Behavior of Intra-QRS Potentials during Induced Ischemia in Isolated Guinea Pig Hearts

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Myocardial ischemia causes conduction changes that are often presented in electrocardiographic recording as intra-QRS changes. The present study analyses behavior of amplitude of intra-QRS potentials in the electrographic recording during myocardial ischemia – in its very early stages as well as during developed ischemia presented as ST elevation in ECG curve. The studied potentials are subtle low-amplitude short pulses found within QRS complexes as notches. Their analysis is performed using wavelet transform due to its suitable time-frequency properties. A characteristic pattern of intra-QRS potential behavior during ischemia is described in guinea pig isolated heart experiments.

1 Introduction

The most frequent manifestation of acute ischemia in ECG is ST segment elevation. Since ischemia causes conduction changes in the heart, irregular depolarization (activation) of the myocardium may occur. As a consequence, there may be certain changes in electrocardiographic recording traced before the visible manifestations of ischemia. This would be represented as intra-QRS changes – so-called intra-QRS potentials. Intra-QRS potentials are high frequency low-level notches which occur whenever in QRS complex in any part of ECG recording. There is much evidence that ischemia changes in the heart muscle may cause alterations in the QRS spectrum, as an expression of the fragmentation of ventricular depolarization [2, 3].

This study analyses behavior of amplitude of appearance of intra-QRS potentials in the segment of ECG during myocardial ischemia in its initial stages as well as during developed ischemia manifested as ST elevation. A high resolution acquisition system was used to record data from guinea pig isolated hearts.

2 Methods

Seven adult guinea pigs of non-specified breed (average weight 393±12 grams, both sexes) were included in this study. After deep ether anesthesia the chest of animal was opened and its heart was quickly excised with a sufficiently long segment of ascending aorta. It was then cannulated and the heart was fixed to the perfusion set-up. All isolated hearts were perfused according to Langendorff at the constant pressure of 85mmHg, by Krebs-Henseleit (K-H) solution of following composition (in mM): NaCl 118, $NaHCO_3$ 24, KCl 4.2, KH_2PO_4 1.2, $MgCl_2$ 1.2, glucose 5.5, Taurine 10, and $CaCl_2$ 1.2. The solution was oxygenated with 95% O_2 and 5% CO_2. All experiments were performed at 37°C.

The isolated hearts were first perfused for 20 minutes – control period. All hearts exhibiting any dysrhytmias were discarded. Then, the period of flow ischemia followed of 15 minutes duration. Next, the period of reperfusion with K-H solution was introduced of the same duration.

A high resolution recording system was assembled with touchless orthogonal lead system with three Ag - AgCl disc electrodes for recording of ECG signals. The signals were digitized by a 12bit AD converter at 2 kHz sampling rate using a data acquisition multifunction card

PCI-6111E (National Instruments, USA). Due to the high sampling rate this system picks up the signal frequency at 1 kHz, which is high enough for the analysis of high frequency intra-QRS potentials [1]. The digital signals were stored for further off-line processing.

Segments of signals were selected from the end of control period to the period of still detectable QRS complex. Continuous wavelet transform (CWT) with a Bior1.5 prototype wavelet was applied on these segments to detect QRS complexes. At sampling rate of 2 kHz, the QRS complex corresponds to the 20th sub-band.

Detected QRS complexes were transformed with a Haar mother wavelet into 100 sub-bands and analysed until unique appearance of first intra-QRS potential [6]. Intra-QRS notches fit with the 15th sub-band of CWT. Results of CWT showed a good frequency resolution for high scales that correspond to low frequencies, and a poor frequency resolution for low scales that correspond to high frequencies. Intra-QRS potentials manifested by a double peak – the signal curve consisted of two local extremes. Figure 1 on the left shows the QRS complex containing intra-QRS notch, on the right - a CWT of the signal where intra-QRS peak can be observed (dark area around the 100th sample). Detected intra-QRS complexes were analyzed and the amplitude of each complex was calculated in proportion to the QRS complex amplitude. In each minute of records, average amplitude and standard deviation were calculated.

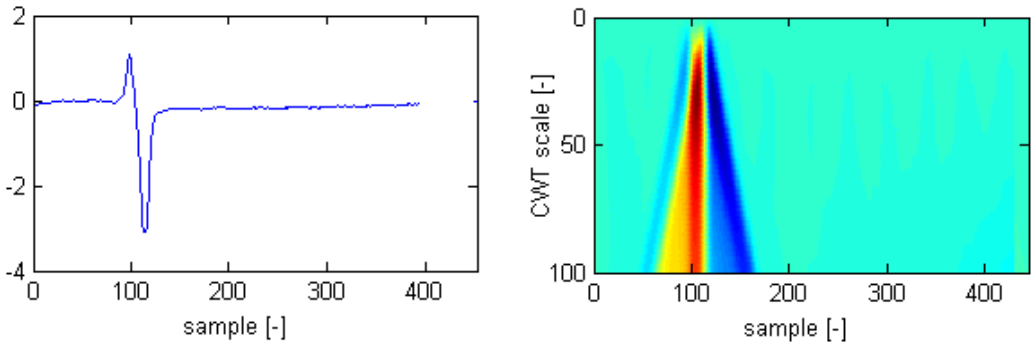

Fig. 1 QRS complex with intra-QRS notch in time domain (on the left), CWT (on the right)

3 Results

Fig. 2 shows the evolution of the amplitude of the detected intra-QRS potentials each minute in range from the beginning of ischemia to still detectable QRS complex (one selected heart as an example). ST segment elevation is present already in the first minute of ischemic period; the amplitude of intra-QRS potentials reaches 3% amplitude of QRS complex. Within the next minute ischemia, the increase in amplitude of intra-QRS potentials of almost 3% appears (which corresponds to the time of onset of ST segment elevation) which next rises to almost 16% in the 6th minute. It is followed generally by a rapid decrease in the amplitude of intra-QRS potential to approximatelly 4% of the amplitude of the QRS complex. In the 8th minute of ischemia, QRS complex as well as intra-QRS potentials cease to be detectable.

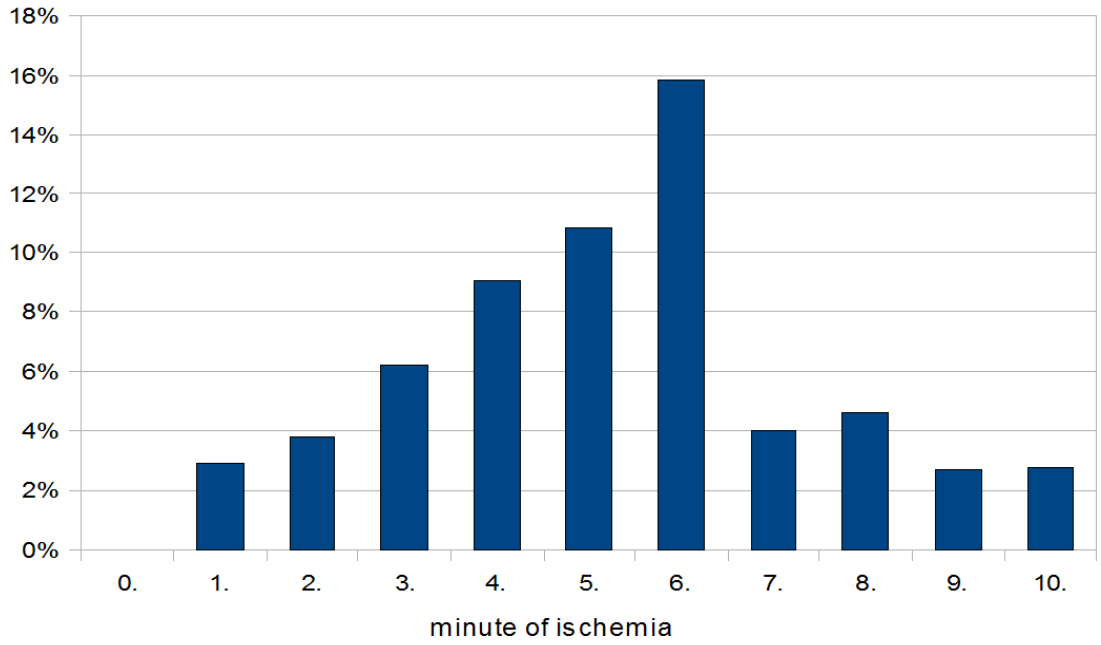

Fig. 2 The evolution of the amplitude of the detected intra-QRS potentials

Fig. 3 shows the average amplitude and its standard deviation (in mV). The data from all guinea pig hearts are included. In the first four minutes, all the data show smallest standard deviation of the average intra-QRS potential (0.015±0.018) mV. The largest amplitude is between the 5th and the 7th minute, specifically in the 6th minute the average amplitude is (0.1384±0.0195) mV and in the 7th minute the amplitude is (0.0703±0.0307) mV.

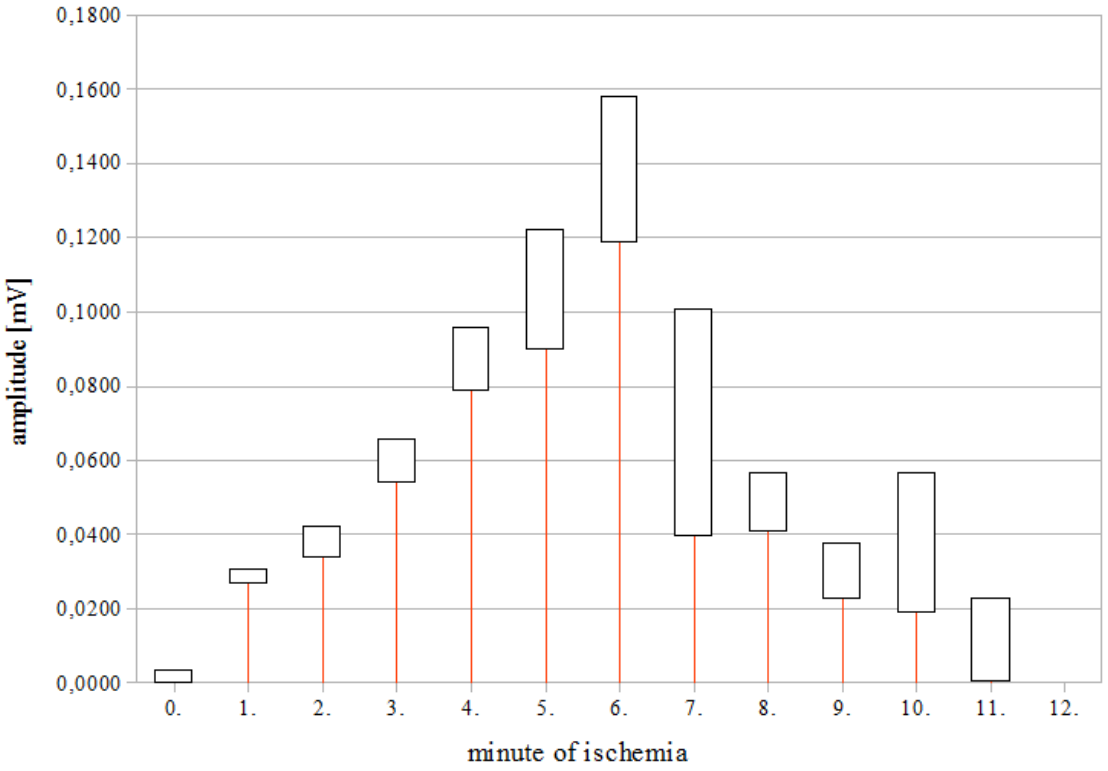

Fig. 3 Average amplitude and standard deviation of detected intra-QRS notches

4 Discussion and Conclusions

To compare the results more easily, both the analyzed data set and the results of analysis are included in the graph in Fig. 3. Presented results show that the occurrence and development of intra-QRS amplitudepredict impending ischemia before it is detectable e.g. as ST segment elevation. (The ischemia was considered visible in electrogram when ST elevations or Parde waves appeared.) The advantage of detection proposed in this paper is very early detection of ischemia [4, 5].

As ischemia proceeded (in the 6^{th} minute), intra-QRS peaks amplitude increased five times, thus making them very well detectable. The signal to noise ratio (SNR) of the signal (or QRS complex) is 37 dB. The SNR of intra-QRS notches alone is almost 8 dB (SNR specifically = 7.95 dB), which is certainly a plausible value for a good detection. Later, as shown in Fig. 3, from approximately the 12^{th} minute it was not possible to detect intra-QRS peak due to poor SNR. The proposed way of detection might help to improve learning and sensitivity of algorithms for detection of intra-QRS potentials and thus improve possibilities to detect subtle, early electrophysiological changes triggered by ischemia before this pathological process is obvious as well-known changes of electrocardiographic curve, such as ST segment elevation.

Acknowledgement

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References

[1] Couderc JP, et al. Stratification of time-frequency abnormalities in the signal-averaged high-resolution ECG in postinfarction patients with and without ventricular tachycardia and congenital long QT syndrome. J. Electrocardiol. 1996. 29 Suppl:180-8.

[2] Gomis P et al Dynamical Behavior of Intra-QRS Potentials During Induced Myocardial Ischemia. In Computers in Cardiology. IEEE, 2001.

[3] Gomis P, Jones D.L, (1997) Analysis of Abnormal Signals Within the QRS Complex of the High-Resolution Electrocardiogram. USA, IEEE 44,8:681-893

[4] Kestler HA, Möher M: Prognostic Value of Intra-QRS and ST-T Micro-Variability – A 2 Year Follow-Up. In Computers in Cardiology. IEEE, 2003.

[5] Pettersson J, Pahlm O, Carro E, Edenbrandt L, Ringborn M, Sörnmo L. Changes in high-frequency QRS components are more sensitive than ST-segment deviation for detecting acute coronary artery occlusion, J Am Coll Cardiol, 2000.

[6] Sekora J et al: A Wavelet Based Detection of Abnormal Intra-QRS Potentials. In Medical Physics and Biomedical Engineering, World Congress 2009. IFMBE Proceedings, 25/ IV. Heidelberg, Germany: Springer, 2009. s. 1468-1470. ISBN: 978-3-642-03881- 5.