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Methods for monitoring and prognosis of clinical status of patients in acute phase of myocardial infarction for computer network based clinical decision support system

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ABSTRACT

The methods for evaluation of crucial factors describing status of cardiologic patients in intensive care units based on advanced signal processing methods were incorporated into prototype network based clinical decision support system. The methods realize: (a) evaluation of heart rate variability in aim to predict clinical outcome; (b) evaluation of central hemodynamics in non-invasive way by means of chest impedance signal analysis; (c) automatic detection and evaluation of ECG T-wave alternans – predictor of sudden cardiac death. Modern standard monitoring equipment has connection to the computer network and possibility to transfer registered signals and clinical data what could be processed and evaluated with such clinical decision system. The remotely accessed methods of the system can significantly improve the quality of monitoring of patient status using standard equipment.

1. Introduction

Increased life expectancy results in an increase in the prevalence of chronic cardiovascular diseases and an increased demand for health care services. Rapid development of information and telecommunication technologies is creating a realistic basis for significant improvement of quality of health care services enabling introduction of computer network based systems of clinical decision support. Considering the enormous significance of cardiovascular diseases, focusing on corresponding cardiologic disease patterns seems almost self-evident. Importance and need for such systems is shown by experience obtained using such systems in Germany and Finland [1,2]. Telecardiology in national and international levels could be used for consultations between small hospitals in rural regions and main hospitals [3]. New powerful software instruments for diagnostics based on advanced signal processing allowing less invasive and more reliable monitoring of crucial parameters of the patient could be realized using computation and storage infrastructure of network based system. Monitoring and quantitative evaluation of central hemodynamics together with automatic detection of risk factors of sudden cardiac death are of crucial importance during the acute phase of myocardial infarction. Standard monitoring equipment used in the intensive care units usually is able to perform evaluation and analysis of only basic parameters reflecting current status of the patient. However modern equipment usually has possibility or already is connected to the local computer network or Internet. Such equipment can be used together with Internet-based clinical decision support systems which allow distribution of computational and storage resources and development of specialized databases of clinical data. Remote data storage and processing significantly enhances possibilities of locally used standard equipment. It opens possibilities to use advanced signal processing methods requiring big computational resources and realize evaluation of significantly more informative features in the signals registered in standard way. Also it opens a possibility for reuse of big variety of earlier collected clinical data for comprehensive testing and evaluation of elaborated methods, what is emphasized in [4].

We elaborated module for monitoring and prognosis of clinical status of patients in the acute phase of myocardial infarction for prototype clinical decision support system. This module consists of methods realizing the evaluation of the parameters of following types: (a) specialized parameters of heart rate variability; (b) parameters reflecting central hemodynamics (cardiac output); (c) parameters for detection and evaluation of T-wave alternans.

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Cardiac autonomic control is profoundly deranged after the acute myocardial infarction, with evidence of impaired vagal control and high levels of sympathetic activity. Heart rate variability is an established non-invasive marker of cardiac autonomic nervous activity in patients recovering from myocardial infarction. The association of higher risk of post-infarction mortality with reduced heart rate variability was first shown in 1977 [5]. The predictive value of heart rate variability was independent from the conventional risk stratification factors used in clinical practice. The standard measurements for the analysis of heart rate variability comprise time domain indices, geometric methods and components of the frequency domain [5]. Low heart rate variability has been shown to be a powerful predictor of cardiac events in patients surviving an acute myocardial infarction. Nevertheless there is a lack of detailed assessment of heart rate variability in the early period of myocardial infarction, especially during the first 24–72 h from long-term recordings. The value of different heart rate variability parameters in predicting dangerous complications of myocardial infarction is still not clear. Discriminant analysis in aim to select the combination of statistically significant variables for prediction of complications was one of the aims of this work.

Cardiac output is one of the core parameters in assessing the status of a patient in acute phase of myocardial infarction. It can be estimated using first derivative of impedance cardiogram (ICG) signal, a simple and non-invasive measurement introduced by Sramek in the 1960s and used till nowadays. However, measured data in some cases remain controversial. This is highly expressed in states causing low cardiac output syndrome cardiogenic shock, severe arrhythmias as well as in healthy obese patients. It led to elaboration and introduction of invasive methods for the evaluation of hemodynamics into clinical practice in 1970. The method of thermodilution using Swan-Ganz catheters became a "golden standard" for the evaluation of hemodynamic changes. However, risk of complications during application of invasive methods and their influence on the outcome of patient's health caused new wave of investigations the aim of which was improvement of non-invasive methods of the evaluation of cardiac output based on ICG analysis. Our previous investigations showed significant disagreement between the results of these two methods in the acute phase of myocardial infarction (immediately after hospitalization), while the results of two methods in the same patients in stabilized situation after 24 h showed quite good correlation [6]. Possibly reason for such disagreement between the methods lies in too simple principle used in standard non-invasive evaluation of cardiac output based on the estimation of the amplitude of the first derivative of ICG according [7]. However it is highly expected that normally nearly uniform contraction of the ventricles could be significantly affected by local ischemic injury in the acute phase of myocardial infarction. It could result in the changes in the shape of the ICG signal. So probably not only the estimates of the amplitude of the first derivative, but quantitative estimates of the shape of the ICG signal should be used for evaluation. Moreover our previous investigations showed significant changes in the shape of the ICG signal correlating with respiratory movements, possibly caused by changing permeability of lung alveoli and electrical conductance of the chest [8]. The commercially available equipment for cardiac output evaluation based on ICG analysis uses averaged estimates of certain time window. Our idea is that most informative features reflecting cardiac output dynamics could be found in the fine structure of the ICG shape of every cardiocycle, taking into account also phases of respiratory movements. Our preliminary approach applying advanced signal processing methods for the analysis of the ICG signal gave promising results significantly increasing reliability of estimates of central hemodynamics obtained in non invasive way even in complicated clinical cases. The clinical data collected using computer network based system allowed to extend our investigation using wide variety of clinical data.

T-wave alternans (TWA) is reported to be a reliable predictor of ventricular sudden cardiac death [9], so timely detection and evaluation of it could help clinicians to take proper actions and save life for a patient. Our approach applying special structural analysis of ECG in combination with principal component analysis (PCA) showed a possibility of reliable detection and evaluation of TWA [10]. The method was elaborated mostly using simulated data from PhysioNet T-Wave Alternans Challenge Database [11]. Computer network based system allowed collection of new clinical data and extension of our investigation using real clinical data and wide variety of cases.

Incorporation of the stand alone methods into computer network based clinical decision support system requires adaptation of them to the limitations of the available infrastructure of the computational and storage resources. On the other hand it opens new possibilities of further developments of the methods using bigger amount of collected clinical data. The aim of this work was to develop methods for monitoring and prognosis of clinical status of patients in the acute phase of myocardial infarction introducing them into prototype clinical decision support system.

2. Methods

2.1. Investigated patients

Signals for investigation were registered during 24 h follow up of the patients hospitalized in the acute phase of myocardial infarction in Cardiology Clinics of Kaunas University of Medicine (Permission of Kaunas Region Ethics Committee for Biomedical Research Nr. 169/2004). The severity of the status of the 250 patients investigated was following: 81 patient was classified as Killip–Kimball class I, 96 – as class II, 26 – as class III and 47 – as class IV. Thirty four patients were forming a special group where cardiac output was evaluated simultaneously by means of non-invasive ICG method and the method of thermodilution, using Swan-Ganz catheters. Severity of the status of 8 of these patients was classified as Killip–Kimball class II, 6 – as class III, and 20 – as class IV.

2.2. Heart rate variability assessment

Establishment of combination of diagnostically valuable estimates of heart rate variability for the prognosis of patient status was done by means of discriminant analysis which selected the estimates best classifying investigated patients into two groups. Patients of one group went through the acute phase of myocardial infarction and had no consequent complications. In-hospital prognostic end-points of the other group were death and non-fatal events: post-infarction angina, progressive heart failure, pulmonary edema and cardiogenic shock. Heart rate variability was evaluated at day 1 and 3 using short-term recordings of the first 5 min of each hour of 24 h recording according to the Guidelines [5]. Statistical analysis was performed using SPSS 12 for Windows. We included the following heart rate variability measures into the model: time-domain measures – heart rate variability triangular indexes of day 1 and 3, frequency-domain measures – power in low frequency range (LF), power in high frequency range (HF), LF and HF expressed in normalized units (i.e. LF or HF/(total power-very low frequency power) $\times$ 100), and LF/HF ratio of day 1 and 3. *F* statistics was used to evaluate the significance of the parameters for group discrimination. The classification model was selected running a stepwise analysis, including the variables that minimize the general Wilks' labmda statistics.