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QRS Template Matching for Recognition of Ventricular Ectopic Beats

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Abstract—We propose a quasi real-time method for discrimination of ventricular ectopic beats from both supraventricular and paced beats in the electrocardiogram (ECG). The heartbeat waveforms were evaluated within a fixed-length window around the fiducial points (100 ms before, 450 ms after). Our algorithm was designed to operate with minimal expert intervention and we define that the operator is required only to initially select up to three 'normal' heartbeats (the most frequently seen supraventricular or paced complexes). These were named original QRS templates and their copies were substituted continuously throughout the ECG analysis to capture slight variations in the heartbeat waveforms of the patient's sustained rhythm. The method is based on matching of the evaluated heartbeat with the QRS templates by a complex set of ECG descriptors, including maximal cross-correlation, area difference and frequency spectrum difference. Temporal features were added by analyzing the R-R intervals. The classification criteria were trained by statistical assessment of the ECG descriptors calculated for all heartbeats in MIT-BIH Supraventricular Arrhythmia Database. The performance of the classifiers was tested on the independent MIT-BIH Arrhythmia Database. The achieved unbiased accuracy is represented by sensitivity of 98.4% and specificity of 98.86%, both being competitive to other published studies. The provided computationally efficient techniques enable the fast post-recording analysis of lengthy Holter-monitor ECG recordings, as well as they can serve as a quasi real-time detection method embedded into surface ECG monitors.

Keywords—Beat classification, Premature ventricular contractions PVC, Time-frequency ECG analysis, Cross-correlation, QRS morphology, ECG Holters, ECG diagnostic systems.

INTRODUCTION

The appearance of ventricular ectopic beats in the electrocardiogram (ECG) is a sign for disturbance in the depolarization process, disorganizing the blood pumping function of the ventricles and preceding in many cases malignant cardiac arrhythmias.[18] Long-term (24 h) ECG recordings, usually collected by Holter devices, are needed for identification of abnormal heartbeats and their manual editing is very time consuming. In the last decades, the application of mathematical models and statistical analyses for better interpretation of the physiologic cardiac events has offered many advantageous solutions for fast automatic recognition of ventricular ectopic beats. In respect to this, some of the most popular methods are based on assessment of the QRS complex as the most characteristic wave in ECG. Classical techniques extract heuristic ECG descriptors, such as the QRS morphology[2,4,14] and interbeat R-R intervals.[4,17] Other ECG descriptors rely on QRS frequency components calculated either by Fourier transform[10] or by computationally efficient algorithms with filter banks.[19] More sophisticated methods apply QRS template-matching procedures, based on different transforms, e.g., Karhunen-Loève transform,[5,13] Hermite functions,[7,8] wavelet transform[16] and Matching Pursuits,[3] to approximate the variety of temporal and frequency characteristics of the QRS complex waveforms. Other techniques for computerized arrhythmia detection employ cross-correlation with predefined ECG templates to identify markers for the individual wave components in one cardiac cycle,[9] and for extrasystole rejection and location of fiducial points intended for signal averaging applications.[1] Although, some of the cited studies have proved the individual advantage of using ECG templates based mainly on sophisticated mathematical transforms, while other studies have emphasized the particular benefit of a number of heuristic QRS features, we still miss a complex study for fast and reliable heartbeat classification which integrates a simplified QRS template-matching technique with some informative heuristic QRS features.

It is the aim of the current study to investigate the potential of the QRS template matching for recognition of ventricular ectopic beats by extraction of a complex set of ECG descriptors, including cross-correlation, morphological, frequency, and temporal characteristics

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Assessment and comparison of different methods for heartbeat classification

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Abstract

The most common way to diagnose cardiac dysfunctions is the ECG signal analysis, usually starting with the assessment of the QRS complex as the most significant wave in the electrocardiogram. Many methods for automatic heartbeats classification have been applied and reported in the literature but the use of different ECG features and the training and testing on different datasets, makes their direct comparison questionable. This paper presents a comparative study of the learning capacity and the classification abilities of four classification methods – *K*th nearest neighbour rule, neural networks, discriminant analysis and fuzzy logic. They were applied on 26 morphological parameters, which include information of amplitude, area, interval durations and the QRS vector in a VCG plane and were tested for five types of ventricular complexes – normal heart beats, premature ventricular contractions, left and right bundled branch blocks, and paced beats.

One global, one basic and two local learning sets were used. A small-sized learning set, containing the five types of QRS complexes collected from all patients in the MIT-BIH database, was used either with or without applying the leave one out rule, thus representing the global and the basic learning set, respectively. The local learning sets consisted of heartbeats only from the tested patient, which were taken either consecutively or randomly.

Using the local learning sets the assessed methods achieved high accuracies, while the small size of the basic learning set was balanced by reduced classification ability. Expectedly, the worst results were obtained with the global learning set.

Keywords: Automatic heartbeat classification; *K*th nearest neighbour rule; Neural networks; Discriminant analysis; Fuzzy logic

1. Introduction

The most common way to study and diagnose cardiac dysfunctions is the ECG signal analysis usually starting with the assessment of the QRS complex as the most significant wave in the electrocardiogram. The normal ventricular complexes (N) are provoked by the sinus node and are related with regular conduction path through the ventricles, which assures their normal narrow waveform. The existence of ectopic centers, as well as, some blocked regions in the ventricles, changes the path of propagation of the activation front and leads to generation of QRS complexes with wide and bizarre waveforms related to premature ventricular contractions (PVC) and left and right bundle branch blocks (LBBB, RBBB). Another type of ventricular complexes, which feature with a particular QRS behavior are the heartbeats provoked by pacemaker – the so-called paced beats (PB). The automatic detection and classification of ventricular beats considerably facilitates the analyses of long-term ECG Holter recordings. Therefore, the accuracy of the automatic heartbeat classification software is of great importance for the precise cardiac dysfunctions diagnosis. It depends on three basic factors – the used heartbeat feature set, the applied classification method and the organization of the training strategy.

Recently, a study compared the adequacy of morphological and time-frequency ECG descriptors for classification of the QRS complexes in five heartbeat classes [1]. An attempt to estimate the influence of the applied classifier and the used learning set on the classification accuracy was performed in

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RESUSCITATION

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CLINICAL PAPER

Clinical experience with a low-energy pulsed biphasic waveform in out-of-hospital cardiac arrest☆

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KEYWORDS
Automated external defibrillator;
Ventricular fibrillation;
Out-of-hospital cardiac arrest;
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Summary The efficiency of a pulsed biphasic waveform (PBW) was compared with that of biphasic truncated exponential (BTE) waveforms. First defibrillation shock outcome was studied in a population of 104 out-of-hospital cardiac arrest patients in ventricular fibrillation as the presenting rhythm. The call to first shock time was 8.2 ± 5.4 min. At 5 s post-shock, defibrillation efficiency was 90%. The arrest was witnessed in only 50% of the patients and only 5% received bystander CPR. Despite these limitations 38% of the patients achieved restoration of a spontaneous circulation at departure from scene and 9.8% were discharged from the hospital. These observations demonstrate a rate of first shock success in termination of ventricular fibrillation comparable to that reported with biphasic truncated exponential waveforms in out-of-hospital cardiac arrest.

Introduction

A relatively small number of patients survive out-of-hospital cardiac arrest (OHCA), with survival from ventricular fibrillation (VF) varying from 14 to 46%.[1–4] In most studies, witnessed arrest, bystander CPR and call to first shock time have been major determinants of survival.[1–7] White et al. have confirmed the importance of short call to first shock times as a determinant of both restoration of sustained spon-

☆ A Spanish translated version of the summary of this article appears as Appendix in the final online version at. . .

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✠ Albert Cansell was the previous Research and Development Director of the Schiller Medical SAS Company. He died suddenly at age 65 on 2 November 2006 in his office.

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Bench study of the accuracy of a commercial AED arrhythmia analysis algorithm in the presence of electromagnetic interferences

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Abstract
This paper presents a bench study on a commercial automated external defibrillator (AED). The objective was to evaluate the performance of the defibrillation advisory system and its robustness against electromagnetic interferences (EMI) with central frequencies of 16.7, 50 and 60 Hz. The shock advisory system uses two 50 and 60 Hz band-pass filters, an adaptive filter to identify and suppress 16.7 Hz interference, and a software technique for arrhythmia analysis based on morphology and frequency ECG parameters. The testing process includes noise-free ECG strips from the internationally recognized MIT-VFDB ECG database that were superimposed with simulated EMI artifacts and supplied to the shock advisory system embedded in a real AED. Measurements under special consideration of the allowed variation of EMI frequency (15.7–17.4, 47–52, 58–62 Hz) and amplitude (1 and 8 mV) were performed to optimize external validity. The accuracy was reported using the American Heart Association (AHA) recommendations for arrhythmia analysis performance. In the case of artifact-free signals, the AHA performance goals were exceeded for both sensitivity and specificity: 99% for ventricular fibrillation (VF), 98% for rapid ventricular tachycardia (VT), 90% for slow VT, 100% for normal sinus rhythm, 100% for asystole and 99% for other non-shockable rhythms. In the presence of EMI, the specificity for some non-shockable rhythms (NSR, N) may be affected in some specific cases of a low signal-to-noise ratio and extreme frequencies, leading to a drop in the

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specificity with no more than 7% point. The specificity for asystole and the sensitivity for VF and rapid VT in the presence of any kind of 16.7, 50 or 60 Hz EMI simulated artifact were shown to reach the equivalence of sensitivity required for non-noisy signals. In conclusion, we proved that the shock advisory system working in a real AED operates accurately according to the AHA recommendations without artifacts and in the presence of EMI. The results may be affected for specificity in the case of a low signal-to-noise ratio or in some extreme frequency setting.

Keywords: ECG signals, recognition of shockable and non-shockable rhythms, VF detection, robustness against EMI, automated external defibrillators

Introduction

Automated external defibrillators (AEDs) are designed to provide life-saving shocks within the first decisive minutes after cardiac arrest. The possible absence of any medical professionals in an out-of-hospital setting requires not only the best ease-of-use (Eames *et al* 2003), but also a high accuracy for arrhythmia recognition for the underlying shock decision of the device (Kerber *et al* 1997).

Artifacts caused by electromagnetic interference (EMI) are known to reduce the ECG-signal quality and impair proper analysis. The identified possible sources of EMI in the out-of-hospital setting are (i) high-voltage power lines and transformers, operating with the mains frequencies of 50 or 60 Hz, and (ii) power lines and generators for the railway networks in several countries with a frequency of 16.7 Hz (Commission decision 2002/733/EC, Kanz *et al* 2004). Strong EMI may overlap with the ECG (Schlimp *et al* 2004, 2007), and probable errors in the rhythm analysis may lead to inappropriate shock decisions.

Although the study of Stolzenberg *et al* (2002) did not encounter any significant errors in the ECG analysis of AEDs, some authors have reported a reduced performance of commercial AEDs, which caused false positive shock decisions in the presence of sinus rhythms in humans (Fleischhackl *et al* 2006) or false negative decisions that prevented the delivery of a necessary shock on shockable rhythms in simulators (Kanz *et al* 2004). A complete validation of the arrhythmia recognition (AR) algorithm for robustness against the influence of environmental EMI is needed, since the systematic measurements of AR accuracy with a variety of ECG recordings that reproduce real-life conditions in the presence of EMI artifacts are missing.

In light of this, the objective of our study was to evaluate the performance of a defibrillation advisory system working in a real AED and its robustness against EMI with central frequencies of 16.7, 50 and 60 Hz. The tests followed the American Heart Association (AHA) recommendations for reporting the AR performance (Kerber *et al* 1997) by using noise-free ECG strips from the internationally recognized MIT-VFDB ECG database. Additionally, they were superimposed with simulated EMI artifacts. Measurements under special consideration of the allowed variation of frequency (Commission decision 2002/733/EC) were performed to optimize external validity.

Material and methods

This observational prospective simulation study took place in the Schiller Laboratories, Wissembourg, France.

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Shock Advisory System for Heart Rhythm Analysis During Cardiopulmonary Resuscitation Using a Single ECG Input of Automated External Defibrillators

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Associate Editor Kenneth R. Lutchen oversaw the review of this article.

Abstract—Minimum "hands-off" intervals during cardiopulmonary resuscitation (CPR) are required to improve the success rate of defibrillation. In support of such life-saving practice, a shock advisory system (SAS) for automatic analysis of the electrocardiogram (ECG) contaminated by chest compression (CC) artefacts is presented. Ease of use for the automated external defibrillators (AEDs) is aimed and therefore only processing of ECG from usual defibrillation pads is required. The proposed SAS relies on assessment of outstanding components of ECG rhythms and CC artefacts in the time and frequency domain. For this purpose, three criteria are introduced to derive quantitative measures of band-pass filtered CC-contaminated ECGs, combined with three more criteria for frequency-band evaluation of reconstructed ECGs (rECG). The rECGs are derived by specific techniques for CC waves similarity assessment and are reproducing to some extent the underlying ECG rhythms. The rhythm classifier embedded in SAS takes a probabilistic decision designed by statistics on the training dataset. Both training and testing are fully performed on real CC-contaminated strips of 10 s extracted from human ECGs of out-of-hospital cardiac arrest interventions. The testing is done on 172 shockable strips (ventricular fibrillations VF), 371 non-shockable strips (NR) and 330 asystoles (ASYS). The achieved sensitivity of 90.1% meets the AHA performance goal for noise-free VF (>90%). The specificity of 88.5% for NR and 83.3% for ASYS are comparable or even better than accuracy reported in literature. It is important to note that, the aim of this SAS is not to recommend shock delivery but to advice the rescuers to "Continue CPR" or to "Stop CPR and Prepare for Shock" thus minimizing "hands-off" intervals.

Keywords—Early defibrillation, Out-of-hospital cardiac

INTRODUCTION

Slightly less than half of the sudden cardiac arrests begin with ventricular fibrillation (VF).[25,32] In such cases, an immediate defibrillation is recommended since each minute delay reduces the probability of patient survival by 10%.[23,32] Cardiopulmonary resuscitation (CPR) has been advised as the best treatment for out-of-hospital cardiac arrests (OHCA) until the arrival of an automated external defibrillator (AED).[16] The CPR contributes to the sustained cerebro-vascular function by preserving a level of oxygen supply to the brain, vital organs and importantly the heart. The latter prevents myocardial ischemia, and VF from deteriorating to asystole, and thus increases the probability of a successful defibrillation.[33] Longer compression periods with minimal "hands-off" time may even increase the rate of restoring the spontaneous circulation.[13,14,28] This fact is supported by the recent American Heart Association (AHA) Guidelines 2008 [29] promoting "hands-only" CPR.

The mechanical activity of chest compressions (CC) during CPR induces large artefact components into the electrocardiogram (ECG) acquired via the defibrillation pads.[15] The superposition of ECG and CC artefacts often resembles ventricular fibrillation/tachycardia (VF/VT),[1] resulting in both specificity (Sp) and sensitivity (Se) reduction of AED shock advisory

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An audiovisual feedback device for compression depth, rate and complete chest recoil can improve the CPR performance of lay persons during self-training on a manikin

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Abstract

This study aims to contribute to the scarce data available about the abilities of untrained lay persons to perform hands-only cardio-pulmonary resuscitation (CPR) on a manikin and the improvement of their skills during training with an autonomous CPR feedback device. The study focuses on the following questions: (i) Is there a need for such a CPR training device? (ii) How adequate are the embedded visual feedback and audio guidance for training of lay persons who learn and correct themselves in real time without instructor guidance? (iii) What is the achieved effect of only 3 min of training? This is a prospective study in which 63 lay persons (volunteers) received a debriefing to basic life support and then performed two consecutive 3 min trials of hands-only CPR on a manikin. The pre-training skills of the lay persons were tested in trial 1. The training process with audio guidance and visual feedback from a cardio compression control device (CC-Device) was recorded in trial 2. After initial debriefing for correct chest compressions (CC) with rate 85–115 min^{-1}, depth 3.8–5.4 cm and complete recoil, in trial 1 the lay persons were able to perform CC without feedback at mean rate 95.9 $\pm$ 18.9 min^{-1}, mean depth 4.13 $\pm$ 1.5 cm, with low proportions of 'correct depth', 'correct rate' and 'correct recoil' at 33%, 43%, 87%, resulting in the scarce proportion of 14% for compressions, which simultaneously fulfill the three quality criteria ('correct all'). In trial 2, the training process by the CC-Device was established by the significant improvement of the CC skills until the 60th second of training, when 'correct depth', 'correct rate' and 'correct recoil' attained the plateau of the highest quality at 82%, 90%, 96%, respectively, resulting in 73% 'correct

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all' compressions within 3 min of training. The training was associated with reduced variance of the mean rate 102.4 ± 4.7 min^{-1} and mean depth 4.3 ± 0.4 cm, indicating a steady CC performance achieved among all trained participants. Multivariable linear regression showed that the compression depth, rate and complete chest recoil did not strongly depend on lay person age, gender, height, weight in pre-training and training stage (correlation coefficient below 0.54). The study confirmed the need for developing CPR abilities in untrained lay persons via training by real-time feedback from the instructor or CC-Device. The CC-Device embedded feedback was shown to be comprehensible and easy to be followed and interpreted. The high quality of the CC-Device-assisted training process of lay persons was confirmed. Thus learning or refresher courses in basic life support could be organized for more people trained at the same time with fewer instructors needed only for the initial debriefing and presentation of the CC-Device.

Keywords: cardio-pulmonary resuscitation (CPR), CPR quality, depth, rate, recoil of chest compressions, basic life support, training

1. Introduction

Since the early 1960s, cardio-pulmonary resuscitation (CPR) has been introduced as a life-saving first aid in case of sudden cardiac death (Ad Hoc Committee on Cardiopulmonary Resuscitation 1966). Many conditions have been documented to provide survival benefits from CPR.

A crucial factor is the quality of chest compressions (CC) for which the American Heart Association (AHA 2005) Guidelines for CPR states (i) optimal CC depth of 1.5–2 inches; (ii) optimal CC rate of about 100 compressions min^{-1}; (iii) complete chest recoil by relieving all pressure from the chest after each compression. All these CC variables assist the proper CPR hemodynamics that maintains the optimal coronary artery perfusion pressure (Wesley 2006).

Another benefit for improved outcome in out-of-hospital cardiac arrest (OHCA) victims is the early bystander CPR not delaying the treatment until the arrival of the emergency medical services (EMS) and the defibrillator (Bossaert and Van Hoeyweghen 1989). Although the long-term survival (to hospital discharge or up to 1 month after OHCA) is reported to be limited (Van Hoeyweghen *et al* 1993, Wik *et al* 1994, Gallagher *et al* 1995, Herlitz *et al* 2005)—0.8–7% for no bystander CPR, 1–6.2% for inadequate bystander CPR, 4.6–23% for high-quality bystander CPR—the odds ratios of survival reported between 1.7 and 23 prove significant benefit of high-quality bystander CPR from trained lay persons or professionals compared to bad quality CPR from untrained lay persons. In Van Hoeyweghen *et al* (1993), a significant effect on survival was not found when comparing incorrect CPR and no bystander CPR.

The review of the results reported for the quality of prehospital CPR (Bossaert and Van Hoeyweghen 1989, Van Hoeyweghen *et al* 1993, Wik *et al* 1994, Gallagher *et al* 1995, Ko *et al* 2005) reveals 16–71% bad quality of bystander CPR by both EMS providers and lay people. Also, in-hospital studies of healthcare professionals (hospital nurses and doctors) indicate poor CPR quality, including too slow CC rates in 28–69% (Abella *et al* 2005a, 2005b) and too shallow CC in 37% (Abella *et al* 2005a), both resulting in low coronary perfusion pressures

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Shock advisory system with minimal delay triggering after end of chest compressions: Accuracy and gained hands-off time

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ABSTRACT

Aims: Shortening hands-off intervals can improve benefits from defibrillation. This study presents the performance of a shock advisory system (SAS), which aims to decrease the pre-shock pauses by triggering fast rhythm analysis at minimal delay after end of chest compressions (CC).

Methods: The SAS is evaluated on a database of 1301 samples from 311 out-of-hospital cardiac arrests (OHCA) from automated external defibrillators (AEDs). The following rhythms are identified: 788 asystoles (ASYS), 20 normal sinus rhythms (NSR), 394 other non-shockable rythms (ONS), 81 ventricular fibrillations (VF), 18 rapid ventricular tachycardias (VThi). SAS is launched in two-stages: first stage for accurate detection of actual end of CC (REoCC); second stage for early "Shock"/"No-Shock" decision by using all available artifact-free ECG signals after REoCC during 3,5,7 s.

Results: Performance of the presented SAS versus AEDs is compared. The median hands-off time gained from earlier starting of ECG analysis is 5.8 s and for earlier shock advice is 12.5 s to 8.5 s when SAS rhythm analysis lasts 3 s to 7 s. The SAS accuracy at 3–7 s is: specificity 97.7–98.9% (ASYS), 100–100% (NSR), 98.5–99.2% (ONS); sensitivity 91.4–98.8% (VF), 88.9–96.7% (VThi).

Conclusion: This study indicates that shortening the pre-shock hands-off pause by more efficient management of the SAS process in AEDs is possible. For analysis duration of 5 s (7 s), the delay between the end of chest compressions and the shock advice can be reduced by 10.5 s (8.5 s) median, while AHA requirements for rhythm detection accuracy are met. The use of this solution in AEDs could provide more reliable rhythm analysis than methods applying filtering techniques during CC.

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Threshold-based system for noise detection in multilead ECG recordings

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Abstract

This paper presents a system for detection of the most common noise types seen on the electrocardiogram (ECG) in order to evaluate whether an episode from 12-lead ECG is reliable for diagnosis. It implements criteria for estimation of the noise corruption level in specific frequency bands, aiming to identify the main sources of ECG quality disruption, such as missing signal or limited dynamics of the QRS components above 4 Hz; presence of high amplitude and steep artifacts seen above 1 Hz; baseline drift estimated at frequencies below 1 Hz; power–line interference in a band ± 2 Hz around its central frequency; high-frequency and electromyographic noises above 20 Hz. All noise tests are designed to process the ECG series in the time domain, including 13 adjustable thresholds for amplitude and slope criteria which are evaluated in adjustable time intervals, as well as number of leads. The system allows flexible extension toward application-specific requirements for the noise levels in acceptable quality ECGs. Training of different thresholds' settings to determine different positive noise detection rates is performed with the annotated set of 1000 ECGs from the PhysioNet database created for the Computing in Cardiology Challenge 2011. Two implementations are highlighted on the receiver operating characteristic (area 0.968) to fit to different applications. The implementation with high sensitivity (Se = 98.7%, Sp = 80.9%) appears as a reliable alarm when there are any incidental problems with the ECG acquisition, while the implementation with high specificity (Sp = 97.8%, Se = 81.8%) is less susceptible to transient problems but rather validates noisy ECGs with acceptable quality during a small portion of the recording.

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MATHEMATIQUES
Informatiques

GENERALIZED NET MODEL OF A PROTOCOL FOR WEANING FROM MECHANICAL VENTILATION

Lyudmila Todorova, Peter Vassilev, Mikhail Matveev, Vessela Krasteva, Irena Jekova, Stefan Hadjitodorov, Georgi Georgiev*, Stoyan Milanov*

(*Submitted by Corresponding Member K. Atanassov on May 27, 2013*)

Abstract

In the present work an attempt is made to evaluate objectively the ventilated patients' condition from the monitored parameters (standard physiological parameters, parameters of the ventilation and respiratory mechanics, parameters of the gas exchange and energy expenditure) in order to determine their readiness for weaning from mechanical ventilation support. This research is a step in improving the care for ventilated patients in order to decrease the period of ventilation support. In the Central Intensive Care Unit, University Emergency Hospital "N. I. Pirogov" an investigation is conducted, with stages described in detail in the paper. A generalized model represents these phases. The decision criteria and the results of their application are evaluated by the so-constructed generalized net and a validity score is updated for each rule to be used in further considerations. The accuracy of the predictive rules has been estimated by calculating the sensitivity, specificity, the positive- and negative predictive value. Due to the relatively small number of patients, the developed GN-model will be refined in the course of the continuing investigation at the Central Intensive Care Unit, University Emergency Hospital "N. I. Pirogov".

Key words: generalized nets, weaning from mechanical ventilation, decision criteria

1. Introduction. The mechanical ventilation support is life-saving for the critically ill. The per cent of patients who undergo breathing support in intensive care units is significant – up to 90% of all entering patients. At the same time they account for 37% of the cost of the intensive care treatment. With the fading of the causes leading to ventilation support, it can be ended relatively

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RESEARCH ARTICLE

Superiority of Classification Tree versus Cluster, Fuzzy and Discriminant Models in a Heartbeat Classification System

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Abstract

This study presents a 2-stage heartbeat classifier of supraventricular (SVB) and ventricular (VB) beats. Stage 1 makes computationally-efficient classification of SVB-beats, using simple correlation threshold criterion for finding close match with a predominant normal (reference) beat template. The non-matched beats are next subjected to measurement of 20 basic features, tracking the beat and reference template morphology and RR-variability for subsequent refined classification in SVB or VB-class by Stage 2. Four linear classifiers are compared: cluster, fuzzy, linear discriminant analysis (LDA) and classification tree (CT), all subjected to iterative training for selection of the optimal feature space among extended 210-sized set, embodying interactive second-order effects between 20 independent features. The optimization process minimizes at equal weight the false positives in SVB-class and false negatives in VB-class. The training with European ST-T, AHA, MIT-BIH Supraventricular Arrhythmia databases found the best performance settings of all classification models: Cluster (30 features), Fuzzy (72 features), LDA (142 coefficients), CT (221 decision nodes) with top-3 best scored features: normalized current RR-interval, higher/lower frequency content ratio, beat-to-template correlation. Unbiased test-validation with MIT-BIH Arrhythmia database rates the classifiers in descending order of their specificity for SVB-class: CT (99.9%), LDA (99.6%), Cluster (99.5%), Fuzzy (99.4%); sensitivity for ventricular ectopic beats as part from VB-class (commonly reported in published beat-classification studies): CT (96.7%), Fuzzy (94.4%), LDA (94.2%), Cluster (92.4%); positive predictivity: CT (99.2%), Cluster (93.6%), LDA (93.0%), Fuzzy (92.4%). CT has superior accuracy by 0.3–6.8% points, with the advantage for easy model complexity configuration by pruning the tree consisted of easy interpretable 'if-then' rules.

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POTENTIAL OF THE PERIPHERAL ELECTROCARDIOGRAM FOR PERSONAL VERIFICATION/IDENTIFICATION

Irena Jekova

(*Submitted by Corresponding Member K. Atanassov on February 23, 2015*)

Abstract

The reliability of automatic person authentication has become critical, considering the necessary security for the cases of financial transactions, access control, travelling, etc. The traditional means for identity validation (PIN codes, passwords, etc.), as well as physiological and behavioural biometric characteristics (fingerprint, iris, speech, etc.) are susceptible to hacker attacks and/or falsification.

The aim of this paper is to present a method for person verification and identification based on correlation of present-to-previous limb ECG leads I (rI) and II (rII) and the calculated from them first principal ECG component (rPCA). For the verification task, the one-to-one scenario is applied and threshold values for the rI, rII and rPCA are derived. The identification task supposes one-to-many scenario and the tested subject is identified according to the maximal correlation with a previously recorded ECG in a database.

The reliability of the method is estimated by applying it over separated in time ECG signals of healthy persons. The best verification sensitivity of 100%, obtained using lead II is combined with 21.4% erroneous verification

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rate. The best verification specificity of 92.3%, obtained using the first principal component is combined with 21.4% erroneous rejection rate. Both peripheral leads provide identification accuracy of 85.7%. Depending on the exact task that has to be solved, one can decide about the used correlation coefficient, their threshold values and possible combinations.

Key words: electrocardiogram (ECG), person identification, validation

Introduction. The reliability of automatic person authentication has become critical in our life, considering the necessary security for the cases of financial transactions, access control, travelling, etc. The traditional means for identity validation, such as PIN codes, passwords and identity cards, are susceptible to hacker attacks and falsification. In the past few decades, identification based on physiological and behavioural biometric characteristics, such as fingerprint, iris, speech, etc., were proposed. However, these biometrics could be easily circumvented, e.g. by using prosthetic finger or iris [1] or voice playback. Considering these drawbacks, recently the efforts have been concentrated on the development of biometric characteristics of next generation that are internal to the human's body and therefore are robust to the above discussed attacks.

The analysis of the electrocardiogram (ECG) as a biometric tool presented two general approaches: (i) methods that use measurements after detection of fiducial points and (ii) analyzes of the overall ECG morphology. The fiducial based approaches had been applied since the very beginning. One of the earliest studies that demonstrated the feasibility of ECG signals for biometrics involved 12 uncorrelated clinical diagnosis features related with P, QRS, T amplitudes and durations [2]. The interpretation of the similarities/differences between individuals' heartbeats was performed by principle component analysis (PCA) score plots. The authors achieved classification rate of 100% using 10 of the features. Individual recognition based on 15 temporal features describing the P-QRS-T segment which were fed into a set of discriminant functions was described in [3]. This group reported accuracy for the individual classification between 97% and 100%. In [4], two-step detection was introduced. It incorporates temporal and amplitude measurements based on fiducial points detection and appearance based features that capture the patterns of the heartbeats. The authors achieved 100% subject identification based on this combined approach.

The methods incorporating time and amplitude characteristics of the heartbeats strongly rely on the correct localization of wave boundaries within the P-QRS-T segment. Therefore, in order to reduce the rejection rate, perfect heartbeat synchronization is required for biometric purposes [5]. For that reason, fiducial independent approaches appeared after 2006. Great part of the proposed methods were based on calculation of correlation coefficients, including autocorrelation (AC) of 5s ECG segments further processed by discriminant analysis, which provides 96.4% accuracy [5]; AC of windowed ECG, followed by discrete cosine transform (DCT) [6] with reported 100% accuracy; maximal correlation

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Real-time arrhythmia detection with supplementary ECG quality and pulse wave monitoring for the reduction of false alarms in ICUs

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Abstract

False intensive care unit (ICU) alarms induce stress in both patients and clinical staff and decrease the quality of care, thus significantly increasing both the hospital recovery time and rehospitalization rates. In the PhysioNet/CinC Challenge 2015 for reducing false arrhythmia alarms in ICU bedside monitor data, this paper validates the application of a real-time arrhythmia detection library (ADLib, Schiller AG) for the robust detection of five types of life-threatening arrhythmia alarms. The strength of the application is to give immediate feedback on the arrhythmia event within a scan interval of 3 s–7.5 s, and to increase the noise immunity of electrocardiogram (ECG) arrhythmia analysis by fusing its decision with supplementary ECG quality interpretation and real-time pulse wave monitoring (quality and hemodynamics) using arterial blood pressure or photoplethysmographic signals. We achieved the third-ranked real-time score (79.41) in the challenge (Event 1), however, the rank was not officially recognized due to the 'closed-source' entry. This study shows the optimization of the alarm decision module, using tunable parameters such as the scan interval, lead quality threshold, and pulse wave features, with a follow-up improvement of the real-time score (80.07). The performance (true positive rate, true negative rate) is reported in the blinded challenge test set for different arrhythmias: asystole (83%, 96%), extreme bradycardia (100%, 90%), extreme tachycardia (98%, 80%), ventricular tachycardia (84%, 82%), and ventricular fibrillation (78%, 84%). Another part of this study considers the validation of ADLib with four reference ECG databases (AHA, EDB, SVDB, MIT-BIH) according to the international recommendations for performance reports in ECG monitors (ANSI/AAMI EC57). The sensitivity (Se) and positive predictivity (+P) are: QRS detector QRS (Se, +P) > 99.7%, ventricular ectopic beat (VEB) classifier VEB (Se, +P) = 95%, and ventricular fibrillation detector VFIB (P + = 94.8%) > VFIB (Se = 86.4%), adjusted to the clinical setting requirements, giving preference to low false positive alarms.

Keywords: ECG monitoring, QRS detection, heartbeat classification, ECG quality, pulse wave analysis, life-threatening arrhythmia, false ICU alarms

(Some figures may appear in colour only in the online journal)

1. Introduction

According to the European Committee for Standardization (CEN: Comité Européen de Normalisation 1995), medical device alarms are classified into three categories: high priority (accompanied by a flashing red light), indicating an urgent life-threatening situation that requires immediate action; medium priority (flashing yellow light) for dangerous conditions, demanding a quick response; and low priority (constant yellow indicator), for alerts that should be brought to the attention of the medical staff. The 'yellow' alarms are typically not very loud and last for 5 s or 6 s, however, the critical 'red' alarms, which are usually configured for life-threatening arrhythmia (Drew *et al* 2014), are much more intense and distinctive and remain switched on until they are acknowledged by the person responsible (Aboukhalil *et al* 2008). The average number of different alarm sounds in the intensive care unit (ICU) has increased from 6 in 1983 (Kerr *et al* 1983) to more than 40 in 2011 (Borowski *et al* 2011), which together with the intentional setting of cardiac monitors to high sensitivity at the expense of specificity (Drew *et al* 2004) and the influence of motion artifacts on their accuracy, expose the medical staff and the patients to a high number of different alarms. There are studies reporting that only 2%–9% of ICU alarms are important for patient management (Tsien and Fackler 1997), 6%–40% are true but clinically insignificant, while ICU false alarms are prevalent with rates as high as 89% (Drew *et al* 2014). False alarms mainly induce stress in both patients and medical staff (Baker 1992, Cropp *et al* 1994, Novaes *et al* 1997, Topf and Thompson 2001, Morrison *et al* 2003), causing fatigue and desensitization to emergency signals and slower response times for the personnel (Chambrin 2001, Donchin and Seagull 2002, Imhoff and Kuhls 2006), as well as sleep disruption and depressed immune systems for the patients (Hagerman *et al* 2005, Parthasarathy and Tobin 2004). This is reported to significantly increase both the hospital recovery time (Cropp *et al* 1994, Donchin and Seagull 2002) and rehospitalization rates (Hagerman *et al* 2005).

These high rates of false arrhythmia alarms suggest significant room for improvement in this field, which is one that has become a topic of intensive research during the last few decades. The first attempts to cope with the problem were based only on the processing of the the electrocardiogram (ECG) via filtering techniques, applied to smooth the heart rate trends (Mäkivirta *et al* 1991) or identify artifacts (Sittig and Factor 1990), and a knowledge-based system (Koski *et al* 1994) to reduce false alarms. These measures achieved alarm rejection rates of 37%–54%, however, they were evaluated using restricted databases.

Considering that false arrhythmia alarms are commonly due to single-channel ECG artifacts and/or low-voltage signals, it is likely that they may be reduced by using all available

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Inter-lead correlation analysis for automated detection of cable reversals in 12/16-lead ECG

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ABSTRACT

Background and objective: A crucial factor for proper electrocardiogram (ECG) interpretation is the correct electrode placement in standard 12-lead ECG and extended 16-lead ECG for accurate diagnosis of acute myocardial infarctions. In the context of optimal patient care, we present and evaluate a new method for automated detection of reversals in peripheral and precordial (standard, right and posterior) leads, based on simple rules with inter-lead correlation dependencies.

Methods: The algorithm for analysis of cable reversals relies on scoring of inter-lead correlations estimated over 4s snapshots with time-coherent data from multiple ECG leads. Peripheral cable reversals are detected by assessment of nine correlation coefficients, comparing V6 to limb leads: (I, II, III, –I, –II, –III, –aVR, –aVL, –aVF). Precordial lead reversals are detected by analysis of the ECG pattern cross-correlation progression within lead sets (V1–V6), (V4R, V3R, V3, V4), and (V4, V5, V6, V8, V9). Disturbed progression identifies the swapped leads.

Results: A test-set, including 2239 ECGs from three independent sources—public 12-lead (PTB, CSE) and proprietary 16-lead (Basel University Hospital) databases—is used for algorithm validation, reporting specificity (Sp) and sensitivity (Se) as true negative and true positive detection of simulated lead swaps. Reversals of limb leads are detected with Se = 95.5–96.9% and 100% when right leg is involved in the reversal. Among all 15 possible pairwise reversals in standard precordial leads, adjacent lead reversals are detected with Se = 93.8% (V5–V6), 95.6% (V2–V3), 95.9% (V3–V4), 97.1% (V1–V2), and 97.8% (V4–V5), increasing to 97.8–99.8% for reversals of anatomically more distant electrodes. The pairwise reversals in the four extra precordial leads are detected with Se = 74.7% (right-sided V4R–V3R), 91.4% (posterior V8–V9), 93.7% (V4R–V9), and 97.7% (V4R–V8, V3R–V9, V3R–V8). Higher true negative rate is achieved with Sp > 99% (standard 12-lead ECG), 81.9% (V4R–V3R), 91.4% (V8–V9), and 100% (V4R–V9, V4R–V8, V3R–V9, V3R–V8), which is reasonable considering the low prevalence of lead swaps in clinical environment.

Conclusions: Inter-lead correlation analysis is able to provide robust detection of cable reversals in standard 12-lead ECG, effectively extended to 16-lead ECG applications that have not previously been addressed.

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Intersubject variability and intrasubject reproducibility of 12-lead ECG metrics: Implications for human verification

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Abstract

Background: Electrocardiogram (ECG) biometrics is an advanced technology, not yet covered by guidelines on criteria, features and leads for maximal authentication accuracy.
Objective: This study aims to define the minimal set of morphological metrics in 12-lead ECG by optimization towards high reliability and security, and validation in a person verification model across a large population.
Methods: A standard 12-lead resting ECG database from 574 non-cardiac patients with two remote recordings (>1 year apart) was used. A commercial ECG analysis module (Schiller AG) measured 202 morphological features, including lead-specific amplitudes, durations, ST-metrics, and axes. Coefficient of variation (CV, intersubject variability) and percent-mean-absolute-difference (PMAD, intrasubject reproducibility) defined the optimization (PMAD/CV → min) and restriction (CV < 30%) criteria for selection of the most stable and distinctive features. Linear discriminant analysis (LDA) validated the non-redundant feature set for person verification.
Results and conclusions: Maximal LDA verification sensitivity (85.3%) and specificity (86.4%) were validated for 11 optimal features: R-amplitude (I,II,V1,V2,V3,V5), S-amplitude (V1,V2), Tnegative-amplitude (aVR), and R-duration (aVF,V1).

Keywords: ECG biometrics; Person authentication; ECG diagnostic morphological features; Optimization criteria; Linear discriminant analysis

Introduction

The biometric authentication via ECG, interacting entirely with physiological characteristics, is robust to hacker attacks and falsification, and it is therefore considered as an advanced technology when high-level automated security is demanded [1]. Two identity recognition scenarios are administered – person verification (one-to-one scenario) and person identification (one-to-many scenario). Existing ECG identity recognition techniques are either fiducial or non-fiducial based. The former are the primary considered in the field as they employ morphological features, typically measured for diagnostic purposes by ECG devices. Thus, the crucial task for precise localization of specific anchor points on the P-QRS-T segment can be managed by certified commercial ECG analysis modules with minimal intervention. The application of such a person identity approach can be easily extended to automated management of in-hospital databases.

Published studies use different types of fiducial based ECG metrics: temporal features [2–5] (hypothized to be invariant to the sensor placement [2]), amplitudes and slopes [4–9] (reported to be more informative than the temporal features [5]), Q, R, S angles [5,7] and frequency charactertistics [10]. The classification techniques employed for identity recognition use linear discriminant analysis (LDA) [2–4], Euclidean distance criteria [7,9], principal component analysis score plots [6], correlation analysis [8], neural networks [5], threshold based approaches [10], etc.

A limitation in the field for person authentication via ECG is the lack of standardized public databases containing multiple ECG recordings per subject with sufficient temporal separation. For that reason, some studies use proprietary databases from limited population [2,3,6,9], single lead [2,3,7,9] or limited time distance between intrasubject ECGs, acquired within a few days [6], in a single day at different

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Research Paper

A real-time quality monitoring system for optimal recording of 12-lead resting ECG

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ABSTRACT

Minimizing the impact of artifacts prior to the start of the ECG recording is an approach for providing a diagnostically reliable data. A solution to this problem is a continuous feedback of the ECG quality and prompt start of the recording at potentially the best quality. The real-time lead quality monitoring library (LQMLib) is introduced to trigger the recording of 10 s resting 12-lead ECG at the optimal snapshot moment (the earliest in time, the best in quality). The triggering condition considers the Snapshot quality (signal-to-noise ratio of the most noisy 4 s segment within 10 s) exceeding an adaptive quality threshold (AQT). The optimal AQT (descending from 85% down to 60% over 1 min) is validated on two independent clinical datasets from an emergency department, including 267/385 standard 12-lead ECGs. The test-validation LQMLib performance is: (84.7–87.2)% of ECGs would be triggered at their maximal Snapshot quality; (31.2–33.1)% at the optimal snapshot time (±2.5 s); (25.7–29.3)% would be started earlier, typical for high quality ECGs with progressively increasing supra-threshold Snapshot quality; (37.2–43.1)% would be recorded with a delay >2.5 s, typical for low quality ECGs with sub-threshold maximal Snapshot quality that is not validated as potentially the best quality until AQT criterion declines later within 1 min.

1. Introduction

The routine use of the standard 12-lead electrocardiogram (ECG) for noninvasive clinical investigation of acute and chronic cardiovascular diseases sets the important issue for ensuring diagnostically interpretable high-quality signals in all ECG leads [1,2]. The acquisition of 12 ECG leads, all of high quality, is a challenging task, considering the susceptibility of each lead to different permanent or transient noises, caused by patient movement, electromyogram artifacts, electromagnetic interferences, etc., which have unpredictable onset and duration and could occur separately or simultaneously, thus compromising the correct ECG interpretation. According to the current clinical guidelines for recording of standard 12-lead ECG, the medical staff is responsible for the proper electrodes placement, patient's body positioning, skin preparation, as well as for the approval of the ECG quality in terms of clearly visible P, QRS, T waveforms, stable and free of interference isoelectric line [3]. The high rate of unusable data due to insufficient quality (5% of 20 million ECGs worldwide) [4] suggests that the human factor is susceptible to shortcomings. There is a significant room for improvement of the recording conditions control by automated ECG quality assessment algorithms, which is one that has become a topic of intensive research during the last few years.

The PhysioNet/Computing in Cardiology (CinC) Challenge 2011 has essentially contributed to the development of different solutions for identifying common distorting factors during ECG acquisition and classification of 12-lead ECG quality as acceptable or unacceptable for diagnostic purposes [5]. Various ECG disturbance detection techniques have been applied for the derivation of analytical ECG quality metrics for the presence of:

- missing leads with constant voltage [6–15] and/or low amplitude [6,10–12,16];
- baseline wander and high-frequency noises [6,7,9,12,13,15–18];
- steep slope and/or high amplitude artifacts [6,8–10,12,15];
- failure in QRS detection [7,8,13];
- disturbances in template and signal morphology features [19];

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Relative Estimation of the Karhunen-Loève Transform Basis Functions for Detection of Ventricular Ectopic Beats

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Abstract

Feasibility of the Karhunen-Loève transform (KLT) for detection of ventricular ectopic beats was studied. The KLT basis functions of normal QRS complexes were derived for a small-sized training set of heartbeats. The relevant KLT features were obtained by comparison between five selected heartbeats of the predominant rhythm and the remaining heartbeats in the tested electrocardiographic (ECG) recording. Statistical analysis of the KLT features for MIT-BIH arrhythmia database contributed to the definition of threshold criteria for discrimination between the predominant and the ventricular ectopic heartbeats. The achieved accuracy was about 97.7% for single-lead analysis and above 98% for joint two-lead processing. The method is attractive and suitable for implementation in an automatic analysis module because of the necessity for supervisor annotation of only five beats of the predominant rhythm in one ECG recording.

1. Introduction

Automatic heartbeat classification using the electrocardiogram (ECG) has been a field of intensive research during the last years. Recently a number of sophisticated ECG modeling methods, competing for higher accuracy, were published. Classical techniques use heuristic ECG descriptors, such as the QRS morphology [1,2]. However, the QRS pattern recognition techniques are considerably affected by noise due to unfavorable signal acquisition conditions. Another group of approaches, theoretically more robust to noise, are based on approximating the QRS complex using a small number of waveforms taken from a suitable dictionary. For example, the Matching Pursuits method has been recently introduced for linear expansions of the QRS waveforms involving non-orthogonal dictionaries based on Wavelet Packets [3,4]. Other noise-tolerant parametric models of the QRS complex use common dictionaries of orthogonal basis functions. Examples of such basis are the Hermite functions [5,6] and the Karhunen-Loève transform (KLT) [7], both providing a low dimension feature space for heartbeat classification. The KLT has also been successfully applied for reconstruction of the ST-T shape in studies of the ventricular repolarization period [8,9]. The KLT was preferred because of its power to approximate a selected segment from the P-QRS-T pattern with both the lowest expected mean-squared error and enhanced noise immunity.

The present study investigates the ability of defined KLT features to improve the accuracy of the KLT method [7] for discrimination between ectopic beats and the beats of the predominant rhythm in one ECG recording.

2. Materials and methods

2.1. ECG database

We analysed 44 of the 48 ECG recordings of the Massachusetts Institute of Technology - Beth Israel Hospital (MIT-BIH) arrhythmia database. We excluded the 4 files with paced beats (102, 104, 107, 217). Each recording has a duration of 30 min and includes two leads – the modified limb lead II and one of the modified leads V1, V2, V4 or V5 [10]. The sampling frequency is 360 Hz and the resolution is 200 samples per mV. The heartbeats were recognized by the fiducial points in the database. We followed the American Heart Association (AHA) records equivalent annotation [10] to form two classes of heartbeats: (i) the class of the ventricular ectopic beats (V); (ii) the class of the normal beats (N), including all normal heartbeats (approximately 70% of the database) and some of the abnormal beats (left bundle branch block, right bundle branch block, aberrantly conducted beat, nodal premature beat, atrial premature beat, nodal or atrial premature beat, nodal escape beat, left or right bundle branch block, atrial ectopic beat and nodal ectopic beat). We further restricted the N class to contain only those heartbeats, which are representative for the predominant rhythm of the patient - normal beats, left bundle branch block and right bundle branch block beats. No selection based on the quality of the signal was performed. Thus the analysis was applied even in the presence of artifact or noise in the ECG.

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Shock advisory tool: Detection of life-threatening cardiac arrhythmias and shock success prediction by means of a common parameter set

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Abstract

The aim of the present work was to study the possibility of a parameter set to assure both reliable detection of shockable rhythms and adequate shock success prediction. A set of 10 parameters, reflecting the frequency characteristics, the variations, the complexity, the periodicity and the symmetry of the ECG signals was subjected to discriminant analysis. The reliability of the derived parameters to provide an adequate shock advisory decision, which accounts the arrhythmia type (shockable or non-shockable) and the possibility for shock success, was studied. Moreover, the influence of different types of artifacts on the accuracy for shockable and non-shockable rhythms classification was evaluated. The shockable rhythm detection ability was estimated towards the AHA recommendations for reliable automatic external defibrillator algorithm performance, while the accuracy for prediction of the shock outcome was compared with the possibility of other proposed methods to differentiate between ventricular fibrillation episodes amenable and non-amenable to defibrillation. The direct comparison of the shockable rhythm detection results with the AHA recommendations for defined rhythm categories proved the adequacy of the processed ECG features to provide accuracy, which meets the AHA performance goal. Besides this, the proposed parameter set proved its adequacy for shock success prediction and the attained prediction accuracy (above 80%) could be considered as acceptable for possible practical application in automatic external defibrillators.

The combination of reliable detection and prediction, as well as the fact that the decision for defibrillation will account not only the rhythm type but also the possibility for successful defibrillation, makes the proposed parameter set a reliable tool for automatic external defibrillator shock-advisory algorithms.

Keywords: Ventricular fibrillation detection; Shock success prediction; Arrhythmia types; Discriminant analysis

1. Introduction

The ventricular fibrillation (VF) and the rapid ventricular tachycardia (VThi—more manufacturers specify frequency above 150 beats min^{-1}) are dangerous cardiac disorders, which require fast response and application of high-energy shock in the heart region. The successful termination of VF and VThi strongly depends on the time elapsed between the onset of the arrhythmia and the defibrillation. The automatic external defibrillators (AED) are devices, which detect and treat VF and VThi without interpretation of the electrocardiogram (ECG) by qualified medical personnel, in out-of-hospital conditions. They assure early defibrillation, which increase the survival rate after cardiac arrest, as reported in refs. [1,2]. According to the American Heart Association (AHA) recommendations for AED algorithm performance [3], detection of shockable rhythm is obligatory for coarse VF and VThi and is absolutely forbidden for normal sinus rhythms (NSR) and other arrhythmias (marked as N), accompanied by a palpable pulse and/or occurring in a conscious patient, like supraventricular tachycardia, sinus bradycardia, atrial fibrillation and flutter, heart block, idioventricular rhythms, premature ventricular contractions and other rhythms, which are not life-threatening. AHA specifies a group of intermediate rhythms including fine ventricular fibrillation, which characterize with low survival rate and ventricular tachycardia that does not meet the criteria for inclusion in the shockable rhythm category (VTlo). For these two types of rhythms, AHA did not set any performance goals for AED analysis algorithms, since the patients with fine VF are unlikely to derive benefit or be at risk from defibrillation and there is not strict criteria concerning the frequency of the ventricular tachycardia, which must be treated with defibrillation. For all

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Detection of Shockable and Non-Shockable Rhythms in Presence of CPR Artifacts by Time-Frequency ECG Analysis

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Abstract

Time-frequency domain features of chest compression (CC) artefacts, non-shockable (NShR) and shockable (ShR) rhythms were investigated. The aim was to provide reliable shock advisory analysis during CC by single channel electrocardiogram (ECG) processing. Three frequency bands were suggested to enhance specific components of the CC artefacts, NShR and ShR rhythms: (i) 2-3 Hz to emphasize the similarity of the basic wave of CC Artefacts; (ii) 4-7 Hz to highlight the irregularity of the fibrillation waves in ShR; (iii) 10-20 Hz to support the presence of QRS complexes in NShR. Based on our studies in the defined frequency bands, an automatic shock-advisory system (SAS) for detection of NShR and ShR in CC-contaminated ECGs was built. SAS assessed with ECGs from a testing dataset provided Se=94.2% for ShR, Sp=87% for NShR, Sp=83.7% for asystoles.

1. Introduction

Early defibrillation and continuous cardiopulmonary resuscitation (CPR) with minimal 'hands-off' intervals are advised to improve the survival rate in out-of-hospital cardiac arrests (OHCA) [1]. To support such life-saving practice, the shock-advisory systems of automated external defibrillators (AEDs) should be capable to reliably analyse the heart rhythm even if it is corrupted by the mechanical activity of the chest compressions (CC).

Different filtering techniques have been proposed in the literature mostly with adaptive schemes managed by reference signals from CC frequency [2-4], or acquired via outer sensors for thoracic impedance, accelerometer, 'ECG common' signal, arterial blood pressure [5-7]. However, any sensor different from defibrillation pads could be considered as an obstacle for an easy AED use.

ECG time-frequency study was applied aiming at reliable shock advisory analysis of CC contaminated arrhythmias by single channel ECG processing.

2. Methods

2.1. ECG data

Recordings of 168 OHCA interventions with AEDs (FredEasy, Schiller Medical SAS, France) collected by the emergency medical service in the region of Nancy (SDIS54 July-December, 2006) were retrospectively processed. They provided large excerpt of CC artefacts induced on human ECG via defi-pads. We hypothesized that the process governing the artefact morphology is non-ergodic due to change of the underlying ECG rhythm (shock delivery, drug injection), as well as to change of the CC features over time (fatigue of the rescuer, swap of rescuer, switching from human to machine compression). This consideration supported the use of several CC-contaminated episodes extracted from one intervention as independent strips included in the ECG dataset.

Two independent reviewers annotated the noise-free ECG rhythm seen during the AED analysis periods. The following rhythm annotations were accepted:

(i) NShR: Non-shockable rhythms, including normal sinus rhythms, ventricular ectopic beats, atrial flutter/fibrillation, bundle branch blocks, bradycardias and supraventricular tachycardias;
(ii) ShR: Shockable rhythms, containing ventricular fibrillations and rapid ventricular tachycardias;
(iii) ASYS: Asystoles with peak-to-peak amplitude below 100 uV for at least 3 seconds.

The CC-contaminated episodes were taken just before the AED analysis periods. They inherited the rhythm annotation of the adjacent AED analysis with the assumption that the ECG rhythm does not change during the last 10 seconds of CC. The following CC artefacts in the ECG channel were considered:

(i) CC-Artefacts: pure CC-artefacts on ASYS;
(ii) CC-artefacts contaminating NShR;
(iii) CC-artefacts contaminating ShR.

All OHCA signals were sampled at 500 Hz, 8-bit.

Evaluation of a Shock Advisory System with Non-Shockable Pediatric Rhythms

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Abstract

This study aims at validation of the specificity (Sp) of a shock advisory system (SAS) in automatic external defibrillators (AED) with non-shockable pediatric ECGs.

Own pediatric ECG database is collected including lead II holter recordings from 46 children - healthy and cardiac patients. A number of 10301 ten-second samples of non-shockable (N) rhythms are analysed. Adult ECG database (MIT-vfdb) is used to show the reference SAS criteria values for N(>18) and shockable S(>18) rhythms.

Specific ECG criteria of an AED SAS are evaluated: heart rate, slope uniformity of positive vs. negative peaks, deflections from signal extrema and signal mean in a narrow frequency band for QRS complexes enhancement.

Pediatric N rhythms, age: (1-4), (5-8), (9-12) vs. adult N(>18) show significant differences in all criteria, shifting in beneficial direction further away from S(>18) when combined criteria are used. The SAS validation for N(1-4), N(5-8), N(9-12) present respectively Sp=100%, 99.8%, 100%, higher than N(>18) with 99.6%.

1. Introduction

Ventricular fibrillation (VF) or ventricular tachycardia (VT), once thought to be rare in children, occur in 25% of in-hospital and at least 7% of out-of-hospital pediatric cardiac arrests [1]. Patients with an initial rhythm VF/VT have better survival than those with asystole/pulseless electrical activity [2], therefore prompt VF/VT treatment improves the survival rate. Since 2005, the European Resuscitation Council Guidelines for pediatric life support [3] recommend the use of pediatric pads and lower energy levels in automated external defibrillators (AED) for children aged 1 to 8 years. Due to insufficient information for safety and efficacy in infants younger than 1 year, the AED use in this age group is not advised.

Recent efforts are spent to assess the performance and to adapt AED algorithms designed for adults to achieve high accuracy also for pediatric rhythms. There are evidences for significant differences between pediatric vs. adult electrocardiogram (ECG) [4]. Reports show that heart rate is sensitive to age groups and thus rate-dependent ECG morphology parameters are significantly affected, particularly in pediatric non-shockable rhythms [5-7]. Insignificant differences are reported for some morphology parameters in shockable pediatric rhythms [5] and spectral parameters in both shockable and non-shockable rhythms [7]. The technical implication of these studies is AEDs that should implement either separated pediatric and adult decision system [8-9] or a unique solution [5,10,11].

The purpose of the present study is to create an ECG database of non-shockable pediatric rhythms and to use this database for assessment of specific ECG criteria in different pediatric age groups. Differences among the ECG criteria between pediatric non-shockable rhythms and a reference adult database are studied. Verification of the safety of a commercial AED in children is aimed by validating the specificity of its shock advisory system embedding the same ECG criteria settings as validated for adults.

2. Materials and methods

2.1. Pediatric ECG database

Pediatric rhythms were collected retrospectively from Holter recordings of children with various cardiac diseases, who underwent annual examinations in the Pediatric Cardiac Unit of the National Heart Hospital, Sofia, Bulgaria. Rhythms were acquired with standard ECG electrodes in modified lead II position and bandwidth (0.5-30)Hz. The ECG holter recordings format is: 250Hz as sampling rate, 12bit resolution, 4.9μV/bit dynamics. The database including 46 children – 6 healthy and 40 cardiac patients, age 1 to 12 years old, consisted only of non-shockable samples without lethal ventricular arrhythmias. Selected 10-second samples from the non-shockable (N) recordings were annotated by three cardiologists into two categories – normal sinus rhythm (NSR) and other non-shockable arrhythmia (ONS). This group includes premature ventricular contractions, supra-ventricular tachycardia (SVT), sinus bradycardia, SA/AV and bundle branch blocks (BBB), atrial fibrillation. The rhythm type assigned to each sample reflects the

Influence of Analysis Duration on the Accuracy of a Shock Advisory System

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Abstract

This study evaluates the influence of analysis duration on the accuracy of AED shock advisory system (SAS), which is adapted to provide 'Shock'/'No Shock' decision in real time at every second from 2s to 10s. MIT-BIH Malignant Ventricular Arrhythmia database is used for validation of the SAS accuracy on a computer.

Four basic ECG criteria used in the presented SAS are evaluated: heart rate, slope uniformity of positive vs. negative peaks, deflections from signal extrema and signal mean in a narrow frequency band for enhancement of the QRS complexes. They show significant differences for shockable and non-shockable rhythms, considering all analysis durations.

The presented SAS with analysis duration from 2s to 10s is fully compliant with the AHA performance goal for AEDs. Short ECG episodes, however, require verification for consistency of the rhythm over time.

1. Introduction

Minimizing the duration of the pre-shock pauses without chest compressions (CC) is beneficial for the survival rate after defibrillation [1-4]. In this respect, the 2010 American Heart Association (AHA) Guidelines for resuscitation recommend limiting CC interruptions to less than 10s [5] which constrains the time for analysis of artifact-free electrocardiogram (ECG) in automatic external defibrillators (AEDs).

Anticipating the new requirements, some researchers have recently published a number of methods for ECG analysis during CC, applying mostly adaptive filtering techniques for suppression of the CC-induced artifacts [6-9] or sophisticated algorithms which are running the rhythm analysis during CC [10,11]. Despite all efforts, accuracy of such methods is 80-90% - still below the AED performance goals recommended by AHA [12].

Another solution for minimizing the pre-shock pause is reduction of the ECG analysis duration. Rosado et al [13] describe a fast ventricular fibrillation detection method, based on Pseudo-Wigner-Ville distribution, using ECG segments of 1.024s. However, it provides limited 86% sensitivity and 94.3% specificity. Other studies report that algorithms, analyzing ECG signal crossings with preset thresholds, improve their performance by increasing the analysis duration, and that a reliable accuracy can be achieved after 7s [14,15]. Throne and Gupta [16] estimate the effect of short duration signal analysis for detection of ventricular fibrillation based on autocorrelation (ACF) and scatter diagram analysis. They have found that, in general, increase of the analysis duration from 1s to 4s improves the accuracy. This relation is also observed by the authors of the ACF method who report adequate performance for 4.5s [17].

The objective of this study is to evaluate the influence of analysis duration (2s to 10s) on the accuracy of AED shock advisory system (SAS).

2. Materials and methods

2.1. ECG signals

The test set of ECG signals is extracted from the first channel of MIT-BIH Malignant Ventricular Arrhythmia Database (MIT-vfdb) [18]. The recordings are subsets of the general databases recognized as standard in ECG testing. These subsets were chosen because they contain a wide variety of shockable and non-shockable rhythms.

ECG strips of 10s are independently annotated by three cardiologists. The annotations follow the AHA classification scheme for shockable and non-shockable rhythms [12] where performance goals are defined only in absence of artifacts. Excluding all cases with inconsistent rhythm over the strip, the following noise-free strips are identified:

510 strips with shockable rhythms:

- 308 VF – coarse ventricular fibrillation > 200μV;
- 202 VThi – rapid ventricular tachycardia with rate > 150 beats-per-minute (bpm);

2448 strips with Non-shockable rhythms:

- 1023 NSR – normal sinus rhythm;
- 1425 ONS – other non-shockable rhythms, including supra-ventricular tachycardia, sinus bradycardia, SA/AV and bundle branch blocks, atrial fibrillation, atrial/ventricular ectopic beats.

Recognition of Diagnostically Useful ECG Recordings: Alert for Corrupted or Interchanged Leads

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Abstract

The upgrade of mobile phones with applications for acquisition, pre-processing and transmitting the patient's ECG to a hospital unit would be of great benefit for prevention against the most frequent mortality caused by heart failure. This idea is promoted by the Computing in Cardiology Challenge 2011, which encourages the development of algorithms for analysis of the ECG quality within few seconds, aiming to warn about diagnostically unacceptable recordings. This paper presents an algorithm for scoring the noise corruption level by evaluation of ECG amplitude dynamics, baseline wander, powerline interference, EMG and peak artifacts. The score achieved for participation in Event1 is 0.908. Additionally unacceptable ECGs with interchanged leads are detected with sensitivity of 96.8% (30/31 files) for peripheral leads and 87% (40/46 files) for chest leads.

1. Introduction

When conditions during ECG acquisition are not rigorously controlled, ECG quality is highly susceptible to external noisy components and other distorting factors which might impede the reliable manual or automated measurements, or hazard the correct diagnosis. Automatic management of large amount of ECGs by analytical quality metrics is shown to improve the quality of ECG annotations reducing human review and costs [1,2].

During the years, members of our team are contributing towards development of methods for improving the ECG quality by filtering the main sources for ECG corruption - powerline interference (PLI), baseline wander (BLW) and electromyographic (EMG) noise. The main goal is to maximally preserve the useful ECG components, commonly overlapped with noises. In this respect, the subtraction procedure eliminates PLI with amplitude and frequency deviation without affecting the ECG spectrum [3]; the BLW bi-directional high-pass recursive filter [4] is optimized towards adapting the cut-off frequency with respect to the frequency components of the ECG signal [5]; the approximation filtering with dynamically varied number of samples and weighting coefficients in respect to the ECG slope, is preserving sharp QRS forms with a considerable reduction of the EMG noise [6]; the 'linearly-angular' procedure for EMG suppression is applying smoothing filtration outside the QRS complexes, and moving averaging inside them with restoration of the sharp Q, R and S peaks [7].

Misplacement of electrodes in 12-lead ECG is reported in 0.4-4% of all clinical recordings – a severe cause of erroneous diagnosis due to simulated false or concealed true ECG abnormalities [8]. Batchvarov et al [9] review the effect of the most common cases for interchange in peripheral and chest leads on P-QRS-T patterns, together with some algorithms for their detection. Specific cable interchanges or ECG abnormalities might disturb the correct detection.

The presented method detects noise corruption and leads interchange for recognition of diagnostically useful ECGs in the Computing in Cardiology Challenge 2011.

2. ECG dataset

The study uses the Challenge 2011 dataset available from PhysioNet [10], including 10-second recordings of standard 12-lead ECGs (sampled at 500Hz, 5μV/LSB resolution, full diagnostic bandwidth 0.05–100Hz). The dataset comprise signals related to common problems which might appear when people with varying amounts of training are recording ECG via disposable or suction cup electrodes connected to mobile phones (misplaced electrodes, poor skin-electrode contact, not connected electrode, PL interference, artifact resulting from patient motion, etc.). Reference annotations of the ECG quality in the context of 'acceptable' or 'unacceptable' recording for diagnostic interpretation are accessible for the challenge in non-blinded and blinded mode:

- Training Data (Set A) with non-blinded annotations, including 773 acceptable and 225 unacceptable ECGs;
- Test Data (Set B) with blinded annotations, including 500 ECGs.

Misplaced electrodes have been manually identified in 74/1498 recordings, publicly available in the list [11].

Clinical Characterization by Principal Component Analysis of Stress Test ECG

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Abstract

The aim of the study is to investigate whether and how QRS-complex and T-wave heterogeneity is influenced by different cardiac risk factors and clinical data.

Digital ECG during stress test was acquired in 106 patients (age 63±10 years, 45 males). Two indices obtained by Principal Component Analysis (PCA): complexity (PCA_1) and non-linear components (PCA_2) were used for the analysis of the heterogeneity of the different clinical groups. Mean, max, and standard deviation values were examined in the study.

Significant difference ($p<0.01 \div 0.05$) between PCA1 of QRS (PCA_1_QRS) was found between subgroups of patients defined according to the presence or absence of angina pectoris, diabetes mellitus, stroke and smokers. Significant difference for PCA_2_QRS was obtained in the presence of angiographically significant coronary artery disease, diabetes mellitus, positive stress test and triglycerides. For the T wave significant difference was found respectively for PCA_1_T in: myocardial infarction, angiographically significant coronary artery disease and gender and for PCA_2_T in: angiographically significant coronary artery disease, percutaneous coronary intervention and gender.

1. Introduction

The principal component analysis (PCA) is a technique that aims to represent a large number of signals by means of a limited number of fundamental values [1]. When applied to digital ECG tracings, the method determines the "principal components" which represent most of the ECG information. The first three eigenvalues of the PCA provide nearly the total energy of the ECG. Since the mathematical procedure calculates fundamental orthogonal components, PCA analysis of the ECG signal is a modern approach, which can substitute in a certain degree the vectocardiography based on the orthogonal X, Y, and Z leads [1].

The study of the heterogeneity of the ventricular repolarization has been implicated by long in the analysis of the genesis of ventricular arrhythmias [2]. Theoretical and experimental studies suggest that ventricular repolarization occurs in a nonlinear and inhomogeneous fashion. Measures of repolarization that take into account the T-wave complexity using PCA should be a useful surface ECG marker of heterogeneity of repolarization.

Whilst the diagnostic [3-5] and prognostic [2,6] value of PCA of the T wave has been demonstrated, the effect of physiological factors on the QRS and T wave complexity is unknown. The T wave shape or polarity can be influenced by age, sex, heart rate, body position, autonomic activity, respiration, temperature, electrolyte concentration, food and mental activity [7-11]. It is possible that these factors can also affect T wave complexity. PCA has been used for the investigation of the effect of heart rate and body position on QRS and T wave complexity [12] and also for the analysis of the post-extrasystolic changes of the T-wave and QRS complex [13].

The aim of the study is to investigate whether and how QRS-complex and T-wave heterogeneity is influenced by different cardiac risk factors and clinical data.

2. Methods and material

2.1. ECG database

We studied 106 patients: age 63±10 years, 45 males, 39 with diabetes mellitus (DM), 85 with AP, 34 with positive stress test, 18 with a history of myocardial infarction (MI), 48 with angiographically significant coronary artery disease (AS-CAD). Controllable risk

Study of Transthoracic Impedance Cardiogram for Assessment of Cardiac Hemodynamics in Atrial Fibrillation Patents

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Abstract: *This study aims to test the usability of the transthoracic impedance cardiogram (ICG) for assessment of the quality of myocardial contractions in atrial fibrillation (AFIB) vs. sinus rhythm (SR), using signals recorded via defibrillation pads during external cardioversion (ECV). Data from 88 patients with persistent AFIB who received planned ECV are processed. AFIB is treated with cardioverter/defibrillator DG4000 (Schiller Médical, France) using a non-escalating protocol 200J/200J/200J. Successful ECV is defined as restoration of SR for >1min. The electrocardiogram (ECG), thoracic baseline impedance (Z) and dynamic impedance components dZ, dZ/dt captured via self-adhesive pads in antero-apical position are processed. Heartbeat contractions are evaluated by several measures extracted from the mean ICG patterns during systole: from dZ pattern – ICG (peak amplitude, range, area); from dZ/dt pattern – ICG velocity (peak, range, area) and left ventricular ejection time (LVET). The hemodynamical indices measured before and after ECV are: mean heart rate over 2 minutes (HR), standard deviation of HR (HRV), systolic (SysBP) and diastolic (DiaBP) blood pressure.*

When the rhythm converts from AFIB to SR (74 patients), all measures on dZ, dZ/dt patterns significantly increase: dZ (64-102%), dZ/dt (31-67%), LVET (18%), $p < 0.05$. Significant decrease of HR (-36%), HRV (-53%), SysBP (-11%) and DiaBP (-19%) are also observed. Unsuccessful ECVs without conversion to SR (14 patients) are, however, associated with non-significant increase of dZ (10-21%), dZ/dt (0.3-29%), LVET (9%), $p > 0.05$ when comparing pre-shock AFIB vs. post-shock AFIB. No clear change in HR (-9%) and HRV (6%), and slight decrease of SysBP (-10%) and DiaBP (-8%) are observed.

The level of improvement of cardiac output quality in post-shock SR vs. pre-shock AFIB as estimated by ICG is related to a set of more than 60 clinical and hemodynamical parameters. Significant correlation coefficients are found to: Beta-Blocker (-0.25), Number of anti-arrhythmic drugs (-0.29), ΔST (0.37), pre-shock HR (0.43), ΔHR (-0.40), pre-shock HRV (0.30), ALT (0.46), ΔCK-MB (-0.32), ΔHR (-0.26), pre-shock DiaBP (0.24).

Keywords: *Impedance cardiography, ICG patterns, Hemodynamical status, Arrhythmia, Automated external defibrillators.*

Detection of Electrode Interchange in Precordial and Orthogonal ECG Leads

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Abstract

This study presents methods for automated detection of interchanged precordial and orthogonal ECG leads that may prevent from incorrect diagnosis and treatment. For precordial leads V1-V6, correlation coefficients of QRS-T patterns and time-alignment of R and S-peaks are assessed. For orthogonal leads (X,Y,Z), analysis of QRS loops in the frontal plane, a set of correlation coefficients and a time-alignment of leads are implemented. The methods are elaborated using 15-lead ECG databases - 77 healthy control recordings from PTB database (training), and the total set of 1220 ECGs in CSE database with various arrhythmias (test). The specificity (Sp) for detection of the correct precordial leads configuration (V1 to V6) is 93.5% (training) and 91% (test) and the mean sensitivity (Se) for 23 simulated most common chest electrode swaps is 95.7% (training) and 95% (test). Sp for detection of the correct orthogonal leads X,Y,Z is 98.7% (training) and 93.3% (test), while mean Se for 47 reversals of electrode couples A/I, F/H, M/E is 98.5%, equal for both training and test databases.

1. Introduction

Misplacement of electrodes in multichannel electrocardiogram (ECG) is reported in 0.4-4% of all clinical recordings – a severe cause of erroneous diagnosis due to simulated false or concealed true ECG abnormalities [1]. The mobile e-health, which is advert as the biggest breakthrough in health systems improvement [2] raises the need for automated detection of electrodes interchange, considering the potential use of portable ECG devices by non-specialists.

Batchvarov et al. [3] review the most common cases for interchange of peripheral and chest leads and their effect on P-QRS-T patterns alteration, together with basic principles for detection of different leads reversals. Most of the published studies elaborate methods for limb leads analysis – recognition of left arm (LA) and left leg (LL) reversal by assessment of P wave amplitude [4] and analysis of QRS and P wave axes [5]; right arm (RA) – right leg (RL) swap alarm by search for flat line ECG in lead II [6]; detection of different LA/LL/RA reversals by direction of inscription of the P loop and/or the frontal P axis [7], analysis of the frontal QRS axis [8], comparison between a composed lead aVF/I and V6 [9], reconstruction of a lead using redundancy of information in the 8 independent leads [10]. Xia et al. [11] propose a combination of features from [5] and [10] to yield a more robust and accurate performance.

Much less studies are found to detect precordial leads reversals. Among above referred methods for limb leads interchange, only two analyse precordial leads – Hedén et al. [5] address 5 adjacent leads reversals (V1/V2, V2/V3, V3/V4, V4/V5, V5/V6), Kors and van Herpen [10] evaluate 9 leads reversals (5 adjacent leads and V1/V3, V4/V6, V4/V5/V6/V1/V2/V3, V6/V5/V4/V3/V2/V1). Recently, Dotsinsky [12] reports preliminary results for detection of 5 chest leads swaps (V1/V3/V2, V2/V1/V3, V4/V6/V5, V5/V4/V6, V1/V2/V4/V3/V5/V6) based on 2 criteria – absolute error of the middle lead vs. averaged sum of the surrounding leads; QRS amplitude evolution (increase from V1 to V3, decrease from V4 to V6).

Possibly because orthogonal ECG leads are seldom recorded in the clinical routine [13], no methods regarding the correct placement of the Frank orthogonal ECG leads (X,Y,Z) are found in the literature.

This study aims to present methods that may prevent from incorrect diagnosis and treatment by automated detection of precodrial and orthogonal leads interchanges.

2. ECG databases

This study uses ECG signals from two independent ECG databases – the publicly-available Physikalisch-Technische Bundesanstalt (PTB) diagnostic ECG database [14] and the Common Standards for Electrocardiography (CSE) database [15]. Both databases provide 15 simultaneously measured ECG leads (the conventional 12 leads together with the 3 Frank leads), sampled at 1000 Hz, 0.5 μV/LSB.

The developed methods for electrode interchange detection are trained with 77 ECG recordings from healthy controls in PTB and are tested with 1220 ECGs from CSE, containing various arrhythmias.

Performance of Heart Rhythm Analysis during Chest Compressions in Out-of-Hospital Cardiac Arrest

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Abstract

This study aims to validate a shock advisory system in automated external defibrillators (AEDs) dedicated for ECG analysis during chest compressions (CC), guiding the rescuer to stop CC for rhythms which should be terminated by a defibrillation shock and to continue CC for non-shockable rhythms. The test-validation on a large database of out-of-hospital cardiac arrest interventions shows that the performance can be improved by increasing the duration of analysis. The combination of 3 successive analyses (delaying the decision to 14s after start of analysis) achieves sensitivity of 89.4% (135/151) – ventricular fibrillations, specificity of 98.7% (73/74) – normal sinus rhythms, 81.2% (1357/1671) – asystoles, 89.6% (566/632) – other non-shockable rhythms. Several examples are shown to illustrate the reconstructed ECG during CC that can be visually interpreted with certainty.

Improving specificity of ECG analysis during CC is of tremendous importance preventing against frequent false positive interrupting the rescuer and the patient CC-treatment.

1. Introduction

Interrupting chest compressions (CC) by automated external defibrillators (AEDs) for a reliable rhythm analysis on an artifact free ECG can adversely affect hemodynamics during cardiopulmonary resuscitation (CPR) and can decrease resuscitation success rates in out-of-hospital cardiac arrest (OHCA) patients [1].

The amount of CPR interruptions could be decreased by running the AED rhythm analysis during CC in order to advise CPR stop only in case a shock is recommended. Chest compressions induce artifacts in ECG, which considerably affect the accuracy of conventional AED rhythm analysis algorithms, therefore new approaches for rhythm analysis during CPR have been recently developed. Major part of them relies on suppression of CC-artifacts by adaptive filtering (AF) before applying the conventional AED shock advice algorithms. AF uses one or more reference channels correlated to the artifact interfering with ECG – multichannel recursive adaptive matching pursuit using compression acceleration, compression depth signal, thoracic impedance, ECG [2]; Least Mean-Square filter using the compression depth signal [3,4] and thoracic impedance [5]; motion artifact reduction system using the CPR force signal [6]; independent component analysis using additional ECG channels [7]. AF techniques using as a reference the CC spectral frequency estimated in a single ECG channel have also been proposed [8,9]. The specificity of such solutions is usually between 80-90%, which leads to unwanted CPR interruptions in OHCA.

This study aims to validate a rhythm analysis system based on assessment of time and frequency components of band-pass filtered raw and reconstructed ECG [10] with a large set of OHCA recordings during CC. The accuracy of the system is evaluated in terms of sensitivity and specificity respectively for stopping CC for rhythms which should be treated by a defibrillation shock and continuing CC for non-shockable rhythms.

2. ECG Database

The ECG database is collected with Fred Easy AEDs (Schiller Médical, France) used by the fire brigade of Paris in OHCA interventions in 2011. A subset of 2528 ECG strips from 596 patients is identified, including episodes during CC which are followed by noise-free AED analysis periods. Reviewers have annotated CC-episode boundaries (beginning of CC, end of CC) using observations of both ECG and impedance channel (IMP) artifacts. Then the rhythm during AED analysis is identified, including: 74 normal sinus rhythms (NSR), 1671 asystoles (ASYS), 632 other non-shockable rhythms (ONS), 151 ventricular fibrillations (VF). Assuming consistence of the ECG rhythm till 20s before the AED analysis period, these annotations are also considered for the preceding CC episode. All signals are recorded at sampling rate of 500 Hz. The ECGs are band-pass filtered (1 to 30 Hz) as supported by the AED input hardware circuits to remove offset and high-frequency noise.

Classification of Supraventricular and Ventricular Beats by QRS Template Matching and Decision Tree

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Abstract

This study presents a two-stage heartbeat classifier. The first stage makes initial assignment of beats towards continuously updated beat templates of the predominant rhythm, and calculates a set of features, tracking the morphology and RR-interval variation, and correlation to noise robust average beat templates. The second stage implements a decision tree for classification of supraventricular (SVB) and ventricular beats (VB). The training process on 3 large ECG databases (AHA, EDB, SVDB) applies splitting and pruning of the tree to different levels. A solution with 150 decision nodes and error cost <0.01 is selected for unbiased test-validation with MIT-BIH database, showing: specificity=99.7% for SVBs, sensitivity=95.9%, positive predictivity=95.1% for VBs. Decision trees combine high performance, rapid interpretation and easy configuration of the complexity.

1. Introduction

Automatic detection and classification of heartbeats is an important computerized diagnostic tool applied in monitoring applications and for assisting cardiologists in the task of long-term ECG inspection by marking the presence of sustained, transient or casual arrhythmias. The analysis of RR-intervals regularity and P-QRS-T waveform complexity by time-domain morphology delineation [1-5] and template matching [1,6] is commonly used for extraction of features which are then subjected to optimization in different decision support systems, aiming at the most reliable classification of normal or abnormal beats. The resource efficient classification methods are based on linear programming, including the K nearest neighbour clustering [2], linear discriminants [3], fuzzy analysis [1,7] and decision trees [4,5,7]. More complex classifiers implement support vector machines [6,8] and artificial neural networks [9,10], the last masking the features which are useful or worthless and how the net is making the decision.

The dimension of redundant feature vectors affects the performance of the classifier if not appropriately optimized. Reduction of the feature space dimension by excluding irrelevant features which carry conflicting, duplicating or little information to the classifier has been applied by means of higher order statistics [11], perturbation method [8], fuzzy c-means clustering [9] or Hermite function decomposition [10].

This study aims at a reliable beat classification method based on correlation with noise robust average beat templates, morphology delineation features and a decision tree with easy configuration of the model complexity.

2. ECG databases

The study involves all full-length recordings in 4 ECG databases with reference heartbeat annotations:

- AHA – AHA database [12]: 80 ECG recordings, 2 leads with duration of 30 min per record ;
- EDB – European ST-T database [13]: 90 ECG recordings, 2 leads with duration of 2 hours;
- SVDB – MIT-BIH Supraventricular Arrhythmia Database [14]: 78 ECG recordings, 2 leads, 30 min;
- MIT-BIH – MIT-BIH Arrhythmia Database [15]: 48 ECG recordings, 2 leads with duration of 30 min.

All ECGs are processed with a common sampling rate of 250 Hz. EDB and AHA keep their original sampling frequency (250 Hz), while MIT-BIH (360 Hz) and SVDB (125 Hz) are linearly interpolated to 250 Hz. Filtering in a bandwidth 0.05–75 Hz is applied, although, signals could be already more band-limited within the databases. Two composite leads are next analysed:

- Magnitude: $mag = \sqrt{lead1^2 + lead2^2}$
- Velocity: $vel = \sqrt{(\Delta lead1)^2 + (\Delta lead2)^2}$

A QRS detector is run and any beat annotation label that can be paired with a valid QRS detection within a window of 150 ms is included in the study. The original beat annotation labels are interpreted according to the ANSI/AAMI EC57 standard [16], and two general heartbeat classes are defined:

- *SVB-class:* the class of beats with supraventricular origin, including sinus node beats (normal beat, left and

Lead Quality Monitoring for Detection of the Optimal Snapshot Time to Record Resting ECG

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Abstract

This study presents a multichannel ECG quality monitoring system, which continuously scans the leads' status (valid/lead-off) and quality (0-100%), according to the ECG components in the low, medium and high frequency bands. The system aims to detect the optimal moment to start the record of a 10s resting ECG within the 1st minute of signal acquisition – the earliest in time, the best in all leads' quality, named 'Optimal Snapshot Time' (OST) and 'Best Snapshot Quality' (BestSQ). The system compares the current leads' quality to an adaptive quality threshold (AQT) whose decreasing trend is trained on 375 ECGs. The validation over 267 ECGs in the test database shows that: 87.2% of the ECGs would be recorded with a quality ≥ 95%BestSQ; 33.1% at the optimal moment OST±2.5s; 29.3% would be started earlier due to their sufficient quality >AQT; 37.2% would be recorded with a delay >2.5s due to their compromised BestSQ, not reaching the AQT level in the vicinity of OST.

1. Introduction

The standard 12-lead resting electrocardiogram (ECG) recorded for 10s on a patient at rest in the supine position is one of the most widely used diagnostic tests in clinical routines of all kinds and for a wide range of diseases. The early starting of the ECG recording with sufficient ECG quality is essential for the patient's comfort and a prompt reliable diagnosis. However, the ECG signals are often contaminated by noise and artifacts that can manifest with similar morphologies as the ECG itself and affect the usability of the signals. Quantifying the noise in the ECG is not straightforward, partially due to the fact that there are many different types of noises and artifacts that can occur simultaneously, and partially because these noises and artifacts are often transient, and largely unpredictable in terms of their onset and duration.

The PhysioNet/Computing in Cardiology Challenge 2011 has addressed the development of methods for ECG quality assessment [1]. Most of the presented solutions apply simple procedures for: (1) detection of leads with constant voltage [2-12] and/or low amplitude [2,6-9,13]; (2) assessment of baseline wander and high-frequency noises by ECG filtering [2,8-10,12-14] or spectrum calculation [3,5,15]; (3) identification of steep and/or high amplitude artifacts [2,4-6,8,9,12] and assessment of the quality of QRS detection [3,4,10]. Some of the presented methods involve more complicated procedures, such as ECG reconstruction using QRS templates [14]; prediction of each ECG lead using other leads [13]; and cross correlation between leads and/or lead segments [7,16]. The algorithms for recognition of diagnostically useful ECGs combine the set of ECG measures in computationally efficient rule-based methods [2,4-15] or feed them in more sophisticated classifiers, such as: a quasi-linear combination between the K^{th} nearest neighbour rule and an ensemble of decision trees [16], linear discriminant analysis, Naive Bayes, support vector machine and multi-layer Perceptron artificial neural network [3].

This study aims to introduce an ECG quality monitoring system, which continuously scans the multi-lead ECG signal and automatically detects the optimal moment (the earliest in time, the best in ECG quality) to start the recording of a 10s resting ECG.

2. Methods

This study presents a real-time monitoring system of the quality of multichannel resting ECG that estimates the 'Global Quality' (0-100%) and the 'Global Status' (0/1) according to the state of all leads over the last 4s:

$$(1)\ \text{Global Quality} = \operatorname*{median}_{i=1}^{\text{Nb Leads}}(\text{Lead Quality}_i)$$

$$(2)\ \text{Global Status} = \min_{i=1}^{\text{Nb Leads}}(\text{Lead Status}_i)$$

, where

$$(3)\ \text{Lead Quality} = \frac{\text{Signal Level}}{\text{Signal Level} + \sum \text{Noise Levels}}.100\,,(\%)$$

$$(4)\ \text{Lead Status} = \begin{cases} 0 & \text{if the lead is 'off'} \\ 1 & \text{if the lead is 'valid'} \end{cases}$$

Detection of Electrode Interchange in Right Precordial and Posterior ECG Leads

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Abstract

This study presents a method for automated detection of misplaced supplementary precordial leads, including the right-sided V3R, V4R and the posterior V8, V9 leads. Considering their uncommon use in clinical routine, a lead reversal is quite probable and could result in erroneous diagnosis and treatment. The method allows real-time implementation by scoring inter-lead cross-correlations over continuous 4s episodes, scanning the normal progression of PQRST waveforms within leads [V4R, V3R, V3, V4] and [V4, V5, V6, V8, V9]. A large 16-lead ECG database with 1333 chest pain patients is used to test the performance of the method for all possible 23 swaps between the supplementary leads V4R, V3R, V8, V9, assuming correct positions of the standard V1-V6. The sensitivity (Se) for lead reversals is Se=94.1±4.6%, ranged between 78.5% and 97.8%, with the most difficult detection of V3R/V4R swap (Se=78.5%), V4R/V9 swap (Se=83.7%), V8/V9 swap (Se=91.8%). The achieved specificity for the correct lead positions is Sp=83.4%.

1. Introduction

Lead reversal has been reported to occur in 0.4-4% of all standard 12-lead ECGs [1]. This proportion might be much higher for 16-lead ECGs, including the uncommon used right-sided precordial and posterior leads.

The automated detection of ECG electrode interchange is a challenging task that has been extensively studied for limb leads, e.g. recognition of left arm (LA) and left leg (LL) reversal by analysis of P wave amplitude [2] and QRS, P wave axes [3]; right arm (RA) and right leg (RL) swap alarm by search for flat line ECG in lead II [4]; detection of different LA/LL/RA reversals by direction of inscription of the P loop and/or the frontal P axis [5], analysis of the frontal QRS axis [6], comparison between a composite lead aVF/I and V6 [7], reconstruction of a lead using redundancy of information in the eight independent leads [8], application of morphology measurements, including QRS and P wave amplitudes, frontal axis and clockwise vector loop rotation combined with redundancy features [9], gathering the features in [3] and [8] for a more robust and accurate performance [10].

The detection of precordial lead reversals is elaborated in fewer studies. Among above referred methods for limb electrode interchange, only three analyse precordial leads: [3] address reversals of 5 adjacent leads (V1/V2, V2/V3, V3/V4, V4/V5, V5/V6), [8] evaluates reversals of 9 leads (5 adjacent leads, V1/V3, V4/V6, V4/V5/V6/V1/V2/V3, V6/V5/V4/V3/V2/V1), [9] handles reversals of 7 leads (5 adjacent leads, V1/V3, V4/V6). Twenty three reversals of precordial leads (V1-V6) are tested in a previous study of our team [11], showing that a method based on inter-lead correlation analysis and time-alignment of R and S peaks could provide a mean accuracy of up to 95.7%/93.5% on 77 healthy subjects with swapped/correct lead set.

Considering that supplementary precordial electrodes are placed for specific diagnostic purposes (improved study of right ventricle pathologies, scanning for presence of posterior myocardial infarction, etc.) and therefore are infrequently acquired, no methods regarding the correct placement of right precordial (V3R, V4R) and posterior (V8, V9) leads are found in the literature. However, their incorrect placement can simulate or mask ECG abnormalities and might lead to wrong therapy decisions.

The aim of this study is to present a method for automated detection of misplaced right precordial and posterior leads, based on the assessment of the cross-correlation between lead pairs.

2. ECG database

The database used in this study contains resting 16-lead ECG recordings (standard 12 leads, 2 right-sided precordial leads (V3R, V4R), 2 posterior leads (V8, V9)), collected from 1333 chest pain patients at the Emergency Department of the Basel University Hospital. The signals are acquired via a Schiller CS-200 Excellence device, with 1kHz sampling rate, 1μV resolution, in a bandwidth of 0.05 to 300Hz. The device does not give any feedback to the user with respect to any lead reversal. The precordial electrode positions are shown in figure 1.

Validation of Arrhythmia Detection Library on Bedside Monitor Data for Triggering Alarms in Intensive Care

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Abstract

False Intensive Care Unit (ICU) alarms induce stress in both patients and clinical staff and decrease the quality of care, thus significantly increasing both the hospital recovery time and re-hospitalization rates. Therefore, PhysioNet/CinC Challenge 2015 encourages the development of algorithms for the analysis of bedside monitor data for robust detection of life-threatening arrhythmias. We participated in the Challenge with: (i) a closed source implementation of Arrhythmia Detection Library (ADLib, Schiller AG), including modules for lead quality monitoring, heartbeat detection, heartbeat classification and ventricular fibrillation detection; (ii) an open source Pulse Wave Analysis Module for verification of the hemodynamic status based on arterial blood pressure and photoplethysmogram signals; (iii) an open source Alarm Decision Module for final alarm rejection/validation.

Our best scored entry in the real-time event is: score 79.41%, with 93%/83% true positive/negative rates. The average/max running time is 12.5/29.5% of quota.

1. Introduction

There are studies reporting that only 2% to 9% of alarms in the Intensive Care Unit (ICU) are important for patient management [1], 6% to 40% are true but clinically insignificant, while ICU false alarms are prevalent with rates as high as 86% [2]. False alarms mainly induce stress in both patients and clinical staff [3,4] and decrease the quality of care [5] that is reported to significantly increase both the hospital recovery time [3] and re-hospitalization rates [6].

The bedside monitoring systems rely on real-time automated ECG analysis for triggering ICU alarms at the time of occurrence of critical arrhythmias. Our team had defined real-time processing techniques for basic ECG analysis modules: QRS detection [7], heartbeat classification [8], ventricular fibrillation/tachycardia detection [9], lead quality monitoring for the recognition of diagnostically useful ECG [10, 11]. Our experience for real-time pulse wave (PW) detection using arterial blood pressure (ABP) [12] would support online monitoring systems with improved ICU false alarms rate that is reported in cases of supplementary ABP analysis [13, 14].

This study aims to validate the Arrhythmia Detection Library (ADLib, Schiller AG) for robust detection of life-threatening cardiac arrhythmias, participating in the 2015 PhysioNet/CinC Challenge [15] with a closed source entry in Event1 (real-time).

2. Challenge database

Two bedside monitor datasets are used [15]: training set (750 recordings with alarm annotations shown in Table1); a blinded test set (500 recordings, publicly unavailable for the purpose of scoring), including 2 ECG leads and up to 2 pulsatile waveforms (photoplethysmogram (PLETH), ABP), sampled at 12-bit, 250Hz, passed through FIR band pass filter [0.05-40Hz] and mains notch filter. The alarm is annotated at 5:00 of each record, triggered by an event appearing up to 10s before that might be present in any signal channel. All signals can be contaminated by artifacts, noise and disconnection failure.

Table 1. Definition of five ICU alarms: asystole (ASYS), extreme bradycardia (BRADY), extreme tachycardia (TACH), ventricular tachycardia (VTACH), ventricular flutter/fibrillation (VFIB), and the distribution of true and false alarm annotations in the training database.

Alarm type	Alarm definition	True alarms	False alarms
ASYS	0 beats in 4s	22	100
BRADY	≥5 beats, HR<40bpm	46	43
TACH	≥17 beats, HR>140bpm	131	9
VTACH	≥5 ventr. beats, HR>100bpm	89	252
VFIB	Fibrillation waves in 4s	6	52

Hemodialysis-induced ST-segment Deviation

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Abstract

ECGs of 59 patients undergoing hemodialysis (HD): 52% males, age 59±13 years, renal disease duration 9.7±6.7 years, hemodialysis duration 5.2±4.4 years were recorded. Serum electrolytes (potassium-K, sodium-Na, phosphorus-Ph and calcium-Ca), urea and creatinine levels were evaluated before and after HD. ECG analysis on an average P-QRS-T interval in order to avoid accidental events or noise was performed.

Pre- and post-HD ECG measurements (mean ± standard deviations) in lead V2 were:

ST-dev_pre: 0.13±0.18 mV; ST-dev_post: 0.15±0.22 mV; p=0.03

QRS-ampl_pre: 1.34±0.65 mV; QRS-ampl_post: 1.55±0.79 mV; p<<0.001

T-ampl_pre: 0.43±0.31 mV; T-ampl_post: 0.36±0.28 mV; p=0.0016.

HD leads to a significant increase in the QRS and decrease of the T-wave amplitude and a considerable shift in the ST-segment. The decrease of the T-wave amplitude and the upward shift of the ST-segment could be explained by potassium decrease during HD. QRS amplitude increase could be explained by the decrease of the extracellular fluid and blood volume and hence a decrease of the cardiac preload.

1. Introduction

Hemodialysis (HD) is the most common method used to treat end-stage renal disease. It removes waste products and free water from the blood, restoring a proper balance of electrolytes. This procedure causes substantial changes in the electrical activity of the heart, observed by analysis of electrocardiograms (ECG).

A session of dialysis results in sudden shifts in volume and electrolytes within a short time that alters the physiological milieu and could lead to sudden changes in the myocardial vulnerability to serious arrhythmias. The most frequent cause of arrhythmias appears to be related to changes in fluid status and electrolytes, particularly potassium [1]

Initial evidence of HD-induced myocardial ischemia has previously come from ECG-based studies demonstrating silent ST-segment depression that occurs during dialysis at rates that vary between 15 and 40% [2]. Singh et al. [3] assessed dialysis-induced ischemia using sestamibi single-photon emission computed tomography. In an unselected group of ten dialysis patients without a history of coronary artery disease, seven developed perfusion defects during dialysis.

Hemodialysis is often associated with a risk of cardiac dysfunction. In a paper of Nakamura et al. [4], measurements and analysis of ST-elevation in pre- and post-HD patients are used for prediction of coronary artery disease and cardiac events. The authors report HD–induced ST-elevation of ≥1 mV, in 18 out of 61 patients. During follow-up of 21±2 months, all patients from the group with ST-elevation, as well as 21 from the rest of the study group experienced cardiac events. The authors explain this common manifestation of symptomatic and silent myocardial ischemia by reduced coronary artery oxygen delivery and increased myocardial oxygen demand during HD. Taki et al. [5] also report 'oxidative stress' in HD patients.

Another reason for the ST-elevation increase during HD could be associated to the hemodynamic instability, and especially to the reduction in myocardial blood flow [6]. Blood flow reduction during HD was analyzed by serial measurements using positron emission tomography. The aim of this study is to investigate the ECGs of patients undergoing hemodialysis and to assess the QRS and T-wave changes, as well as the ST-segment deviation induced by the procedure.

Objective of the current research is the analysis of the ECG changes induced by HD in order to obtain risk markers of arrhythmia, heart failure or cardiac death.

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Assessment of the Efficacy of Pulsed Biphasic Defibrillation Shocks for Treatment of Out-of-hospital Cardiac Arrest

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Abstract: This study evaluates the efficacy of a Pulsed Biphasic Waveform (PBW) for treatment of out-of-hospital cardiac arrest (OHCA) patients in ventricular fibrillation (VF). Large database (2001-2006), collected with automated external defibrillators (AED), (FRED®, Schiller Medical SAS, France), is processed.

In Study1 we compared the defibrillation efficacy of two energy stacks (90—130—180 J) vs. (130—130—180 J) in 248 OHCA VF patients. The analysis of the first shock PBW efficacy proves that energies as low as 90 J are able to terminate VF in a large proportion of OHCA patients (77% at 5 s and 69% at 30 s). Although the results show a trend towards the benefit of higher energy PBW with 130 J (86% at 5 s, 73% at 30 s), the difference in shock efficacy does not reach statistical significance. Both PBW energy stacks (90—130—180 J) and (130—130—180 J) achieve equal success rates of defibrillation. Analysis of the post-shock rhythm after the first shock is also provided.

For Study2 of 21 patients with PBW shocks (130—130—180 J), we assessed some attending OHCA circumstances: call-to-shock delay (median 16min, range 11-41 min), phone advices of CPR (67%). About 50% of the patients were admitted alive to hospital, and 19% were discharged from hospital. After the first shock, patients admitted to hospital are more often presenting organized rhythm (OR) (27% to 55%) than patients not admitted (0% to 10%), with significant difference at 15 s and 30 s. Post-shock VFs appear significantly rare until 15s for patients admitted to hospital (0% to 9%) than for patients not admitted to hospital (40% to 50%). Return of OR (ROOR) and efficacy to defibrillate VF at 5 s and 15 s with first shock are important markers to predict patient admission to hospital.

Keywords: Automated external defibrillator, Pulsed biphasic waveform, Low energy defibrillation, Outcome from defibrillation.

Разпознаване на екстрасистоли в електрокардиограмата: обзор на методи и алгоритми, приложими в квазиреално време

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1. Увод

Ритмичната дейност на сърцето се управлява от специфична проводна система, която възбужда предсърдията и камерите в строго определена последователност. В електрокардиограмата (ЕКГ) камерните съкращения (контракции) съответстват на относително постоянни по форма QRS комплекси. Разстоянията между тях (RR интервали) характеризират сърдечния ритъм, който се променя слабо в синхрон с дихателния акт. При нарушения в проводната система някои зони на сърдечния мускул (миокарда) могат да предизвикат ненавременни съкращения – екстрасистоли, за които дължината на RR интервалите и/или формата на QRS комплексите се променят значително. Екстрасистолите, генерирани в предсърдията (надкамерни), водят само до разлики в RR интервалите, защото възбудата достига до камерите по специфичния за тях проводен път. За разлика от тях камерните екстрасистоли се различават и по форма от нормалните QRS комплекси. Единичната екстрасистола не предизвиква симптоми, но появата на множество единични екстрасистоли е знак за нарушения в процесите на деполяризация, който в редица случаи предшества възникването на животозастрашаващи сърдечни аритмии.

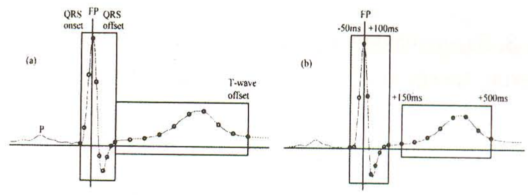
Автоматичното разпознаване и класификация на камерните контракции като нормални QRS комплекси и екстрасистоли е обект на дългогодишни изследвания. Това е основата на ритъмния анализ, който се прилага при продължителни 24-часови записи на ЕКГ (Holter системи) и при мониторните системи в интензивните и хирургичните отделения за откриване и следене на нарушения в сърдечната функция.

2. Разпознаване на екстрасистоли

Автоматичното разпознаване на екстрасистоли и разделянето им на камерни и предсърдни изисква преди всичко сигурна детекция на всички видове камерни съкращения. Това включва предварително отхвърляне на други високи и стръмни вълни в ЕКГ (например Т вълни, в редки случаи Р вълни), често в условия на мускулни смущения и артефакти, породени от влошен контакт между електродите и кожата на пациента. За разграничаване между нормалните QRS комплекси и екстрасистоли в алгоритмите се прилагат допълнителни критерии на второ ниво.

Повечето разработки в тази област са приложими извън реално време, главно в Holter системите. Автоматичните класификатори използват много и различни методи като невронни мрежи, самоорганизиращи се мрежи, wavelet трансформации, главните компоненти (Karhunen – Loeve), полиноми на Hermite, линейни дискриминатори и други.

Класификаторът на de Chazal и други [1] се основава на морфологични признаци и продължителности на RR интервали. Методът прилага предварителна обработка на ЕКГ сигналите с два медианни филтъра. Първият с ширина 200 ms подтиска QRS комплексите и Р вълните. Вторият с ширина 600 ms отстранява Т вълните. Изходът представлява физиологичния дрейф на нулевата линия, който се елиминира чрез изваждане от оригиналния сигнал. Филтърът за премахване на мрежовите и ВЧ смущения има гранична честота 35 Hz. Класификаторът не съдържа QRS детектор. Комплексите се разпознават по реперните точки (fiducial points, FP), анотирани в базата данни. Броят на признаците, използвани в класификатора, е значителен. Определят се четири вида RR интервали – текущ, предхождащ, следващ и усреднен. Наличието или отсъствието на Р вълна се отчита с Булева променлива. Морфологичните признаци се извличат от QRS комплексите и Т вълните. Използват се различни прозорци и честоти за повторна дискретизация чрез линейна интерполация (*фиг. 1*). При



Фиг. 1. Извличане на морфологични признаци от QRS комплексите и Т вълните (Фигурата е заимствана от [1])

първия подход (вляво) сигналът от началото до края на QRS комплекса се представя с определен брой дискрети. В този случай честотата за повторна дискретизация зависи от ширината на QRS-Т сегмента. При втория подход (вдясно) QRS комплексът и Т вълната се дискретизират с различни честоти. Всички признаци са групирани в 12 конфигурации. При разработката са използвани ЕКГ записи от MIT-BIH Arrhythmia база данни. Върху обучаваща извадка е направен избор на класификатор, основан на линейни дискриминатори. Върху тестваща извадка е проведена независима оценка на метода за класификация. Резултатите показват 75.9% чувствителност, 38.5% точност на положителното разпознаване и 4.7% точност на отрицателното разпознаване за надкамерни екстрасистоли. Съответните данни за камерните

Весела Кръстева, Ирена Жекова, Николай Мудров, Тодор Стоянов

АВТОМАТИЧНИ ВЪНШНИ ДЕФИБРИЛАТОРИ

Дефибрилацията е животоспасяваща процедура за възстановяване на ритмичната дейност на сърцето с помощта на мощен електрически импулс. Стимулацията на сърцето от този тип предотвратява около 70—80% от случаите на внезапна сърдечна смърт, провокирана от аритмии — камерна фибрилация и бърза камерна тахикардия. Живозастрашаващите аритмии, свързани с липса на ефективно кръвообръщение и риск от мозъчна смърт в рамките на няколко минути, налагат необходимостта от спешна реанимация с единственото възможно лечение — ранна електрическа дефибрилация, съпроводена с механичен сърдечен масаж и обдишване. Ранната дефибрилация в извънболнични условия стана възможна благодарение на т.нар. автоматични външни дефибрилатори (АВД). Те са разпространени на публично достъпни места и се използват от парамедици (обучени доброволци, пожарникари, полицаи).

Специфичното приложение на АВД определя необходимостта от внедряване на редица иновационни решения и технологии, свързани със:

- генериране на дефибрилационни импулси с оптимална форма за постигане на положителен ефект с по-ниски енергии и в резултат — при понисък риск от увреждане на миокарда. Тази технология трябва да е съобразена и със съвременните тенденции за разработване на компактни АВД апарати;
- автоматичен анализ на електрокардиограмата (ЕКГ) за автономно вземане на решение за нанасяне на дефибрилационен шок, без необходимост от интерпретация на ритъма на пациента от медицинско лице. Подобни експертни системи за автоматичен ЕКГ анализ трябва да притежават голямо бързодействие и изключително висока точност, съобразена с всички актуални международни изисквания за безопасност на пациента;
- система, осигуряваща работата на АВД в условия на непряк сърдечен масаж. Съвременните препоръки за продължителен сърдечен масаж с минимални паузи налагат необходимостта от надежден анализ на ЕКГ, дори когато тя е зашумена с артефакти от механичния масаж върху гръдния кош. Друга полезна функция на АВД е свързана с непрекъснатия контрол на качеството на сърдечния масаж, чрез измерване на дълбочината и честотата на компресиите. Тази обратна връзка служи като водач за оказване на адекватна реанимация.

Дефибрилационни импулси. Теоретичното проектиране на дефибрилационен импулс с оптимална форма не би представлявало проблем, ако механизмите, играещи основна роля при дефибрилация, бяха известни априори. За съжаление отговорът на сърцето към електрически шок е сложна комбинация от редица непредсказуеми фактори, свързани с прекратяването на активационните фронтове на фибрилация, възбуждането или удължаването на времето за рефрактерност на „критична маса„ на миокарда, инициирането на нови активационни фронтове, рефибрилацията и др. Отчитайки физиологичните особености на сърцето, гръдния кош, кожно-електродния контакт и тяхното влияние върху интензитета и формата на тока през миокарда, задачата за оптимална дефибрилация значително се усложнява. Тя може да бъде решена само чрез едновременно провеждане на теоретични и експериментални изследвания.

Първоначално е предложен модел електрическа еквивалентна схема на системата — дефибрилатор—трансторакален импеданс—миокардна клетка, който позволява изследването на изменението на трансмембранния потенциал при въздействие с различни по форма дефибрилационни импулси. На базата на този модел са формулирани критериите за оптимална дефибрилация и са разработени методи за динамична настройка на параметрите на импулса в зависимост от индивидуалните характеристики на системата по време на шок, свързани с времеконстантата на сърдечната клетка, торакалния импеданс на пациента, капацитета на кондензаторите в дефибрилатора, отдаваната енергия, респективно интензитета на прилаганите напрежение и ток. Предложени са три нови форми на балансирани бифазни импулси с повишена ефективност:

— импулс тип „отрязана експонента“ с времетраене на фазите 4 ms и балансирано съотношение 3:1 на зарядите на положителна първа спрямо отрицателна втора фаза (фиг. 1а);

— импулс с високочестотна модулация на балансираните импулси с честота на елементарните импулси 5 kHz и 50% коефициент на запълване (фиг. 1б);

— импулс високочестотна широчинно-импулсна модулация на балансираните импулси по синусоидален закон (фиг. 1в).

BIO*AUTOMATION*, 2009, **13** (2), 84-96

Rhythm Analysis by Heartbeat Classification in the Electrocardiogram

(Review article of the research achievements of the members of the Centre of Biomedical Engineering, Bulgarian Academy of Sciences)

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Abstract: *The morphological and rhythm analysis of the electrocardiogram (ECG) is based on ventricular beats detection, wave parameters measurement, as amplitudes, widths, polarities, intervals and relations between them, and a subsequent classification supporting the diagnostic process. Number of algorithms for detection and classification of the QRS complexes have been developed by researchers in the Centre of Biomedical Engineering – Bulgarian Academy of Sciences, and are reviewed in this material. Combined criteria have been introduced dealing with the QRS areas and amplitudes, the waveshapes evaluated by steep slopes and sharp peaks, vectorcardiographic (VCG) loop descriptors, RR intervals irregularities. Algorithms have been designed for application on a single ECG lead, a synthesized lead derived by multichannel synchronous recordings, or simultaneous multilead analysis. Some approaches are based on templates matching, cross-correlation or rely on a continuous updating of adaptive thresholds. Various beat classification methods have been designed involving discriminant analysis, the K-th nearest neighbors, fuzzy sets, genetic algorithms, neural networks, etc. The efficiency of the developed methods has been assessed using internationally recognized arrhythmia ECG databases with annotated beats and rhythm disturbances. In general, high values for specificity and sensitivity competitive to those reported in the literature have been achieved.*

Keywords: *Electrocardiography, QRS detection, Rhythm analysis, Automatic beat classification, Morphological parameters, Time-frequency analysis, Template matching, Karhunen-Loève transform, Independent component analysis, K-th nearest neighbors.*

Introduction

The ventricular contractions and the depolarization phenomenon are identified in the electrocardiogram (ECG) by characteristic high-amplitude waves, named QRS complexes. Distances between them (RR intervals) define the rhythm, which is strongly influenced by the emotions and the physical activity and less in line by the respiratory act. In heart conduction disorders, ventricular excitation may not originate as it is normal from the sinus node, but from other ectopic centers in the myocardium. Thus premature contractions are generated, called also extrasystoles or ectopic beats. Typically, they are recognized by the irregular coupling RR intervals. The premature atrial contractions (PACs) produce normally shaped QRS complexes, while the premature ventricular contractions (PVCs) are generating a variety of QRS waveforms, quite differing from the normal ones. The premature beat itself does not cause symptoms but the occurrence of multiple single premature beats is considered clinically important, since it is a sign for disturbance in the depolarization process preceding in many cases the appearance of malignant cardiac arrhythmias.

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Cardio Compression Control Device: Development, Calibration and Testing

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Abstract: *Cardio-pulmonary resuscitation (CPR) is a life-saving first aid which is part of the treatment given in case of sudden cardiac death. According to the American Heart Association (AHA) 2005 Guidelines for CPR, there are three key components related to the chest compressions which should be considered: (i) optimal compression depth between 3.8 and 5.4 centimeters; (ii) optimal compression rate between 85 and 115 compressions per minute; (iii) complete chest recoil by releasing all pressure from the chest after each chest compression (CC).*
A device for automatic control of the quality of chest compressions during CPR was developed. It embedded hardware and software solutions for simultaneous measurement of the depth, rate and the chest recoil thus providing a feedback about the efficiency of the cardiac massage at each CC compression. The system is applicable as a training device for basic education in CPR or as a consulting system for rescuers on the scene of the cardiac incident. The accuracy of the CC Device was adjusted by theoretical and experimental calibration, and tested by planned experiments, as well as experiments with a medical team.

Keywords: *Chest compressions quality monitoring, CPR training device, Accelerometer.*

Introduction

Chest compressions (CC) are part of the cardio-pulmonary resuscitation (CPR) – a life-saving first aid, which is applied in case of sudden cardiac death. The chest compression has two phases – the active phase, when force is applied downward on the chest, and the passive phase, when pressure is released and the chest is allowed to recoil to its normal shape. During the active phase, the heart is squeezed between the sternum and the spine, compressing the ventricles and causing blood to be pumped out to the lungs and body. Venous blood returns to the heart during the passive phase, flowing through the atria and into the ventricles. During cardiac arrest, venous blood returns to the heart only if the intrathoracic pressure is less than the intra-abdominal pressure. This is critical to the effectiveness of CPR [5].

Performing qualitative CPR in the treatment of cardiac arrest may increase the patient's chance of survival and may improve the outcome for a complete neurological recovery [3]. The American Heart Association (AHA) 2005 Guidelines for CPR [1] state that methods should be developed to improve the quality of CPR delivered at the scene of cardiac arrest by healthcare providers and lay rescuers. Based on what is now known about the pathophysiology of the cardiac arrest, the physiology of CPR and the latest research, the AHA

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Hands-off Intervals during Cardiopulmonary Resuscitation: Duration and Effect on the ECG Analysis

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Summary: Recent works are aimed at development of shock advisory systems (SAS) for automated external defibrillators (AEDs), which continuously analyze the electrocardiogram (ECG) during non-interrupted chest compressions (CC). Being also part of the cardiopulmonary resuscitation (CPR), small 'hands-off' intervals (CC pauses) for insufflations are interrupting the CC, and thus the SAS analysis process. This study is applied on 530 CC-contaminated ECG strips taken from 168 patients who undergo out-of-hospital resuscitation interventions with AEDs. A statistical study of the short duration CC pauses is performed, showing non-normal distribution with median value of 4 seconds, quartile range between 3 and 5 seconds, min-max range between 1 and 10 seconds. Another focus is the effect of skipping the CC pauses on the SAS accuracy by supplying continuous non-linear CC-corrupted ECG signal for analysis. The SAS is tested with different coupling intervals [t1, t2], where t1 is the time before the CC pause, t2 is the time after the CC pause, t1+t2=10 seconds. The SAS accuracy on CC-corrupted linear signals [10s+0s] compared to non-linear signals [9s+1s], [8s+2s], [7s+3s], [6s+4s], [5s+5s] shows insignificant difference (p>0.05) for the different arrhythmia: ventricular fibrillation between 86% and 90.3%, normal rhythms between 88.4% and 93.5%, asystole between 80.4% and 87.3%. Several examples illustrate the performance of the SAS analysis process on various CC artefacts and ECG arrhythmias.

Keywords: CPR artefacts, Cardiac compression pauses, Shock advisory system, AED.

1. INTRODUCTION

Cardiopulmonary resuscitation (CPR) has been advised as the best treatment for out-of-hospital cardiac arrests (OHCA) before the arrival of an automated external defibrillator (AED) [3]. Minimum 'hands-off' intervals during CPR are advised to improve the success rate of defibrillation since chest compressions (CC) are supplying non-interrupted blood flow to the brain, the heart and other vital organs. CC thus prevent from ischemia and increase the rate of return to spontaneous circulation [2, 5, 6, 7]. According to the ERC

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Filtering of Chest Compression Artefacts in the Electrocardiogram

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Summary: Long interruptions of cardiopulmonary resuscitation (CPR) in case of a sudden cardiac arrest result in higher failure rate of resuscitation. The current work concerns the filtering of the chest compression (CC) artefacts during CPR, which is essential for the CPR continuation during electrocardiogram (ECG) analysis by automated external defibrillators (AEDs). We have studied two possible approaches – one based on high-pass filter (HPF), and another using band-stop filter (BSF) with adjustable cut-off frequency. The purpose is to improve the quality of the signal provided to the ECG analysis module, aiming at a reliable decision to Stop CC if VF is present or to Continue CC for all other rhythms, including asystole (ASYS) or 'normal' rhythms with ventricular complexes (NR). The two filters are tested with artificially constructed ECG+CC signals, as well as with real ECGs recorded during CPR. The HPF passes the high-frequency components of the QRS complexes and effectively suppresses CC artefacts. This allows correct recognition of NR and ASYS. However, HPF suppresses the VF amplitude thus compromising the VF detection sensitivity. The BSF is favorable for detection of NR and VF but presents problems for ASYS detection because there are often attending residual high-frequency components belonging to the CC artefacts.

Keywords: ECG, AED, CPR, ventricular fibrillation, chest compression artefact, band-stop filter, high-pass filter, adjustable cut-off frequency

1. INTRODUCTION

Public access defibrillation (PAD) programs recommend the use of automated external defibrillators (AED) for early treatment of out-of-hospital cardiac arrests (OHCA) advising 2 minutes of uninterrupted cardiopulmonary resuscitation (CPR), without a check for termination of ventricular fibrillation (VF) or a check for signs of life or a pulse [7]. The chest compressions (CC) during CPR induce large artefact components into the electrocardiogram (ECG) acquired via the defibrillation pads [6]. The superposition of ECG and CC artefacts results in accuracy reduction of AED shock advisory

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Online Adaptive Filter for Mains Interference Suppression in Diagnostic Electrocardiographs: Cases of Amplitude and Frequency Deviation

Todor Venkov Stoyanov, Ivaylo Ivanov Christov, Irena Ilieva Jekova and Vessela Tzvetanova Krasteva

Abstract – **In this paper we present a real-time adaptive filter for power-line interference suppression. The filter meets the IEC 60601-2-51 Standard requirements for diagnostic electrocardiographs with ringing noise < 25 μV when QRS slopes are up to 60 μV/ms. The filter can follow an amplitude change ratio as high as 2400 μV/s and a frequency change ratio as high as 0.15 Hz/s for 50 and 60 Hz mains interference.**

Keywords – **Power-line interference, Adaptive filter 50/60Hz, Ringing noise, ECG Standard**

I. INTRODUCTION

Measurements on the electrocardiogram (ECG) waves are very important in clinical diagnosis. However, there usually exists stray capacitance between the patient and the power lines (PL), and thus ECG measurements are easily contaminated by 50/60 Hz mains interference. Although modern instrumentation amplifiers have high common mode rejection ratio, as well as shielding and grounding are applied while recording ECG, the recorded traces are often contaminated by power-line interference (PLI). In order to avoid wrong identification of the ECG characteristics and their impact on the analysis and the diagnostic accuracy, the international standards in ECG processing tolerate original signal distortion not greater than 25 μV [1].

There are different published techniques for 50 Hz and 60 Hz PLI elimination [2-5]. Some of them aim at a simple solution for removal of the fundamental PLI frequency by comb filters [2] but they distort the high-frequency QRS components and perform well only when the PLI frequency is fixed exactly at the stop band of the filter. The subtraction procedure is promoted to preserve the ECG components by applying different techniques in linear and non-linear ECG segments. Recently, the authors of the subtraction procedure have upgraded its work in case of power-line frequency deviation [3]. Another promising approach for PLI elimination is the adaptive filtering technique, applied with or without an additional reference channel [4,5]. To avoid the use of external antennas, a method for automatic measurement of PLI frequency and generation of reference sinusoid is presented in [6].

This paper introduces an adaptive filter with reference channel, working in cases of amplitude and frequency deviation. The results are presented to demonstrate the level at which the proposed filter meets the international requirements for 50/60 Hz suppression in diagnostic ECG.

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II. ADAPTIVE FILTER CONCEPTION

The block diagram of the developed adaptive filter is presented in Fig. 1. Its sample-by-sample architecture is designed to process the input signal in real time.

The algorithm embeds 3 modules:
1) module for measurement of the PLI amplitude and frequency; 2) module, generating the reference signal for the adaptive filter (REF input); 3) adaptive filter.

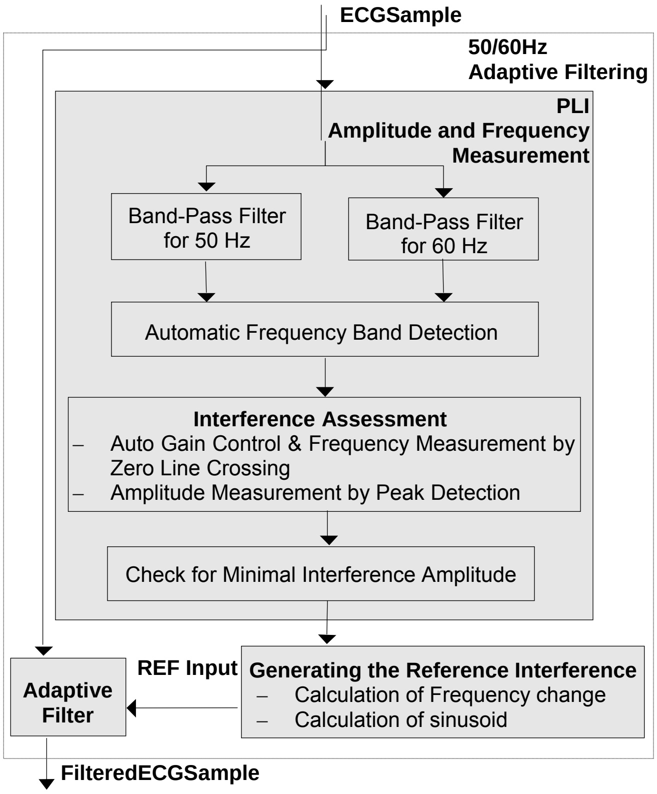

FIGURE 1. DIAGRAM OF THE SOFTWARE CONCEPTION FOR ADAPTIVE 50/60 HZ FILTERING.

Measurement of the interference amplitude and frequency

This module consists of the following steps:

Step1 *Band-pass filtration*: Two band-pass (BP) filters at 50 and 60 Hz are used for identification of the PLI central frequency, as shown in Fig. 2. The BP filters are with 3-rd order characteristics, used to provide steep, well separable bands with minimal influence from the QRS components while extracting the PLI component.

Step2 *Automatic frequency band detection*: By comparing the output signal energy of the two BP filters, the algorithm internally switches between 50 and 60 Hz processing.

Assessment of the Cardiac Hemodynamics During Cardioversion Using Impedance Measurements: Preliminary Results

Irena Ilieva Jekova, Vessela Tzvetanova Krasteva and Tsvetan Nikolaev Mudrov

Abstract – **This paper investigates the impedance variation (ΔZ) and its synchronization with the electrocardiogram (ECG) both captured via the defibrillation pads during cardioversion. The observed beat-to-beat ΔZ patterns are presented in terms of showing that the level of synchronization is better for sinus rhythms and worse for atrial fibrillations. The preliminary results suggest a set of time-amplitude descriptors of patterns which are assessed to express the cardiac output recovery after cardioversion.**

Keywords – **impedance cardiography, hemodynamical status, cardioversion.**

I. INTRODUCTION

Hemodynamic evaluation is helpful for optimization of treatment and monitoring of clinical outcomes in cardiac patients. Impedance cardiography (ICG) is a technology that provides a cost-effective, noninvasive monitoring of hemodynamic parameters, which are needed in heart failure treatment, by 4 or 2 electrode system placed at the base of the neck and at the base of the thorax. ICG applies a constant, low-amplitude, high-frequency current to the thorax and measures the corresponding voltage to detect changes in thoracic electrical impedance [1]. There are two primary components of the impedance: 1) base impedance, depending on the thoracic blood and plasma volume, chest skeletal muscle, cardiac muscle, lung tissue, chest wall fat, and air; and 2) dynamic impedance, associated with change of the blood flow in the aorta during the cardiac cycle. Since arterial blood flow is pulsatile and arterial vessel walls are compliant, pulsatile changes in blood volume occur in the thoracic arterial system, predominantly in the aorta, as a result of ventricular function. During systole, a beat-to-beat voltage drop is associated with increased blood volume and flow in the aorta.

Recently, a number of reports on the clinical use of ICG are published. Authors have suggested that ICG measurements are useful for diagnosis of heart failure, monitoring of the patient clinical status, and assisting in medicine decisions [1]. The dynamic, beat-to-beat changes in impedance are applicable for calculation of hemodynamic parameters, such as stroke volume and cardiac output which show accurate correlation to the values calculated from direct measurements from pulmonary artery catheters [2]. However, data continue to suggest poor correlation between current generation ICG devices and invasive measurements of cardiac output, especially in heart failure patients. Kamath et al [3] claim that the utility of ICG in patients hospitalized with advanced heart failure is uncertain and that although it provides some information about the cardiac output, the authors found modest correlation between ICG (BioZ - CardioDynamics, San Diego, CA) and the invasively measured values. Donati et al [4] found great discrepancy between the cardiac index measured with ICG system (Solar ICG module; GE Medical Systems Technology, Milwaukee, USA, 2001) and with transpulmonary thermodilution (PiCCO system). The cardiac index measurements obtained with the ICG system were underestimated when compared with the PiCCO system.

The authors in [5] study the application of ICG in automated external defibrillators (AEDs) as an additional non-ECG sensor for improving the accuracy in detection of life-threatening rhythms with poor heart hemodynamics. They report that ICG signals captured via the two ECG/ defibrillation pads are informative for detection of satisfactory cardiac output in the cases of sinus rhythm and non-shockable ventricular tachycardia at 80%, and for recognition of absent or low cardiac output in the cases of asystole, agolal rhythm and ventricular fibrillation at 95.1%.

The aim of this work is to study ICG signals captured via defibrillator pads during cardioversion, in order to identify a typical beat-to-beat pattern in the impedance variation signal. The correlation of the pattern descriptors with the hemodynamical status of the heart will be studied by comparison between normal sinus rhythm and the pumping dysfunction in atrial fibrillation/flutter.

II. EXPERIMENTAL SETTING

The experimental setting includes a defibrillator and a measurement device connected to the patient via 2 defibrillation pads. The following devices are used:

- A commercial defibrillator DG4000 (Schiller Medical SA, France). It produces shocks and injects high-frequency (HF) current through the defibrillation pads;
- An in-house developed measurement device, named DEFIMPULSE Recorder [6]. The following signals are recorded for the aims of this study: 1) the electrocardiogram (ECG) lead used by DG4000 for rhythm analysis; 2) the slow Z variation (ΔZ) of the impedance under the defibrillation electrodes. Both ECG and ΔZ signals are captured at 250 Hz sampling rate, 12bit resolution and are stored in a SD flash card.

With the permission of the ethical committee, the experimental setting was installed in the Coronary Care Unit of the National Heart Hospital, Sofia, Bulgaria for study of patients undergoing planned cardioversion.

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Transthoracic Impedance Cardiogram Indicates for Compromised Cardiac Hemodynamics in Different Supraventricular and Ventricular Arrhythmias

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Abstract - **This paper investigates the usability of the transthoracic impedance cardiogram (ICG) for providing information about the different quality of myocardial contraction in sinus rhythm (SR), asystole, 3 supraventricular and 3 ventricular arrhythmias when using the signal recorded via the defibrillation pads during external cardioversion. All arrhythmias are compared to SR to reveal significant drop of six ICG amplitude and velocity measures, defined for ICG patterns during systole. The ICG measures are also found to be significantly correlated with the duration of the coupling RR interval. The results suggest that the ICG acquired via defibrillation pads is a potential hemodynamical sensor, which could be used to rate the severity of arrhythmia and to improve the detection of pulseless electrical activity in AEDs.**

Keywords – **impedance cardiography, hemodynamical status, arrhythmia.**

I. INTRODUCTION

The monitoring of cardiac hemodynamics could provide valuable additional information to the electrocardiogram (ECG) analysis for determination of the patient's clinical status. In this respect, measurement of the impedance cardiogram (ICG) is becoming increasingly available in the clinical setting as a tool for assessment of hemodynamics and volume status in patients with heart failure [1].

The common 4 electrode ICG is shown to be a useful technique for monitoring the homodynamic effect (stroke volume and cardiac output) of the electrical therapy in patients with atrial fibrillation (AFIB) or sinus bradicardia who restore sinus rhythm (SR) after cardioversion or electrical stimulation [2].

Another study [3] reports an effective application of tetrapolar ICG holter for indirect evaluation of cardiac contractility by estimation of beat-to-beat stroke volume changes, and measurement of the ejection time and preejection period for SR beats and single, bigeminal or trigeminal premature ventricular contractions (PVC). The authors prove good correlation between the results obtained by ICG analysis and a reference echocardiographic method.

Related to application in automated external defibrillators (AEDs), Johnston et al [4] have studied the ICG captured via the defibrillation pads as an additional non-ECG sensor for improving the detection accuracy of life-threatening rhythms with poor heart hemodynamics. They report promising results for detection of satisfactory cardiac output in cases of sinus rhythm and non-shockable ventricular tachycardia at 80%, and for recognition of absent or low cardiac output in cases of asystole, agonal rhythms and ventricular fibrillations at 95.1%.

The aim of this study is to test the usability of the transthoracic impedance cardiogram for providing information about the different quality of myocardial contraction in sinus rhythm, asystole, 3 supraventricular and 3 ventricular arrhythmias when using the signal recorded via the defibrillation pads during cardioversion.

II. MATERIAL

This study comprises clinical data from 152 patients admitted to receive planned or emergency external cardioversion (ECV) from May 2010 to May 2012 in the Intensive care unit of the National Heart Hospital, Sofia. The ECV is performed with the permission of the local Ethics Committee, following standard hospital procedures, all patients signing a written informed consent.

The experimental setting includes:

- A commercial cardioverter/defibrillator DG4000 (Schiller Medical SA, France) – applies pulsed biphasic shocks via self-adhesive defibrillation pads in antero-apical position, with active area (2x75 cm^2). DG4000 injects low-intensity high-frequency current via the same pads to measure the thoracic impedance;
- A prototype device, named DEFIMPULSE Recorder [5] – records the ECG lead II and the ICG signal captured via the defi pads. Both signals are sampled at 250 Hz, 12 bit resolution, and are stored in a SD flash card.

ECG and ICG recordings before and after ECV shocks are retrospectively evaluated. QRS detector is applied to identify R-peaks as reference points of the heartbeats which are then manually annotated to belong to different rhythm categories as follows: 7759 beats for SR, 21739 beats for AFIB, 7049 beats for atrial flutter (AFL), 706 beats for supraventricular tachycardia (SVT), 423 PVCs, 10724 beats for ventricular tachycardia (VT). Ventricular fibrillation (VF) and asystole (ASYS) are rarely developed arrhytmias during ECV, observed in only 2 patients, for which R-peak reference points could not be identified. The annotation for these cases is done by artificial reference points distanced at 500 ms intervals, thus collecting 122 reference points for VF and 351 for ASYS.

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Decision Support System for Prediction of the Weaning Outcome from Mechanical Ventilation

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Abstract – **This study presents a system for prediction of the weaning outcome based on classification trees and linear discriminant analysis. The design of several classification models involves anthropometric and diagnostic indicators, metabolic, ventilation, hemodynamic and heart rate variability indices, measured just before the weaning attempt and/or during five different modes of volume controlled and pressure support ventilation. The designed decision support system provides maximal balanced Se=94.7%, Sp=96.8% when the initial data are supplied to a classification tree rule.**

Keywords – **mechanical ventilation, weaning predictors**

I. INTRODUCTION

The weaning from controlled mechanical ventilation (CMV) is a challenge in intensive care that requires an expert decision based on a complex knowledge of a large number of clinical and respiratory parameters, and analysis of their evolution over time [1]. The removal of the respiratory support should be performed as soon as the autonomous respiration could be sustained, considering the substantial risks associated with both extubation delay and extubation failure. The research efforts during last years are directed towards investigation of weaning predictors, commonly measured over ventilation signals:

- The rapid shallow breathing index (RSBI) calculated as RR/Vt (respiratory rate vs. tidal volume) – values <65 are reported for successful weaning [1], values >130 are representative for unsuccessful weaning [2], although a prospective study of Lee et al [3] conclude that RSBI <130 does not necessarily preclude successful extubation.
- Maximal negative inspiratory pressure (MIP), providing information about the strength of the inspiratory musculature – decreased MIP values and increased airway occlusion pressure (P0.1), especially when normalized towards MIP, are related with extubation failure [4];
- Minute ventilation (MV), indicative for the magnitude of the ventilatory load – values <10 l/min are associated with successful weaning [4];

Recently, a clinical decision support system has been reported to provide a reliable weaning prediction based on demographic information, physiology, diagnostic and treatment factors supplied to a support vector machine [5].

In the last decade, a number of studies have presented another point of view over CMV discontinuation, driving the attention on the cardiovascular stress during the procedure. It is shown that patients who failed at weaning manifest cardio-vascular insufficiency during the weaning attempt [6,7]. Analysis of cardiac autonomic control during weaning is shown to derive valuable information about the presence or absence of pathologic autonomic balance. The associated changes in the autonomic nervous system activity are investigated in a number of studies which use time-frequency heart rate variability (HRV) analysis to unmask existing abnormalities in the control mechanisms of the autonomic regulation response at different phases of the weaning [7-9].

This study presents a system for prediction of the weaning outcome based on classification trees and linear discriminant analysis. The design of several classification models involves different set of features, including anthropometric and diagnostic indicators, metabolic, ventilation, hemodynamic and HRV indices, measured just before the weaning attempt, and/or during five different modes of volume controlled and pressure support ventilation.

II. STUDY POPULATION

The study enrolls data from 50 patients undergoing weaning with AVEA ventilator system (Cardinal Health, USA) in the Central Intensive Care Unit of the University Emergency Hospital 'Pirogov' - Sofia, from August 2010 to June 2013. The study population consists of 31 men and 19 women, mean age of 62±16.5 years, who have received CMV for at least 72 hours prior the weaning attempt. Considering the weaning outcome at the 2^{nd} hour of a spontaneous breathing trial (SBT) the patients are divided into successful (N=31) and failure (N=19) group.

III. DATA COLLECTION AND PROCESSING

Study protocol

The study is following a predefined weaning protocol approved by the local Ethics Committee. Just before the weaning attempt (INIT state), the physician has collected initial data related to the vital, hemodynamic, ventilation and metabolic status. Each patient is passed through the following weaning modes, when ventilation signals and measurements, together with ECG signals are collected:

- *CMV/SNP:* CMV on patient, sedated with short-acting hypnotic. CMV is maintained for at least 10 min, with settings at the same level as immediately before the study, i.e. RR=12 min^{-1}, Vt=10 ml/kg, positive end-expiratory pressure PEEP=5 cmH2O and fraction of the inspired O2, FiO2=40%. Normal ventilation is suspended to achieve end-expiratory occlusion of the airways and to evaluate spontaneous breathing efforts of the patient;
- *CMV/SP:* – CMV is maintained with settings as in *CMV/SNR*. The sedated patient is additionally paralyzed with a short-acting/intermediate neuro-muscular blocker

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Respiration Detection Implemented in Multichannel ECG Front End Module: A Preliminary Study

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Abstract – **A new generation single-chip low-power ECG analog front-end module (ADAS1000) is used to develop a system for 12-lead high-resolution ECG and impedance-based respiration acquisition. The developed respiration rate (RR) measurement algorithm is validated on a test respiration database, including more than 650 reference 15s-window sliding of 5s with annotated respiration periods and assigned to apnea, normal, deep breathing episodes acquired in leads I and II. The mean RR error is found within 0.7 to 4.7 bpm, significantly inversely related with the respiration amplitude.**

Keywords – **impedance, respiration, analog front end ECG**

I. Introduction

Continuous monitoring of respiratory activity is mandatory in clinical high-risk conditions, and appropriate monitoring equipment is life-saving [1]. The approaches for respiration measurement are categorized as applying direct or indirect methods. In direct methods, a sensor is coupled to the airway to quantify different properties of the air transported into and out of the lungs, e.g. the temperature changes in the air (nasal thermistors), the change in carbon dioxide in inhaled and exhaled air (carbon dioxide sensors), etc. Although the direct measurement methods tend to be more accurate, they could interfere with the normal respiration and could cause discomfort for the patient.

The most commonly employed indirect methods are impedance and inductance plethysmography [2]. In inductance plethysmography, sensors are placed around the chest and abdomen. They are excited by a low-current, high-frequency (300 kHz) electrical oscillator circuit. Movement of the chest and abdomen during respiration causes the sensors to generate magnetic fields, which are measured as voltage changes over time. The impedance plethysmography, applies low amplitude, high frequency (50 to 500 kHz) alternating current between two surface electrodes to record thoracic movements or volume changes during a respiratory cycle. The voltage drop between the electrodes is proportional to the impedance, which increases during inspiration and decreases during expiration. A common problem for the above two indirect respiration detection methods is that blood flow generates cardiac-synchronous changes in the acquired respiratory signal which could be a significant source of error [3].

The big advantage of the impedance-based respiration detection is the signal acquisition via standard body surface electrodes without additional sensors. This option for thoracic impedance measurement is recently embedded in a new generation of a single chip low power Analog Front End (AFE) modules [4,5] which simplify the task of acquiring and ensuring high quality ECG signals in monitor and diagnostic multichannel ECG applications, such as bedside patient monitoring, portable telemetry, holters, defibrillators, ambulatory monitors, patient transport, stress testing, etc. The need for fast and reliable impedance-based respiration detection module becomes a challenging task.

This paper aims to provide a module for respiration rate measurement which is implemented in a high-resolution multichannel ECG monitoring system. The validation on the test respiration database is also presented.

II. Hardware

This work presents a realization of a standard 12-lead ECG and respiration monitoring system using two cascaded AFE chips ADAS1000 (Analog Devices) [4], connected in master and slave mode according to the block diagram in Fig. 1. Ten electrodes, placed on the chest, are used for ECG signal acquisition. Two of them (lead I, II or III) are also employed for respiration signal measurement. All electrodes are directly connected to the AFE input via first-order low-pass filters to remove high-frequency noises and anti-aliasing effect before the 19-bit analog-to-digital conversion (ADC) in ADAS1000. ADAS1000 implements in one low power AFE chip, all of the features that are commonly required for a complete ECG module:

- High-resolution measurement of 5 ECG channels.
- Internal pace detection algorithm.
- Detection of bad electrode contact.
- Generation of Wilson Central Terminal.
- Driven right leg.
- Patient cable shield driving for suppression of the common mode interferences.

ADAS1000 integrates the option for measurement of one thoracic impedance channel by injecting high-frequency current with fixed amplitude between two ECG electrodes. The parameters of the current pulses are programmable:

- Frequency setting (46.5 to 64 kHz).
- Current amplitude (8 to 64 μA_{p-p}).
- Selection of the reference ECG lead for the thoracic impedance measurement (i.e. selection of internal respiration paths in leads I, II or III).
- Programmable input gain (10 states) providing measurement resolution of 0.02 to 0.2 Ω.

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АНАЛИЗ НА ЖИВОТОЗАСТРАШАВАЩИ СЪРДЕЧНИ АРИТМИИ С ПРИЛОЖЕНИЕ В АВТОМАТИЧНИТЕ ВЪНШНИ ДЕФИБРИЛАТОРИ

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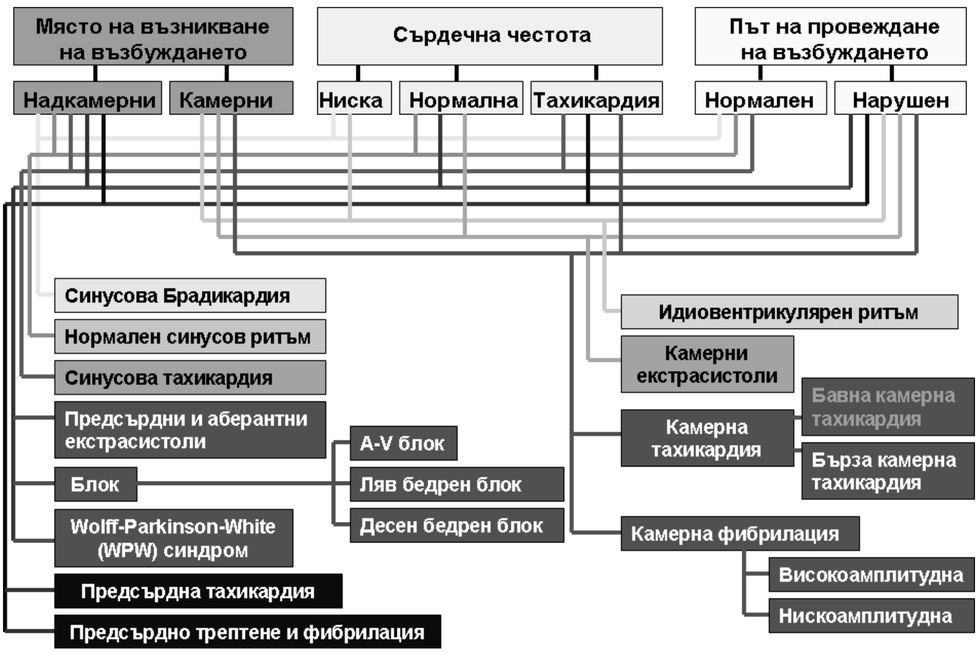
Резюме

Докладът е посветен на проблеми, свързани с автоматичния анализ на електрокардиографски (ЕКГ) сигнали в дефибрилатори. Разгледани са разработени от нас методи за анализ на животозастрашаващи сърдечни аритмии във времева, честотна област и с нелинейно предсказване. По-специално внимание е обърнато на алгоритъм, работещ в реално време, който е вграден в прототип на анализиращ модул за автоматичен външен дефибрилатор. Постигнатата много висока точност над 98% има безспорен практически принос, предвид животоспасяващото значение на правилното решение (автоматично определено) за прилагане на високоволтов шок.

1. Сърдечни ритми в норма и патология

Приблизително еднаквото съотношение между параметрите на отделните вълни в ЕКГ свидетелства за изключително надеждна синхронизация на сърдечната активност при нормални физиологични условия. Нарушаването на фактор, поддържащ тази синхронизация провокира появата на сърдечни аритмии, регистрирани чрез характерна промяна във формата, последователността и честотата на вълните в ЕКГ. На фиг. 1 е показана систематизирана класификация на отделните типове аритмии, според патологията в проводната система на сърцето, а именно промяна на мястото на възникване, честотата и пътя на провеждане на възбудната вълна в сърцето. Аритмиите са класифицирани в 2 основни групи според степента на нарушаване на кръвообръщението. В първа група са включени всички надкамерни ритми и бавните камерни аритмии, които са свързани с частично нарушаване на кръвообръщението – такива ритми **НЕ** трябва да бъдат третирани с електрически шок. Във втора група спадат животозастрашаващите аритмии – бърза камерна тахикардия и фибрилация, водещи до пълно спиране на кръвообръщението и загуба на съзнание – такива аритмии трябва **ЗАДЪЛЖИТЕЛНО** и незабавно да бъдат прекратени с електрическа дефибрилация.



Фиг. 1. Класификационна схема на сърдечни ритми в норма и патология

TIME AND FREQUENCY DOMAIN ANALYSIS OF FIVE HEARTBEAT TYPES

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The analysis of the electrocardiographic (ECG) signals, especially the QRS complex as the most characteristic wave, is a widely accepted approach to study and to classify cardiac dysfunctions. Five heartbeat types were studied (normal beats, ventricular extrasystoles, left and right bundle branch blocks and paced beats), searching for specific behavior in the timing and the frequency content of the QRS complex, due to changes in the rhythm origination and the conduction path. In the time domain the interbeat differences of the RR intervals were evaluated. In the frequency domain the QRS power spectrum was estimated by fast Fourier transform and a summary power spectrum in narrow frequency bands of 0.5 Hz (FFT-BPS) was calculated. Specific patterns of the FFT-BPS for each heartbeat type were derived and differences in the spectral frequencies were assessed. The observations allowed to define a spectral based parameter set, which jointly with the RR intervals could be easily processed by a standard classifier for the heartbeat type.

Keywords: heartbeat classification, QRS complex, Fourier transform, RR intervals

1. INTRODUCTION

Analysis of the electrocardiogram (ECG) for detecting different types of heartbeats is of major importance in the diagnosis of cardiac dysfunctions, due to abnormal changes of both the rhythm origination and the conduction path. Automatic classification of the heartbeats has been previously done using RR intervals [1], as well as using a variety of features to represent the alterations of the QRS waveform, most popular of which are based on the QRS morphology [1, 2]. More sophisticated methods apply QRS template matching procedures, such as the Matching Pursuits [2] to expand the QRS waveform into a single time-frequency basis, like the wavelet basis. Other authors prefer to avoid the fixed basis decomposition of the heartbeats and to study only the ECG frequency content by Fourier transform. Minami et al [3] classified the spectrum for three kinds of rhythms: supraventricular rhythm, ventricular rhythm and ventricular fibrillation. However, the defined arrhythmia classes are too general and clinical treatments in each class are not identical. More detailed heartbeat classification is necessary for the automatic diagnostic systems and therefore we need spectral analysis data of definitive heartbeat types.

It is the aim of the present work to study the frequency spectrum of five heartbeat types. We expect specific spectral distributions which facilitate the derivation of spectral pattern for each heartbeat type. Adequate estimation of this pattern is important to define a spectral based parameter set, which reliably identifies each one of the heartbeat types. We suggest improving the confidence of the feature set by additional analysis of the heart-rate variations based on assessment of the difference between the coupling RR intervals for each beat. The investigation is directed to computer-based ECG systems and to enhancement of their diagnostic ability.

DIFFERENCE-BASED PARAMETER SET FOR LOCAL HEARTBEAT CLASSIFICATION: RANKING OF THE PARAMETERS

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The initial step in the diagnosis of cardiac dysfunctions is the detection and classification of different types of heartbeats in the electrocardiogram (ECG). The aim of the present work was to assess the ability of a difference-based parameter set, containing information for an amount of morphological heartbeat features and for the RR intervals, to provide an adequate local heartbeat classification without requiring manual annotation of patient specific heartbeats. The study was performed on all ECG recordings from the internationally recognised MIT-BIH arrhythmia database. The results showed that the proposed difference-based parameter set could be a suitable tool for classification of ventricular ectopic beats.

Keywords: heartbeat classification, morphological parameters, RR intervals

1. INTRODUCTION

The initial step in the diagnosis of cardiac dysfunctions is the detection and classification of different types of heartbeats in the electrocardiogram (ECG). Some arrhythmias appear infrequently, and in order to capture them the clinicians use Holter devices. The use of specific algorithms for automatic analysis of ECG recordings may facilitate the analysis of the very long Holter ECG recordings. A particular aspect of the developed algorithms for automatic beat classification is the adopted learning strategy. It is studied, paying attention to the organization of the classifiers' training set, and considering two main approaches: *local* learning set and *global* learning set [1,2,3,4]. In the first case the learning set is customized to the tested patient, while in the latter it is built from a large ECG database. Traditionally the local learning set requires a cardiologist to annotate a set of heartbeats of the patient which are used afterwards as a basis for the classification. It is obvious that this is associated with time-consuming manual editing of the patient's ECG recording. On the other hand, the capacity of the global learning set to classify new records without additional training is balanced by a lower accuracy, since the morphology of the QRS complexes (of one and the same type) differ not only from patient to patient, but also from lead to lead of a same individual. Besides the learning strategy, an important point is the parameter set, which is selected to characterize the heartbeats. Some of the most popular ECG descriptors are based on assessment of the QRS complex morphology [1,3,4]. Other authors use time-frequency based parameters [4] or features calculated by QRS template matching procedures, based on different transforms, e.g. Karhunen-Loève transform [5], Hermite functions [6,7].

The aim of the present work was to assess the ability of a difference-based parameter set, containing information for an amount of morphological heartbeat

COMPARISON OF SPECTRAL COMPONENTS OF CPR COMPRESSIONS AND VARIOUS SHOCKABLE AND NON-SHOCKABLE RHYTHMS IN ECG

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This report is related to a preliminary study in support to the novel AED feature required, that is to analyse the ECG and propose shock advisory decision even during CPR. We investigated the frequency spectra of a large set of pure CPR compressions on asystole and real noise-free shockable and non-shockable ECG signals taken from out-of-hospital resuscitation interventions over 10 s episodes, as well as, over each single CPR cycle and heartbeat. The deviation of the spectral components of successive CPR cycles and various spectral parameters are estimated. Statistical analysis of the spectral characteristics allows to specify the most probable behavior of CPR and to design filters that minimally suppress the significant ECG frequency components and keep useful information for discrimination of shockable and non-shockable rhythms.

Keywords: ECG signal processing in AEDs, Cardio-Pulmonary massage, FFT

1. INTRODUCTION

Continuous cardiopulmonary resuscitation (CPR) is the best treatment of out-of-hospital cardiac arrests since it contributes to the sustained cerebro-vascular function until the arrival of an automatic external defibrillator (AED). The actual guidelines for resuscitation and use of AEDs require interruption of the CPR massage during automated analysis of the electrocardiogram (ECG) [1]. The chest compression artifacts originating mainly from the electrode-to-skin interface with possible components arising from the mechanical stimulation of the heart and thoracic muscles [2] could lead to false AED shock advisory decision. However, long interruptions of CPR result in lack of cerebral and myocardial blood flow and can significantly reduce the recovery rate of spontaneous circulation and the 24-hour survival rate [3,4]. It is expected that the future concepts in basic life support will enhance the CPR effect by allowing continuous CPR even during the ECG analysis process in AEDs. For this purpose the CPR artifacts should be effectively removed.

Recently many approaches on CPR artifacts suppression have been developed, based on high-pass filters with fixed coefficients [5], adaptive filters using the thoracic compressions as a reference signal [6], sophisticated adaptive approaches requiring up to four reference signals strongly correlated to the interference [7], etc. However, the problem is opened for building a CPR filter with minimal supression of the significant ECG frequency components. The optimal filter design could be defined after discovery of evidences for discrimination between the spectra of CPR and the different ECG arrhythmias.

TRANSTHORACIC IMPEDANCE PATTERNS DURING SYSTOLE REVEAL AN IMPROVEMENT OF CARDIAC HEMODYNAMICS AFTER EXTERNAL CARDIOVERSION OF ATRIAL FIBRILLATION

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Abstract

This study aims to test the usability of the transthoracic impedance cardiogram (ICG) for assessment of the quality of myocardial contractions in atrial fibrillation (AFIB) vs. sinus rhythm (SR), using signals recorded via defibrillation pads during external cardioversion (ECV). Data from 88 patients with persistent AFIB who received planned ECV are processed. AFIB is treated with cardioverter/defibrillator DG4000 (Schiller Médical, France) using a non-escalating protocol 200J/200J/200J. Successful ECV is defined as restoration of SR for >1min. The electrocardiogram (ECG), thoracic baseline impedance (Z) and dynamic impedance components dZ, dZ/dt captured via self-adhesive pads in antero-apical position are processed. Heartbeat contractions are evaluated by several measures extracted from the mean ICG patterns during systole: from dZ pattern - ICG peak (amplitude, range, area); from dZ/dt pattern - ICG velocity peak (range, area) and left ventricular ejection time (LVET). The hemodynamical indices measured before and after ECV are: mean heart rate over 2 minutes (HR), standard deviation of HR (HRV), systolic (SysBP) and diastolic (DiaBP) blood pressure.

When the rhythm converts from AFIB to SR (74 patients), all measures on dZ, dZ/dt patterns significantly increase: dZ (64-102%), dZ/dt (31-67%), LVET (18%), $p<0.05$. Significant decrease of HR (-36%), HRV (-53%), SysBP (-11%) and DiaBP (-19%) are also observed. Unsuccessful ECVs without conversion to SR (14 patients) are, however, associated with non-significant increase of dZ (10-21%), dZ/dt (0.3-29%), LVET (9%), $p>0.05$ when comparing initial AFIB vs. post-shock AFIB. No clear change in HR (-9%) and HRV (6%), and slight decrease of SysBP (-10%) and DiaBP (-8%) are observed.

The superiority of dZ, dZ/dt pattern measures in post-shock SR vs. pre-shock AFIB is related to clinical data.

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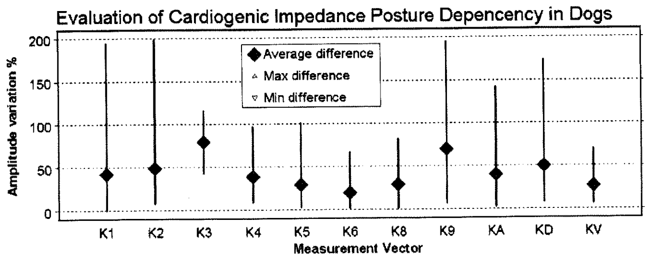
can alter signal amplitudes. Therefore, to ensure accurate results, it is essential to choose an appropriate measurement configuration and consider body posture and activity.



19-11

Efficiency of 90 Joules vs 130 Joules pulsed biphasic in out-of-hospital cardiac arrest

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Low energy shocks for the treatment of out-of-hospital cardiac arrest is mandatory to decrease the possible shock related myocardial damage and to reduce the equipment size and weight. A study has been performed to compare the efficiency of 90 as opposed to 130 Joules (J) to defibrillate patients in out-of-hospital cardiac arrest in collaboration with the fire brigades of Nancy (France), between April 2001 and January 2004. A preliminary study on 157 patients showed that a "call to patient's side" delay was 10.1±7.5 min. The defibrillation pulse was a US patented pulsed biphasic waveform. The patients were classified in two groups each composed of three energy levels: Group A consists of 119 patients in whom the first shocks was: 90 Joules, Group B consists of 129 patients receiving 130 J as the first shock. The termination of VF was studied at 5, 15, 30 s relatively to the first energy level used in each group.
Conclusion Energies as low as 90 J are able to defibrillate a large proportion of patients stressing the value of the new waveform. The difference in shock efficiency in the treatment of out of hospital cardiac arrest does not reach statistical significance but shows a tendency towards the benefit of 130 J as opposed to 90 J to defibrillate VF.

Time (s)	Group A (%)	Group B (%)	P	
5	77.3	86	0.07	NS
15	74	79.8	0.27	NS
30	69	72.9	0.49	NS

19-12

Prognostic significance of pro BNP test in patients with CHF. High values are related to prognosis, ICD discharges

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Introduction ProBNP is currently applied in the management and risk stratification of patients with CHF, and in the effectiveness evaluation of devices therapy (DT).
Patients and Methods In the SHAPE project, two groups of CHF patients were evaluated: Group A) 160 consecutive non selected patients, Group B) of 19 patients with CHF and an ICD) 7 patients, with VVI or CRT therapies.
Results In Group A, in the 20 patients with a proBNP of more than 2,500–3,000 pg/ml, we observed five episodes of HF and two CD in the following 3 months, four recurrences of minor CHF, in the group with a proBNP value betweeen 2,500 and 1,500. No problems or clinical recurrences, were observed below 500 or less of proBNP. In the range between 501 and 1,500 pg/ml, all the patients had history of cardiac disease, CHF or abnormal EF%, but no clinical episodes were observed. In Group B, 6/19 with appropriate discharges or ATP treatments, were observed with a mean value of proBNP of 2,000±560 pg/ml. In one patient, with a reduced value of proBNP, a severe hypokalemia was the cause of the arrhythmic storm and of ICD discharges. Conversely, no discharges were observed in 13/19, with a mean value of 450±550.
Conclusions Patients, with appropriate DT interventions, show higher mean value of proBNP. Thus, patients with unstable CHF, as documented by high blood peptide values, are at high risk of ventricular arrhythmias.

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ECAS 2008 ABSTRACT

Value of pulsed biphasic defibrillation shocks for the treatment of Out-of-Hospital Cardiac Arrest

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Purpose Effectiveness of Biphasic Defibrillation Waveform (BDW) shocks for the treatment of Out-of-Hospital Cardiac Arrest (OHCA) has been proven to be more effective than monophasic in clinical practice [1]. The goal of this work is to study the safety and efficacy of a new pulsed biphasic waveform (PBW) on patients in OHCA using ERC 2005 Guidelines.

Materials and Methods A two-tiered emergency district (Nancy, France, 258,000 inhabitants) was involved between July and December 2006 where 84 patients experienced OHCA. The ROSC and discharge from the hospital is compared to data from the literature. *t* test is used to compare outcomes with literature.

Results Fifty-four OHCA (64%) have been witnessed (18 rescuer witnesses). Twenty-one (25%) who experienced OHCA had documented witnessed VF. The call-to-shock time was 17.9 min (±7.7), median=16 min (min=11 min, max=41). Fourteen of the witnessed OHCA patients (67%) received bystander CPR, six of them (28%) were rescuer witnesses. Half of VF patient events took place at home (n=10, 48%), 9 (43%) in public places. Fourteen (58%) had ROSC at any time of intervention. Eleven (46%) patients had ROSC at arrival and were admitted to the hospital. Discharge is known for ten patients, four (19%) were discharged alive without neurological alteration. None of ROSC and discharge outcomes lead to significant value: (ROSC in [1]: 61% over 51 patients [p=0.25], [2]: 69% for 29 patients [p=0.11]; discharge in [1]:14% over 51 patients [p=0.6], [2]: 31% for 29 patients [p=0.34]). The delays were higher in this study as compared to [1] (median=8 min) and [2] (average 6.3± 1.5 min [p<0.0001]).

Conclusions Despite disadvantaging call-to-shock delay, this study using PBW in Out-of-Hospital Cardiac Arrest combined with ERC 2005 Guidelines, showed comparable outcomes to standard biphasic waveforms.

References

1. Van Alem, A. P., et al. (2003). *Resuscitation*, *58*, 17–24.
2. Gliner, B. E., & White, R. D. (1999). *Resuscitation*, *41*, 133–144.

* This abstract is part of the Fourth Annual Congress of the European Cardiac Arrhythmia Society, April 13–15, 2008, Marseille, France, Palais des Congrès Parc Chanot.

Circulation

RESUSCITATION SCIENCE SYMPOSIUM ABSTRACTS
SESSION TITLE: BEST ORIGINAL RESUSCITATION SCIENCE POSTER SESSION

Abstract 219: Combination of Algorithms to Decrease Preshock Pause for Automated External Defibrillators

Jean-philippe Didon, Irena Jekova, Sarah Ménétré, Todor Stoyanov, Vessela Krasteva

Circulation. 2011;124:A219

Abstract

BACKGROUND Long pre-shock 'hands-off' intervals without chest compressions (CC) are associated with defibrillation failure. Current guidelines recommend shortening the 'hands-off' intervals. The aim of this study is to present the performance of a Shock advisory System (SAS) which is designed for triggering a fast ECG analysis at minimal delay after the end of chest compression (EoCC).

METHOD A subset of 1263 strips is identified from 311 Out-of-hospital cardiac arrest (OHCA) interventions. AED rhythms include 1182 Non-Shockable strips (788 asystoles (ASYS), 394 other non-shockable rhythms (ONS)), and 81 ventricular fibrillations (VF). The SAS with minimum 'hands-off' intervals first detect the real end of CC (ReEoCC) offset considered as the earliest triggering point for a reliable ECG analysis without CC artifacts. Then, it performs a fast ECG analysis to lead to "Shock/No shock" decision. Specificity (Sp) for ASYS and ONS and sensitivity (Se) for VF are computed

RESULTS The ECG analysis is triggered immediately at ReEoCC. The gain in time for earlier starting of the ECG analysis is found to be 5.6±3.6 seconds. The accuracy of the SAS is tested for 6 seconds analysis duration. The SAS "Shock/No shock" decision is provided 10.6±3.9 seconds earlier than the current AED decision. The SAS performance is compared to the AHA recommendations for Sp, Se and 90% one-sided lower confidence limit (LCL90) for noise-free signals (Table 1).

CONCLUSION The accuracy of SAS for fast ECG analysis at minimal delay after the end of CC fulfills the AHA goals (Sp/Se and LCL90) for ASYS, ONS and VF rhythms. A reduction of 'hands-off' time of 10.6 seconds (between end of CC and end of analysis) in average can be expected, when compared to current AED decision delay. Table 1: Accuracy of SAS with minimum 'hands-off' intervals

	ASYS		ONS		VF	
	Sp	LCL90	Sp	LCL90	Se	LCL90
Results	98.9% 779/788	98.2%	98.7% 389/394	97.8%	96.3% 78/81	92.8%
Goals	>95%	>92 %	>95%	>88 %	>90%	>87 %
Min Size	100		30		200	

Circulation

RESUSCITATION SCIENCE SYMPOSIUM
SESSION TITLE: SESSION XII: BEST ORIGINAL RESUSCITATION SCIENCE POSTER SESSION

Abstract 193: Transthoracic Impedance Patterns During Systole Reveal Changes in Cardiac Hemodynamics Using External Defibrillators

Jean-philippe Didon, Irena Jekova, Sarah Ménétré, Elina Trendafilova, Vessela Krasteva

Circulation. 2012;126:A193

Article Info & Metrics

Abstract

BACKGROUND: This study aims to test the Automated external defibrillators (AED) transthoracic impedance cardiogram (EICG) as a potential sensor for detection of compromised hemodynamics in different arrythmias (atrial fibrillation (AFIB), atrial flutter (AFL), ventricular tachycardia (VT)) vs. sinus rhythm (SR).

METHOD: ECG and ICG recordings via pads in antero-apical position from 106 patients with AFIB, AFL, VT, who received external cardioversion (ECV) with external cardioverter/defibrillator are retrospectively processed. EICG patterns are accumulated to compute EICG measures (maximal EICG velocity (dZ/dt-PEAK), ventricular ejection time (VET), ventricular ejection ratio (VER=VET/ RR interval)), static impedance (Z). Hemodynamical indices are collected: heart rate (HR), HR variability (HRV), systolic and diastolic blood pressure (SYS, DIA).

RESULTS: ANOVA test indicates that EICG measures significantly differ in AFIB, AFL, VT vs. SR (Table 1). Multiple linear regression shows that EICG measures are significantly dependent on hemodynamical indices (HR, HRV, SYS, DIA) with multiple correlation coefficient R=0.49 (VET), 0.54 (dZ/dt-PEAK), p<0.001, whereas Z is not correlated. Linear discriminant analysis (LDA) shows that a combination of dZ/dt-PEAK, VET, VER is able to discriminate either AFIB, or AFL, or VT from SR with respective accuracy of 92.8%, 93.9%, 99.1%.

CONCLUSION: EICG measures are significantly correlated to hemodynamical indices and are altered in AFIB, AFL, VT compared to SR. EICG is a potential sensor for compromised cardiac hemodynamics in AFIB, AFL, VT with a discrimination ability for VT vs. SR of 99.1%, but lower for AFIB and AFL vs. SR (around 93%).

	RHYTHM			
Measure	SR (N=106) Mean±Std.Err	VT (N=8) Mean±Std.Err	AFIB (N=74) Mean±Std.Err	AFL (N=24) Mean±Std.Err
dZ/dt-PEAK (Ω/s)	2.51±0.09*	1.41±0.33	1.50±0.11	1.38±0.19
VET (ms)	292±7*	168±25*	256±8	239±14
VER	0.323±0.009*	0.458±0.036	0.436±0.012	0.423±0.021
Z (Ω)	94±2	108±8	93±3	99±4

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ISCE Poster Session I

Detection performance of an automatic lead reversal detection module

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Background: Lead reversal and lead mismatch can simulate ECG abnormalities such as ectopic beats, intraventricular conduction disturbances, chamber enlargement or ventricular pre-excitation. Further simulation or concealing of myocardial ischemia or infarction might be seen on the ECG trace as well which might lead to the wrong decision of therapy. Lead reversal such as right arm (RA) and left arm (LA) usually can be detected by an experienced ECG reader or by computer algorithms. In such cases, a second ECG can be taken. Lead reversal has been reported to occur in 0.4–4% of all cases in standard 12-lead ECGs.

Methods: We performed a retrospective analysis of 532 16-lead ECGs including standard 12-lead plus right precordial leads V3r and V4r as well as the posterior leads V8 and V9. The ECGs were acquired from chest pain patients at an emergency department. The ECG device did not give any feedback to the user with respect to lead reversal or lead mismatch at all before, during or after acquisition. A lead reversal detection module based on correlation analysis of 3 subsets within the acquired 16 ECG leads was investigated. The numbers of possible lead reversal in each subset were computed.

Results: We found in 24 cases possible lead reversal in the standard limb leads (I, II, III, aVR, aVL, aVF), 40 in the standard chest leads (V1–V6) subset of the standard 12-lead, 99 in the subset of V3r and V4r and 43 in the V8 and V9 subset. Therefore, the amount of possible lead reversal found was 5%, 8%, 19% and 8% in the corresponding lead subset with the highest number in the right precordial leads V3r and V4r.

Conclusions: Lead reversal might be much higher than estimated. Clinically accepted lead systems that are known and used since some time such as the standard 12-lead system give compared to the combinations of possible mistakes the lowest relative lead reversal number.

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Detection of atrial fibrillation using contactless facial videoplethysmography

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[b]*Xerox Corporation, Webster, NY*

Introduction: We developed a new method to measure the beat-to-beat blood pulse based on non-contact video recordings of a patient's face. We hypothesize that the accuracy of this technology enables the detection of increased blood pulse variability due to the presence of atrial fibrillation (AF).

Methods: We enrolled adult patients referred for electrical cardioversion to treat persistent AF. We simultaneously recorded 12-lead Holter ECGs and video of the patients' face at a distance of ~4 feet prior, during and after the procedure. We extracted the beat-to-beat pulse rates expressed as pulses per minute (ppm) by detecting the subtle variation of the skin color of the patients' face: videoplethysmography (VPG). The ECG signal was used as a reference to compare the variability of the heart rate (RR intervals) to the pulse rate (pulse peak intervals) using 5 parameters standard deviation of intervals (SDRR), root means square of successive differences of intervals (RMSSD), Shannon entropy (ShE), standard deviation of the minor axis (SD1) and of the major axis (SD2) of the Lorentz plots of these intervals. We extracted two stable 15-second signals per patient one before (AF) and one after (sinus) successful cardioversion. Stability was defined by the absence of patient's head movement.

Results: Stable recordings from 10 subjects (64 ± 6 years, 7 males) were analyzed. The VPG and ECG-based heart and pulse rates were not statistically different: 74 ± 25 vs. 73 ± 23 bpm (p = 0.44) during AF, and 55 ± 12 vs. 54 ± 12 ppm (p = 0.4) during sinus rhythm. All ventricular contractions during sinus rhythm were detected using the VPG signals. During AF, 2% of the cardiac beats measured on the ECG signals were undetected on the VPG signal. A consistent and significant decrease in beat-to-beat pulse variability was measured in the VPG signals after successful cardioversion for SDRR (133 ± 89 vs. 51 ± 24, p = 0.002), RMSSD (176 ± 90 vs. 70 ± 34, p = 0.002), SD1 (129 ± 58 vs. 51 ± 23, p = 0.002), and SD2 (139 ± 74 vs. 46 ± 17, p = 0.002).

Conclusions: Our preliminary results support the concept that contactless video-based monitoring of human face for the detection of abnormal pulse variability due to AF is feasible.

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The predictive power of ECG metrics for bradyasystolic cardiac arrest

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Objectives: We investigated 10 metrics derived from four leads of electrocardiographic (ECG) signals from hospital patient monitors to study their power for predicting adult bradyasystolic cardiac arrests.

Methods: A retrospective case–control study was designed to analyze 10 ECG metrics from 22 adult bradyasystolic and their 303 control patients. The 10 metrics were PR interval, P-wave duration, QRS duration, RR interval, QT interval, estimate of serum K+ using only frontal leads (SerumK2), T-wave complexity, and ST segment levels for leads I, II, V1 (ST I, ST II, ST V1), most of which are not available from patient monitors. We used four ECG lead signals from hospital patient monitors, sampled at 240 Hz. A software program provided by Mortara Instrument was used to automatically extract the metrics. A robust linear fitting of the time series of these metrics was implemented to obtain the slopes of consecutive trending windows of each metric. True positive rate (TPR) and false positive rate (FPR) of absolute values of slopes of these metrics were derived to evaluate their predictive power.

Results: Sliding analysis windows of 5 minutes was used to extract the metrics from the time series signal, and successive windows overlapped by 4 minutes. Slopes were derived from 2-hour trending windows of each metric. It was observed that each metric could achieve a TPR of at least 4.6% with an FPR no more than 1.8%. Specifically, QRS duration (absolute value of slope >21.3 ms/hour), ST I (absolute value of slope >53.3 ms/hour), and ST II (absolute value of slope >87.2 ms/hour) achieved a TPR of 13.6% (FPR = 1.7%), 13.6% (FPR = 1.3%), and 9.1% (FPR = 0.8%), respectively.

Conclusions: ECG metrics in addition to what are available from patient monitors are able to detect a small subset of patients with bradyasystolic

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