therapeutic interventions.

The *European Society of Cardiology ST-T Database* (ESC DB) [3], which contains 90 annotated AECG recordings with known or suspected ischemia, supports not only development and evaluation of automated transient ischemia detectors, but also basic research connected to quantifying and characterizing *temporal patterns* of ST changes. We have previously described observations of distinctly different temporal patterns of ST changes in the ESC DB [4]: "salvo" patterns (quasi-periodic episodes separated by short intervals, appearing in bursts), slow repetitive patterns (quasi-periodic episodes separated by longer intervals, without discernable bursting), and sporadic activity (isolated episodes without apparent periodicity). We further suggested that different physiologic mechanisms responsible for ischemia might account for these different patterns.

In the present study, we tested this hypothesis using records from the ESC DB. We measured heart rate changes and incidence of arrhythmias associated with ST changes within these records, and related these measurements to the temporal patterns of ST changes we reported previously.

2. Methods

We classified the 90 records of the ESC DB into groups according to the temporal patterns of ST deviation, using high resolution time series of ST deviation levels and of ST segment Karhunen-Loève coefficients. Due to the limited duration of the records (2 hours each), the classification of records assigned to the 'slow repetitive pattern' group is in some cases ambiguous, so we restricted our study to two very different sets of records:

The salvo group: 7 records containing salvos of 4 to 7 ischemic ST episodes each (e0103, e0108, e0113, e0114, e0125, e0127, and e0302)

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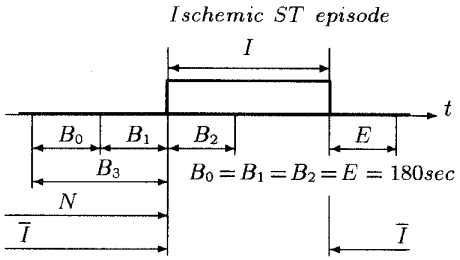

Figure 1. Parameter measurement windows. I is the current episode; the other seven windows are defined relative to I, as shown. N denotes the entire interval from the end of the previous ischemic ST episode (or the beginning of the record) to the beginning of the current episode I, and $\overline{I}$ intervals outside ischemia.

The single-episode group: 25 of the 27 records containing a single ischemic ST episode (records e0159 and e0163 were excluded because they contain too few RR intervals during ischemia to characterize HR)

We hypothesized that the ST episodes in the first group were due to reduced oxygen supply resulting from quasi-periodic coronary vasoconstrictions or vasospasms, and that those in the second group were due to increased oxygen demand resulting from sporadic physical activity.

Using techniques we have described previously [5, 6, 7], we obtained an instantaneous heart rate (IHR) time series for each of the 90 records, with abnormal and noise-corrupted beats removed. From the IHR time series, we measured HR, the mean heart rate, and its standard deviation. We also derived three time series of frequency-domain parameters, sampled at intervals of 64 seconds and calculated over 128-second windows. These were LF and HF, the fractions of total IHR power in the low (0.04 to 0.15 Hz) and high (0.15 to 0.4 Hz) frequency bands; and LF/HF, the sympathovagal balance. (We chose to study fractional IHR power in these bands, calculated from normalised Lomb periodograms of the baseline-corrected IHR time series [7], in order to reveal changes in sympathetic and parasympathetic activity.)

In the neighborhood of each ischemic episode, we defined eight time windows for parameter measurement (see figure 1). For each ischemic episode, we derived the ratios HR_{B1}/HR_{B0} and HR_{B2}/HR_{B0} (which reflect changes in HR prior to and immediately after the beginning of an episode, respectively). We also computed the mean values of LF, HF, and LF/HF during each of the intervals N, B_3, B_1, and I.

HR	HR_{B1}/HR_{B0}	HR_{B2}/HR_{B0}	$\overline{HR}$
Salvos	1.013	1.046	68.3(6.1)
All records	1.062	1.164	74.5(9.3)
Single−ep	1.102	1.254	78.6(10.8)

Table 1. Aggregate average ratios (see text) between the mean heart rates of the IHR at the beginning of an ischemic ST episode and the mean heart rate throughout the recording ($\overline{HR}$); standard deviations are bracketed.

Using the reference annotation files for the ESC DB, we also measured rates of occurrence of ventricular ectopic beats (VEBs) during each of the intervals B_1, I, E, and $\overline{I}$. We defined the VEB frequency, V, as the fraction of all beats in each interval that were VEBs. For each ischemic episode, we derived the ratios V_I/V_{B1}, V_E/V_I, V_E/V_{B1}, and $V_I/V_{\overline{I}}$, expressing changes in amount of ventricular ectopy in the neighborhood of an ischemic episode.

We characterized each record by averaging the time- and frequency-domain HR statistics and the VEB rate statistics obtained in this way for each ischemic episode in the record, and by the mean heart rate, $\overline{HR}$, and standard deviations for the entire record.

Finally, we characterized each of the two groups of interest by averaging the statistics for each record in the group, and similarly obtained statistics describing the entire database by averaging these statistics for all 90 records.

Changes in heart rate occur for many reasons, such as exercise, respiration, metabolic changes, and physical or mental stress. We predicted that the time-domain IHR statistics would reflect a greater increase in the IHR prior to an ischemic ST episode in the single-episode group than in the salvo group. Changes in IHR appear to follow autonomic tone, i.e., sympathetic stimulation tends to increase heart rate, and parasympathetic (vagal) tone tends to decrease heart rate [8]. The frequency-domain IHR statistics were expected to reveal the influences of both autonomic tones and their interrelationships during ischemia. We expected the VEB statistics to show whether ischemic episodes are correlated with changes in VEB rates.

3. Results

Table 1 summarizes our findings for the time-domain IHR statistics. In the salvo group, heart rate increased from a mean of 68.3 bpm (st.d.= 6.1) by 1.3% immediately prior to (interval B_1) and 4.6% immediately after (interval B_2) the beginning of each ischemic episode.

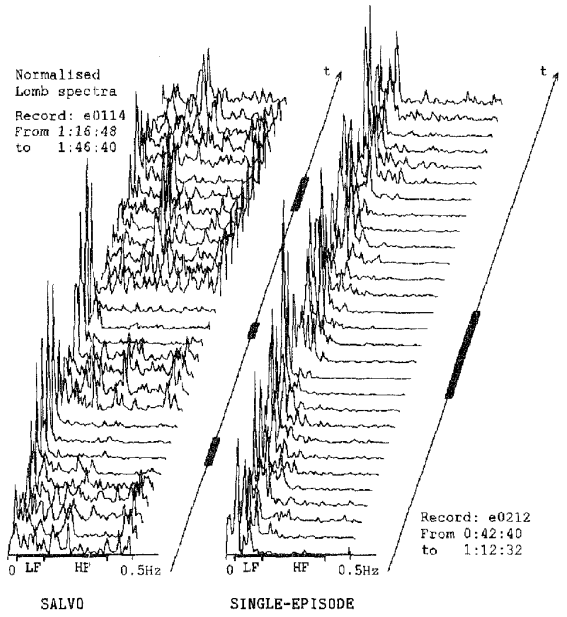

Figure 2. Normalised Lomb periodograms during ST change for the records e0114 (salvo group) and e0212 (single-episode group). Ischemic episodes are indicated bold along the time axis.

In the single-episode group, heart rate increased from a mean of 78.6 bpm (st.d.= 10.8) by 10.2% immediately prior to and 25.4% immediately after the beginning. The single-episode group shows a higher mean heart rate overall, a larger standard deviation, and a greater increase in heart rate prior to the beginning of an ischemic episode.

Heart rate power spectra during ST changes in typical representatives of salvo and single-episode groups are shown in figure 2. As shown in table 2, *LF* and *HF* powers decreased during ischemia in both groups, but the drop was most marked in the salvo group.

The ratios of sympathovagal balance, *LF*/*HF*, are shown in table 3. For all groups, we found increases in this ratio with ischemia, suggesting the dominance of sympathetic over parasympathetic activity during ischemia. For the salvo group, the ratio rose from 3.72 (over the entire interval before ischemia) to a peak of 5.39 during ischemia. For the single-episode group the ratio dropped slightly from 7.06 (before ischemia), to a minimum of 6.27 in the three-minute interval prior to the ischemic episode, and after that rose rapidly to 7.73 during ischemia.

Table 4 summarizes our observations of changes in VEB rates with ischemia. In the salvo group, the frequency of VEBs rose by a factor of 11.35 during an ischemic ST episode (interval I), and fell by a factor of 0.39 immediately after the episode (interval E) while remaining higher by a factor of 4.43 than during interval B_1, immediately before the episode. In the single-episode group, the incidence of VEBs rose by a smaller factor of 2.80 during, and fell by factors of 0.60 and 1.67, respectively, after the ischemic episode. We observed that VEB frequency in the salvo group increased by a greater factor during ischemia, and decreased more slowly following ischemia.

Power	*LF*				*HF*			
$[*10^{-3}]$	N	B_3	B_1	I	N	B_3	B_1	I
Salvos	19.5	20.2	20.3	16.8	8.5	8.1	7.5	4.2
	(3.9)	(3.6)	(4.6)	(5.2)	(3.4)	(4.4)	(4.6)	(1.5)
All records	20.8	19.4	18.0	16.5	5.9	5.4	5.1	4.0
	(4.8)	(5.3)	(6.4)	(6.0)	(3.6)	(3.6)	(3.7)	(2.3)
Single–	21.7	19.3	17.8	17.1	5.2	4.7	4.3	3.4
episodes	(6.1)	(6.0)	(7.3)	(7.3)	(3.5)	(2.9)	(2.8)	(2.2)

Table 2. Average normalised (relative) low and high frequency powers (*LF*, *HF*) in the intervals before and during ischemia. Standard deviations are bracketed.

LF/HF	N	B_3	B_1	I
Salvos	3.72	4.39	4.75	5.39
All records	6.03	5.87	5.76	6.23
Single−ep	7.06	6.44	6.27	7.73

Table 3. Ratios of sympathovagal balance (*LF*/*HF*) during the intervals surrounding an ischemic ST episode.

VEBs	V_I/V_{B1}	V_E/V_I	V_E/V_{B1}	$V_I/V_{\overline{I}}$
Salvos	11.35	0.39	4.43	6.48
All records	2.83	0.44	1.25	3.60
Single−ep	2.80	0.60	1.67	3.44

Table 4. Ratios of aggregate gross frequencies of occurrence of VEBs prior to (B_1), during (I), after (E), and outside of ischemia ($\overline{I}$).

4. Discussion and conclusions

We note that the time-domain IHR statistics are consistent with our hypothesis that sporadic ischemia (as in the single-episode group) is a response to exercise or stress-induced increase in oxygen demand, while the

salvo patterns of ischemia may result from vasoconstrictions or vasospasms unrelated to physical activity.

Low vagal activity, i.e., low *HF* power and high *LF/HF* - is associated with a variety of disease states with increased risk of mortality including sudden cardiac death [9]. Furthermore, interventions such as *exercise*, *postural changes* (including tilt), *mental* and *physical stress*, and *coronary occlusions* influence the low frequency band (sympathetic activity) and increase the *LF* power and the *LF/HF* [9]. The trend of high *LF/HF* with dominant sympathetic activity (less rapid decrease in *LF* than in *HF*) occurs in both groups during ischemia. *LF/HF* was the highest for the single-episode group.

In both groups sympathetic (*LF*) activity dominates during the interval before an ischemic episode, and reaches its highest level during ischemia. The salvo group, however, shows a much more dramatic decrease in *HF* power during episodes of ischemia (figure 2.). The single-episode group had a higher *LF/HF* ratio in all intervals. Our results are consistent with other studies that have shown decreases in *LF* and *HF*, together with an increase in *LF/HF* power during ischemia [10, 11, 12, 13].

Notably, we observed increases in VEB rate during ischemia, which were particularly striking in the salvo group. At least one previous study found no positive relationship between silent ischemia and ventricular arrhythmias [14]. Since silent and symptomatic ischemic episodes are not differentiated in the ESC DB, more study is needed to understand the relationship of VEB rate to ischemia; nevertheless, it appears that in one important patient category (the salvo group), levels of ventricular ectopy are correlated with ischemia.

All the observations in this study support our specific hypothesis that the salvo patterns reflect oscillating coronary vasoconstrictions and vasospasms and that the isolated episodes result from episodes of physical exertion. The two-hour record length used in the ESC DB was a significant limitation in this study, since it made classification of the records into groups difficult. In order to differentiate records with regard to temporal patterns more accurately, significantly longer recordings would be helpful for further studies.

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