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Evaluation of ischemic injury of the cardiac tissue by using the principal component analysis of an epicardial electrogram

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ABSTRACT

Monitoring and control of the heart tissue viability is of crucial importance during heart surgery operations. In most cases the heart tissue suffers from an ischemic injury that causes a decrease in the velocity of electrical excitation propagation in it and influences the shape of the excitation wave front that spreads over the injured area. It is reflected in a more complex shape of the registered epicardial electrogram as compared to normal. A method for quantitative evaluation of the complexity of the shape of the epicardial electrogram based on the principal component analysis is here proposed for evaluation of the ischemic injury of the cardiac tissue. A minimal, yet sufficient, number of the principal components (the optimal basis functions) for truncated expansion of the epicardial electrogram signals could be used as an estimate of signal complexity. The method for determination of such a minimal, yet sufficient, number of principal components were developed by using epicardial electrograms registered during in situ experiments on dogs in which local ischemia was evoked by ligation of a coronary vessel.

1. Introduction

In many cases coronary bypass operations are the most effective method for treating the ischemic heart disease which remains the most widespread reason of morbidity and mortality in medium and well-developed countries [1]. As reported by the American Heart Association (http://www.americanheart.org/), on average more than 400 operations per 1 million of population are performed annually. The success of cardiac surgery and the postoperative healing process highly depend on tissue preservation during surgery. New methods of cardioplegia, protocols of ischemic preconditioning have been developed and introduced to improve tissue preservation during surgery [2]. Nowadays, development of techniques of minimized surgical invasion (such as “off pump” operations on the beating heart) is the main tendency followed in cardiac surgery [3–5]. Reliable methods for “on-line” monitoring of tissue viability would be a useful supplementation to such techniques and could significantly improve the results of surgical treatment. The first results on ischemic injury monitoring by using a unipolar electrogram were published 15 years ago [6]. Local ischemia causes a decrease in the velocity of electrical excitation propagation in the cardiac tissue which is expressed by a decrease in the amplitude and an increase in the duration of a unipolar electrogram [7]. Some empiric recipes for signal shape evaluation are available

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(such as S-T segment elevation [8]), however, reliability of quantitative evaluation of such parameters remains problematic. Frequency parameters of the electrogram signal could be used as estimates of changes caused by the ischemic injury [9]. A decrease in the velocity of excitation propagation caused by developing local ischemia influences the shape of excitation front that spreads over the injured area. We observe it in the shape of the registered electrogram that becomes more and more complex. To evaluate the changes in the electrogram signal shape, extraction of representative features from the signal is needed. The number of features in the initial set describing each digitized electrogram cardiocycle is equal to the number of samples in the representing vector. Some signal decomposition methods give representation of vectors of signal samples by using universal basis functions. Coefficients of basis functions form a set of features representing each particular electrogram cardiocycle. Dimensionality of such set of features is significantly lower than the initial one. Wavelet transform might serve as an illustration of a signal decomposition method in which the universal basis functions are used and the representation of the signal is given (the signal is represented in the time-frequency domain). This method could be used for quantitative evaluation of electrocardiosignals [10]. An optimal reduction in dimensionality of set of parameters could be achieved by using the principal component analysis (PCA). The method reduces dimensionality of the represented data set and enables to retain the highest possible degree of variation present in it [11]. PCA transforms the original data set into a new set of vectors (the principal components) which are uncorrelated and involve information represented by several correlated variables in the original set. The vectors (the principal components) are the optimal basis functions to be used for signal decomposition. The vectors produced by PCA are ordered according to the variation present in all of the original variables. The first vector retains most of the variation and the subsequent ones are ordered in a descending order. Due to this feature, the deterministic part of the signal could be effectively separated from zero-mean noise by using only some first vectors for signal representation. Evaluation of morphology changes of the signal could be realized by using these first vectors only. An example of such usage for processing evoked potentials in the brain was reported in [12]. Examples of using PCA for evaluation of morphology changes of an ECG were reported in [13,14]. However, the selection of a subset of vectors (the principal components) representing the deterministic part of the signal is still a topic of discussion. The most obvious criterion for such selection could be based on part of the signal energy represented by every vector. However, it does not give good results as the signal/noise ratio is unknown. Some authors propose using cross-validation methods based on the number of statistically based rules for the selection of a vectors subset [17,18]. Such methods are usually computationally intensive, however, simplifications proposed by [16] make them easy to use. Most authors use a subset of vectors selected by using the most obvious methods based on the represented signal energy basis. A subset representing at least 90% of the signal energy (consisting of up to 10 vectors), is used for evaluation and/or classification of the shape of unipolar endocardial electrograms in [15]. As a conclusion of the review of the proposed methods for the selection of the subset of vectors in [11], most of them are ad hoc rules-of-thumb and suffer from a lack of a formal basis. In this work energy-based and cross-validation methods (such as [17] or [18]) were tested for selection of the subset of vectors representing the deterministic part of the epicardial electrogram signal. The aim was to estimate the minimal number of PCA produced uncorrelated vectors (the principal components) required for representation of the deterministic part of the epicardial electrogram signals registered under normal and ischemic conditions. As every principal component involves information represented by several correlated variables in the original set, their number should represent the number of uncorrelated processes determining the signal shape. In other words, more complicated the signal shape changes in the processed signal set will require more vectors (principal components) included into the minimal subset for representation of the deterministic part of the signal. The shape of the epicardial electrogram is known to become more and more complex in deep ischemia. Our idea is that the minimal amount of the principal components required for representation of the epicardial electrogram signal set could reflect the complexity of the signal shape changes in it and be a quantitative estimate to be used for evaluation of the ischemic injury.

2. Methods

2.1. Signal registration and preprocessing

The epicardial electrogram signals were registered during experiments on dogs in situ (Permission of the Lithuanian Laboratory Animal Science Ethical Committee No. 0027.2001.02.14). The animals were pre-medicated with intramuscular diazepam 0.7 mg/kg and droperidol 0.3 mg/kg. Anesthesia was maintained with 0.15% sodium thiopental solution 6 mg/kg/h. Fifteen minutes before sternotomy, 0.1 mg/kg phentanyl solution was given intramuscularly. The dogs were endotracheally intubated and ventilated with ambient room air when thoracotomy in the fourth intercostal space was performed. The heart was exposed in a pericardial cradle and the epicardial electrograms were registered by using unipolar electrodes. A short-time (1–5 min) local ischemia was evoked by ligation of either first or second diagonal branches of left anterior descending artery (LAD). At least 20 min of relaxation followed each ligation. Two epicardial electrogram signals were registered synchronically. One signal was registered from the ischemic zone, i.e. the area fed by the coronary vessel which was occluded during our test, and the other (control) signal was registered from the intact area in the ventricle away from the occluded vessel, where no changes caused by circulation disorders were expected. No accurate definition of the borderline between the two areas has been determined; we put the electrodes somewhere in the visually estimated middle part of the areas in question. The epicardial electrogram signals were amplified by using a specially designed amplifier (Gain: 1000, frequency response: from 0.01 to 500 Hz.). The amplified epicardial electrogram signals were digitized by using a 12 bit A/D converter DAS-1802 (Keithley, USA). The signal registration and analysis programs were written in the Borland Delphi 5.0 programming language by using Data Acquisition