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Biometric verification by cross-correlation analysis of 12-lead ECG patterns: Ranking of the most reliable peripheral and chest leads

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Abstract

Background: Electrocardiogram (ECG)-based biometrics relies on the most stable and unique beat patterns, i.e. those with maximal intra-subject and minimal inter-subject waveform differences seen from different leads. We investigated methodology to evaluate those differences, aiming to rank the most prominent single and multi-lead ECG sets for biometric verification across a large population.
Methods: A clinical standard 12-lead resting ECG database, including 460 pairs of remote recordings (distanced 1 year apart) was used. Inter-subject beat waveform differences were studied by cross-correlation and amplitude relations of average PQRST (500 ms) and QRS (100 ms) patterns, using 8 features/lead in 12-leads. Biometric verification models based on stepwise linear discriminant classifier were trained on the first half of records. True verification rate (TVR) on the remaining test data was further reported as a common mean of the correctly verified equal subjects (true acceptance rate) and correctly rejected different subjects (true rejection rate).
Results and conclusions: In single-lead ECG human identity applications, we found maximal TVR (87–89%) for the frontal plane leads (I, −aVR, II) within (0–60°) sector. Other leads were ranked: inferior (85%), lateral to septal (82–81%), with intermittent V3 drop (77.6%), suggesting anatomical landmark displacements. ECG pattern view from multi-lead sets improved TVR: chest (91.3%), limb (94.6%), 12-leads (96.3%).

Keywords: ECG biometrics; Human identity recognition; Cross-correlation analysis; QRS, PQRST patterns; Linear discriminant analysis; True verification rate

Introduction

In the last decade the electrocardiogram (ECG) based biometrics is a field of active research, focused on numerous applications in remote healthcare monitoring [1] with biosensors integrated into mobile devices [2,3], wearable smart watch-type devices [4], secure wireless body area sensor networks [5,6], and continuous authentication applications with adaptive strategies to follow individual beat variations in 24 h ECG recordings [7]. Other applications utilize the unique beat behavioral in short duration ECG recordings over 15–120 s in one-lead configuration for finger-based ECG biometrics [8–10] and merely 10s in 12-lead configuration for patient validation support and error screening of digital 'in-hospital' ECG databases [11]. The ECG, being continuously available, low-cost and routine acceptable physiological measurement, is considered to exhibit personalized beat patterns of electrical activity in respect of timing and geometry that could be, however, affected by a number of physiological factors, including age, body weight, stress, activity and cardiac abnormalities [1,12,13]. State-of-the-art research reveals the validity of single and multi-lead ECG for human biometrics in both verification [2,4,6–15] and identification [3,10,13,14,16–19] scenarios when persons with known and unknown identity are recognized, respectively.

The ECG biometric features are either morphological or waveform based. The former include temporal, amplitude, area and angle features of fiducial points over the PQRST pattern [2,10], whose correct measurement could be ensured by certified commercial ECG analysis software [11] and device [16]. Waveform-based features are calculated over the whole PQRST pattern by Euclidean distance [15], autocorrelation [9], cross-correlation [4,12,13,18,19], wavelet decomposition [3], short-time Fourier transform and log-likelihood ratio [8], or are fully independent from the fiducial point detection, using an autocorrelation over long parts of the signal, followed by a

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

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A R T I C L E I N F O

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A B S T R A C T

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 (ReEoCC); 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.

1. Introduction

Current use of automated external defibrillators (AEDs) is not only dedicated to deliver electrical shocks to victims of sudden cardiac arrest due to ventricular fibrillation (VF), but also to support the rescuer team during the intervention. AED instructions follow a standard basic life support (BLS) protocol, including cardiopulmonary resuscitation (CPR) as a series of chest compressions (CC) interrupted by insufflations. On a regular basis, however, CPR is stopped to allow the AED shock advisory system (SAS) to analyze the patient rhythm on an artifact free electrocardiogram (ECG) aiming at accurate indication for shock or immediate CPR resumption.

The importance of early CPR jointly with defibrillation within 3 to 5 min of collapse has been highlighted in ERC Guidelines for Resuscitation. In addition to 2005 Guidelines,[1] 2010 Guidelines[2,3] recommend to minimize interruptions in CC during the entire resuscitation attempt. These hands-off intervals with no blood flow and significant drop of the coronary perfusion pressure have been reported to reduce the likelihood of successful defibrillation in animal and human studies.[4,5]

Pre-shock pauses required for ECG analysis in the AED are one important cause of CC interruption. Decreasing the duration of pre-shock analysis would help to minimize interruptions of chest compressions. A relationship has been found between improved defibrillation success and shorter pre-shock pauses. In a multicenter observational clinical study,[6] shock efficacy increased from 38% to 94% when pre-shock pause decreases from more than 30 s to less than 10 s. Another study reports increased likelihood of return of spontaneous circulation (ROSC) with pre-shock pauses of less than 3 s in OHCA.[7]

Pre-shock pauses can be decreased by changing the scheduling the tasks performed during CPR. In DEFI 2005,[8] Jost et al. used a standard SAS slipped into the CPR series of CC 30 s before the intended shock delivery. These 30 s are used to charge the capacitor. When delivered, the shock benefits from a reduced delay after the actual end of CC from 19 to 9 s. The shock efficacy in both of these groups is not known. Although the control arm of the

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E-mail address: jean-philippe.didon@schiller.fr (J.-P. Didon et al.).

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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 $95.9 \pm 18.9\ \mathrm{min}^{-1}$, mean depth 4.13 ± 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 for Heart Rhythm Analysis During Cardiopulmonary Resuscitation Using a Single ECG Input of Automated External Defibrillators

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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 arrest (OHCA), Chest compression artefacts, Shockable and non-shockable rhythms, Time and frequency ECG analysis, AED, CPR.

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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 systems (SASs).[3,6,11,19] Therefore, the current practice recommends CPR interruption when it is necessary to assess the rhythm[7] thus providing noise-free ECGs as required for a reliable shock/no-shock decision in AEDs.[21] The adverse effects of the "hands-off" intervals during the regular AED analyses are associated with intermittent lack of cerebral and myocardial blood flow that was reported to be deleterious to the

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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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Online Digital Filter and QRS Detector Applicable in Low Resource ECG Monitoring Systems

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Abstract—The present work describes fast computation methods for real-time digital filtration and QRS detection, both applicable in autonomous personal ECG systems for long-term monitoring. Since such devices work under considerable artifacts of intensive body and electrode movements, the input filtering should provide high-quality ECG signals supporting the accurate ECG interpretation. In this respect, we propose a combined high-pass and power-line interference rejection filter, introducing the simple principle of averaging of samples with a predefined distance between them. In our implementation (sampling frequency of 250 Hz), we applied averaging over 17 samples distanced by 10 samples (*Filter10x17*), thus realizing a comb filter with a zero at 50 Hz and high-pass cut-off at 1.1 Hz. *Filter10x17* affords very fast filtering procedure at the price of minimal computing resources. Another benefit concerns the small ECG distortions introduced by the filter, providing its powerful application in the preprocessing module of diagnostic systems analyzing the ECG morphology. *Filter10x17* does not attenuate the QRS amplitude, or introduce significant ST-segment elevation/depression. The filter output produces a constant error, leading to uniform shifting of the entire P-QRS-T segment toward about 5% of the R-peak amplitude. Tests with standardized ECG signals proved that *Filter10x17* is capable to remove very strong baseline wanderings, and to fully suppress 50 Hz interferences. By changing the number of the averaged samples and the distance between them, a filter design with different cut-off and zero frequency could be easily achieved. The real-time QRS detector is designed with simplified computations over single channel, low-resolution ECGs. It relies on simple evaluations of amplitudes and slopes, including history of their mean values estimated over the preceding beats, smart adjustable thresholds, as well as linear logical rules for identification of the R-peaks in real-time. The performance of the QRS detector was tested with internationally recognized ECG databases (AHA, MIT-BIH, European ST-T database), showing mean sensitivity of 99.65% and positive predictive value of 99.57%. The performance of the presented QRS detector can be highly rated, comparable and even better than other published real-time QRS detectors. Examples representing some typical unfavorable conditions in real ECGs, illustrate the common operation of *Filter10x17* and the QRS detector.

Keywords—Real-time ECG analysis, ECG preprocessing, High-pass filtering, Baseline wander, Power-line interference filtering, QRS detection, ECG monitoring of high-risk cardiac patients.

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INTRODUCTION

The long-term electrocardiogram (ECG) monitoring of high-risk cardiac patients by computer-assisted bedside or ambulatory systems, demands for fast and real-time ECG analysis methods, providing high-fidelity of the automated cardiac diagnosis. The scope of the present article is focused on the two basic preprocessing steps—filtering and the QRS detection, both defining the quality of the input of the ECG interpretation module.[14]

The adequate preprocessor filter design must provide maximal artifact rejection with minimal ECG distortions. However, the spectra of ECG and artifacts in their variety often overlap,[30] implying that there would be a compromise depending on the specific application. For example, the baseline wander (BW), frequently induced by motion and respiratory artifacts in long-term ECG recordings, is insufficiently suppressed by the 0.05 Hz low-frequency cutoff for diagnostic electrocardiography,[25] recommended mainly to preserve the fidelity of the low-frequency ECG components during repolarization (ST-segment). Better BW reduction is achieved in the ECG rhythm monitors, for which the recommendations are less severe, allowing (0.67–1 Hz) low-frequency cutoff at the price of markedly distortion of the repolarization and even the QRS complex amplitude.[11] The latter compromise is acceptable for the systems, working under considerable artifacts of intensive body and electrode movements,

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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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Real-time detection of pathological cardiac events in the electrocardiogram

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Abstract

The development of accurate and fast methods for real-time electrocardiogram (ECG) analysis is mandatory in handheld fully automated monitoring devices for high-risk cardiac patients. The present work describes a simple software method for fast detection of pathological cardiac events. It implements real-time procedures for QRS detection, interbeat RR-intervals analysis, QRS waveform evaluation and a decision-tree beat classifier. Two QRS descriptors are defined to assess (i) the RR interval deviation from the mean RR interval and (ii) the QRS waveform deviation from the QRS pattern of the sustained rhythm. The calculation of the second parameter requires a specific technique, in order to satisfy the demand for straight signal processing with minimum iterations and small memory size. This technique includes fast and resource efficient estimation of a histogram matrix, which accumulates dynamically the amplitude-temporal distribution of the successive QRS pattern waveforms. The pilot version of the method is developed in Matlab and it is tested with internationally recognized ECG databases. The assessment of the online single lead QRS detector showed sensitivity and positive predictivity of above 99%. The classification rules for detection of pathological ventricular beats were defined empirically by statistical analysis. The attained specificity and sensitivity are about 99.5% and 95.7% for all databases and about 99.81% and 98.87% for the noise free dataset. The method is applicable in low computational cost systems for long-term ECG monitoring, such as intelligent holters, automatic event/alarm recorders or personal devices with intermittent wireless data transfer to a central terminal.

Keywords: electrocardiography, monitoring of high-risk cardiac patients, real-time ECG analysis

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Transthoracic impedance study with large self-adhesive electrodes in two conventional positions for defibrillation

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Abstract

The external defibrillation requires the application of high voltage electrical impulses via large external electrodes, placed on selected locations on the thorax surface. The position of the electrodes is one of the major determinants of the transthoracic impedance (TTI) which influences the intracardiac current flow during electric shock and the defibrillation success. The variety of factors which influence the TTI measurements raised our interest to investigate the range of TTI values and the temporal TTI variance during long-term application of the defibrillation self-adhesive electrodes in two conventional positions on the patients' chest—*position* 1 (sub-clavicular/sub-axillar position) and *position* 2 (antero-posterior position). The prospective study included 86 randomly selected volunteers (39 male and 49 female, 67 patients with normal skin, 13 patients with dry skin and 6 patients with greasy skin, 16 patients with chest pilosity and 70 patients without chest pilosity). The TTI was measured according to the interelectrode voltage drop obtained by passage of a low-amplitude high-frequency current (32 kHz) between the two self-adhesive electrodes (active area about 92 cm^2). For each patient, the TTI values were measured within 10 s, 1 min and 5 min after sticking the electrodes to the skin surface, independently for the two tested electrode positions. We found that the expected TTI range is between 58 Ω and 152 Ω for *position* 1 and between 55 Ω and 149 Ω for *position* 2. Although the two TTI ranges are comparable, we measured significantly higher TTI mean of about (107.2 ± 22.3) Ω for *position* 1 compared to (96.6 ± 19.2) Ω for *position* 2 ($p = 0.001$). This fact suggested that the antero-posterior position of the electrodes is favourable for defibrillation. Within the investigated time interval of 5 min, we observed a significant TTI reduction with about 6.9% (7.4 Ω/107.2 Ω) for *position* 1 and about 5.3% (5.1 Ω/96.6 Ω) for *position* 2. We suppose that the long-term application of the self-adhesive electrodes would lead to improvement of the physical conditions for the conduction of the defibrillation current and to diminution of the energy loss in the electrode–skin contact impedance. We found that gender is important when the *position 1* is used because women have significantly higher TTI (111 ± 20.3) Ω compared to the TTI of men (102.6 ± 24) Ω ($p = 0.0442$). Although we found some specifics of the electrode–skin contact layer, we can conclude that because of the insignificant differences in TTI, the operator of the defibrillator paddles does not need to take into consideration the skin type and pilosity of the patients. The analysis of the correlations between TTI and the individual patient characteristics (chest size, weight, height, age) showed that these patient characteristics are unreliable factors for prediction of the TTI values and optimal defibrillation pulse parameters and energy.

Keywords: transthoracic electrical impedance, defibrillation, PAD electrodes, low-amplitude high-frequency current, pre-shock measurement

1. Introduction

The electrical therapy of the heart, including pacing and defibrillation, is a widespread and well-established procedure for resuscitation of cardiac arrest victims (International Liaison Committee 2000). The therapy can be conducted by either direct contact or indirectly through the thorax surface. The first method requires an invasive intervention aiming at implantation and permanent monitoring. The latter technique is also referred to as external approach. Its noninvasive nature makes it easily accessible and suitable for emergency cases. An example of such a technique is the public access defibrillation. The external electrical therapy requires the application of high voltage electrical impulses via external electrodes, placed on selected locations on the thorax surface. The electrodes have a large contact area (70–120 cm^2) (Geddes *et al* 1976) and provide high and supposedly a uniform current density distribution in the heart. It is needed for excitation of sufficient mass of myocardial cells to force them to return to normal rhythm.

Obviously, higher energies are required for successful intervention when pulses are delivered from a more remote site. Higher energy also implies chest muscle contraction, pain and risk of thermal injuries in the vicinity of the electrodes. Therefore, the design of special paddles, e.g. preference for circular edge electrodes rather than square ones, use of contact gel or an interface layer of intermediate resistivity, or addition of a high-resistivity perimeter ring (Krasteva and Papazov 2002), may be required in order to limit harmful side-effects from the nonuniform current density distribution.

The defibrillator load impedance, which includes the electrode–skin and the patient transthoracic impedance (TTI), determines the current amplitude, the energy delivered and consequently the defibrillation success (Dalzell *et al* 1989, KenKnight *et al* 1995, Kerber *et al* 1996, Savino *et al* 1983). Lower energy requirement for defibrillation was observed in patients with low TTI (Kerber *et al* 1984). Different techniques for the prediction of the TTI before or during defibrillation were used in the design of current-based defibrillators (Monzón and Guillén 1985, Dalzell *et al* 1989, Kerber *et al* 1996), 'impedance-compensating' defibrillators with automatic control of the output energy (Kerber *et al* 1988) and defibrillators with adaptive modulation of the high-frequency chopping pulses (Krasteva *et al* 2003). Prediction equations were developed based on the statistical comparison between the

Letters to the Editor

On the Optimal Defibrillation Waveform—How to Reconcile Theory and Experiment?

Vessela Tz. Krasteva and Peter L. M. Kerkhof

***Abstract*—Medical intervention by electrical current as applied to humans or animals may have tremendous therapeutic impact if delivered while being carefully controlled. Otherwise, the situation can be harmful in terms of injury or even become lethal. These consequences demand close inspection of all relevant biological and technical factors. Regarding methods to counter fibrillation of the heart substantial progress has been made, but defining a gold standard for the waveshape and energy delivery remains a serious challenge. The anticipated answer is not simply a range somewhere between a maximum and a minimum, but most likely an "intelligently" selected case-specific optimum, delicately positioned between effective and unsafe. Combining insight from theory with pertinent experimental findings may offer a clearer view on an unresolved issue that often points to a cross-road of life and death.**

***Index Terms*—Defibrillation waveform, emergency intervention, optimal design.**

I. Modeling Studies Regarding External Defibrillation

The theoretical design of the optimal defibrillation waveform would not pose a problem if the mechanisms involved in cardiac defibrillation were *a priori* clear. Unfortunately, like many other complex systems, the response of the heart to an electrical shock is an intricate combination of several unpredictable factors, including halting of fibrillation activation fronts, excitation or prolongation of refractoriness within a critical mass of myocardium, initiation of new activation fronts, and refibrillation, besides other factors. Modeling is not feasible before collecting basic information by means of appropriate experiments. Such an approach has already been pursued for a simple cell-response model in conjunction with the "charge-burping" hypothesis [1]–[4], which was founded on the empirical results derived from internal defibrillation studies. Later, Fishler [5] extended this lumped-component model to external defibrillation, supported by adequate mathematical formulations which transfer some theoretical predictions regarding the cardiac cell-response to various monophasic and biphasic waveshapes. Considering defibrillation as a threshold phenomenon, the basic idea for monophasic waveshape optimization is to search for the most energy efficient waveform that delivers a minimal amount of energy when a preset amount of charge is deposited to the cell membrane. Optimization for biphasic waveforms concerns two criteria: the optimal first phase, which is equivalent to the optimized monophasic shock, and the optimal second phase waveform, which again with minimal energy forces the transmembrane potential to return back to its resting state within a preset time interval. Otherwise, the theory indicates that any charge left on the cell membrane after the end of the defibrillation pulse would be proarrhythmic, i.e. predisposes to reinitiation of fibrillation. However, the reported modeling study [5] investigated only four types of waveshapes, i.h.c. ascending exponential, ascending ramp, rectangular and descending exponential (listed here in decreasing order of energy efficiency). With small adjustments, the underlying mathematical formulations could be applied as a powerful generic tool for designing alternative waveshapes, or predicting the performance of existing ones. The essential weak point, however, remains the experimental verification of the constituting theory. Although at the time of publication the absence of contradictions with available experimental studies was considered as important support, there could be added more direct confirmation by investigating the possible reconciliation of theory and practice.

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II. Experimental Verification

The study by Malkin *et al.* [6] was designed to fill this gap and to experimentally test Fishler's theoretical concept as discussed above, by conducting an extensive number of animal experiments concerning defibrillation. Two factors make their study unique and distinguishable compared to other published experimental research concerning defibrillation. First, the specific design of the tested defibrillation pulses, which have exactly the same waveshapes as those considered by Fishler from a theoretical point. Second, the pulses were selected to comprise a broad range of durations in order to cover a wide spectrum of energy efficacies, similar to predicted by the theory. The comparison between theory and experiment, however, needs a specific assumption, in order to fit the experimental success rate measured at fixed energy to the theoretical pseudo-threshold defined at several energy levels. This specific point was well established in the paper, although one general limitation can be perceived, namely the inevitable fact related to the unknown value of the myocardial cell membrane time constant. This constant is reported to amount up to 4 ms, presumably depending on the specific defibrillation conditions. This unknown quantity in the formulas provided by Fishler, who employs normalized time units by defining the duration-to-time-constant ratio, was interpreted in the work of Malkin *et al.* by choosing a particular value for the time constant that ultimately appears not to match closely enough the underlying tissue value. It remains obscure what the precise reasons were for assuming just one particular value for monophasic pulses, and assuming three other values for biphasic pulses. The latter considerably extended the number of experiments, thus reaching the reasonable maximum of trials that each animal can tolerate, but leaving untested some interesting options. For example, for biphasic pulses with constant first phase, the paper reports only about 10% improvement for the long duration second phase versus a short duration second phase. This finding partially supports the theoretical benefit of biphasic pulses, but does not answer several questions of paramount interest: 1) Is the superiority of a long second phase versus short second phase more preferably due to the delivery of more energy? 2) Is a second phase longer than the one previously defined likely to lead to a decline in efficacy, because the transmembrane potential underdamping is expected to be proarrhythmic? 3) Can the envisioned comparison of a waveshape with constant first phase and different second phases be considered as a solid proof of the theory, which was derived by scoring the efficacy of different waveshapes with fixed second phases to drive the transmembrane voltage back to zero? 4) What is the influence of the second phase over the efficacy of the

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Assessment of the stability of morphological ECG features and their potential for person verification/identification

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Abstract. This study investigates the potential of a set of ECG morphological features for person verification\identification. The measurements are done over 145 pairs of ECG recordings from healthy subjects, acquired 5 years apart (T1, T2 = T1+5 years). Time, amplitude, area and slope descriptors of the QRS-T pattern are analysed in 4 ECG leads, forming quasi-orthogonal lead system (II&III, V1, V5). The correspondence between feature values in T1 and T2 is verified via factor analysis by principal components extraction method; correlation analysis applied over the measurements in T1 and T2; synthesis of regression equations for prediction of features' values in T2 based on T1 measurements; and cluster analysis for assessment of the correspondence between measured and predicted feature values. Thus, 11 amplitude descriptors of the QRS complex are highlighted as stable, i.e. keeping their strong correlation (≥0.7) within a certain factor, weak correlation (<0.3) with the features from the remaining factors and presenting high correlation in the two measurement periods that is a sign for their person verification\identification potential. The observed coincidence between feature values measured in T2 and predicted via the designed regression models (r=0.93) suggests about the confidence of person identification via the proposed morphological features.

1 Introduction

Nowadays, research on automatic person identification is a rapidly developing area, considering not only the security requirements for the cases of financial transactions, access control, travelling, but also the remote health monitoring scenarios in the clinical and emergency medicine, as well as the organization and processing of hospital databases. The efforts of many researchers are focused on the application of internal body physiological biometric characteristics, which provide robustness to hacker attacks and falsification and are available in most of the health monitoring scenarios. The analysis of the electrocardiogram (ECG) in this respect started about a decade ago, applying either methods that use measurements after detection of fiducial points or analysis of the ECG morphology.

The fiducial-based approaches 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. According to the data cited in literature, the identification accuracy could reach values between 97% and 100%, based on the following analysis approaches: 12 uncorrelated diagnostic features of P-QRS-T amplitudes and durations, processed by Principle Component analysis score plots applied over a database with 20 subjects [1]; 15 P-QRS-T temporal features, fed to discriminant functions over 29 subjects under various stress conditions [2]; fiducial based temporal and amplitude measurements combined with features that capture the heartbeat patterns, tested over 31 healthy subjects: 18 with a single ECG record and 13 with more than one ECG record [3].

The fiducial independent approaches for person identification are based on assessment of the P, QRS, T waveforms similarity in the analysed ECG recordings by calculation of correlation coefficients, which are subsequently processed with different techniques. The achieved identification accuracy is: 100% via discrete cosine transform over a database with 14 subjects [4]; 96.2% provided by discriminant analysis over 61 subjects [5]; 91.4% [6] and 85.7% [7] via assessment of the maximal correlation coefficient of a single-lead ECG for 11 and 14 subjects, respectively, improved to 100% while 12-lead ECG is analysed for the database with 11 subjects [6].

Majority of the cited methods are tested with small-sized ECG databases [1,2,4,7] or track intra-subject changes of ECG characteristics measured in very short distanced time intervals or even in the same session

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Biometrics via Spatial P-QRS-T Loop Features: Effect of Different VCG Transformations

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Abstract

The objective of biometrics is to identify subjects based on physiological or behavioral characteristics. This paper considers the spatial P-QRS-T loops of the vector-cardiogram (VCG), aiming to identify the most reliable VCG-based features for human verification. We analyze clinical standard 12-lead resting electrocardiograms (ECGs) from 460 non-cardiac patients with 2 recordings (>1 year apart). We build human verification models for nine ECG to VCG transformations. This study gives clear justification that VCG is applicable for human biometrics with true verification rate TVR=83.5-91.4%. The 'Uijen' transformation has the best TVR for all VCG features (91.4%) and individual features for P-loop (70.9%), T-loop (77.1%), QRS-loop (89.6%), Frontal plane (84.5%), Sagittal plane (84.1%), 3D (91.1%), while 'Dower' and 'Kors' are the best for the Horizontal plane (84.5%).

1. Introduction

The objective of biometrics is to identify subjects based on physiological or behavioural characteristics, such as fingerprint, iris, face, voice, which however could easily be mimicked via fake finger, iris, face photos, playback, do not provide liveness detection [1] and are a topic for discussion on privacy protection [2]. The electrocardiogram (ECG) has been investigated as an advanced signal for human biometrics, presenting vital signs. The human verification or identification solutions employ a single ECG lead [3, 4], limb leads [5] or standard 12-lead ECG [6, 7], based on temporal and amplitude ECG features [6], cross-correlation analysis [5, 7], PQRST pattern matching [3, 4].

The spatial features of the cardiac vector represented by the vectorcardiogram (VCG) are expected to be useful for biometric applications, considering the inter-subject differences of the VCG loop orientation and shape, and its independence from the heart rate [8]. However, we could find a few studies based on VCG biometrics, all of them solving the human identification task, using:

- Support vector machine classifier, applied over QRS- and T-loop features derived via inverse Dower transform [9] or pseudo-inverse transform, including only the limb leads [10];
- Neural networks classifier, applied over equal distance descriptor coefficients or Fourier descriptor coefficients of the QRS-loop constructed by plotting the QRS in lead I (x-axis) against lead aVF (y-axis), i.e. the QRS-loop projection in the vertical plane [8].

This paper considers the spatial P-QRS-T loops of the VCG, aiming to identify the most reliable VCG-based features for human verification. Presuming that different techniques for transformation of 12-lead ECG to VCG [11-13] and P-QRS-T loops projections in the Frontal, Horizontal and Sagittal planes [14] have specific diagnostic significance, we aim to compare their effect on human verification.

2. ECG database

The study is using a proprietary clinical ECG database (Schiller AG, Switzerland), which contains two 10s-sessions of standard 12-lead resting ECGs from 460 non-cardiac patients (235/225 male/female, 18-106 years old), admitted in the emergency department of the University Hospital Basel during the period (2004-2009). The ECGs are recorded via the commercial ECG device SCHILLER (500Hz, 2.5μV/LSB, bandwidth 0.05-150Hz) at distant time sessions S1 and S2>S1+1year. The person verification scheme for comparison of subjects between S1 and S2 gives N=460 pairs with equal identity (ID) and N*(N-1)=211140 pairs with different ID. Our approach to handle the imbalance ratio (459:1) of different-to-equal ID pairs considers two independent datasets:

- *Training dataset*: 230/230 ECG pairs of equal/ different IDs, presuming that the verification classifier should be trained on the first half of subjects using balanced data, not over fitted to any of the classes.
- *Test dataset*: 230/210910 ECG pairs of equal/ different IDs, ensuring that unbiased classifier performance is further reported on a big dataset, including all available cases fully independent from the training.

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Multi-parametric Analysis for Atrial Fibrillation Classification in ECG

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Abstract

This study participates in the PhysioNet/CinC Challenge 2017 dedicated to the discrimination of atrial fibrillation (AF) from Normal sinus rhythm (Normal), other arrhythmia (Other) and strong noise using single short ECG lead recordings. Our Matlab entry applies multi-parametric AF classification based on: noise detection; heart rate variability analysis (HRV); beat morphology analysis after robust synthesis of an average beat and delineation of P, QRS, T waves; detection of atrial activity by the presence of a P-wave in the average beat and f-waves during TQ intervals. A Linear discriminant classifier is optimized by maximization of the Challenge F1 score, adjusting the prior probabilities of 4 classes and stepwise selection of a non-redundant feature set. Top-5 features, which contribute to >90% of F1 score are 3 HRV features, P-wave presence and mean correlation of all beats against the average beat. On the blinded test set, our entry has F1 score: 0.89 (Normal), 0.85 (AF), 0.67 (Other), 0.80 (Overall).

1. Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia, and is the major risk factor for death, stroke, hospitalization, heart failure and coronary artery disease [1,2]. It affects about 2-3% of the population in Europe [3]. The prevalence of AF increases with age (from about 0.14% of younger <49 years old, to about 14% of older >80 years old) and gender (male to female ratio is 1.2:1).

AF appears as a result of reentry within multiple circuits in the atria and reflects the electrocardiogram (ECG) with the occurrence of irregular multiform fibrillatory f-waves. Those f-waves are present in overall ECG, but are masked by the high amplitude QRS and T waves, thus could be observed only in TQ intervals, predominantly in V1, and occasionally in the peripheral leads. The extremely low, reaching to zero amplitudes of f-waves, makes the AF detection very difficult.

The AF detection is based on a single or multiple analyses for the presence of arrhythmia [4,5], rapid heart rate (HR), presence of f-waves in the isoelectric TQ interval [4,6,7] and absence of P-waves [8,9].

Some authors are paying attention to the noise that accompanies the ECG and its impact on the AF detection algorithms. Oster and Clifford [5] are analyzing the performance of the AF detection algorithms as a function of the QRS detection performance, RR interval irregularity, P-wave absence, f-waves existence, and in presence of noise. They are showing a linear decrease of the AF detection accuracy with reduction of the signal-to-noise ratio. Christov et al. [4] are reporting a false positive detection of their 'wave rectification method' in the presence of electromyographic (EMG) noise, and a false negative detection after EMG filtering.

The 2017 PhysioNet/CinC Challenge [10] provides the ground for competitive improvement of AF detection algorithms with extensive application: easily accessible single lead ECG; short analysis interval (10-60s); reliable AF discrimination from a broad range of sinus rhythms and non-AF arrhythmias; rejection of potentially unreliable classification in the presence of strong noises. This study participates in the Challenge, aiming to explore the feasibility of multi-parametric AF classification based on: noise detection; heart rate variability (HRV) analysis; beat morphology analysis after robust synthesis of an average beat and delineation of P, QRS, T waves; detection of atrial activity by the presence of a P-wave in the average beat and f-waves during the TQ intervals.

2. Challenge database

The Challenge provides a dataset with short single lead ECG recordings [10], including 8528 ECGs (training) and 3658 ECGs (hidden test) for scoring of 4 classes:

1) Normal sinus rhythm (Normal) – 5050 cases (59%)
2) Atrial fibrillation (AF) – 738 cases (9%)
3) Other arrhythmia (Other) – 2456 cases (29%)
4) Too noisy to be classified (Noise) – 284 cases (3%).

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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

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.

Assessment of the Potential of Morphological ECG Features for Person Identification

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Abstract

This study investigates the potential of ECG morphological feature set for person identification. The measurements are done over 145 pairs of ECG recordings from healthy subjects, acquired 5 years apart. Time, amplitude, area and slope descriptors of the QRS-T pattern are analyzed in 4 ECG leads, forming quasi-orthogonal lead system (II&III, V1, V5). The inter-subject variation, the difference of means in 1st vs. 2nd recording measurements, as well as the cross-correlation between features are estimated. Thus, 2 area and 4 amplitude descriptors of the QRS complex are highlighted. The population heterogeneity in the space of the selected features is verified via Factor analysis by Principal components extraction method. It confirms the orthogonality of the 6 features (each of them has significant factor loading for a particular factor). The analysis shows that the first 3 factors have eigenvalues higher than 1, both for the measurements in the 1st and the 2nd ECG recording and they accumulate respectively 68% and 64 % of the total data variation, which is a sign for their person identification potential.

1. Introduction

Nowadays, research on automatic person identification is focused on internal body physiological biometric characteristics, robust to hacker attacks and falsification. The analysis of the electrocardiogram (ECG) in this respect started about a decade ago, applying either methods that use measurements after detection of fiducial points or analysis of the overall ECG morphology.

The methods relying on fiducial based approach report: identification based on 12 uncorrelated diagnostic features of P-QRS-T amplitudes and durations, processed by Principle Component analysis score plots, achieved 100% identification accuracy (IDA) over a database with 20 subjects [1]; identification employing 15 P-QRS-T temporal features, fed to discriminant functions, providing IDA between 97% and 100% over 29 subjects under various stress conditions [2]; identification via fiducial based temporal and amplitude measurements combined with features that capture the heartbeat patterns [3]. The latter combined approach provides 100% IDA when tested over 31 healthy subjects: 18 with a single ECG record and 13 with more than one ECG record.

Great part of the fiducial independent approaches for identification is based on autocorrelation (AC). The subsequent processing with discrete cosine transform results in 100% IDA over a database with 14 subjects [4]; application of discriminant analysis [5] provides 96.2% IDA for 48 patients with single ECG recording and 13 healthy subjects with more than one ECG record; assessment of the maximal correlation coefficient of a single-lead assures 91.4% [6] and 85.7% [7] over databases with 11 subjects and 14 subjects, respectively, while 12-lead ECG assures 100% IDA over the database with 11 subjects [6]. Another method calculates the two-dimensional heart vector formed by the limb ECG leads and its first and second derivatives achieves 98.1% IDA by a distance based approach over 74 subjects [8]. Processing of a normalized QRS complex via Multilyer perceptron provides 96.1% IDA over a database with 30 healthy subjects [9]. ECG decomposition in a number of intrinsic mode functions combined with Welch spectral analysis for heartbeat features extraction, followed by a K-Nearest Neighbors classifier leads to 95.6% IDA over 108 subjects having one ECG record with ST-segment changes and 12 healthy subjects with more than one ECG record [10].

Majority of the cited methods are tested with small-sized ECG databases [1,2,4,7,9] or track intra-subject changes of ECG characteristics measured in very short distanced time intervals [2,3,5,9,10]. This might bias the reported high identification/verification accuracy from the real case scenario.

The aim of this study is to investigate ECG inter-individual differences observed in a set of morphological features in order to assess their potential for person identification. The study is conducted on a large ECG dataset, containing two different ECG recordings per subject acquired 5 years apart.

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 Kth 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:

$$(1)\ \text{Global Quality} = \underset{i=1}{\overset{\text{Nb Leads}}{\text{median}}}(\text{Lead Quality}_i)$$

$$(2)\ \text{Global Status} = \underset{i=1}{\overset{\text{Nb Leads}}{\min}}(\text{Lead Status}_i)$$

, where

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

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

Cardiac Autonomic Innervation Following Coronary Artery Bypass Grafting Evaluated by High Resolution Heart Rate Variability

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Abstract

Objective of this preliminary study is to propose a method to assess the status of autonomic nervous regulation and adaptation reserves of the body in patients with multivessel coronary artery disease (MCAD) in the preoperative and early postoperative period after CABG. A modified Indicator of the Activity of Regulatory Systems (IARS) has been used, whose value is determined by the estimated 5 HRV indices: heart rate (HR), standard deviation of examined normal RR interval (SDNN), geometrical HRV index, low frequency (LF) and very low frequency (VLF) bands of total HRV spectrum.

The results show: i. Significantly higher sympathetic tone towards the parasympathetic contour preoperative (p <0.001) and postoperative (p <0.0001), and this prevalence increases postoperative; ii. Parasympathetic tone is moderately suppressed preoperative and to a greater extend postoperative (p <0.05); iii. Compared to the moderate stress of the regulatory systems preoperative (IASR = 4.07), in the early postoperative period, they are in a state of high tone (IASR = 5.36; p <0.05), with increased activity of renin-angiotensin-aldosterone system to provide a higher adaptability of the organism.

1. Introduction

Surgical revascularization is the most commonly performed cardiac intervention. An important point in patients with coronary artery disease (CAD) is the decision about the type of revascularization - coronary artery bypass grafting (CABG) or percutaneous coronary intervention (PCI). Publications in literature are showing the benefits of CABG versus the PCI in terms of late mortality [1]. Surgical treatment is recommended most often when two or more branches (vascular systems) are affected and there are no contraindications for surgery [2]. Usually in patients with FC III-IV of NYHA conservative treatment is insufficient. The decision for surgical revascularization determines the currently growing interest in methods for finding informative features for cardiac surgery indication, prognosis and follow-up of the intervention. The ability of the vegetative nervous system (VNS) to respond to myocardial ischemia by increased activity of the efferent and afferent contours, is bringing it out to a forefront research in this aspect. Current goals are: to form a diagnosis of violations in the regulation of the sinoatrial node in patients with CAD for surgical treatment, tracking the dynamics of the condition of the patients postoperative, and to determine the risk of complications in cardiac surgery intervention. An opinion has been formed that the assessment of cardiac autonomic regulation may be an independent marker of success of the cardiac surgery [3-5]

Indicators of heart rate variability (HRV) are used to assess the state of the mechanisms regulating the physiological functions of the body, including: the total activity of the regulatory contours; the neuro-humoral cardiac regulation; and the autonomic balance - the ratio between the sympathetic and parasympathetic part of the autonomic nervous system (ANS). According to many authors, HRV is an integral indicator of the functional state of the cardiovascular system and the body as a whole [4,6,7].

Statistical (time) and spectral (frequency) indices are used in the analysis of HRV. More rarely complex quantitative indicators for an overall assessment of the variability are applied.

The index of total variability in the time domain (standard deviation of normal-to-normal RR intervals – SDNN) and the total spectral power (TP) have their independent significance for the overall assessment of HRV. Sets of indices or a complex indicator for the tone of the VNS contours are needed to assess their individual regulatory activity.

The evaluation of the activity of the parasympathetic part of the VNS is of great importance to the analysis of the functional status of patients with CAD. The parasympathetic activity defines the functional reserve of the body with coronary disease; it characterizes changes

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.

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.

Is there an Optimal Shape of the Defibrillation Shock: Constant Current vs. Pulsed Biphasic Waveforms?

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Abstract: *Three waveforms for transthoracic defibrillation are assessed and compared: the Pulsed Biphasic Waveform (PBW), the Rectilinear Biphasic Waveform (RBW), and the "lossless" constant current (LLCC) pulses. Two indices are introduced: 1) $k_f = W/W_0$ – the ratio between the delivered energy W and the energy W_0 of a rectangular pulse with the same duration and electric charge; 2) $\eta_C = W/W_{C0}$ – the level of utilizing the initially loaded capacitor energy W_{C0}. The envisioned comparative study shows that η_C index is favorable for both PBW and LLCC, while k_f of both RBW and LLCC demonstrates advantage over the PBW in the range of small inter-electrode thoracic impedances below 80 Ω. Some design considerations are also discussed. The attractive LLCC concept needs large and heavy inductive coil to support the constant current amplitude, besides it is capable to induce strong electromagnetic influences due to the complex current control. The RBW technology controls the delivery of current through a series of internal resistors which are, however, a source of high heat losses. The PBW implements controlled duty cycle of high-frequency chopped pulses to adapt the energy delivery in respect of the patient impedance measured at the beginning of the shock. PBW technology makes use of small capacitors which allows the construction of light weight and small-size portable devices for transthoracic defibrillation.*

Obviously, there is no outstanding optimal defibrillation waveform, however, the PBW technology reveals some advantages.

Keywords: *Defibrillation, Pulsed biphasic waveform (PBW), Rectilinear biphasic waveform (RBW), Lossless constant current pulses, Energy, Current.*

Introduction

Most of the sudden cardiac arrests begin with ventricular fibrillation [1-2]. In such cases an immediate defibrillation is recommended since each delay reduces the probability of patient survival [3].

About two decades ago, the public access defibrillation has been introduced as the only effective technique for immediate treatment of out-of-hospital cardiac arrest (OHCA) incidents [4]. Death from sudden cardiac arrest is preventable if bystander quickly retrieves and applies an automated external defibrillator (AED) before the arrival of the emergency medical services. Early defibrillation via AEDs can significantly improve the patient outcomes, including the rate of successful defibrillation, return of spontaneous circulation, survival to hospital discharge and the neurological recovery. The easy access and the use of AEDs by nonmedical first responders or lay bystanders, the portability of AEDs, as well as the AED's efficacy and safety are the major considerations in the International Resuscitation Guidelines [5-7].

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.*

Algorithm for Real-Time Pulse Wave Detection Dedicated to Non-Invasive Pulse Sensing

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Abstract

This study presents a simple algorithm for pulse wave PW detection dedicated to real-time pulse sensing devices in an emergency. Two basic principles are implemented – identification of extrema by time-amplitude criteria, and validation of the most prominent rising edges preceding the systolic peak according to criteria for slope and similarity to neighbors within 4 s. The pilot version of the algorithm (Matlab implementation) is developed and tested over independent subsets of arterial pressure PW signals from MGH/MF waveform PhysioNet database. Referring to ECG-synchronized beat annotations, the following performance is reported for the test set: positive predictivity PPV=96.4 %, sensitivity Se=98.9 % (443116/447983) for normal beats, Se=92 % (5522/6004) for supraventricular beats, Se=78.7 % (2834/3603) for premature ventricular beats, Se=97 % (27691/28547) for paced beats. The algorithm is also implemented in a prototype with photoplethysmographic (PPG) sensor for detection of carotid pulse from the neck region. It has been validated on 10 volunteers for whom ECG and PPG signals with duration of 10 s are superimposed to confirm 100 % coincidence between QRS and detected PWs. The results prove that the presented method is a reliable tool for non-invasive pulse sensing in an emergency.

1. Introduction

The pulse wave (PW), induced on each artery or vena by blood circulation, provokes three coherent events: blood flow (flow pulse), blood pressure change (pressure pulse) and extension of transverse profile (volume pulse) [1]. The PW typical morphology has a steep rising edge during systole and a falling edge with a dicrotic notch, followed by a dicrotic peak, concerned with diastole and wave reflections from the periphery. The PW contour is influenced by physiological conditions and diseases [2].

Studies with different levels of PW contour analysis are published, including detection of systolic peak [3-6], PW onset [7] and additionally dicrotic notch/peak [8, 9].

The systolic peaks are identified by detection of all PW extrema and consecutive validation of candidates by filtering adapted to the heart rate and rank-based features estimation [3] or analysis of the refractory period between detected local maxima [4]. Studies suggest improvement of the PW signal quality by pre-processing techniques based on wavelet cascaded adaptive filtration for baseline wander correction [5], moving averaging and template matching for smoothing of high-frequency fluctuation [6].

Considering that the strategy of only peak detection is inappropriate for studying PW velocity and delay after QRS, Zong et al [7] propose an algorithm to determine the PW onset by conversion of arterial blood pressure in a slope sum function and subsequent adaptive thresholding.

PW morphological analysis is used as a technique for assessing different vascular diseases. Detection of all fiducial points (onset, systolic peak, dicrotic notch/peak) is provided by more detailed evaluation of PW contours [8, 9]. The offline algorithm [8] incorporates information about the heart rate, amplitude and interbeat intervals to identify the locations of the different components on the intracranial pressure. The method in [9] calculates the derivative of arterial blood pressure to detect pairs of maximal inflection and zero-line crossing points which are then backwards validated as systolic peak and pulse onset according to combinatorial amplitude and interval criteria. The dicrotic notch is then detected right away.

Palpation of the carotid pulse is the traditional method for assessment of circulation in unresponsive cardiac arrest victim and any single determination of carotid pulselessness is the diagnostic step that immediately leads to the initiation of cardiopulmonary resuscitation. As advocated in resuscitation guidelines, the time for a single pulse check is limited to <10 s for healthcare providers and not recommended for lay rescuers [10]. The main consideration is the limited reliability of pulse palpation for confirming presence or absence of circulation.

This study aims at providing a tool for fast detection of carotid pulse in an emergency, including a simple algorithm for PW analysis embedded in a prototype with photoplethysmographic sensor. The algorithm is tested on annotated database with large excerpt of arrhythmias.

Profile of Autonomic Cardiac Control in Patients who are Not Considered Ready for Weaning from Mechanical Ventilation

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Abstract

This study tracks the global tendency of the heart rate variability (HRV) profile over five ventilation modes, aiming to find evidences on the hypothesis that patients who failed during the weaning process manifest important differences in the autonomic nervous system activity. This preliminary study enrols 17 patients (7 successful (S), 10 failure (F)) who underwent weaning with AVEA ventilator. Time- and frequency- domain HRV analysis is applied over 5-min ECG episodes recorded at the beginning of 5 ventilation modes: (1) controlled mechanical ventilation (CMV) on a sedated patient; (2) CMV on a sedated and paralyzed patient; (3) Pressure support ventilation with zero back-up pressure PSV(0); (4) PSV at 12-25 cmH$_2$O; (5) Spontaneous breathing trial (SBT) at 8 cmH$_2$O. Our results support the finding of other authors that during SBT, the patients who succeed in weaning show a prevalently sympathetic modulation, while relatively increased vagal activity is typical for the F-group. PSV(0) is however an outstanding test for which F-patients manifest about 3 to 20 fold increased sympathetic and vagal activity compared to the S-group.

1. Introduction

The weaning from controlled mechanical ventilation (CMV) 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 [1,2]. CMV discontinuation is a cardiovascular stress so that patients who failed at weaning manifest cardio-vascular insufficiency during the weaning attempt [3]. Analysis of cardiac autonomic control during weaning has been 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 [4] to unmask any existing abnormalities in one or several control mechanisms of the autonomic regulation response at different phases of the weaning [5-9].

Despite the introduction of several new ventilation modes, assist-control volume-cycled ventilation continues to be the most commonly applicable. However, regional differences are reported in the utilization of ventilation modes [10]. This preliminary investigation applies time and frequency domain HRV analysis during a weaning study with five different modes of mechanical ventilation, aiming to provide a global overview of the profile of the cardiac autonomic control and thus to observe the most outstanding changes which could predict whether the patient is ready or not to maintain spontaneous breathing trial (SBT).

2. Materials and methods

2.1. Study population

This study enrols patients undergoing weaning with AVEA ventilator system (Cardinal Health, USA) in the Central Intensive Care Unit of the University Emergency Hospital ‘N. Pirogov’, Sofia, Bulgaria from August 2011 to July 2012. The study population consists of 13 men and 4 women, mean age of 62.4±14.7 years, Simplified Acute Physiology Score (SAPS II) of 30.4±8. According to inclusion criteria, the enrolled patients do not have cardiac arrhythmias, neurological diseases, do not take pre-medication with cardiovascular drugs, and receive CMV for at least 72 hours prior the study. The decision to start weaning and weaning outcome has been made by the primary care physician following general weaning and extubation criteria [11]. All patients are divided into successful (S, n=7) and failure (F, n=10) group according to the weaning outcome at the 2nd hour of SBT, which is the final phase of the study protocol (as defined below).

Basic respiratory and hemodynamic parameters are measured by AVEA during the whole study, among which are blood pressure (SYS, DIA), respiratory rate (*f*).

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].

Cardiac Syndrome X Electrocardiographic Profile Using High-Resolution Signal-Averaged VCG

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Abstract

Cardiac syndrome X (CSX) is a clinical condition characterized by angina, positive stress test and negative coronary angiography. Myocardial ischemia is suggested to influence the typical ischemic changes in the electrocardiogram (ECG) observed during stress test. The aim of this study is to obtain CSX patterns of the vectorcardiographic (VCG) loops in the horizontal (H), frontal (F) and right sagittal (RS) planes of the Frank corrected orthogonal leads (X,Y,Z) and to assess their similarity with the reference VCG loops of normal subjects.

The results after synthesis of the VCG patterns in H, F, RS planes and identification of the magnitudes, angles and rotation of the maximal QRS and T vectors, as well as the angles of instant vectors at 0.01-0.04s suggest that CSX electrocardiographic profile could be considered as a variant of the normal profile, however, it contains some VCG changes seen in the ischemic heart disease.

1. Introduction

The concept of cardiac syndrome X (CSX) includes patients, mainly women before or in the period of menopause fulfilling the following three major criteria: chest pain, positive exercise-strain test, normal coronary angiogram [1-3]. The chest pain is a leading symptom of these patients, usually stronger and more prolonged than the typical angina pectoris which is also more difficult to control by the standard antiischemic therapy [4,5]. Impaired functional cardio-vascular capacity is usual for these patients. As a result, they are often re-hospitalised, new unnecessary angiograms are done and quality of life of these patients worsens [6].

Investigations on the prognosis of these patients show that their life-expectancy does not differ considerably from the rest of the population, excluding those with rhythm and conductance disorders like left-bundle branch blocks, as such patients is likely to develop dilated cardiomyopathy (NLHBI WISE study with mean duration of follow-up for 5.2 years) [7].

Analysis of the high-resolution vectorcardiogram (VCG) enables detection of electrical activity of individual and/or typical for patient group fragments of the cardiac muscle that opens up a possibility of developing a qualitatively new diagnostic method. Comparing VCG to the standard electrocardiogram (ECG), the former shows the advantage of having better sensitivity for analysis of the repolarization process and myocardial ischemia [8-10].

The signal-averaged VCG is an informative electrophysiologic method for assessment of the myocardial condition and for classification of an individual VCG patient profile either to a population of normal subjects or to a particular cardiac pathology. The aim of this study is to obtain CSX patterns of the VCG loops in the horizontal, frontal and right sagittal planes of the Frank corrected orthogonal leads (X,Y,Z) and to assess their similarity with the reference VCG loops of normal subjects.

2. Materials and methods

The study involved 56 high-resolution ECG recordings (1kHz) at rest collected from 28 women (mean age 55.3±9.5 years) using 12-channel ECG data acquisition system [11] in the Clinic of Cardiology, Medical University – Sofia, and in the Clinic of Cardiology, University Hospital of Emergency Medicine "Pirogov", Sofia, Bulgaria. All patients were with fulfilled criteria for CSX at the period of pre- or postmenopause and with "clear" coronary arteries verified from angiography or multi-slice computed tomography. Stratification by risk factors, comorbidity and pharmacological management have been done using a standardized protocol.

The study was based on assessment of the high-resolution Frank corrected orthogonal leads (X,Y,Z), synthesized from the 12-standard ECG leads by applying the transformations (1) [12]:

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

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.

Possibilities of signal-averaged orthogonal and vector electrocardiography for locating and size evaluation of acute myocardial infarction with ST-elevation

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ABSTRACT

Objective: The signal-averaged electrocardiography (SAECG) is known to be a useful tool for extraction and analysis of low-amplitude signal components. We found SAECG may be useful for precise location of the site of the myocardial necrosis and assessment of the severity of impaired left ventricular systolic function of patients with ST-elevation myocardial infarct (STEMI) in the acute phase.

Methods: High-resolution (1 MHz) ECG from 3 groups were collected: healthy controls (20), patients with anterior (17) and inferior STEMI (21). The three orthogonal leads X, Y, Z were synthesized from the 12 standard leads by known transformation. Synchronized averaging was carried out over hundred P-QRS-T intervals of each orthogonal lead. The resulting intervals of all subjects within a group were additionally averaged. The obtained X, Y and Z patterns, as well as the derived loops in the vectorcardiographic planes (VCG patterns) were studied for significant divergences.

Results: The summarized analysis presenting the possibilities of QRS- and T-vector indicators for correct classification of patients with STEMI shows that the determined discriminators classify correctly 91.4% of the examined patients. The optimized set of QRS-vector indicators for discrimination between healthy controls and patients with inferior STEMI include angle α of the maximal vector in both the sagittal and the horizontal plane. These two indicators show as high predictive value as all QRS-vector indicators – 82.9%. The optimized combination of QRS-vector indicators for discrimination between healthy controls and patients with anterior STEMI includes amplitude of the maximal vector in the frontal and sagittal planes, angle α of the maximal vector in the sagittal plane and the area of the loop in the frontal plane. This optimized combination has a common mean percentage of correctly classified patients of about 91.9%. The accuracy for infarct zone localization is improved with optimized combinations involving together QRS- and T-vector indicators. The achieved common mean percentages of correct classifications are 94.6% (healthy controls-anterior STEMI), 92.7% (healthy controls-inferior STEMI) and 97.4% (anterior STEMI-inferior STEMI). The set of all QRS-and T-vector indicators of patients with anterior STEMI regarding 2D-echocardiographic ejection fraction shows very high correlation coefficient, reaching about 0.99. In contrast, we did not find significantly high correlation in patients with inferior STEMI.

Conclusions: Both the signal-averaged orthogonal ECG and the synthesized on its basis VCG show markedly high sensitivity regarding location of ST-elevation myocardial infarct. The possibility for facilitated and fast performance of this examination in clinical conditions, including emergency, the lack of necessity of specially trained staff for carrying out the examination and interpretation of the results, as well as the very low prime cost, make this electrophysiological method very suitable for application in the routine clinical practice for qualitative and quantitative assessment of patients with acute coronary syndromes. *(Anadolu Kardiyol Derg 2007: 7 Suppl 1; 193-7)*

Key words: high-resolution signal-averaged electrocardiography, synthesized orthogonal electrocardiography, vectorcardiography, acute myocardial infarction.

Introduction

In principle, the signal-averaged high-resolution electrocardiography (SAECG) is a technique involving computerized analysis of small segments of a standard electrocardiography (ECG) in order to detect late potentials (1, 2). It allows subtraction and analysis of low-amplitude components in the signal, containing important diagnostics information, but inadmissible for analysis using conventional 12-channel ECG. The high resolution SAECG and vectorcardiography (VCG) were employed recently as methods for qualitative and quantitative diagnosis of patients with acute myocardial infarction (AMI). The existing scarce data in worldwide literature about quantitative assessment of patients with AMI by SAECG suggest very high diagnostic value of this method (3-6). In this research, we studied the possibilities to create standards, characterizing ST-elevation myocardial infarction with different location and size using synthesized from SAECG orthogonal X, Y and Z leads and VCG loops.

Methods

ECG Data

High-resolution (1 MHz sampling rate) ECG recordings were collected by 12-channel ECG data acquisition system (7) at the intensive coronary unit. The following groups were included in the study:

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Assessment of the Infarct Size in High-Resolution Electrocardiograms

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Abstract

The present study was focused on high-resolution orthogonal electrocardiography (HR-OECG) analysis for assessment of the zone of necrosis after acute myocardial infarct (AMI). We examined HR-OECG recordings of 13 healthy controls, 9 patients with anterior AMI and 13 patients with inferior AMI. The AMI size was evaluated by the enzyme levels of creatine kinase-common (CPK) and its MB-fraction (CPK-MB). Multiple regression models were derived where the observed enzyme level was the dependent variable and the predictor variables were selected among the defined morphological descriptors of the QRS-T pattern. Since the measured amplitudes and durations of the QRS-T pattern for the three leads of the HR-OECG recordings depend on the AMI localization, we investigated the discriminating ability of these OECG descriptors for recognition of the two studied AMI types - anterior and inferior. The results showed that some of the OECG descriptors, which were selected in the best regression models of the enzyme fractions, were also included in the best discriminating sets. The results of this study indicate the need for further investigations of the HR-OECG potential as a fast and accurate method for assessment of the AMI size and localization.

1. Introduction

The early prognosis of the patents' outcome during the acute phase of myocardial infarction (MI) is directly related to the size of the functioning myocardium. In patients without indications for previous MI attacks, the prognosis depends on the size of the damaged myocardium supplied by the culprit coronary artery distal to the occlusion. Non-invasive methods for evaluation of the MI size applicable at the bedside of the patient and providing fast, easy, and accurate measurements are recently moved forward.

During the last years, the high-resolution electrocardiogram (ECG) has been widely introduced in the clinical practice [1]. This method is based on computerized amplification, digital filtering and signal averaging of specific ECG segments. Thus even the low amplitude signal components become eligible for reliable analysis. The most common application of the high-resolution ECG is in studies of the late potentials of myocardial depolarization (i.e. the atrial or ventricular late potentials) [2].

The technique for ECG signal averaging involves accumulation of periodic signals such as the consecutive heart cycles in time. By adding many consecutive heart cycles, the overall noise components of the signal sum that are unsynchronized with the physiological pattern will decrease while the stable signal components remain unchanged. The suppression of the uncorrelated noise components is proportional to the square root of the number of the averaged cycles. Thus, by diminution of the ECG signal inherent noise, a specific steady pattern of the heart cycle is derived for the ECG recording of one patient. The enhanced cardiac cycles for a group of cardiac patients form a set of standard patterns with improved resolution. This set becomes a basis for further classification study with quantitative diagnostic aim. We applied the method in high-resolution ECG for assessment of the myocardium status after MI, particularly for evaluation of the size of the necrotic zone during the acute infarction phase.

The orthogonal electrocardiography (OECG) is an informative method for MI diagnostics - estimation of the localization and size, especially in cases of abnormal Q-waves and several necrotic zones [3,4]. A lot of quantitative OECG descriptors have been studied, providing different accuracy levels, i.e. specificity and sensitivity concerning the nosology of heart and the assigned diagnostic indices. We should note that clear OECG criteria for assessment of the myocardial condition have not been defined yet, as well as the set of the most informative parameters for precise evaluation of the zone of acute MI necrosis remains unspecified [5]. Therefore, we studied the possibility for reliable evaluation of the infarction size using a set of OECG descriptors, which were derived by averaging the heart cycles in the three high-resolution orthogonal Frank leads. Moreover, we applied sensitive selection of the most reliable parameters for assessment of the MI size in dependence of the MI localization.

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.

Analysis of QRS Patterns in 15-Lead ECG for Person Verification

Vessela Tzvetanova Krasteva, Irena Ilieva Jekova and Roger Abächerli

Abstract – **This paper presents a method for evaluation of similarity and difference scores of QRS patterns in 15-lead ECG for the aims of person verification. An ECG database with 316 healthy subjects, including two records per subject taken >1year apart is used to simulate the real case scenario. Discriminant analysis estimates the best specificity/sensitivity for limb+chest leads (92.9/92.1%), lower for limb leads (92.1/89.6%), and the top-scored single leads: aVR (84.6/84%), II (83.8/83.5%), I (81.2/80.2%).**

Keywords – **ECG Biometrics, multilead ECG scoring, QRS patterns, Discriminant analysis, person verification.**

I. INTRODUCTION

The analysis of the electrocardiogram (ECG) as a biometric tool has been started about a decade ago in the context of two typical scenarios for application:

1) Person verification (one-to-one scenario): the ECG of the tested subject is compared to previously recorded ECG with known identity (ID). The tested person is either verified or rejected.
2) Person identification (one-to-many scenario): the ECG of the subject under identity examination is compared to previously recorded set of ECGs in a specific database. The tested person is identified as a subject with unique ID among all in the database.

Two general methods could be distinguished:

1) using measurements after fiducial points detection;
2) analyzing the overall ECG waveform morphology.

At first, the fiducial based approaches are applied. The earliest work involves 12 uncorrelated diagnostic features of P-QRS-T amplitudes and durations [1]. The inter-subject heartbeat similarities are studied via Principle Component analysis score plots. The authors report 100% identification accuracy (IDA) over a database with 20 subjects. Other authors employ 15 temporal features of the P-QRS-T segment into a set of discriminant functions [2]. They report IDA in the range from 97% to 100% over 29 subjects under various stress conditions. A two-step identification method involves temporal and amplitude measurements based on fiducial points detection together with appearance based features that capture the heartbeat patterns [3]. This combined approach provides 100% IDA when tested over 31 healthy subjects: 18 with a single ECG record [4] and 13 with more than one ECG record [5].

Fiducial independent approaches have been developed since 2006. Person identification via autocorrelation (AC) and discrete cosine transform of windowed ECG reports 100% IDA over a database with 14 subjects [6]. Another study also utilizes AC of 5s ECG for person identification and verification [7]. Classification of AC functions via discriminant analysis achieves 96.2% IDA, 87% and 99% verification sensitivity and specificity, reported for a joint dataset [4,8] and 13 healthy subjects with more than one ECG record [5]. The maximal correlation coefficient of a single-lead and 12-lead ECG is reported to provide 91.4% and 100% IDA over a database with 11 subjects [9]. Another effective method calculates the two-dimensional heart vector formed by the limb ECG leads and its first and second derivatives, reporting 98.1% IDA and 97.2% verification accuracy by a distance based approach over 74 subjects [10]. The processing of a normalized QRS complex via Multilyer perceptron provides 96.1% IDA over a database with 30 healthy subjects [11]. Recently, a human ECG identification system has been announced based on ECG decomposition in a number of intrinsic mode functions combined with Welch spectral analysis for extraction of significant heartbeat features [12]. The classification with the K-Nearest Neighbors provides 95.6% IDA over a joint dataset with 108 subjects having one ECG record with ST-segment changes [13,14] and 12 healthy subjects with more than one ECG record [5].

Majority of the cited methods are tested with small-sized ECG databases [1,2,6,8,11] or track intra-subject changes of ECG characteristics measured in very short distanced temporal intervals [2,3,7,11,12]. This might bias the reported high identification/verification accuracy from the real case scenario.

This works aims to compare inter-subject QRS patterns of 15-lead ECG and to rate leads by similarity and difference scores via Discriminant analysis for the purpose of person verification. The use of a large sized ECG-database with two different records per subject taken >1year apart aims at an unbiased accuracy report.

II. ECG DATABASE

The ECG database is collected in the period 2004-2009, including 316 patients at the Emergency Department of the University Hospital Basel. The ECGs are acquired via SCHILLER CS-200 Excellence device with 500Hz sampling rate, 2.5µV resolution.

The database has the following content:

- Includes subjects with a healthy cardiac status, 143 man, 173 woman, aged from 18 to 89 years;
- Includes two 10s resting ECG recordings per subject taken at different times distanced from 1 to 2 years.
- All ECG recordings have a high quality signal in 15 ECG leads – limb (I, II, III, aVR, aVL, aVF), chest (V1-V6), synthesized orthogonal (X, Y, Z).

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High-resolution Signal Acquisition Module Recording 18-Lead ECG for Person Authentication

Tatyana Dimitrova Neycheva, Todor Venkov Stoyanov, Vessela Tzvetanova Krasteva, Ivo Tsvetanov Iliev, Serafim Dimitrov Tabakov, Valentin Viktorovich Tsibulko and Irena Ilieva Jekova

Abstract – **This paper presents a high-resolution 16-channel ECG acquisition module with 24-bit amplitude resolution and sampling rate of 2kHz. The module is applied for collection of ECG database for the aims of development and testing of methods for person authentication via ECG. Such database could support the definition of optimal number of ECG leads and the optimal feature set and would facilitate the decision about the ECG applicability as a person biometric characteristic in different environments.**

Keywords – **ECG device, 24-bit ADC, 18-lead ECG, biometrics, person verification, identification**

I. INTRODUCTION

Nowadays, the reliability of the automatic person verification/identification is very important, considering the necessity of high security level in cases of financial transactions; access control for buildings, rooms and information; traveling, etc. Due to the technological development of compact sensors for acquisition of biological signals and the progress in biomedical signal processing for diagnostic purposes in the last decade, the idea for application of signals generated in the human's body for person authentication gains support. The analysis of the electrocardiogram (ECG) as a biometric tool was started about a decade ago, incorporating two general approaches: (i) methods, using measurements after detection of fiducial points; (ii) methods, analyzing the overall morphology of the ECG waveform. All methods rely on detailed zoom of specific temporal and amplitude ECG characteristics, and therefore, the more precisely the ECG is acquired (high sampling rate and amplitude resolution), the more reliable person verification/ identification can be supported.

Single lead ECG for person identification is acquired from palms [1] and fingers [2]. Although the described ECG devices implicitly assure comfort for the tested person, according to some authors, the reduction of the number of analyzed ECG leads limits the accuracy [3]. Others, however, report reliable identification accuracy of 94.3-95% with limited number of ECG leads [1,2]. Considering this uncertainty and the extended application of person authentication not only in social environment but also in medical setting, assisting and securing the collection of personal medical information, there is a need for high-resolution multi-channel ECG acquisition module, which could be used for collection of ECG data with redundancy. Such ECG database could be further analyzed in order to extract valuable information about the most reliable leads and features for person authentication.

This paper presents a 24-bit 16-channel ECG acquisition module, which is applied for collection of 18-lead ECG database for the aims of a detailed framework of the person verification/identification task. Such database could support the definition of the optimal number of ECG leads and feature set, and would facilitate the decision about the ECG applicability as a personal biometric characteristic in different environments.

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II. HARDWARE CONCEPT

The presented ECG module provides synchronous acquisition of 16 ECG channels and one respiration channel via impedance measurement in lead I, with the capability for real-time data transfer to PC. The ECG is sampled at 2kHz, 24-bit amplitude resolution over an input range of ±400 mV (about 0.05μV/LSB).

The block diagram (Fig. 1) is including:

1) Two 8-channel Texas Instruments ADS1298R demonstration boards (ADC1, ADC2), each one embedding complete ECG Front-End module based on 24-bit, delta-sigma (ΔΣ) analog-to-digital converter (ADC) with a built-in programmable gain amplifier (PGA), internal reference, and an onboard oscillator.
2) Custom interface board providing PC connection of the ECG module. The board is based on the microcontroller Cortex STM32F103C8 and the USB to serial UART interface circuit FT232RL. The FT232RL data sheet claims operating rate at up to 3Mbps that guarantees the correct transfer of 16-channel, 24-bit data, sampled at 2kHz.

The power supply of the designed ECG acquisition module is 5V, provided via the available USB interface. The chips STM32F103C8 and FT232RL are powered directly from PC, while ADC1 and ADC2 are electrically isolated from the apart hardware according to IEC60601 standard, so that the ECG acquisition module complies with the requirements for patient safety. The DC-DC converter AM1D, rated to 6kV DC isolation, is used to produce an isolated power supply. The digital signals are

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

Irena Ilieva Jekova, Vessela Tzvetanova Krasteva, Georgi Zheliazkov Georgiev, Lyudmila Pavlova Todorova, Peter Mladenov Vassilev and Mikhail Georgiev Matveev

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 2nd 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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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.

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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.

Measurements on Ventilatory Signals during Volume Controlled and Pressure Support Ventilation to Predict the Weaning Outcome

Irena Ilieva Jekova, Vessela Tzvetanova Krasteva, Georgi Zheliazkov Georgiev, Lyudmila Pavlova Todorova, Peter Mladenov Vassilev and Mikhail Georgiev Matveev

Abstract – **This study investigates volume and pressure signals during four phases of volume controlled and pressure support ventilation, aiming to find predictors of the weaning outcome. The work of breathing to overcome the resistive properties of the respiratory system, the airway occlusion pressure (P0.1) and the maximal inspiratory pressure during sniff test show significantly different mean values comparing successful vs. unsuccessful patients. A model for prediction of the weaning outcome is derived by stepwise discriminant analysis with sensitivity of 88.9% and specificity of 84.2%.**

Keywords – **mechanical ventilation, weaning predictors**

I. Introduction

The process of weaning from mechanical ventilation is a challenge in intensive care that requires assessment and interpretation of both objective and subjective clinical indicators. 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 determination of the exact moment for ventilatory support discontinuation involves significant clinical experience, relying on the physician's subjective decision, that limits the weaning success rate to about 35-60% [1-3]. Aiming to minimize the risks, the research efforts during the last years are directed towards investigation of outcome predictors applicable to different phases of the weaning process.

Measurement of the inspiratory work of breathing (WOB) by integrating the area under the pressure-volume curve has been advocated because WOB elevation is a sign for inspiratory muscle fatigue with expected subsequent weaning failure [4]. According to DeHaven et al [5], about 90% of tachypnoeic trauma patients (during a room-air continuous positive airway pressure trial) tolerate extubation when the total WOB is ≤1.1 J/l, however, this observation is not confirmed by Levy et al [6] who have found that an elevated work of breathing >0.8 J/l is not associated with extubation failure among patients tolerating a trial of spontaneous breathing.

Several studies have suggested the prediction potential of decreased maximal inspiratory pressure (MIP) [7] and increased airway occlusion pressure (P0.1), especially when normalized towards MIP [7,8], observed in patients who have failed extubation.

The rapid shallow breathing index (RSBI) is also noted as successful predictor with a threshold value >130 for unsuccessful weaning [9], although a prospective study of Lee et al [10] conclude that RSBI under the threshold does not necessarily preclude successful extubation of patients on a partial ventilatory support.

More sophisticated analyses on the respiratory pattern variability are proposed to yield important information about the likelihood of extubation success. White et al [11] have found higher interbreath interval complexity assessed by nonlinear techniques for patients with successful weaning, while Casaseca-de-la-Higuera et al [12] report significantly lower sample entropy of respiration rate, inspiratory and expiratory tidal volume for such patients.

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 [13].

This study investigates various measures of ventilatory signals captured during four different phases of volume controlled and pressure support ventilation, aiming to study their potential as weaning outcome predictors. A linear discriminant model with top-ranked predictors is derived.

II. Study Population

This study enrolls data from 28 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 July 2012. The study population consists of 21 men and 7 women, mean age of 63±14.8 years, who have received mechanical ventilation for at least 72 hours prior the weaning attempt, initiated according to general weaning criteria [14] by a primary care physician. Considering the weaning outcome at the 2nd hour of a spontaneous breathing trial (SBT) the patients are divided into successful (N=19) and failure (N=9) group.

III. Data Collection

Ventilatory signals

Four synchronous ventilatory signals are collected:

- Flow, [l/min];
- Tidal volume (*Vt*), [l];
- Airway pressure (*Paw*), [cmH2O];
- Esophageal pressure (*Pes*), [cmH2O].

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Monitoring of the Patient Feedback during Weaning Procedure from Mechanical Ventilation

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Abstract – **This paper investigates the flow, volume and pressure signals collected during weaning from mechanical ventilation. A protocol, which permits the estimation of the patient status by a set of measurements at each step, is defined. Procedures for detection of maximal negative inspiratory pressure, maximal lung inflation pressure, airway pressure immediately after the occlusion, static end-inspiratory pressure and respiratory rate are elaborated.**

Keywords – **mechanical ventilation, weaning predictors.**

I. INTRODUCTION

The mechanical ventilator support is a life-saving measure, which is applied to almost 90% of all patients in the intensive care units. In about 30% of the patients, the process of stopping the mechanical ventilation is difficult, denoted by the term ‘weaning from mechanical ventilation’. Every unnecessary delay in weaning provokes risks of specific ventilator-induced diaphragmatic injury or various complications, that affect the respiratory system (ventilator associated pneumonias, ventilator induced lung injury), the closely related cardio-vascular system or the distant organs (kidneys, liver and brain). Delays are also related with prolonged stay in the intensive care unit and more costs for treatment, as well as with the respective increased mortality [1-4]. Therefore, it is crucial to recognize the earliest moment when the patient is capable of spontaneous breathing. At the same time, the premature discontinuation of the ventilatory support and especially the premature elimination of the artificial airways may lead to a number of life-threatening complications. The determination of the exact moment for discontinuation of ventilatory support is often difficult, based on subjective physician assessment and requires significant clinical experience and knowledge.

For many years the research efforts has been focused on the investigation of indices, predicting the outcome of weaning. Predictors applicable to different phases in the process of weaning are:

1) In case of spontaneous breathing trials:

- Tidal Volume (*Vt*);
- Respiratory rate (*f*);
- The ratio of the above *f/Vt* which reflects the imbalance between the mechanical load and the muscle capacity so that in unsuccessful trials of spontaneous breathing *f/Vt* increases early during the course of the trial (with maximal value seen on average before the second minute from the beginning of the trial). The so called *RSBI* has the highest negative predictive value among the ones used;
- The tendency of change of the maximal negative inspiratory pressure (*Pimax*) in the esophageal pressure shows both good positive and negative predictive value [5].

2) In case of continuing mechanical ventilation:

- *RSBI*;
- Pressure Time Product (*PTP*), derived from the esophageal pressure curve;
- *Pimax*, providing information about the strength of the inspiratory musculature but is highly dependent on the patient cooperation and is futile in people with damaged pyramidal tracts;
- Minute ventilation (*MV*), indicative for the magnitude of the ventilatory load;
- Ratio between the negative pressure at 100ms after airways occlusion and Pimax (*P0.1/Pimax*) which is a complex index of the intensity of respiratory drive and the strength of the inspiratory musculature. It shows the highest positive predictive value among the used indices;
- Compliance-Respiratory Rate-Oxygenation-Pressure (*CROP*) score, integrating information concerning the respiratory mechanics, inspiratory musculature strength, effectiveness of arterial oxygenation and respiratory rate and shows relatively high predictive value.

A non-pulmonary weaning index (*NPWI*), is proposed also as predictor of the successful weaning [6]. It provides high accuracy and is easily calculated. However, it could not give information about the exact moment for discontinuation of ventilatory support as it takes into account only the influence of non-pulmonary indicators – albumin and total serum protein, being measured two or three times a week in the clinical practice.

The debates about the advantages and disadvantages of currently used indicators for weaning from mechanical ventilation continue. Most researchers share the opinion that none of them may be accepted as completely reliable [4,5,7]. This fact determines and guides the research efforts to seek out new indicators.

The aim of this work is to study signals recorded during weaning from mechanical ventilation, in order to identify their typical behavior and to elaborate methods for assessment of efficient weaning predictors.

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Pre- and Post- Shock Thoracic Impedance Relations in External Electrical Cardioversion

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Abstract – **This work presents results from a clinical study for cardioversion of 107 patients with continuous recordings of pre- and post-shock thoracic impedance (Z) in 143 shocks. Clinical data from patients are assessed to identify significant predictors of pre-shock Z, such as body mass index, body fat, circumference, weight, gender, sequence of cardioversion. We found equal probability for increasing vs. decreasing trend of post-shock Z change from 0.5s to 30s after shock with mean <2%, maximum <6% compared to pre-shock Z. The transient process of post-shock Z recovery lasts ≤4s. The post-shock Z variance is not dependent on the energy of the shock.**

Keywords – **trans-thoracic impedance, defibrillation, self-adhesive pads, stacked shocks.**

I. INTRODUCTION

High-intensity electrical pulses trough the thorax are applied to terminate life-threatening ventrucular/atrial fibrillation by external defibrillation/cardioversion of the heart. The thoracic electrical impedance, which is influenced by the electrode-skin interface and the impedance of the underlying tissues, is inversely related to the intensity of the current crossing the thorax, and therefore, it is the major factor affecting the transmyocardial current, the delivered energy, the pulse waveform, and consequently the therapeutic effect. An inverse relationship between the thoracic impedance and defibrillation success rate has been observed in previous studies [1,2]. Relying on early data for progressive decrease of transthoracic impedance on time interval between repeated monophasic shocks [3], stacked-shocks were recommended because of low first-shock efficacy of monophasic shocks and theoretical decrease in impedance following each shock [4]. Thoracic impedance varies substantially among humans, ranging from 30 to 200 Ohm [5-8], depending on the patients' and electrode-interface characteristics, and this variation makes the prescription of the proper level of electrical intervention difficult.

Because the factors affecting thoracic impedance are largely unknown, this study aims to identify its independent patient-specific determinants in cardioversion. Besides, we test the hypothesis of thoracic impedance decrease after shocks by studying the long-term post-shock impedance variance.

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II. DATABASE

The study comprises clinical data from 107 patients admitted to receive elective external cardioversion (ECV) of atrial flutter (AFL) and fibrillation (AFIB) from May 2010 to July 2011 in Intensive care unit, the National Heart Hospital, Sofia. The ECV is following standard hospital procedures, all patients signing a written informed consent.

The electrical shocks are administered through standard clinical self-adhesive defibrillation pads, with active area (2x75cm^2), placed in antero-apical position. A commercial cardioverter/defibrillator Defigard DG4000 (Schiller Médical, France) is used to deliver biphasic shocks with Multipulse Biowave® technology with impedance-compensated energy delivery.

According to the study protocol, in case a shock fails to recover sustained sinus rhythm for at least 1 minute, a stack of 3 shocks with non-escalating energy setting is applied:

(1) AFL: 120/120/200J – 29 patients, 29/3/2 shocks
(2) AFIB: 200/200/200J – 78 patients, 78/20/11 shocks.

Considering the above listed number of shocks, the total number of processed shocks is 143, including 107 first shocks (120J and 200J), 23 second shocks (120J and 200J), 32 shocks with 120J, and 111 shocks with 200J. The time interval between consecutive shocks is less than 1 minute.

III. MEASUREMENT SETTING

In-house developed measurement system DEFIMPULSE Recorder [9] is installed in series between DG4000 and the patient to continuously record signals acquired between the two ECG/defibrillator pads during ECV: high-intensity voltage/current pulses, ECG, the thoracic impedance (Z) – measured as the attenuation of a low-intensity (10μAp-p), high-frequency (30kHz) current through the patient. The Z-signal is sampled at 250Hz, resolution of 0.061Ω/LSB. The measurement system complies with all requirements for safety and is used after approval from ethical committee.

A software is developed for automatic processing of the Z-signal, providing measurements (an average value within 100 ms window) at different pre- and post- shock times as listed below (illustrated in Fig.1):

(1) Pre-shock: 1 measurement taking the Z-value at 1s before the artifact of the shock;
(2) Post shock: 24 measurements taking the Z-value at different delays after the shock. The delays are:
  - from 0.5s to 10s with step of 0.5s aiming at precise scanning of the transient process just after the shock;
  - from 15s to 30s with step of 5s aiming at long-term tracing of the impedance change. Extending the measurement time to more than 30s after the shock is not reasonable since next shock could be delivered meanwhile in case of stacked shocks.

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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Device for Data Collection During Cardioversion

Tsvetan Nikolaev Mudrov, Vessela Tzvetanova Krasteva, Irena Ilieva Jekova, Nikolay Tsvetanov Mudrov, Mikhail Georgiev Matveev and Todor Venkov Stoyanov

Abstract – **This study presents a measurement system, named DEFIMPULSE Recorder, developed for collection of high-resolution data associated with the patient response during cardioversion. DEFIMPULSE Recorder acquires signals via the two ECG/defibrillator pads and provides: (i) recording of high-intensity voltage and current pulses during defibrillation shocks; (ii) long-term recording of ECG, high-frequency impedance (baseline and variance). The correlation of this extended dataset with the patient diagnostic indicators is a powerful tool for statistical assessment of the optimal stimuli settings with improved efficacy of the treatment.**

Keywords – **DEFIMPULSE Recorder, Defibrillation pulses, ECG, High-frequency impedance, ICG**

I. Introduction

High-intensity electrical pulses trough the human tissues are applied with a therapeutic effect, such as for termination of life-threatening ventrucular/atrial fibrillation by defibrillation/cardioversion of the heart [1,2], or for increasing permeability of drug injection in cancer cells by electrochemotherapy [3,4]. The interelectrode impedance, which is influenced by the electrode-skin interface and the impedance of the underlying tissues, is the major factor affecting the current intensity, the delivered energy, the pulse waveform, and therefore the therapeutic efficacy. An inverse relationship between the transthoracic impedance (TTI) and defibrillation success rate has been observed in previous studies [5,6]. TTI varies substantially among humans, ranging from 30 to 200 Ohm [7,8], and this variation makes prescribing the proper level of electrical intervention difficult. Therefore, the novel generation of external defibrillators has been designed to support patient-specific adjustment of the defibrillation pulses depending on the real time impedance measurement before or during the shock. The manufacturers hold up different polices for impedance compensation, such as the rectilinear waveform with delivery of near constant current during a fixed-duration shocks [8], truncated exponential waveforms with duration-based compensation by prolonging the shock duration to compensate the increased TTI [9], Multipulse Biowave waveform with adjustment of the high-frequency chopping series to deliver the exact energy setting at almost constant mean current [10,11]. Study of such variety of adjustable waveforms, as well as the largely unknown factors affecting TTI would become possible by means of a precise shock recording device, by which the voltage and current waveforms could be reviewed, and TTI values before and during the shock could be measured.

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Other basic activities are the complex analyses of the patient status, the need for shock indication, as well as the shock outcome. In defibrillation/cardioversion, the traditional diagnosis is made by expert reading of the electrocardiogram (ECG). An additional non-ECG sensor, such as the impedance cardiogram (ICG) is suggested as a valuable haemodinamic sensor aiming to increase the specificity for detection of pulseless electrical activity in automated external defibrillators (AEDs) [12]. Scarce information is still available about the quantitative correlation between the cardiac output and the variation of the high-frequency transthoracic impedance in ICG as captured via the two ECG/defibrillator pads.

The developments in this study aim at a system for collection of synchronized database during intervention with high-voltage electrical pulses, such as during cardioversion, which could support any future investigations towards optimization of the patient-specific shock settings and improved automated diagnosis of the patient status.

II. Hardware Concept

This study presents a measurement system, named DEFIMPULSE Recorder, which is developed for high-resolution recording of signals associated with the patient response during defibrillation shock. As shown in Fig.1, the DEFIMPULSE Recorder implements two independent modules: (i) *Module1* for acquisition and recording of high-intensity voltage and current pulses; (ii) *Module2* for long-term monitoring and recording of ECG and high-frequency impedance (base and variance). Both modules use a single bipolar input via the two ECG/defibrillator pads. This allows a simplified measurement system, with no additional sensors connected to the patient.

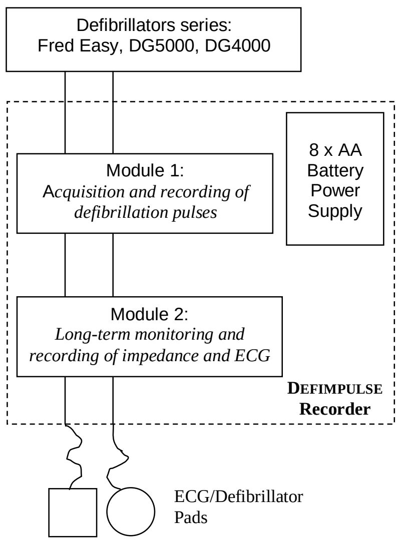

Fig1. Block diagram of DEFIMPULSE Recorder connected in series between the defibrillator and the patient.

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.

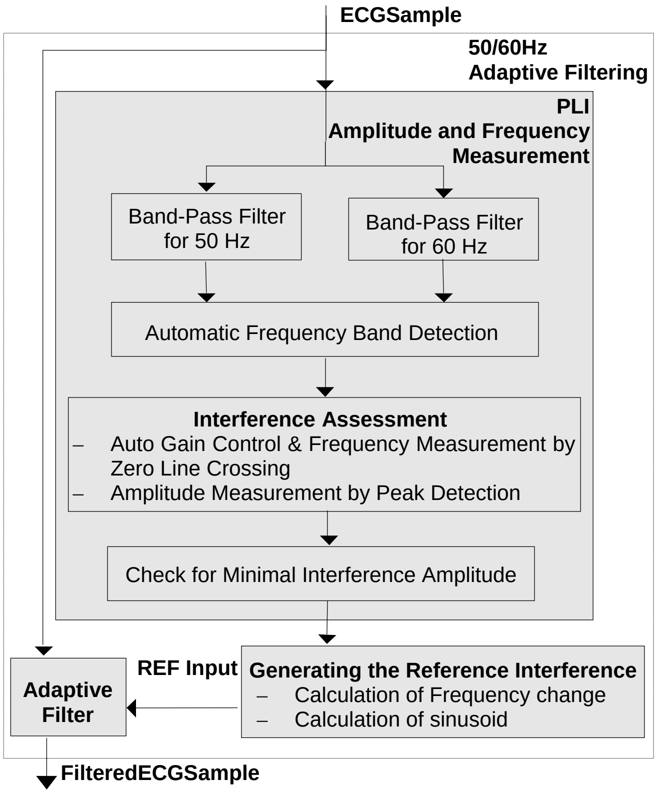

Figure 1. Diagram of the software conception for adaptive 50/60 Hz filtering.

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.

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High-Q Comb FIR Filter for Mains Interference Elimination

Dobromir Petkov Dobrev, Tatyana Dimitrova Neycheva, Vesela Tzvetanova Krasteva and Ivo Tsvetanov Iliev

Abstract - **This paper presents a linear phase comb filter for power-line interference suppression. By a correlated average using samples delayed on multiple power-line periods, and subtracting the result from the input stream, a high-pass comb filter with high-Q notches at all power-line harmonics is attained. The high-pass roll-off of the filter is compensated with appropriate low-pass roll-off, and the resultant characteristic has an all-pass (flat) frequency response and notches only at the power-line harmonics. The filter design is based on a high-pass high-Q comb filter, in parallel with a low-pass moving-average stage to restore the low-frequency filtered components. The Q-factor depends on the time for averaging. The presented filter is evaluated by Matlab simulations with real ECG signal contaminated with high amplitude power-line interference. The simulations show that this filter has minimal influence on the processed ECG signal. Due to the filter's constant group delay (linear phase response) and high-Q notches only at the power-line harmonics, the presented filter is appropriate for power-line rejection in almost all biosignal acquisition applications. The filter is applicable for real-time execution by means of conventional low-cost microcontrollers.**

Keywords – **Power-line interference, Comb filter, FIR filter, First difference filter, Moving-average filter**

I. INTRODUCTION

A significant problem in the recording and processing of biomedical signals is the presence of the power-line interference (PLI). The source of PLI is the power grid from where it is coupled through the medium of magnetic or electric fields. The magnetic field interference is induced in the loop area between the electrode leads. Minimizing the area, e.g. by twisting or holding the acquisition cables close together, results in minimized magnetic field interference. Owing to the low value of the power-line (PL) frequency (50Hz or 60Hz), and the reduced area between the electrode wires, the induced magnetic field interference can be neglected in practice.

The electric field interference is caused by a capacitive coupling of the body and the electrode cables to the live-wire of the mains supply. Although the coupling of the electrode cable can be canceled by shielding, the body shielding is impractical, because the entire body must be locked in a Faraday cage. Thus the body capacitive coupling to the mains supply permanently exists, typically it is around 3pF to the live-wire and around 100pF to the neutral wire (ground) of the household electricity. This produces 200nA typical interference current continuously to flow from the live-wire through the body, reaching the ground. In cases of increased coupling, the interference current can gain in strength to intensities as high as several microamperes.

The flowing interference current generates a common mode voltage over the amplifier common mode input impedance, moreover (especially in two-electrode front-ends) a part of this current multiplied by the electrode impedance difference produces a differential voltage, which is amplified together with the useful signal. Thus, at the amplifier output there is an AC noise remaining as a consequence of the electrode impedance imbalance and/or due to the finite value of the amplifier CMRR [1], even when special signal acquisition techniques are provided (cable shielding, driven right leg, body potential driving, etc.). A further reduction of the interference should be implemented by either post-digital or post-analog filters.

Normally, the PLI spectrum contains a fundamental frequency and odd harmonics with decaying over frequency amplitudes. Due to the nonlinear transfer characteristics of the power transformers, even harmonics with small amplitudes could also appear. The body capacitive coupling to PL, together with the input impedances of both body and amplifier, form a first order high-pass filter wherein the PL fundamental frequency and its harmonics take a place in the filter stop-band area. Thus, the transferred interference has a high-pass filtered spectrum with emphasized higher harmonics, and if PLI is observed on the scope, it has a waveform, which is different from the ideal sine wave. That is why, it is important, especially for a high-resolution electrocardiogram (ECG), the implemented PLI post-processing filter to have a comb frequency response for all, or at least for the odd harmonics of PLI.

An extensive research has been focused on the challenge for designing digital filters in the ECG systems, aiming to reject PLI, while preserving the fidelity of ST-segments and QRS-complexes. For the effective rejection of the PLI, there are a number of works, introducing notch filters [2, 3], comb filters [4, 5, 6, 7], adaptive filters [8, 9], subtraction procedure [10], lock-in techniques [11], etc.

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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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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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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.*

AUTOMATIC ANALYSIS AND VISUALIZATION OF MULTILEAD LONG-TERM ECG RECORDINGS

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Abstract: *Long-term ECG data collected during physical exercises (stress tests) and ordinary daily activity (holter recordings) are necessary for extended diagnosis of ischemia and transient cardiac arrhythmias. Owing to the computer-assisted systems, the cardiologist decision is considerably facilitated by fast methods for automated ECG analysis. The main requirements to such sophisticated system are high accuracy for identification of each normal and abnormal cardiac contraction, correct measurements over the beats' waveform, as well as adequate visualization of the results in the context of easy diagnostic interpretation. This work presents a PC-based application for automatic analysis of multilead ECG recordings. It implements fast algorithms for multilead QRS detection and classification of the QRS waveforms considering each user-selected channel. Categorized long-term diagrams are plotted showing the timing of each consecutive beat. The RR-interval trend is also provided. Signal-averaged technique is applied to obtain noise-free and stable P-QRS-T pattern at preset time-intervals during physical exercise. Continuos measurements of the P-QRS-T patterns allow the tracing of any changes provoked over time. Adequate graph representation facilitates the iterative visual identification of such changes. The basic software is opened for cardiologist-assistant supplements.*

1. Introduction

Electrocardiographic (ECG) measurements during controlled exercise stress test (treadmill, bicycle, ergometer) are indicated for observing the effects of increases in the myocardial demand for oxygen and finding an evidence of ischemia [1]. Besides, long-term ECG recordings during daily activity (holter recordings) are necessary for identification of patients at risk of arrhythmias (with and without sustained symptoms), and for extended diagnosis of transient arrhythmias [2]. In order to facilitate the cardiologist decision, major efforts are directed towards developments of software solutions for ECG signal processing, which are directly applicable in computer-based systems. It is obvious that an interpretive multilead ECG system for the laptop or desktop computer, connected to ECG acquisition module with wireless data transfer, is a practical and preferable tool for any cardiologist. The latest technologies allow continuous recording of high-resolution ECG signals, which enhance the possibilities of precise cardiac diagnosis. The challenge for development of interactive software application for automatic multilead ECG analysis, which implements accurate algorithms for ECG signal processing and adequate visualization of the results, is under the scope of the present article.

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2. Method and software implementation

Short description of the methodology and the sequence of processing branches implemented in the computer-based ECG system, is described bellow. The software application (Visual C) is running under Windows with minimal PC resource requirements.

2.1 Preprocessing

- *Processing of high-resolution ECG signals* sampled at 1kHz, 12-bit per channel.
- *Reading of 8 input channels* in consent to the typical configuration of multilead analogue ECG acquisition modules. The standard 12 ECG leads are recalculated according to the mathematical transforms described in [3].
- *Preprocessing filtration* of each input channel – it is obligatory for suppression of the most common artifacts, which are induced during ECG acquisition, e.g. baseline wandering, powerline interference and electromyogram noise. Following the principles of ECG signal processing [3], we developed digital filtering procedures, which were successfully applied during real-time detection of pathological ECG events in one previous study of the authors [4]. The same filtering procedures were implemented in the PC-based ECG system, adapted to warrant pass-band of 0.05 Hz - 30 Hz for the ECG analysis module (ECG1), as well as pass-band of 2 Hz – 18 Hz for the QRS detection module (ECG2).
- *Noise detector* – Artificially induced unnatural components in the ECG signal should not be considered during analysis and their appearance should be marked. Digital procedure for detection of artifacts with amplitude at the saturation level, as well as with extremely steep slope was implemented, and applied independently for each ECG lead (on ECG2).
- *Visualization* of 12-lead ECG (see Fig.1);
- *Visual tools* for user-friendly software management:
  (i) manual disable of unconnected or low-quality ECG channels;
  (ii) manual selection of the most informative lead to perform analysis;
  (iii) measurements on manually picked ECG waves – amplitude and duration.

2.2 ECG Analysis

- *QRS detector* – The position of each ventricular complex should be accurately recognized. We embedded a digital procedure for single-channel QRS detector based on analysis of dynamic amplitude and slope thresholds that was previously developed for microcontroller based ECG devices with on-line operation [4]. Besides its simplicity and fast signal processing, the procedure supports our next ECG analysis methods, which require correct localization of a reference point on the QRS complex waveform, corresponding to the maximal amplitude R-peak. The QRS detector [4] was optimized for 8-bit, 250 Hz sampling frequency, and

P205

The usefulness of the area and flow velocities of the left atrial appendage for the prediction of atrial fibrillation relapse

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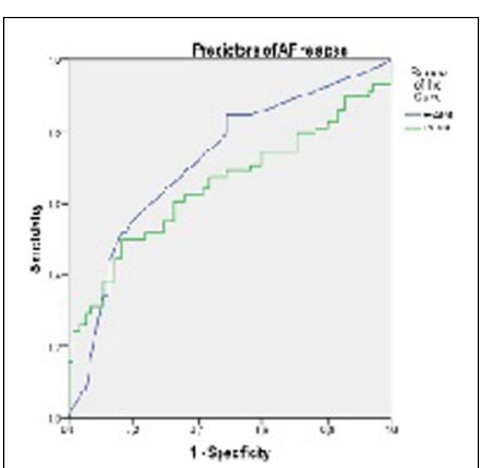
Introduction: Left atrial volume (LA Vol) is a recognized predictor of atrial fibrillation (AF) relapse. Other parameters such as the area, the filling (fV) and emptying velocities (eV) of the left atrial appendage (LAA) have been suggested.

Purpose: Assess the additional value of the area, fV and eV of the LAA for the predicition of AF relapse.

Methods: Cross-sectional study of 319 consecutive patients (P) with non-valvular AF (67.7% men, 68 ± 11 years, CHA2DS2VASc 3 ± 1.5), who underwent transthoracic echocardiography (TTE) and TEE previous to a successful electric cardioversion. By TTE was evaluated the LA Vol. By TEE was measured the LAA area, fV and eV. P were followed during 53 ± 26 months. A predictor model for relapse of AF (RFAPM) was created by logistic regression based on following parameters: LA Vol> 56.5ml/m2, LAA area> 3.28cm2, eV <20 cm/s and fV <20 cm/s. The RFAPM was compared with LA Vol by ROC curve analysis

Results: Relapse of AF was identified in 44.8% of P. By univariate analysis, predictors of AF relapse were: LA Vol (with 57.4 ± 22.9 ml/m2 vs. 48.9 ± without 15.3ml/m2, p=0.015); LAA area (with 3.6 ± 1.4cm2 vs. without 1.3cm2, p=0.032); eV <20 cm/s (OR 2.54, 95% CI 1.32-4.89, p=0.004); fV <20 cm/s (OR 2.26 95% CI 1.05-4.86, p=0.034). By multivariate analysis, LA Vol was an independent predictor (OR 1.003, 95% CI 1001-1005, p = 0.008), with AUC 0.607, 95% CI 0519-0690, p = 0.032. By ROC curve analysis the RFAPM showed a higher accuracy for prediction of AF relapse (AUC 0 715 95% 0623-0756, p=0.001), with a significant difference from the ROC curve of LA Vol (AUC difference 0.077, p=0.05)



Predictors of AF relapse.

Conclusion: Area, fV and eV of the LAA, are predictors of AF relapse and provide additional value to LA Vol. These parameters may be useful to stratify the risk of AF relapse.

P206

Individualized protocol for cardioversion in patients with atrial fibrillation

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This study aims to compare the efficacy and safety of a protocol individualized to body surface area (BSA) to escalating and non-escalating energy protocols for elective cardioversion (CVS) in patients with persistent atrial fibrillation (AF). Multipulse biphasic shocks and self-adhesive pads in anterolateral position are applied, with ECG and vital signs monitoring for 2h after CVS. High sensititive troponin is measured before and 8 to 12h after CVS.

Three protocols are used:

1) Individualized protocol (I) (93 patients)
   - BSA ⩾ 2.0m2: 120J–200J–200J–200J (29 patients)
   - BSA>2.0m2: 200J–200J–200J–200J (64 patients)
2) Escalating energy protocol (E): 120J–200J–200J–360J (monophasic pulse) (112 patients)
3) Non-escalating energy protocol (NE): 200J–200J–200J–360J (monophasic pulse) (169 patients).

During each shock voltage, current and impedance (TTI) are recorded. Before each shock pre-shock impedance (Z) is measured as the attenuation of low-intensity high-frequency (30kHz) current.

The three patient groups do not differ significantly in terms of sex, age, duration of the current episode of arrhythmia, presence of structural heart disease, left ventricular ejection fraction, left atrial anteroposterior diameter and antiarrhythmic drug therapy. Body mass index and BSA are significantly higher in group (I). The success rates of CVS are: 90.3%(I), 95.5%(E), 88.8%(NE), p=NS; mean number of shocks is:1.48(I), 1.68(E), 1.54(NE), p=NS.

First-shock success is achieved in: 72%(I)-79.3%(120J), 68.8%(200J) vs. 54.5%(E), 72.9%(NE), p=0.003. A 360J monophasic shock is used in 6 patients (E): successful in 3/6, and 19 patients (NE): successful in none (0/19), p=NS. Z before the first shock is comparable in the 3 groups: 99Ω(I), 96Ω(E), 102Ω(NE), p=NS. TTI is significantly lower in shocks with higher energy irrespective of the protocol and the number of the shock: 94.7Ω(120J) vs. 89.4Ω(200J), p=0.007.

Safety analysis is performed in patients who have not received monophasic shocks: the rate of non-sustained AF after successful CVS is comparable in the 3 groups, bradycardia<50bpm is significantly less frequent with (I) protocol: 14%(I) vs. 38.7%(E), 21.9%(NE), p<0.0001. An increase in hsTnI levels is observed in 2%(E), 2.8%(NE) and in none of the patients in (I), p=NS.

Multivariate regression analysis shows that BSA (OR 6.08, 95% CI (2.44-15.14), p<0.0001) and protocol (I) (OR 3.24, (1.65-6.37), p<0.0001) are independent predictors of first-shock success. In conclusion, the use of a protocol individualized to BSA results in a high first-shock success rate with the best safety profile.

P207

Impact of new-onset atrial fibrillation in ST-segment elevation myocardial infarction

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Introduction/goal: New-onset atrial fibrillation (NOAF) is a relatively common complication of acute myocardial infarction, associated with more adverse events and higher mortality. The aims of this study were to evaluate the incidence and impact of NOAF in a population of ST-segment elevation myocardial infarction (STEMI) patients (pts).

Methods: We retrospectively analysed the registries of pts with STEMI included in the National Registry of Acute Coronary Syndromes, between October of 2010 and October 2014. NOAF was defined as paroxysmal or persistent atrial fibrillation unknown prior to admission. Demographic data, cardiovascular risk factors and previous history, admission data, coronary angiography results, treatment and complications during hospitalization were analysed and then multivariate analysis was performed regarding the endpoints in-hospital mortality (IHM), stroke and heart failure (HF).

Results: A total of 4566 STEMI pts were considered, 306 (6.7%) with NOAF. These pts were significantly older, more frequently hypertensive and diabetic and had a higher prevalence of previous HF, valvular heart disease, stroke, peripheral artery disease, renal failure, chronic obstructive lung disease and dementia. They presented more frequently with HF at admission (27.8% of NOAF pts had a Killip class >1 vs 13.8% of pts without NOAF; p<0.001). There were no differences between the two groups regarding total ischemic time (TIT), culprit lesion, number of diseased vessels and percentage of reperfused pts. Stroke (2.0% vs 0.8%; p=0.043), need for blood transfusion (5.2% vs 1.9%; p<0.001) and IHM (15.7% vs 5.3%; p<0.001) were higher among NOAF pts. After adjusting for all significant variables NOAF was independently related to higher IHM (OR 2.93, CI95% 1.57-5.49; p=0.001), more HF (OR 3.09, CI95% 2.18-4.38; p<0.001), and more stroke (OR 5.38, CI95% 2.10-13.78; p<0.001).

Discussion/Conclusions: In this analysis NOAF was associated with higher rates of adverse events and IHM in STEMI pts. Focus on the impact of NOAF in these pts is warranted.

P208

Galectin-3 as a predictor of new-onset atrial fibrillation after acute coronary syndrome in patients with type 2 diabetes mellitus

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Objective: We sought to evaluate changes in the Galectin-3 (Gal-3) level in patients with type 2 diabetes mellitus (DM-2) after acute coronary syndrome (ACS) and to determine the utility of Gal-3 as a predictor of new-onset atrial fibrillation (AF).

Materials and methods: A total of 73 patients (age 52,8 ± 4,2 years; 35 of them women) after ACS with varying degrees of compensation of DM-2 were included. 16 patients with the level of glycosylated hemoglobin (HbA1c) < 7% constituted group 1; 34 patients with HbA1c level 7-9% - group 2; and 23 patients with HbA1c > 9% - group 3. 37% of the patients had 1-2 degrees hypertension, 42% - manifestations of heart failure I and II NYHA class. Serum Gal-3 concentration was measured by enzyme immunoassay analyzer using reagents Human Gal-3 Platinum ELISA, Austria. Gal-3 level was additional information resulting from spatial analysis allowed to demonstrate organized electrical activity during VF. The aim of our tests was to verify the hypothesis assuming a "chaotic" characteristics of electrical phenomena during VF and VT, so far classified on the basis of the standard ECG.

Material and methods: Cardiac arrest in 15 rabbits was induced with 3 methods: an alternating current with the use of transesophageal electrode (n-5), intravenous application of epinephrine (n-5), or calcium chloratum (n-5). Defibrillation shock was performed 5 minutes after cardiac arrest. When defibrillation was unsuccessful, CPR was performed. ECG data was analyzed using a numerical technique, based on discrete signal wavelet packet analysis, of determining chaotic states of a signal has been presented.

Results: Transition from a non-chaotic state to a chaotic state manifests itself in the magnitude and distribution of system response wavelet expansion coefficients. The analysis of the ECG during VT proved the existence of a continuous Fourier spectrum of the investigated signal. It was found that the signal packet wavelet expansion coefficients occur only for low frequency ranges of the signal. The results show that the ECG signals of VT have characteristics corresponding to chaotic states. It was further shown that the Fourier spectrum of the VT ECG signal has the dominant features of discrete distributions, and the signal wavelet packet expansion coefficients occur in all the frequency ranges of the signal. The VF signal did not show characteristics attributed to chaotic states.

Conclusions: The standard ECG does not allow to analyze developed chaotic process in myocardium during VF, however it is possible to find chaotic characteristic in VT. The ongoing study is currently conducted in patients with VT/VF. The preliminary results, obtained from 15 subjects, support the findings of the experimental research.

94

A comparison of two protocols for elective cardioversion in patients with atrial fibrillation

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We compared the efficacy and safety of two protocols for elective cardioversion (CVS) in patients with atrial fibrillation (AF) with biphasic pulses Multipulse Biowave and self-adhesive pads in anterior-lateral position according to the standard hospital procedure. Biomarkers of myocardial necrosis were obtained before and 8 to 12 hours after CVS.

Protocol E (with escalation of energy) 120 J – 200 J – 200 J – 360 J (Monophasic pulse) – 116 patients

Protocol NE (without escalation of energy) 200 J – 200 J – 200 J – 360 J (Monophasic pulse) – 172 patients

During each shock voltage and current waveforms were recorded and impedance during the shock (TTI) was deduced. Before each shock pre-shock impedance (Z) was measured as the attenuation of a low-intensity high-frequency (30kHz) current.

The two groups did not differ significantly in terms of sex, age, duration of the current episode of arrhythmia, presence of structural heart disease, left ventricular ejection fraction, left atrial anteroposterior diameter, antiarrhythmic drug therapy.

The success rate (sinus rhythm restoration for at least 1 minute) was 92.2% in group E versus 87.8% in group NE (p=NS) with a trend to fewer shocks in group NE (1.55 shocks versus 1.73), p=0.1.

First-shock success was achieved in 61 patients (52.5%) in group E versus 124 (72%) in group NE, p=0.0006. A 360 J monophasic shock was used in 7 patients in group E (successful in 3 of them) and 17 patients in group NE (not successful in any of them) - p=NS. Z before the first shock was significantly higher in group E 103.27 (SD 27.9) versus 96 (SD 16.7) – p=0.01. TTI was significantly lower in shocks with higher energy.

Post shock arrhythmias and biomarkers of myocardial necrosis did not differ significantly between two groups.

Multivariate regression analysis shows that body surface area (BSA) (OR 4.66; 95 % CI 1.496-14.564; p=0.008), duration of current arrhythmia event (OR 1.002; 95 % CI 1.0-1.004; p=0.065) and energy of the first shock (OR 0.99; 95 % CI 0.983-0.997; p=0.007) are independent predictors of first-shock success, but Z before the first shock is not. BSA is an only independent predictor of success with low energy (120 J) first shock (OR 11.12; 95% CI 1.68-73.56; p=0.12).

In conclusion, the use of a non-escalating energy protocol results in a significantly higher first-shock success rate, but does not change significantly the overall efficacy and safety of cardioversion. Probably a protocol individualized to a patient's BSA and/or arrhythmia duration will improve the efficacy and safety of CVS.

95

Early angiography associates with improved outcomes after out of hospital cardiac arrest

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Purpose: We determine whether early access to the angiographic suite (defined as arrest to procedure time <90 minutes) improves survival in out of hospital arrest (OOHA).

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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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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

0022-0736

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

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%).

Measure	RHYTHM 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

Device Stroke volume Electrocardiography Electric countershock

REFERENCE. 1. Stidwill R, Rosser D, Singer M. Intensive Care Med. 1998;24:1209–16.
GRANT ACKNOWLEDGMENT. Medical Research Council (UK)

0225
INFLUENCE OF BODY DIMENSIONS IN THE ANALYSIS OF PULMONARY PULSATILITY BY ELECTRICAL IMPEDANCE TOMOGRAPHY

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INTRODUCTION. Electrical impedance tomography (EIT) is a non-invasive diagnostic and monitoring tool that allows evaluation of impedance variations related to intra-thoracic changes in both blood and air content. Impedance changes associated with the cardiac systole can be estimated by EIT (pulmonary pulsatility, DZp), which purportedly represents the impedance variation associated with the right ventricle stroke volume (SV). We hypothesized that the pulmonary pulsatility is also affected by body dimensions.

OBJECTIVES. Our purpose was to evaluate if body dimensions (weight and length) influence the correlation between DZp and SV.

METHODS. Six Agroceres pigs, with a median weight of 45 kg (range 27–60 kg) and median length of 110 cm (range 100–126 cm) were instrumented with pulmonary artery and arterial catheters, and mechanically ventilated with tidal volume (V_T) 10 mL/Kg and PEEP of 10 cmH_2O. An EIT belt with 32 equidistant electrodes was placed around the circumference of the thorax just below the level of the axilla. To compare DZp with SV, four or more hemodynamic conditions were evaluated: baseline, hemorrhage (removal of 30 % of the estimated volemia) and successive volume challenges (500 mL of Ringer lactate's solution) until the animal ceased to increase the cardiac output by more than 15 % compared to the previous condition. During each hemodynamic condition, with all other ventilator parameters kept constant, two different tidal volumes were applied (V_T 6 mL/kg and V_T 10 mL/kg with a variable dead space to keep the end-tidal CO_2 constant). To extract the pulsatility signal from the raw signal (ventilation and pulsatility combined), we used electrocardiography-gating. A region of interest (ROI) which included both lungs was selected for measurement of the DZp. We explored the relationship between DZp and SV with hierarchical regression analysis using as predictors dummy variables for each experiment, interactions between dummies and SV, as well as weight, length, and body surface area.

RESULTS. The correlation between DZp and SV was poor ($R^2 = 0.27$), but improved significantly after the addition of the dummy variables and interactions terms ($R^2 = 0.76$ and 0.86, respectively), indicating a strong correlation between DZp and SV within each experiment. Subsequent analyses demonstrated that weight and length accounted partially for the between-experiments variability in the correlation of DZp and SV ($R^2 = 0.64$ and 0.71, respectively).

CONCLUSIONS. Our results are compatible with a strong within-experiment but weak between-experiment correlation of DZp and SV. The correlation between-experiments improved significantly after taking into account the body dimensions, suggesting that body weight and length be considered in EIT estimates of SV.

ACKNOWLEDGMENT. Research and Education Institute, Hospital Sírio-Libanês. FAPESP-Support Research Foundation of the State of São Paulo.

0226
COMPARISON OF TWO METHODS FOR ANALYSIS OF PULMONARY PULSATILITY BY ELECTRICAL IMPEDANCE TOMOGRAPHY: APNEA AND ELECTROCARDIOGRAPHY-GATING

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INTRODUCTION. Electrical impedance tomography (EIT) is a non-invasive diagnostic and monitoring tool that allows evaluation of impedance variations related to intra-thoracic changes in both blood and air content. The raw impedance signal is composed of impedance changes associated with the movement of air (ventilation) and with the cardiac systole (pulmonary pulsatility, DZp). The separation of the ventilation and DZp components of the raw impedance signal can be done by different techniques. The simplest method consists of a breath hold (apnea), which eliminates the ventilation component of the impedance changes. This method is limited in that the apnea itself can induce changes in DZp. Retrospective electrocardiographic (ECG) gating, in which impedance-gated data are retrospectively assigned to a cardiac cycle phase, offers the possibility to separate the DZp component of the raw signal during ongoing ventilation.

OBJECTIVES. Our aim was to compare two different methods, apnea and ECG-gating, for analysis of DZp and correlate both with the right ventricle stroke volume corrected by weight (SV).

METHODS. Six Agroceres pigs, with a median weight of 45 kg (range 27–60 kg) and median length of 110 cm (range 100–126 cm) were instrumented with pulmonary artery and arterial catheters, and mechanically ventilated with tidal volume (V_T) 10 mL/kg and PEEP of 10 cmH_2O. An EIT belt with 32 equidistant electrodes was placed around the circumference of the thorax just below the level of the axilla. To compare DZp with SV, four or more hemodynamic conditions were evaluated: baseline, hemorrhage (removal of 30 % of the estimated volemia) and successive volume challenges (500 mL of Ringer lactate's solution) until the animal ceased to increase the cardiac output by more than 15 % compared to the previous condition. During each hemodynamic condition, with all other ventilator parameters kept constant, two different tidal volumes were applied (V_T 6 mL/kg and V_T 10 mL/kg with a variable dead space to keep the end-tidal CO_2 constant). DZp was computed for each condition using the ECG-gating technique or during a 30-s apnea. A region of interest (ROI) which included both lungs was selected for measurement of DZp. We used the Pearson correlation test to evaluate the correlation between both techniques and between DZp and SV.

We found a strong correlation between DZp acquired with ECG-gating and during apnea (ρ 0.93). The correlation between DZp and SV was ρ 0.82 for the ECG-gating technique and ρ 0.72 for the apnea technique.

CONCLUSION. We found that both, ECG-gating and apnea methods, can be used for determination of DZp. Given that it does not require a breath hold, ECG-gating offers the advantage of allowing continuous monitoring of DZp.

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0227
A PRELIMINARY STUDY ASSESSING THE ACOUSTICAL ENVIRONMENT OF AN INTENSIVE CARE UNIT

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INTRODUCTION. Noise is generated in an ICU by a variety of sources including care, conversation and supportive equipment. Of these, staff conversation and equipment alarms are cited as the most disturbing [1]. This noise is frequently implicated in causing sleep disturbance and may have deleterious effects on patient recovery and staff wellbeing alike.

OBJECTIVES. To gather initial acoustical data to inform the future deployment of an in situ distributed noise monitoring system.

METHODS. Eleven sets of 30 min recordings were collected from eight areas of the ICU, using a Norsonic 121 sound level meter and a ½″ microphone (Norsonic, type 1201/30323). The microphone was mounted on extensible tripod and protected from air conditioning influence using a 6 cm windscreen. The instrument was programmed to acquire FAST-averaged, A weighted sound pressure levels in 1/3 octaves (35 bands between 8 Hz and 20 kHz). Results were analysed in 15 min time periods.

RESULTS. There was consistency of sound pressure levels across the eight bed spaces surveyed. However, these data show a potentially critical situation, as both equivalent continuous (L_{Aeq}) and background sound pressure levels (L_{90}) were significantly higher than the values recommended by the World Health Organization in 1999, with peak sound pressure levels (L_{Amax}) greater than 80 dB in the all of bed spaces in the open unit. In the single patient room, peak levels reached 80 dB, but equivalent continuous and background levels were lower than the open unit.

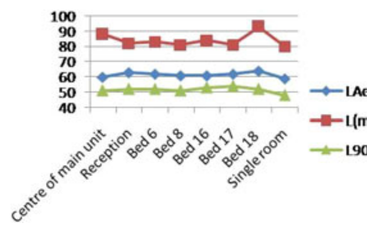

Fig. 1 Sound pressure levels in ICU

CONCLUSIONS. These results indicate a noisier environment than recommended, but are consistent with previous studies in ICU. Future studies will investigate the accuracy of the measurements and inform our configuration of a distributed noise monitoring system.

REFERENCE. 1. Xie H, Kang J, Mills G. Clinical review: the impact of noise on patient's sleep and the effectiveness of noise reduction strategies in intensive care units. Crit Care. 2009;13:208.

GRANT ACKNOWLEDGMENT. The authors acknowledge funding from the National Physical Laboratory Strategic Research Program and St George's Hospital NHS Trust Special Trustees.

0228
MONITORING OF THE WEANING PROCESS IN PATIENTS WITH SUCCESSFUL OUTCOME AFTER MECHANICAL VENTILATION

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INTRODUCTION. Mechanical ventilator support (MSV) is a life-saving measure applied to about 90 % of patients in intensive care units. Weaning from MSV is difficult in 30 % of the cases [1–3].

OBJECTIVES. Specific features of pressure and volume signals acquired at different procedures during the process of MSV stopping are measured aiming to identify the typical ranges for patients susceptible to weaning success.

METHODS. Data are collected by AVEA ventilator system (Cardinal Health, USA). Considering the weaning success at 12th hour, 12 patients are eligible for the study. Different signal features are measured at 5 procedures:

Procedure1: End-expiratory occlusion of the airways during controlled mechanical ventilation (CMV) of sedated patient to evaluate spontaneous breathing efforts from the airway pressure (Paw) by the maximal inspiratory pressure (MIP), the mean amplitude, duration and slope of the negative swings during inspiration attempts (DPpeak, Ti, Slope);

Procedure2: Series of ventilations with different tidal volumes (Vt) in sedated-paralyzed patient to evaluate on Paw the work of breathing (WOB) to overcome: the intrinsic positive end-expiratory pressure (WOBpeep); the elastic (WOBe), viscoelastic (WOBve) and resistive (WOBr) properties of the respiratory system;

Procedure3: Pressure support ventilation (PSV) at zero back-up pressure to evaluate Paw at 100 ms of airways occlusion (P0.1);

Procedure4: PSV with decreasing support levels of Paw (Psup) in 1–4 steps to evaluate P0.1 and MIP during 20 s of PSV interruption (mean value for several interruptions at a constant Psup level);

Procedure5: Spontaneous breathing trial with Psup = 8 cmH2O to evaluate MIP as above.

RESULTS. All measurements are presented as mean ± standard deviation. Procedure1: MIP = 3.8 ± 0.7 cmH2O, DPpeak = 1.9 ± 0.8 cmH2O, Ti = 1.2 ± 0.4 s, Slope = 1.8 ± 1 cmH2O/s; Procedure2: WOBpeep = 1696 ± 646 mL.cmH2O, WOBe = 3998 ± 1754 mL.cmH2O, WOBve = 950 ± 1003 mL.cmH2O, WOBr = 3531 ± 1020 mL.cmH2O; Procedure3: P0.1 = -2.4 ± 1.6 cmH2O; Procedure4: Psup = 19.3 ± 4 cmH2O (levels 1-4), MIP = -11.1 ± 9.3 cmH2O (levels 1-4), P0.1 = 0.4 ± 1.7 cmH2O (level 1). Procedure5: Psup = 9.1 ± 0.5 cmH2O, MIP = -17.7 ± 10.5 cmH2O.

CONCLUSIONS. The reported ranges of measurements on Vt, Paw signals for assessment of the patient status during 5 procedures of the weaning process show the response of patients who are ready for MSV stopping. These features could support objective criteria for prediction of positive outcome.

REFERENCES. 1. Epstein S. Weaning from ventilatory support. Curr Opin Crit Care. 2009;15(1):36–43. 2. Funk GC, Anders S, Breyer MK, et al. Incidence and outcome of weaning from mechanical ventilation according to new categories. Eur Respir J.

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	

Resuscitation Cardiac arrest Cardiopulmonary resuscitation Fibrillation Ventricular fibrillation

Circulation

RESUSCITATION SCIENCE SYMPOSIUM
SESSION TITLE: SESSION VIII: BEST ORIGINAL RESUSCITATION SCIENCE

Abstract 253: Method for Minimal Delay Triggering of VF Detection During Cardio Pulmonary Resuscitation

Jean-philippe Didon, Sarah Menetre, Irena Jekova, Vessela Krasteva

Circulation. 2010;122:A253

Abstract

Background: The detection of ventricular fibrillation (VF) by Automated External Defibrillators (AED) during cardiopulmonary resuscitation (CPR) is influenced by artifacts from chest compressions (CC). CC-free ECG signals for accurate VF analysis are scarce and found mostly during the short-time 'hands-off' intervals. Therefore, an appropriate detection of the end of CC (EoCC) is important for immediate triggering of the VF analysis. The aim of this study is to present the accuracy of that part of a shock advisory system (SAS) which is designed for triggering of CC-free VF detection process at minimal delay.

Method: Recordings of 40 OHCA interventions with AEDs (FredEasy, Schiller Medical SAS, France) are retrospectively processed. 1400 EoCC events are identified by manual annotation of the time when the CC artifacts in both ECG and impedance (DZ) channels disappear after periods with CC contamination. The EoCC detections are obtained by running SAS process based on DZ channel analysis by measurements of waves and rates of CC artifacts.

Results: Since there is no standard for reporting the accuracy of EoCC detection algorithms, we evaluate the percentage of the EoCC detections provided within 4 confidence delays around the EoCC annotation. With the 565 EoCCs from the learning database, the algorithm reaches an accuracy of 79.3%, 86.5%, 92.2%, 95.6% for 0.3s, 0.5s, 0.7s, 1s delays respectively. A validation performed on 835 different EoCCs from a test database showed no significantly different results.

Conclusion: To our knowledge this is the first study reporting the minimal delay at which VF detection analysis can be triggered after EoCC. The collection of CC-free ECG is crucial for the VF detection accuracy, therefore the assessment of the triggering method guarantees a certain ECG quality. Our observations over EoCC events in real OHCA performed by different rescuers show different waveforms and durations of the DZ channel transition process just after EoCC. The SAS provides a minimal delay of 0.3s in about 79% of EoCCs and 90% of EoCCs are detected within a delay of 0.7s.

Device Fibrillation Cardiopulmonary resuscitation

Previous
Back to top

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Moderated Posters

Arrhythmias

Sunday 17 October 2010, 15:45–16:15 Moderated Poster

P192

Ventricular tachycardia after myocardial infarction. Nonfluoroscopic mapping possibilities

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Diagnostic and medical tactics in group of patients with IHD. complicated by ventricular tachycardia a tachycardia now still remains an unresolved problem.

Materials and Methods: 44 patients are executed endocardial EP investigation and catheter RF ablation. In 18 cases mapping was spent in the conditions of electroanatomic system "Carto". The indication to operation were paroxysmal or continuous-relapsing ventricular tachycardia. Duration of the anamnesis had been made from 2 months till 3 years (1.7±0.8 years). Pharmacological therapy was spent 3.3±1.2 by preparations without effect. Amiodarone was accepted 75% of patients. The age of patients 61±6 years. In total it is noted 39 morphological types of VT. To four patients ICD was implanted. All of them had IHD as a basic desease and the anamnesis of ischemical heart attack, in 7 cases with formation of left ventricle aneurysm. The fraction of ejection has on the average 31±7%. On synus rhythm definition of a zone slow (fractionated) conduction, pace mapping and anatomic «Carto» left ventricle reconstruction was carried out. Against VT reconstruction of the interested chamber of heart, in synergysm with pacemapping was carried out. Average duration of fluoroscopic time of operation has made 34.5±10 minutes. At 2 patients it was carried out empirical ablation all possible circles reentry in left ventricle (since in one case it was impossible to induce VT during EPI, and in other is documented "fast" VT, accompanied by syncope).

As final point of ablation was considered impossibility of an induction of any morphological type of VT.

Results: Efficiency has made 79% – elimination of all morphological types and 85% – elimination of separate morphological types VT. 2 patients had effective appointment antiarrhythmic drug therapy (early inefficient). Supervision terms have made 2–36 months (on the average 19.3).

Conclusion: Thus, RF ablation is as much as possible effective and safe method of treatment, but labour-consuming technology of intervention treatment of the patients suffering VT after myocardial infarction.

P193

Compromising bradycardia: Management in the emergency department of National Heart Institute

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The need to treat bradycardias is dictated primarily by the clinical presentation of the patient. There are only a few reports available on the management and outcome of patients presenting with compromising bradycardia to the emergency department (ED).

This study include 210 consecutive patients, with compromising bradycardia, admitted to the emergency department of National Heart Institute (tertiary Care hospital) within eight month period, 107 patients (51%) females, 103 patients (49%) males, whose age ranged from 25 to 89 years.

The aim of this study is to report the incidence, symptoms, presenting rhythm, underlying mechanism, management, and outcome of patients presenting with compromising bradycardia to ER and need for temporary and permanent pacing.

The study showed that of the 210 patients presenting with compromising bradycardia, about 60% required temporary emergency pacing for initial stabilisation, and about 53% had to undergo implantation of a permanent pacemaker system. In about 48% (100 out of 210) of the patients, some kind of cause-specific treatment was necessary. initial stabilization does nt rule out need to PPM. even, Permanent PM maybe last resort even if initial temprary pacing was nt done. 28 patients per month (IQR 24—31) with compromising bradycardia were admitted to the department, which are 70 out of 10,000 patients seeking medical care at the ED for any reason (incidence 0.007). The leading clinical symptom in patients was syncope in [80 (38%) patients], followed by dizziness in [44 (21%) patients], angina in [42 (20%) patients], dyspnoea/heart failure in [32 (15%) patients] and collapse in [12 (6%) patients]. In our observation, syncope and dizziness were present in more than half of the patients. A permanent pacemaker was necessary in 112 out of the 210 patients (50%). In (101; 90%) a single lead device., and in 11 (10%) patients a DDD, was implanted. Analysis of ECG-recordings showed high grade AVblock in [97 (46%) patients] as the presenting rhythm. sinus bradycardia in [47 (22%) patients], sinu-atrial arrest in [15 (7%) patients], atrial fibrillation with slow ventricular response in [26 (12%) patients] and pacemaker-failure in [25 (12%) patients], sinu-atrial arrest in [15 (7%) patients].

Consecutively, in our study, bradycardia in ER high percentage of necessity of a permanent pacemaker, due to high grade AV-block, sick-sinus syndrome and pacemaker dysfunction.

P194

Variation of the transthoracic impedance in a sequence of cardioversion shocks

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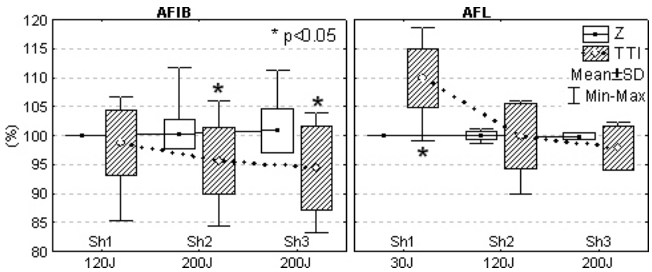
Introduction: Transthoracic impedance in defibrillation/cardioversion has been referred as a predictor of the shock outcome suggesting that sequence of shocks with escalating energies affect the impedance thus improving the success rate. This study provides evidences that escalating energy protocol does not affect the pre-shock impedance (Z) but only the impedance during the shock (TTI) which is correlated to the energy setting (E).

Methods: Cardioversion shocks in 96 patients are studied. Escalating E protocol is adopted for a sequence of 3 shocks Sh1/Sh2/Sh3: 120/200/200 J for atrial fibrillation (AFIB), 30/120/200 J for atrial flutter (AFL). The number of processed shocks is: 62/26/11 (AFIB) and 34/17/3 (AFL). During each shock, voltage and current waveforms are recorded and TTI is deduced. Before each shock, Z is measured as the attenuation of a low-intensity, high-frequency (30 kHz) current.

Results: Measurement of Z before Sh1 is stated as 100% basis value. For the sequence of shocks, the percentage change of TTI and Z is evaluated (see Figure). The t-test shows no significant variation of Z relative to E and shock number ($p > 0.05$). In contrast, TTI is significantly higher at 30 J (AFL, $p < 0.001$) and respectively lower at 200J (AFIB, $p < 0.01$). Significant correlation is found for the TTI percentage change in function of E ($r = 0.65$, $p < 0.001$).

Conclusions: Stable impedance with variation of less than 1% is measured before first, second and third shocks with up to 6-fold energy escalation. This finding supports the hypothesis that the high-frequency Z is not influenced by the shock sequence and cannot be used to explain the success of repeating defibrillation. Conversely TTI during shock, changes significantly from 110% down to 95% and is related to the energy setting.



Z, TTI percentage change vs. Z before Sh1.

P195

Conversion efficacy and safety of Ibutilide, amiodarone and propaphenone in patients with atrial fibrillation or atrial flutter, of 3–48 h duration

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Purpose: The aim of this report is to determine if differences in efficacy and safety exist between Propaphenone (PR.), Ibutilide (IB) and Amiodarone (AMIO.) (in patients with paroxysmal Atrial Fibrillation (P.A.Fib.), or Paroxysmal Atrial Flutter (P.A.Flutt.), across various age categories.

Methods: In a general cardiology practice 94 patients with Atrial Fibrillation or Atrial Flutter, of 3–48 h. duration were observed. Management of patients involved knowledge of their underlying conditions f.e. haemodynamically stable, without contradictions to Ibutilide (IB), Amiodarone (AMIO.) or Propaphenone (PR.) and. without active infection. If sinus rhythm was not restored with the first antiarrhythmic drug we used another one according to international guide lines. Successful cardioversion was defined as arrhythmia termination within 48 hours. At the same time we observed the patients for severe complications (f.e. sustained polymorphic ventricular tachycardia the most important and dangerous complication of IB and AMIO., or transient hypotension because of PR. etc.). The results of the study were analyzed, using the excel and the method of $\chi 2$.

Results: See Table 1. The efficacy of Ibutilide is better than this one of Propaphenone (when they are used as a first choice) and it is considered to be (not quite) statistically significant $p = 0.0793$. The conversion rate and safety of antiarrhythmic drugs were not significantly different in all the other cases (between PR. and AMIO., IB. and AMIO., IB. and PR.)

Conclusions: The efficacy of IB. for conversion of P.A.Fib. or P.A.Flutt. to Sinus. rhythm, was better than this one of PR. (not quite statistically significant), when they are used as the first antiarrhythmic agent. As regards the safety of PR., AMIO., and IB., complications are rare and without long-term adverse effects.

Table 1: Results

Antiarrhythmic	Patients with PAfib	Successful cardioversion	Number of patients who used second antiarrhythmic	Succesful cardioversion	severe complications
Propaphenone	47	39 (83%)	0*	0	0 (0%)
Amiodarone	26	23 (88%)	4	3 (75%)	0 (0%)
Ibutilide	21	21 (100%)	5	4 (80%)	1 (3.8%)

*Propaphenone was never used as a second choice.

P196

Role of natriuretic peptides and high sensitivity CRP as predictors of recurrence following cardioversion of paroxysmal atrial fibrillationin emergency department

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Background: Levels of brain- (BNP), atrial-natriuretic peptides (ANP) and C-reactive protein (CRP) are increased in patients with atrial fibrillation. Additionally, BNP and high sensitivity CRP levels predicted cardioversion success and sinus rhythm maintenance in patients with chronic atrial fibrillation. In our study we tested whether ANP, BNP and CRP levels would predict success of cardioversion and persistence of sinus rhythm in patients with paroxysmal atrial fibrillation (PAF).

Methods: We enrolled 23 patients undergoing cardioversion of PAF of less than 48 hour duration. ANP, BNP and CRP levels were measured prior, 60 min and 12 hours post cardioversion. Atrial dimensions and left ventricular function were assessed by echocardiography. Patients were followed for six months.

Results: Pharmacological cardioversion was initially attempted in 16 patients, and was successful in 6 (38%). Patients with unsuccessful pharmacological cardioversion and all remaining patients were DC cardioverted. Sius rhythm was restored in all patients. Patients had normal dimensions of left atrium (3.9 ± 0.5 cm) and ejection fraction (55 ± 5%). Twelve hours after cardioversion, levels of ANP decreased from 230 ± 150 to110 ± 100 pg/ml ($p < 0.05$), and BNP from 344 ± 186 to 205 ± 106 pg/ml (NS). There were no changes in CRP levels 5.2 ± 6 vs 5.7 ± 5.4 mg/dl. None of the three markers predicted success of pharmacological cardioversion to sinus rhythm. During follow up, 8 of 23 (34%) patients had recurrence of PAF. When ANP, BNP, CRP, atrial diameter, ejection fraction, and age were included in multiple regression analysis, only pre-cardioversion levels of BNP predicted recurrence of PAF.

Conclusion: In patients with recent onset PAF, only BNP, but not ANP and CRP levels, predicted recurrence of atrial fibrillation after cardioversion.

P197

Incidence and prognosis of arrhythmias complicating acute myocardial infarction: data from Mantova Hospital CCU

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Introduction: Coronary care units (CCU) arose for the necessity of reducing sudden cardiac death incidence in patients admitted to hospital for acute myocardial infarction. Aim of the present study is to analyze the clinical impact of significant arrhythmias in Mantova Hospital CCU.

Materials and methods: We used a database, also active in CCU, useful to register all arrhythmias and their clinical complications during hospitalization.

Results: The study considered a population of 1963 consecutive patients admitted to CCU for acute myocardial infarction in a period of 4.5 years, divided in ST-elevation myocardial infarction (935 pts), non ST-elevation myocardial infarction (729 pts) and sub acute myocardial infarction (299 pts). The median of hospitalization was 8 days (3 days in CCU and 5 days in Cardiology), a period of time corresponding to the major incidence of arrhythmic and clinical cardiac events. Most arrhythmias was atria fibrillation and/or flutter (8.5%), ventricular fibrillation (5.1%), total atrio-ventricular block (3.6%) and non-sustained ventricular tachycardia (2.6%), while supra ventricular arrhythmias (1.3%), first or second degree atria-ventricular block (1.3%) and . . . were less frequent. These arrhythmias were distributed among the different types of myocardial infarction as indicated in the table below, with greater incidence of ventricular arrhythmias in ST-elevation myocardial infarction, although in sub acute myocardial infarction a greater mortality was detected.

Ventricular fibrillation (45%) and total atrio-ventricular block (70%) were more premature (within 24 hours), while atrial-fibrillation (48%) and non sustained ventricular tachycardia (45%) resulted more late. General population in-hospital mortality was 5.23% and it didn't differ

Circulation

CORE 4: HEART RHYTHM DISORDERS AND RESUSCITATION SCIENCE

Abstract 2452: A New VF Detection Method During Cardio Pulmonary Resuscitation That Minimizes Hands-off Time

Vessela Krasteva, Irena Jekova, Sarah Ménétré, Todor Stoyanov, Ivan Dotsinsky, Jean-Philippe Didon

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Abstract

Background: Chest compressions (CC) and Defibrillation with Automated External Defibrillator (AED) is the optimum treatment for ventricular fibrillation (VF) patients. Minimum 'hands-off' intervals are required to improve the success rate of defibrillation. In support of such life-saving practice, we developed a two-stage shock advisory system, which takes a decision to pause cardiac massage in a first stage, and to prepare a shock in a second stage. We tested whether the system would meet the AHA recommendations for shock advisory decision in AEDs (specificity (Sp)>95 % for Non Shockable Rhythms (NS), sensitivity (Se)>90 % for VF).

Methods: Recordings of 168 OHCA interventions with AEDs (FredEasy, Schiller Medical SAS, France) were retrospectively processed. 825 ECG segments were identified for analysis, consisted of 10-seconds with CC artefacts followed by 3-seconds with no CC artefacts. Independent reviewers annotated the rhythm seen on the noise-free segment. The annotation is then accepted for the total 10s+3s ECG episode. Annotated ECG segments include: 670 NS (386 asystoles (ASYS), 284 other non shockable rythms (ONS)), 155 VF, with artifact and rhythm distributions reflecting those found in the 168 patients. AED analysis algorithm works in two stages. The first stage analyses 10 seconds of ECG with CC artefacts, the decision can be 'Continue CC' or 'Prepare Shock'. The second stage relies on a short-time ECG analysis with no CC artifacts during the 3 seconds following the end of CC. The decision can be 'Shock' or 'Cancel Shock'.

Results: The first stage of the algorithm correctly advises 'Continue CC' for 83.7% of ASYS (323/386) and 87% of ONS (247/284). The warning 'Prepare Shock' is correct for 94.2% of VF (146/155). The second stage advises 'Cancel Shock' for 97.4% of ASYS (376/386) and 99.7% of ONS (283/284). Shock is recommended in 99.4% of VF (154/155).

Conclusions: The first stage of the algorithm avoids CC pauses in about 85% of the non-shockables rhythms (NS), improving the chances of resuscitation. The sensitivity during CC (94%) is above AHA recommendations. The final decision for shock delivery taken by the second stage with short-time ECG analysis is exceeding the AHA recommendations for both Sp (98% for NS) and Se (99.4%).

Previous   Back to top

This Issue

Circulation
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Table of Contents

Previous

Jump to

Article
Info & Metrics

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Conclusions: Regular exercise has beneficial effects on cardiovascular system. Static or dynamic exercise did not impair repolarization in healthy young sportsmen.

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ECG-50
Diurnal variation in QT dispersion in patients with low hemoglobin level

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Introduction: The aim of this study is to evaluate QTc dispersion in patients with anemia, compared with a control group, to assess for a tendency for arrhythmias.

Methods: Eighteen patients with a hemoglobin levels of 7.2 ± 2 g/dL and hematocrit 24% ± 8% were included in the study. A control group of 34 patients with hemoglobin levels of 14.9 ± 3 g/dL and hematocrit 44% ± 9% were included also. The electrocardiograms were obtained every 8 hours in both groups from the patients. QT dispersion and maximum and minimum QTc were measured from 24-hour Holter electrocardiograms.

Results: QTc dispersion was greatest in the morning, whereas there was a significant decrease in the afternoon and late at night (morning QTcd = 42 ± 5 milliseconds; afternoon, 38 ± 7 milliseconds; midnight, 36 ± 6 milliseconds; $P < .05$) in the patients with anemia. In the group with normal hemoglobin levels, the greatest level of QTc dispersion was observed in the morning (QTcd = 55 ± 10 milliseconds, $P < .05$), which showed a significant decrease in the afternoon (QTcd = 49 ± 9, $P < .05$) and midnight (QTcd = 37 ± 8 milliseconds, $P < .059$) respectively.

Conclusions: QTc dispersion shows a diurnal variation both in the healthy patients and patients with anemia, with a significant increase in the morning, which may be indicative of a higher predisposition to cardiac events early in the morning.

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ECG-51
The effect of ischemia grade and starting time to treatment for thrombolytic therapy in ST-elevation myocardial infarction

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Introduction: Among patients with ST-elevation myocardial infarction, those with grade III ischemia have rapid progression of necrosis over time and less myocardial salvage.

Methods: We assessed the relation of baseline electrocardiographic ischemia grade and starting time to treatment in 46 patients who treated with thrombolytic therapy for ST-elevation myocardial infarction. Patients were divided in 2 groups based on enrollment electrocardiogram (grade III ischemia): (1) absence of S wave below isoelectric baseline in leads that usually have a terminal S configuration or (2) ST-J point amplitude above 50% of the R wave amplitude in all other leads (n = 22). To be included the grade III group, grade III criteria in more than 2 adjacent leads were required. Patients with ST elevation but without grade III criteria were classified as having grade II (n = 24). ST resolution above 50% in maximal ST-elevation lead at 90 minutes for TPA and 120 minutes for SKZ were taken as a reperfusion criteria.

Results: Thrombolytic therapy was more successful if it was started in the first 2 hours of the chest pain in both groups. In the early group (in which treatment was started at first 2 hours of the chest pain) with grade II ischemia, thrombolytic therapy was successful in 8 patients (89%). In the late group (in which treatment was started at 2 to 12 hours of the chest pain) with grade II ischemia, thrombolytic therapy was successful in 11 patients (73%). Among patients with grade III ischemia, the ratios were 6 to 8 (%75) for early group and 8 to 14 (57%) for the late group.

Conclusions: Although thrombolytic therapy seemed to be more successful in the grade II than grade III group in respect to administration time, it did not reach statistical significance.

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Magnetocardiography and Vectocardiography

Posters

MAG-1
Stress testing in coronary artery disease by magnetic field imaging: a 3-dimensional current distribution model

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Introduction: Magnetic field imaging (MFI) combines de- and repolarization registration of the cardiac electromagnetic field with a 3-dimensional current distribution model. An interesting application for MFI is the possibility to detect myocardial ischemia under stress.

Methods: Using a new reconstruction technique, one can generate a pseudocurrent distribution on the epicardial surface: the comparison of the time evolution of such current distributions at rest and under stress shows differences in coronary artery disease (CAD). The model works with a realistic epicardial surface generated on the basis of computed tomography or MRT data or with a standardized ellipsoidal model. To take into account the vectorial character of the epicardial current distribution, the current flow in the epicardial surface element is represented in the graphic display by a cone, thus indicating the direction of current flow; the height of the cone represents the current intensity. To improve readability of the display and to provide an overview of regional behavior, the cones are also color coded: green indicates strong activity; red indicates poor activity.

Results: As an example of the method, data of pharmacologic stress MFI on a patient with CAD will be presented. The newly developed algorithm operates in different segments of the electromagnetic heartbeat. The indicated myocardial area strongly correlated to invasive coronary angiography results. In such a situation, the advantage provided by the friendly ellipsoidal surface on the numerical solution of the inverse problem seems to overcome the advantage of a realistic heart model.

Conclusions: Magnetic field imaging is a promising procedure for a noninvasive stress testing as well as screening method for localization of myocardial ischemia.

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MAG-2
Possibilities of signal-averaged orthogonal and vector electrocardiography for locating and evaluating the size of acute myocardial infarction

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Introduction: Signal-averaged electrocardiography (SAECG) is known to be useful tool for extraction and analysis of low-amplitude signal components. We found SAECG may be applied to locating and evaluating the size of acute myocardial infarction (AMI).

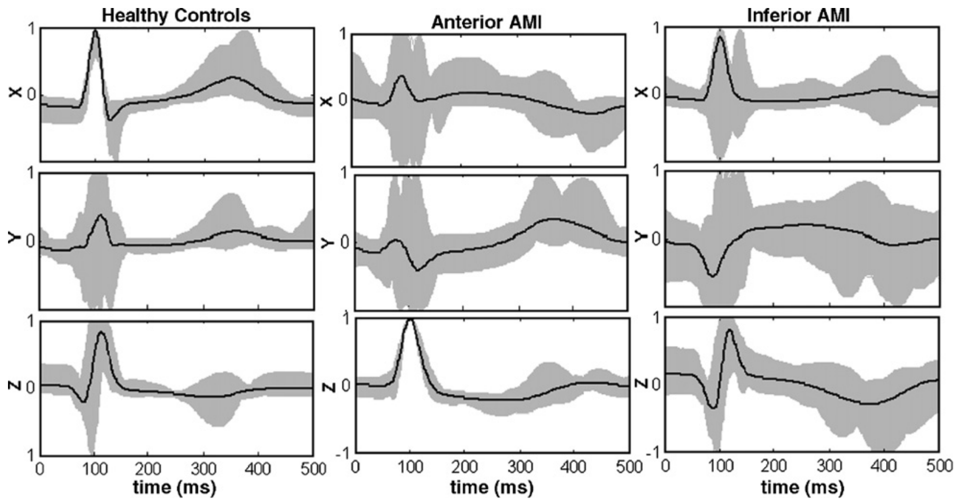

Fig. 1. (Abstract 2)

Methods: High-resolution (1 MHz) ECGs from 3 groups were collected: healthy controls (20), patients with anterior AMI (15), and patients with inferior AMI (27). The 3 orthogonal leads *X*, *Y*, and *Z* were synthesized from the 12-standard leads by known transformation. Synchronized averaging was carried out over a hundred P-QRS-T intervals of each orthogonal lead. The resulting intervals of all subjects within a group were additionally averaged. The obtained *X*, *Y*, and *Z* patterns as well as the derived loops in the vectorcardiographic (VCG) planes (VCG patterns) were studied for significant divergences.

Results: (1) Morphologic components of the *X*, *Y*, and *Z* scalar patterns were compared, and the divergence values between the groups were assessed, with $P < .05$ regarded as significant. The deviations of the individual averaged P-QRS-T intervals from the corresponding *X*, *Y*, and *Z* patterns were used to obtain specific variation contours (Fig. 1). (2) Sets of geometric indicators were derived from the VCG patterns to classify the patients into control and AMI groups.

Conclusions: More than 80% correct classifications for each group were obtained. It is found that accurate locating and size evaluation of AMI is quite possible by using morphologic components and indicators.

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MAG-3

A proposed new theory for spontaneous ventricular fibrillation or flutter or ventricular premature contractions based on negative sequence voltages in patients with acute myocardial infarction

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Introduction: A study (Am J Emerg Med 2003) of patients with acute aortic dissection has found that abnormal sense of inscription direction (ASID) and L-W ratio of the T loop in the emergency vectorcardiogram (VCG) puts patients at high risk of postoperationally unexpected ventricular tachyarrhythmia (UVT). A further study (IJBEM 2003) of the P loop found that the ASID had partial negative sequence (PNS) or complete negative sequence (CNS) type similar to the physics problem of generators. Biostatistic methods have never succeeded in evaluating mathematical physics in the medical literature.

Methods: A total of 121 patients with suspected AMI received serial recording of frank VCG. Both positive and negative proofs about spontaneous ventricular fibrillation, flutter, and ventricular premature contractions in the literature are also reviewed.

Results: Among them, 25 (21%) developed UVT. Seven had no VCG before their UVT and cardioversion. Of the remaining 18 patients, 13 (72%; 1 PNS, 2 PNS + CNS, and 10 CNS) had the same abnormalities of the T loop as the patients with acute aortic dissection; 4 had partial and 1 had no abnormality because the time gap between VCG and UVT was too wide (between 4 and 22 days).

Conclusions: Negative sequence voltages appear as an abnormal inscription direction in the repolarization process of the ventricle. It could happen in a diseased or electrocardiographic normal heart. The heart will generate a ventricular premature contraction (physiologic pacing) or contractions (physiologic overdrive suppression) to abolish the negative sequence voltage–induced abnormal activation propagation. The threshold at which this physiologic correction will appear through the autonomic nervous system is variable depending on the individual patient (ie, heart conditions, body weight, age). If it is not successful, ventricular flutter from single foci or chaotic ventricular fibrillation from multiple foci will ensue. With the help of chamber enlargement and/or abnormal conduction within the ventricle, abnormal rhythms will be sustained.

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MAG-4

Vectorcardiographic recordings of QT interval predicts long QT syndrome

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Introduction: Manual measurements of QT intervals are time-consuming and burdened with inter- and intraindividual variation. The available automatic systems for QT measurements have not been validated in a genotyped population of long QT syndrome (LQTS). We hypothesized that vectorcardiogram (VCG) recordings could determine the QT interval with high precision and predict whether an individual has LQTS.

Methods: The population consisted of 42 individuals (23 female and 19 male) with different mutations: 22 LQT1, 9 LQT2, and 11 healthy individuals. Mean age was 27.5 years (range, 1-68 years). Twelve-lead electrocardiogram (ECG) automatic measurements were made with a Mac5000 system (GE Medical System); VCG automatic measurements were made with Mida1000 (Ortivus). The manual measurements were done

Table 1

Rating according to Goldenberg (2006)	Children 1-15 y (ms)	Adult man (ms)	Adult woman (ms)
Normal	<440	<430	<450
Borderline	440-460	430-450	450-470
Prolonged	>460	>450	>470

Резултати: При този ретроспективен обзор на пациентите, оперирани в нащата клиника, се установи, че процентът на пейсмейкър инфекциите е 0,5%! Изолираните причинители са били Staphylococcus epidirmidis и Staphylococcus aureus. Нито един от тези пациенти не бе подложен на повторна оперативна интервенция, но всички бяха активно лекувани с два или три антибиотика (Аб) i.v., включително и с локално приложение през дренажните тръби в пейсмейкърния джоб. Продължителността на Аб курс варираше от 15 до 30 дни. При нито един пациент не се отбеляза повторен прием в клиниката поради реинфекция.

Изводи: Ниският процент на пейсмейкър инфекции в нашата клиника се обяснява с по-продължителния престой (от 2 до 4 дни). През това време пациетът е на i.v. Аб профилактика. Стриктното придържане към изискването на НЗОК за минимален болничен престой от 1 ден и последващата необходимост от Аб профилактика p.o. в домашни условия е вероятната причина за по-високия процент на тези инфекции в други клиники. Използването на хипойодни разтвори интраоперативно през последните години също допринесе за значимото намаление на това сериозно усложнение.

П № 30. ПРЕДИКТОРИ ЗА УСПЕХ ОТ ПЪРВИ ШОК С НИСКА ЕНЕРГИЯ ПРИ КАРДИОВЕРСИЯ НА ПАЦИЕНТИ С ПРЕДСЪРДНО МЪЖДЕНЕ

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Увод. При трансторакална кардиоверсия (КВС) на пациенти с персистиращо предсърдно мъждене (ПМ) може да се прилагат протоколи с нарастваща енергия или да се започне направо с максимална енергия, като резултатите за успех в литературата са противоречиви. Основният предиктор за успех на КВС е трансторакалният импеданс.

Цел. Да се намерят предиктори за успех на първия електрошок с ниска енергия при пациенти с персистиращо ПМ, подложени на планова трансторакална КВС.

Метод. Анализирани са данните на 74 пациенти с персистиращо ПМ, при които е осъществена планова КВС с бифазни импеданс-компенсирани импулси (DEFIGUARD 4000) по стандартен болничен протокол. Измерван е трансторакалният импеданс непосредствено преди процедурата и по време на всеки шок. Прилагани са последователно следните енергии: 120 J → 200 J → 200 J → 360 J (последният шок е с монофазни импулси) през самозалепващи се електроди в предно-латерална позиция. Успех от първия шок е приет при възстановяване на синусов ритъм за поне 1 минута.

Резултати. В група А (успех от първи шок) са включени 43 болни, в група В (неуспех от първи шок) – 31 пациенти. Двете групи не се различават по пол, възраст, антропометрични показатели, наличие на структурно сърдечно заболяване, предшестваща антиаритмична терапия, давност на аритмията, размери на ляво предсърдие и левокамерна ФИ, изходен трансторакален импеданс. В група А е сигнификантно по-малък теледиастолният обем на ЛК (ТДО) – 95,7 ml ± 29,4 срещу 111,6 ml ± 33,3 ml, p = 0.046. Приложихме стъпков линеен дискриминантен анализ – ТДО предиктира успех от първи шок с ниска енергия с точност от 65%.

Изводи. При използване на импеданс-компенсирани импулси трансторакалният импеданс не е предиктор за успех. ТДО на ЛК предсказва с умерена точност успех от първи шок с ниска енергия. Въз основа на предшестващите ехокардиографски данни (ТДО на ЛК) може да се индивидуализира приложението на начална по-ниска или максимална енергия при планова КВС на пациенти с персистиращо ПМ и да се избегнат ненужни шокове с максимална енергия или продължителна процедура с множество шокове и по-дълга анестезия.

П № 31. СРАВНЕНИЕ НА ПРОТОКОЛИ С ЕСКАЛИРАЩИ И НЕЕСКАЛИРАЩИ ЕНЕРГИИ ПРИ КАРДИОВЕРСИЯ НА ПАЦИЕНТИ С ПЕРСИСТИРАЩО ПРЕДСЪРДНО МЪЖДЕНЕ – ЕДНОЦЕНТРОВО ПРОУЧВАНЕ

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В международните ръководства за лечение на пациенти с предсърдно мъждене оптималният избор на начална и последващи енергии при трансторакален електрошок с бифазни импулси не е известен и всеки производител на дефибрилатори дава свои препоръки.

Анализирахме проспективно ефективността и безопасността на два клинични протокола в четири стъпки: с ескалиращи енергии (120 J → 200 J → 200 J → 360 J), група E (N = 74 болни) и с неескалиращи енергии (200 J → 200 J → 200 J → 360 J), група NE (N = 116 болни), като първите три шока са с бифазни импулси Multipulse Biowave®, дефибрилатор DG4000 (Schiller Médical, France), а последният е с монофазни импулси. Процедурата е проведена съгласно стандартен болничен протокол със самозалепващи се електроди в преднолатерална позиция.

Резултати: Двете групи не се различават по пол, възраст, антропометрични показатели (ръст, тегло, BMI, телесна повърхност, обиколка на гръден кош, окосменост, тип кожа), продължителност на аритмията, наличие на структурно сърдечно заболяване, предно-заден размер на ЛП, ФИ, предшестваща антиаритмична терапия.

Ефективност: Успех (възстановен синусов ритъм за повече от 1 min) е постигнат при 94,6% в група E спрямо 87,1% в група NE – p = 0,07, със средно 1,64 шока в група E спрямо 1,5 шока в група NE – p = 0,33. Успех от първи шок е постигнат сигнификантно по-често в група NE (75% спрямо 58,1% в група E, p = 0,012). Монофазен импулс е използван съпоставимо рядко – при 4 болни в група E, като при двама от тях е бил ефективен, и при 12 болни в група NE, като при нито един от тях не е бил ефективен.

Безопасност: Двете групи не се различават по честота и вид на постшок ритъмните и проводните нарушения, както и по проследените хемодинамични параметри. Само при 3-ма болни в група E и при 6 в група NE се наблюдават патологични стойности на тропонин постпроцедурно (p = 0,82).

В заключение: Двата протокола са еднакво ефективни и безопасни, като успех от първи шок се постига по-често при неескалиращия протокол. Това би скъсило процедурата и времето за анестезия.

П № 32. КЛИНИЧЕН ОПИТ – ТЕЕ ЗА ОЦЕНКА НА ЕМБОЛИЧНИЯ РИСК ПРИ ПАЦИЕНТИ С ППМ И ЕЛЕКТРИЧЕСКО РЕГУЛИРАНЕ НА РИТЪМА ПОСЛЕДОВАТЕЛНО С ЕДНА ОБЩА АНЕСТЕЗИЯ

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ТЕЕ е задължително условие за оценка на емболичния риск при персистиращо предсърдно мъждене след минимум четириседмична оптимална антикоагулация. Изследването се осъществява под обща венозна анестезия. При липса на интракавитарни тромботични структури по време на същата анестезия се осъществява електрическо регулиране на ритъма.

Целта на съобщението е споделянето на нашия клиничен опит. Постига се оптимален комфорт на пациента при извършване на ТЕЕ. Не се използват мидикаменти за локална анестезия, антиеметични и седатива. Намалява се рискът от усложнения при пациенти с тежка ЛК дисфункция .

За периода м. 01.2010 – м. 05.2012 г. са осъществени 135 ТЕЕ с последващо електрическо регулиране на ритъма с обща венозна анестезия. Пациентите са антикоагулирани с индиректен антикоагулант (синтром) и само 2-ма – с прадакса (Dabigatran). Не се използват за подготовка на ТЕЕ седативни медикаменти, антиеметици (риск от хипотония), както и локална анестезия с лидокаин (риск от бронхоспазъм, повишена саливация).

Общата анестезия се осъществява от анестезиолог. Използвани анестетици – пропофол; фентанил. Продължителност – 7-8 min.

При наличие на тромботични структури и висок емболичен риск (18 от изследваните пациенти) не се осъществява ел. регулиране на ритъма.

При нисък риск следва задълбочаване на анестезията и кардиоверзио.

Този алгоритъм на работа се наложи в името на комфорта на пациента и за намаляване на риска от усложнения при увредени пациенти (12 от изследваните са били с тежка ЛК дисфункция). Работата е екипна. Сигурността за пациента е по-голяма.

П № 33. АСИМПТОМНО ПРЕДСЪРДНО МЪЖДЕНЕ ПРИ ЕКГ ТЕЛЕМОНИТОРИРАНЕ НА ПАЦИЕНТИ С МОЗЪЧЕН ИНСУЛТ

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Въведение: При 25% от пациентите с мозъчен инсулт се установяват епизоди на пароксизмално предсърдно мъждене (ППМ). Проучвания с холтер-ЕКГ мониториране показват, че честотата на асимптомното ППМ значително надвишава тази на симптомното. Усложненията обаче са еднакво често срещани при двата вида ритъмно нарушение.

Цел: Оценка на възможността за установяване на ППМ с помощта на ЕКГ телемониториране при пациенти с мозъчен инсулт..

Методи: Седемнайсет пациенти са завършили проучването. Средната възраст в изследваната група е 54 ± 16 год., 15 пациенти (88%) са мъже, 71% са с артериална хипертония, 71% – с дислипидемия, 59% – пушачи, 29% – със захарен диабет. Нито един от пациентите няма анамнеза за ПМ. Средният изчислен CHA_2DS_2-VASC точков сбор е 3.5 ± 1.1. Критерии за включване е наличието на инсулт в рамките на две седмици преди началото на телемониторирането, без явен емболигенен източник.

Резултати: Средният период на телемониториране беше 22 ± 6 дни като през него установихме епизоди на ППМ при пет от участниците (29%). При четирима от тях епизодите на ПМ бяха с продължителност до 30 s, а при един – над 30 s. При всички пациенти беше започната антикоагулантна терапия.

Демографските характеристики, разпределението на рисковите фактори, съпътстващата терапия и ехокардиографските параметри не показаха съществени разлики при сравнение между пациентите с регистриран епизод на ППМ и тези с липса на такова ритъмно нарушение.

По време на телемониторирането бяха установени и други ритъмни нарушения: хронотропна инкомпетентност с персистираща синусова тахикардия при един пациент; комплексна камерна екстрасистолия при двама от участниците и чести надкамерни екстрасистоли при други трима.

Заключение: ЕКГ телемониторирането при пациенти след мозъчен инсулт позволява установяването на асимптомни епизоди на ПМ и съответно оптимизиране на антитромбоцитната терапия.

П № 26. ИМПЛАНТАЦИЯ НА ЛЕВОКАМЕРЕН ЕЛЕКТРОД ПРИ СЪРДЕЧНО-СЪДОВИ СТРУКТУРНИ АНОМАЛИИ

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Намирането на оптимална позиция за пласиране на левокамерен електрод (ЛК) при ресинхронизираща терапия е най-често срещаният лимитиращ фактор за успеха на процедурата. Съществуват естествени анатомични варианти на венозната система и на коронарния синус, които затрудняват въвеждането на електрода за ЛК. Представяме три клинични случая със структурни съдови аномалии на сърцето, налагащи техническа оценка на имплантацията на електрода за ЛК.

Първият клиничен случай представя пациент с имплантация на CPT–P система за стимулация. Интрапроцедурно се установява акцесорна вена кава супериор, като единствен алтернативен венозен достъп за имплантация на третия електрод.

Вторият клиничен случай представя пациент с имплантация на CPT–P система за стимулация, като единственият възможен венозен достъп за имплантация на стимулиращите електроди е през акцесорна вена кава супериор. Налице са технически и анатомични пречки за имплантацията на ЛК електрод.

Третият клиничен случай представя пациент с вродена сърдечна малформация с морфология на обща камера, след операция модифициран фонтан с пълен AV блок и имлантиран VVI-R пейсмейкър с епимиокарден електрод. Високият праг на стимулация на епимиокардния електрод и честите реимплантации наложиха търсене на алтернативен метод на стимулация на общата камера през коронарния синус.

Заключение: Анатомичните вариации на венозната система на сърцето и наличните вродени малформации, често поставят пред изпитание техническите умения на оператора и преоценката за мястото и начина на имплантация на ЛК. Алтернатива на епимиокардната стимулация при пациенти с ВСМ и обща камера е имплантация на ендокарден електрод, пласирна в коронарния синус.

П № 27. СРАВНЕНИЕ НА ДВА ВИДА ПРОТОКОЛ ЗА КАРДИОВЕРСИЯ С БИФАЗНИ ИМПУЛСИ ПРИ ПАЦИЕНТИ С ПРЕДСЪРДНО МЪЖДЕНЕ

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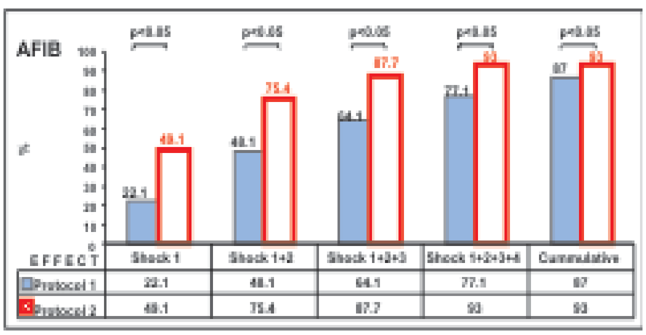
Увод и цел: Протоколът за трансторакална електрическа КВС при пациенти с предсърдно мъждене (ПМ) е индивидуален за всеки вид бифазни импулси. Целта на проучването е да се сравнят ефикасността и безопасността на два вида step-up протокол с бифазни импулси Multipulse Biowave® при пациенти с персистиращо ПМ.

Материал и методи: Протокол 1 включва 70 J – 120 J – 150 J – 180 J – 360 J (Mono), а протокол 2: 120 J – 200 J – 200 J – 360 J (Mono). За ефективна КВС е прието възстановяване на синусов ритъм за поне 1 минута. Изследвани са биохимични маркери за миокардна некроза преди и 8-12 часа след процедурата.

Резултати: Група 1 (131 болни, 60,3% мъже) и група 2 (114 болни, 59,6% мъже) не се различават по наличие на структурно заболяване и сърдечна недостатъчност, BMI, антиаритмична терапия, размери на ЛП, ФИ, но болните в група 2 са по-възрастни (52,7 години срещу 60,5 г.; p = 0,009) и по-често имат артериална хипертония (51,9% срещу 65,8%; p = 0,02). Налице е тенденция за по-голяма ефективност (възстановен синусов ритъм) при протокол 2 (93%) спрямо протокол 1 (87%), p = 0,092, като това се постига с по-ниска кумулативна енергия в гр. 2 (296 J спрямо 375 J; p = 0,021), с по-малко шокове (1,86 срещу 2,87; p < 0,0001) и с по-малко използване на монофазен импулс (10,5% срещу 22,1%; p = 0,011). Ефективността на първо, второ, трето и четвърто стъпало на КВС е сигнификантно по-висока при използване на протокол 2 – фиг. 1.

Биохимичните маркери за миокардна некроза след КВС (обща CK, CK-MB и TnI) не се различават в двете групи.

Изводи: Протокол 2 предлага по-голяма ефективност с по-малко шокове, по-ниска сумарна енергия и по-висока ефективност на първите шокове при същата безопасност в сравнение с протокол 1.



Фиг. 1. Ефективност на протокол 1 и протокол 2 на всяко стъпало при ПМ

П № 28. СРАВНЕНИЕ НА ДВА ВИДА ПРОТОКОЛ ЗА ТРАНСТОРАКАЛНА КАРДИОВЕРСИЯ С БИФАЗНИ ИМПУЛСИ ПРИ ПАЦИЕНТИ С ПЕРСИСТИРАЩО ПРЕДСЪРДНО ТРЕПТЕНЕ

Е. Трендафилова[1], В. Кръстева[2], Ц. Мудров[2], Ж. Дидон[3], П. Тасовска[1], А. Александров[1], И. Паскалева[1], Н. Гочева[1]
[1]Университетска национална кардиологична болница – София; [2]Централна лаборатория по биомедицинско инженерство, БАН – София; [3]Schiller Medical Company – Wissembourg, France

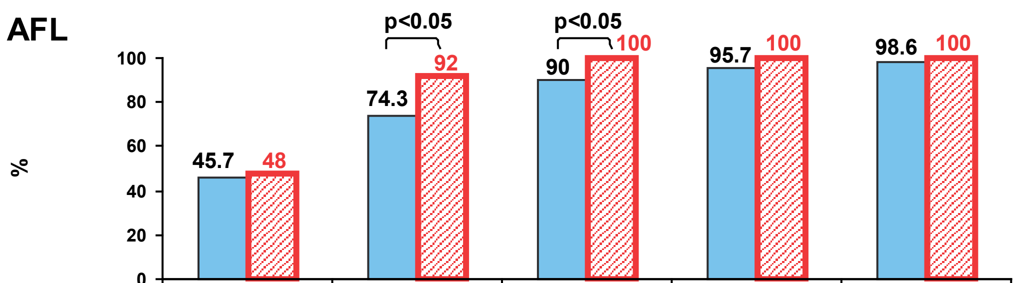
Увод и цел: Протоколът за трансторакална електрическа КВС при пациенти с предсърдно трептене (ПТ) е индивидуален за всеки вид бифазни импулси. Целта на проучването е да се сравнят ефикасността и безопасността на два вида step-up протокол с бифазни импулси Multipulse Biowave® при пациенти с персистиращо ПТ.

Материал и методи: Протокол 1 включва 30 J – 120 J – 150 J– 180 J– 360 J (Mono), а протокол 2: 30 J – 120 J – 200 J – 360 J (Mono). За ефективна КВС е прието възстановяване на синусов ритъм за поне 1 минута. Изследвани са биохимични маркери за миокардна некроза преди и 8-12 часа след процедурата.

Резултати: Група 1 (70 болни, 72,9% мъже) и група 2 (50 болни, 74% мъже) не се различават по възраст, наличие на структурно заболяване и сърдечна недостатъчност, антиаритмична терапия, размери на ЛП, ФИ, но болните в група 2 по-често имат артериална хипертония (44.3% срещу 68%; p = 0,008) и са с по-висок BMI (27,4 срещу 29,4; p = 0,04) и по-голяма телесна повърхност (1,94 срещу 2,02; p = 0,03). Налице е еднаква ефективност (възстановен синусов ритъм) при двата протокола (98,6% срещу 100%; p = 0,58), не се намират разлики в кумулативната енергия (137 J срещу 114 J; p = 0,39), но при протокол 2 са използвани по-малко шокове (1,6 срещу 1,94; p = 0,05) и не се е стигало до приложение на монофазен импулс. Ефективността на второ и трето стъпало на КВС е сигнификантно по-висока при използване на протокол 2 – фиг. 1.

Биохимичните маркери за миокардна некроза след КВС (обща СК, СК-МВ и TnI) не се различават в двете групи.

Изводи: Протокол 2 предлага еднаква ефективност с по-малко шокове и по-висока ефективност на първите шокове при същата безопасност в сравнение с протокол 1.



EFFECT	Shock 1	Shock 1+2	Shock 1+2+3	Shock 1+2+3+4	Cummulative
Protocol 1	45.7	74.3	90	95.7	98.6
Protocol 2	48	92	100	100	100

Фиг. 1. Ефективност на протокол 1 и протокол 2 на всяко стъпало при ПТ

П № 29. ВЛИЯНИЕ НА НАЧИНА НА ИЗМЕРВАНЕ НА ТРАНСТОРАКАЛЕН ИМПЕДАНС ВЪРХУ НЕГОВАТА ВАРИАЦИЯ ПРИ ПОРЕДИЦА ОТ ШОКОВЕ С ЕСКАЛИРАЩ ПРОТОКОЛ НА КАРДИОВЕРСИЯ

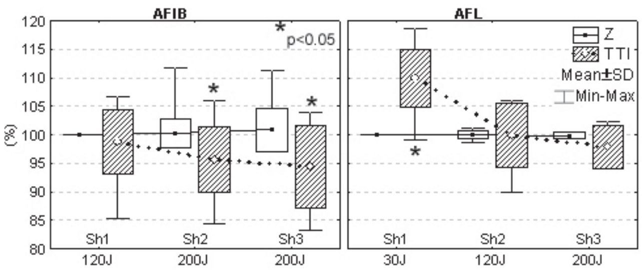
Е. Трендафилова[1], В. Кръстева[2], Ц. Мудров[2], Ж. Ф. Дидон[3], П. Тасовска[1], А. Александров[1], Н. Гочева[1], И. Паскалева[1]
[1]Национална кардиологична болница – София, България; [2]Централна лаборатория по биомедицинско инженерство БАН – София, България; [3]Schiller Medical SA – Висембург, Франция

Трансторакалният импеданс при дефибрилация/кардиоверсия се приема за фактор, влияещ върху ефективността от шока. Предполага се, че поредица от последователни шокове с нарастващи енергии променят импеданса и по този начин спомагат за постигане на успешна кардиоверсия. Това изследване дава доказателства, че последователност от шокове с нарастващи енергии не променя импеданса преди шока (Z), а влияе само върху импеданса по време на шока (TTI), който корелира със зададената енергия (E).

Методи: Изследването включва 96 пациенти, подложени на планова кардиоверсия. Избран е ескалиращ step-up протокол на енергиите при последователност от 3 шока Sh1/Sh2/Sh3: 120/200/200 J за предсърдно мъждене (AFIB), 30/120/200 J за предсърдно трептене (AFL). Общият брой шокове, включени в изследването, е: 62/26/11 (AFIB) и 34/17/3 (AFL). Посредством специализирана апаратура е регистриран импедансът преди и по време на всеки шок, както следва: 1) Z преди шока, измерен чрез анализ на затихването на високочестотен ток (30kHz) с нисък интензитет (10 uA); 2) TTI по време на шока, измерен като средна стойност на омичното съпротивление на тока и напрежението на дефибрилационния импулс.

Резултати: Измерената средна стойност на Z преди Sh1 се приема за 100% база. Оценена е процентната промяна на TTI и Z спрямо тази база за поредицата от шокове (вж. фиг. 1). Статистически анализ с помощта на t-тест показва несигнификантна вариация на Z по отношение на енергията E и поредния номер на шока ($p > 0.05$). За разлика от Z TTI има статистически по-висока средна стойност от 110% при 30 J (AFL, $p < 0.001$) и съответно – по-ниска средна стойност от 95% при 200 J (AFIB, $p < 0.01$). Установена е сигнификантна корелация на процентния спад на стойността на TTI при увеличаване на енергията E ($r = -0.65$, $p < 0.001$).

Заключение: Измерен е стабилен импеданс Z с вариация под 1% преди първи, втори и трети шок, които имат с до 6 пъти нарастване на енергиите. Това наблюдение поддържа хипотезата, че високочестотният импеданс Z не се влияе от шоковата поредица и не може да се интерпретира като фактор, обясняващ успеха при повторна дефибрилация. За разлика от него импедансът TTI по време на шока зависи силно от енергията и от поредния номер на шока, като може да се очаква спад от 110% до под 95% за енергия между 30 J и 200 J.



Фиг. 1: Процентна промяна на Z, TTI при поредица от шокове, отнесена към изходната стойност на Z преди първи шок

П № 30. ВЛИЯНИЕ НА ЕНЕРГИЯТА НА ШОКА ВЪРХУ ТРАНСТОРАКАЛНИЯ ИМПЕДАНС ПРИ КАРДИОВЕРСИЯ

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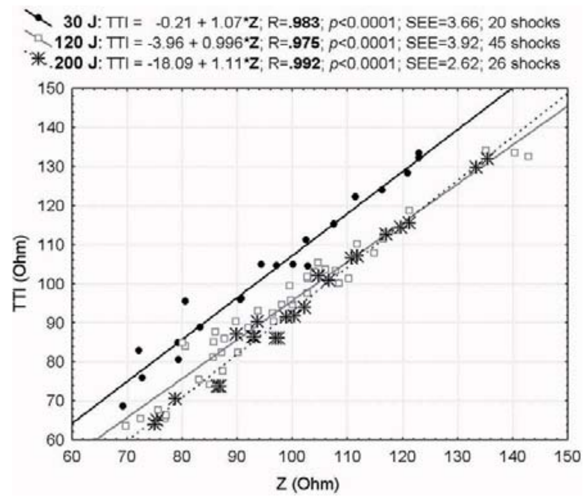
Увод. Трансторакалният импеданс при дефибрилация/кардиоверсия е важен фактор, който определя интензитета на тока през сърцето, променя формата на дефибрилационния импулс и по този начин влияе върху ефективността на шока. Предсказването на импеданса преди момента на нанасяне на шока дава възможности за иновативни решения при производството на дефибрилатори с адаптивна корекция на формата на дефибрилационния импулс.

Цел. Целта на това изследване е да покаже, че импедансът, измерен преди шока (Z), може да служи за предсказване на импеданса по време на шока (TTI), при отчитане на избраната енергия (E).

Методи: Изследването включва 58 пациенти, подложени на планова кардиоверсия с ескалиращ step-up протокол на енергиите на последователните шокове: 30-120-200 J за предсърдно трептене (AFL); 120-120-200 J за предсърдно мъждене (AFIB). Общият брой регистрирани шокове е 91, включващи 20/45/26 шока съответно с енергии 30/120/200 J, анализирани сумарно за AFL и AFIB. Чрез използването на специализирана апаратура е регистриран импеданс преди и по време на всеки шок, както следва: (1) Z преди шока, измерен чрез анализ на затихването на високочестотен ток (30kHz) с нисък интензитет (10 uA); (2) TTI по време на шока, измерен като средна стойност на омичното съпротивление на тока и напрежението на дефибрилационния импулс.

Резултати: Използвана е линейна регресия за изчисляване на зависимостта TTI = f(Z), приемайки енергията E за категоризираща променлива (вж. фиг. 1). Анализът на ковариацията (ANCOVA) показва, че трите регресионни прави, съответстващи на E от 30/120/200 J, са различими, със статистически различни коефициенти на пресечната точка с ординатата ($p < 0.001$), но с неразличими коефициенти на наклона ($p > 0.2$).

Заключение: Установяваме силна корелация между TTI и Z ($R > 0.975$), която може да служи за предсказване на импеданса по време на шока, вземайки предвид импеданса преди шока и избраната енергия. Анализът на пресечната точка с ординатата показва, че TTI намалява при увеличаване на енергията. При известни параметри на дефибрилационния импулс TTI и E могат да послужат за точно определяне на тока, преминал през сърцето. Тази корелация е изключително ценна при дизайн на постояннотокови дефибрилатори със система за адаптивно компенсиране на импеданса.



Фиг. 1. Линейна регресия TTI = f(Z) за избрани енергии 30/120/200 J

П № 31. АБЛАЦИЯ НА БАВНИЯ ПЪТ ЧРЕЗ ТРАНССЕПТАЛЕН ДОСТЪП ПРИ ПАЦИЕНТ С КОРИГИРАН ЧАСТИЧЕН AV КАНАЛ И AVNRT ОТ ОБИЧАЕН ТИП

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Въведение: AV нодалната риенрти тахикардия е най-често срещаната правилна надкамерна тахикардия. Механизмът на тахикардия е риентри и се дължи на наличието на поне два или повече проводни пътя в AV възела. Радиофреквентната катетърна аблация е метод на избор при лечението на този вид тахикардия. Възможно е селективно прекъсване както на бързия, така и на бавния път в AV възела. Селективното прекъсване на бавния път е най-предпочитаният метод. Обикновено аблацията се осъществява в дясното предсърдие. Много рядко аблацията вдясно е невъзможна поради анатомична особеност или структурно сърдечно заболяване. В тези случай се използва левостранен достъп.

Изложение: Представяме случай на пациентка с коригиран частичан AV канал, посредством перикардна заплатка, при което триъгълникът на Кох и AV възелът

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.

COMBINED HIGH-PASS AND POWER-LINE INTERFERENCE REJECTER FILTER FOR ECG SIGNAL PROCESSING

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In this study we introduce one alternative approach for ECG high-pass filtering and interference rejection based on the simple principle for averaging of samples N with a predefined distance between them D. FilterDxN has a comb frequency characteristic with high-pass cut-off defined by the number of samples N and zeros at the integer ratio of the sampling frequency fs divided by the number of samples D. For a predefined fs, FilterDxN is easily adjusted to different cut-off and zero frequencies only by changing D and N. In this work, we present the mathematical background for deriving the frequency response of FilterDxN, as well as one particular application of the filter, i.e. Filter10x19 designed for fs=250 Hz, high-pass at 1 Hz, zero at 50 Hz. Tests with both standardized and real ECG signals proved that Filter10x19 is capable to remove very intensive baseline wanderings, and to fully suppress 50 Hz interferences with minimal affect on the ECG waveform. FilterDxN would be preferable in ECG systems operating in real time because of its linear filter equation with integer coefficients that hasten the speed of computations.

Keywords: Real-time ECG filtering, average filter, baseline drift, mains interference.

1. INTRODUCTION

Long-term electrocardiogram (ECG) monitoring devices work under considerable artifacts of intensive body and electrode movements or power-line interference. An adequate preprocessing filtering is required to provide high-quality ECG signals, supporting the accurate ECG interpretation. An extensive research is focused on the challenge for designing novel digital filters, which can correct baseline drift or reject power-line interference, while preserving the fidelity of ST and QRS. Various approaches for drift suppression have been proposed based on smart filtering techniques, such as the moving average filters [1], bi-directional high-pass filter [2,3], nonlinear filter banks [4], adaptive filtering [5], wavelet transforms [6], etc. For the effective rejection of the power-line interference, there are also a number of works, introducing notch filters [4,7], comb filters [8], adaptive filters [5], subtraction procedure [9], etc. Although the different filter solutions are attractive because of the reasonable frequency characteristics, most of them are not applicable in real time, since they rely on heavy computations or require certain ECG analysis prior to applying the filtering technique. The digital filters with integer coefficients are preferable for real-time applications but it is difficult to achieve desired frequency characteristics [10]. In this work we will present one alternative solution of integer-coefficients filter, which provides an adequate high-pass and power-line filtering.

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.

NOISE DETECTION ALGORITHM FOR AUTOMATIC EXTERNAL DEFIBRILLATORS

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Nowadays the application of automatic external defibrillators (AEDs) becomes a widespread practice for early treatment of out-of-hospital cardiac arrest patients. A reliable recognition of life-threatening cardiac arrhythmias is required. However, it may be impeded by artifacts, which compromise the quality of the electrocardiogram (ECG). The aim of this study was to develop software procedures for detection of some typical for AED application artifacts, such as: (i) amplifier saturation; (ii) baseline wander; (iii) single steep and high-amplitude artifacts; (iv) tremor. The developed real-time operating procedures were synchronized with the implemented algorithm for ventricular fibrillation detection. Thus, the in-time detection of significant artifacts would prevent from a compromised shock-advisory decision. The presented algorithm was developed in Matlab environment. It was tested with ECG recordings from an out-of-hospital database, which contains various types of noises and different arrhythmias.

Keywords: ECG analysis, shock advisory algorithms, arrhythmias, artifacts

1. INTRODUCTION

Nowadays the application of automatic external defibrillators (AEDs) becomes a widespread practice for early treatment of out-of-hospital cardiac arrest patients. To realize the goal of providing access to AEDs for use by first responders without extensive medical training, the device used must be able to accurately assess the cardiac state of the patient, to detect life-threatening arrhythmias and to make an appropriate therapy decision [1]. An AED has to make its decision on the basis of the electrocardiogram (ECG), obtained by only two adhesive electrodes with variable quality of the electrode contacts and variable positioning on the patient's chest. Since no information about pulse or respiration is fed into the device, the reliable and accurate detection of life-threatening cardiac arrhythmias, only from the surface ECG, is a rather difficult task. It can be further complicated in the presence of noise artifacts overlapping with the analyzed signal. This may lead to inaccurate ECG waveform analysis and wrong shock advisory decision [2]. Artifact is an electrical signal induced in the ECG that is unrelated to the heart signal. Sources of artifact can be characterized as controllable or non-controllable by the responder.

- Controllable artifacts include signals resulting from directly touching the pads, moving the patient, cardiopulmonary resuscitation (CPR), transportation, radio transmissions, etc.
- Non-controllable artifacts may be caused by electrical interference, patient seizures, gasping (agonal respiration), an implantable pacemaker, ect.

REAL-TIME DETECTION OF ACCIDENTAL PATHOLOGIC CARDIAC EVENTS IN THE ELECTROCARDIOGRAM

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The major efforts for improving the automated cardiac diagnostics are directed towards developments of innovative hardware and software solutions for computer-assisted electrocardiogram (ECG) monitoring systems. The presented work describes a method for fast detection of pathologic cardiac events by real-time ECG analysis. It is convenient for embedding in microcontroller-based autonomous system for monitoring of high-risk cardiac patients. The algorithm involved on-line operating procedures, including preprocessing filtration, threshold-based QRS detection, interbeat RR-intervals analysis and QRS pattern waveform analysis. Aiming at a simple solution, we adopted specific strategies for signal processing acceleration and for reduction of the operational memory size, such as the resolution reduction of the QRS pattern waveform. Moreover we implemented simplified techniques for rating of the similarity between the QRS pattern of the tested beat and the accumulated QRS pattern of the preceding heartbeats. The repetition of similar QRS pattern waveforms combined with small variances of the RR-intervals, was interpreted as a normal rhythm. However, the appearance of a number of deviations either from the mean RR interval, or from the cumulative QRS pattern waveform, was detected as a sustained pathologic event. The developed algorithm was implemented in Matlab environment. It was tested with internationally recognized ECG databases. Several examples are presented and discussed.

Keywords: ECG monitoring, high-risk cardiac patients, real-time ECG analysis

1. INTRODUCTION

The major efforts for improving the automated cardiac diagnostics are directed towards developments of innovative hardware and software solutions for computer-assisted electrocardiogram (ECG) monitoring systems. The main task to identify patients at risk of arrhythmias, both with and without sustained symptoms is managed for example by the systems for long-term (24 h) heart activity registration, i.e. ECG holters. The bedside ambulatory systems are also very important for monitoring of the vital characteristics of inbed hospitalized patients for a long period of time (reanimation, intensive care rooms, nursing home) [1]. Frequently, critical conditions happen just after disconnection from the ambulatory monitors, in the phase of starting moving, rehabilitation, self-service, etc., i.e. in circumstances without attendance on the patient condition when the nurse/personal care for the patient is recommendable.

Thanks to the fast developments of novel wireless communication technologies, such as Bluetooth, Zigbee, 802.11, etc. [2-4], the implementation of portable autonomous systems for continuous ECG monitoring becomes possible. The build-in algorithm for real-time ECG analysis must guarantee reliable and accurate detection of pathologic cardiac events. The instantaneous wireless alarm transfer to the central