Cardiovascular Variability

Clinical Applications of Linear and Nonlinear Components

BY MARCO DI RIENZO AND ALBERTO PORTA

The cardiovascular system is composed of a variety of specialized subsystems that interact with each other under the influence of internal and external inputs, including central commands, reflex mechanisms, and humoral factors. The concomitant action of all these subsystems produces continuous adjustments in the cardiovascular variables (e.g., heart rate, heart contractility, blood pressure, vascular tone, etc.) referred to as *cardiovascular variability*. A large body of evidence indicates that this variability includes linear and nonlinear components and conveys important biological information that might help in the understanding of the underlying physiology and facilitate diagnosis and prognosis of cardiovascular dysfunctions.

A pivotal role in the identification and extraction of the informative features from cardiovascular variability is played by signal processing techniques and mathematical models. Over the years, a lot of work has been done in these areas, leading to important advancements in our comprehension of cardiovascular pathophysiology. However, it should be considered that, in spite of these positive results, at the moment, the real applicability of these tools in clinical practice is still limited. This is particularly the case for the nonlinear approaches, where traditionalism and, in some instances, complex mathematical formalisms make these techniques more difficult to be widely accepted in the clinical world. Thus, additional efforts are still required to fully exploit the informative potentialities of cardiovascular variability, particularly through the identification of additional aspects of the cardiovascular dynamics having a stronger clinical relevance and the development of efficient algorithms for data processing. Moreover, trials based on the long-term ambulatory monitoring of large, healthy and pathological populations would be certainly useful to further support the clinical applicability of cardiovascular variability in the evaluation of aging process, recovery from acute events, and evolution of chronic diseases. In these cases, however, it becomes essential to have smart devices to monitor biological data during daily life in a simple way and for long time periods.

Digital Object Identifier 10.1109/MEMB.2009.934909

This special issue of the *IEEE Engineering in Medicine and Biology Magazine* focuses on some of the aforementioned topics and aims at providing an overview of the most recent advancements in this field. These points have been addressed in 12 articles by experts working in different areas, including physiology, medicine, computer science, biology, physics, mathematics, and bioengineering. These articles are the extended version of papers presented at the European Study Group on Cardiovascular Oscillations (ESGCO) meeting held in Parma in 2008. The contributions given in this issue can be subdivided into two groups.

The first group of four papers focuses on methods, models, and devices for the assessment of cardiovascular function. In particular, Chon et al. illustrate their recent findings on a simplified method to estimate approximate entropy; Żebrowski et al. propose a new integrated model of the atrium, sinoatrial, and atrioventricular nodes to explain the occurrence of cardiac interval alternans; Laude et al. report on the enhancements of the sequence technique to improve the assessment of spontaneous baroreflex sensitivity in mice from the analysis of beat-by-beat arterial blood pressure and RR-interval series; and Di Rienzo et al. present a textile-based device for the monitoring of cardiorespiratory function in freely moving patients and active people.

The second group of articles in this issue focuses on the clinical applications of linear and nonlinear techniques and models. More specifically, Maier et al. investigate the possibility to detect obstructive apneas from the joint analysis of QRS areas estimated from multiple ECG leads; Van Leeuwen et al. propose a model to investigate the influence of maternal respiration on the coupling between mother and fetus cardiac rhythms; Mitsis et al. explore the influence of the autonomic nervous system on cerebral hemodynamics in resting conditions by using a two-input nonlinear model; Ursino et al. present a mathematical model to explore the complex relationship among cerebrovascular dynamics, intracranial pressure, Cushing response, and short-term systemic regulation; Valencia et al. propose a methodology, based on a symbolic transformation of heart period series, to predict sudden cardiac death in patients with dilated cardiomyopathy; Tobaldini et al. validate the ability of a symbolic analysis of blood pressure and pulse-interval

0739-5175/09/$26.00©2009IEEE

series to track the improvement of the cardiovascular control in an animal model of congestive heart failure; Migeotte et al. investigate the hypothesis that the effects of hypergravity on the components of heart-period variability related to breathing may mimic the effects observed on astronauts on return from spaceflights; Akay et al., through a nonlinear analysis based on Lempel-Ziv estimator, investigated the effects of a Ca^{2+} channel blocker on the brain hippocampal γ oscillations, often occurring in association with disturbances in the autonomic cardioregulatory function in epileptic patients.

We do hope that the concepts and ideas included in this special issue might be helpful for people working in this field, stimulate future investigations, and foster the development of new techniques for the assessment of the patient's health status in clinical practice.

Finally, we thank Dr. John Enderle, the previous editor-in-chief, for having given us the opportunity to publish this special issue and for his support in the early stage of the revision process, and the present editor-in-chief, Prof. Michael Neuman, for the help in the final steps of the publication.

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Digital Object Identifier 10.1109/MEMB.2009.935166