Computers in Biology and Medicine 42 (2012) 265–266

Contents lists available at SciVerse ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

Preface

Computing complexity in cardiovascular oscillations: Selected papers from the 6th Conference of the ESGCO

The cardiovascular system involves various sub-systems, the principle components being the heart, vessel bed, and lungs. These organ systems are embedded within the nervous system, giving rise to oscillatory phenomena on various time scales. These interacting systems offer a fertile environment for the investigation of complex interactions, control loops, synchronization, irreversibility, and temporal structures. This is an ideal ground for the development and application of mathematical models, the implementation of novel signal processing techniques, the computational investigation of linear and nonlinear phenomena, the development of algorithms for quantifying physiological function, and the characterization of pathological conditions.

The present issue of *Computers in Biology and Medicine* addresses a number of these topics, based on a selection of contributions made at the 6th conference of the European Study Group on Cardiovascular Oscillations (ESGCO), which was held in Berlin in 2010. In the study of cardiovascular oscillations the most easily and frequently observed metric is the change in heart rate (or, the change in interbeat intervals), derived from the familiar QRST landmarks of the ECG. These changes are subsumed under the term heart rate variability (HRV) and their observation under various conditions has led to numerous measures that quantify aspects of cardiovascular states and interactions [1]. Measures derived from statistical or geometrical properties of time series of beat-to-beat intervals are generally referred to as time domain measures, and reflect the overall variance of the interbeat intervals, their short-term changes, and the density distributions of the interbeat values. Normal physiological oscillations in beat duration can be subjected to spectral analysis, in which the power associated with different frequency bands is examined. Specific bands have been shown to reflect modulation of cardiac function by activity in branches of the autonomic nervous system, as well as the influence of rhythmic fluctuations of associated phenomena such as blood pressure and respiration. The investigation of blood pressure and respiratory rhythms has benefited from these methods of signal analysis.

Leaving aside linear approaches, the field of nonlinear dynamics offers a multitude of methods with which complexity, information content, temporal structure, dimensionality, and scaling properties can be quantified [2]. The theory of nonlinear dynamics delivers fundamental mathematical concepts enabling the characterization of complex systems. On the basis of such characterizations, we may be able to better understand the functioning of single organ systems, as well as to identify and quantify the interaction between multiple systems. Nonlinear measures can quantify aspects of HRV that are not captured by linear measures, and discrimination between normal and pathological states may thus be improved [3].

The contributions in this special issue come from different disciplines, and address a number of the issues mentioned above, with an emphasis on a computational point of view. The topics include nonlinear modeling, coupling and information flow, symbolic dynamics, entropy, scaling, and fractals. These concepts are investigated in the contexts of: oscillatory phenomena in blood vessels and blood flow; the effects of graded tilt, exercise, or anesthesia; and, under conditions of pregnancy. The data examined are often bivariate or multivariate. Various disease conditions, such as hypertension, aneurysm, stenosis, cardiac arrhythmia, congestive heart disease and obstructive sleep apnea, are studied with respect to complex cardiovascular oscillations.

Modeling, also using nonlinear approaches, has been applied by a number of authors in this issue to better understand pathological aspects of the functional anatomy of blood vessels and the flow within them. Buchner et al. [4] used nonlinear modeling of smooth muscle cell aggregates in vessel walls to simulate physiologically relevant electrophysiological oscillatory regimes such as circumferential and spiral waves, and micro-reentry phenomena. The results give insight into the initiation and sustenance of cardiac arrhythmias. Schelin et al. [5] numerically model the dynamics of abnormal blood flow. It is shown that in the context of sudden changes in vessel geometry, chaotic advection (flow in which initially close particles may diverge quite suddenly) may lead to a spatial distribution of blood particles whose filaments take on a fractal structure. A further paper on quantifying blood flow on an experimental level deals with cerebral microcirculation: the group around Aletti et al. [6] shows that transcranial near-infrared spectroscopy (tNIRS) may be used to investigate cortical cardiovascular phenomena noninvasively. Using combined tNIRS and laser Doppler flowmetry, the authors show that it is possible to dissect the tNIRS signal into components arising from the surface and from deep cortical hemodynamics.

Several papers in the issue examine the magnitude and direction of interactions between the cardiac, circulatory, and respiratory systems. Using both model simulation and data from physiological and clinical challenges to the autonomic nervous system, they offer a better understanding of the information flow between these systems. Faes et al. [7] investigate the complex short-term interaction between coupled cardiovascular systems, with the aim of determining causal relationships. This is done by using corrected conditional entropy of time series data as a measure of information flow between heart rate, blood pressure and respiratory rate. The method is examined in simulations and in physiological data. Porta et al. [8] evaluate open- and closed-loop multivariate dynamical adjustment models for their ability to estimate the strength of cardiovascular and cardiopulmonary

0010-4825/$ - see front matter
doi:10.1016/j.compbiomed.2012.01.008

coupling. These models are used to describe the physiological interactions between heart rate, respiration and blood pressure during head-up tilt. Bassani et al. [9] assess the coupling between heart rate and blood pressure using Granger causality under conditions induced by anesthesia (Granger causality is a statistical method for assessing if one time series is useful in predicting another time series, a method that has been widely applied, as, for example, in another recent special issue of this journal, dealing with neural connectivity [10]). This approach allows for the non-invasive assessment of the sensitivity of the baroreceptor reflex (or baroreflex, the homeostatic mechanism which changes heart rate in an attempt to maintain blood pressure within a physiologically optimal range) under conditions of depressed autonomic function.

A time series constructed from the time between consecutive R waves on an ECG (the R–R or interbeat interval), can be transformed into a series of symbols based upon the differences between consecutive interbeat intervals. This offers access to specific features that may be masked when quantifying heart rate variability on the basis of the original time series. Several such course-graining approaches have been developed to assess cardiovascular dynamics. Cysarz et al. [11] study the quantification of the complexity of eight-bit sequences of symbols based on increases or decreases in instantaneous heart rate. This offers a novel approach in the assessment of baroreflex activity induced by graded tilt experiments. The authors propose that relatively short-term autonomic changes may be quantified by this approach. The work of Parlitz et al. [12] introduces ordinal pattern statistics which, in contrast to Cysarz et al. symbolizes the patterns of increases and decreases in beat duration not just between two but those formed by three or four successive beats. The authors apply these as well as standard time and frequency measures and other symbolic dynamics measures in healthy subjects and in patients with congestive heart disease. Ordinal pattern statistics show remarkable performances with respect to well-established HRV indices, thus suggesting their potential application to differentiate pathological from healthy populations. Penzel et al. [13] describe a bivariate analysis involving symbolic dynamics, in which both heart rate and blood pressure variables are symbolized, as applied in normotensive and hypertensive patients with obstructive sleep apnea, before and after treatment. This approach enables investigation of the coupling strength between heart rate and blood pressure under a variety of conditions, including exercise challenges.

Pregnancy offers the opportunity to investigate the cardiovascular system under unique conditions. On one hand, changes in fetal HRV reflect the effect of growth on early human development; progressive neural integration can be monitored with a variety of HRV measures. On the other hand, the examination of the challenges induced by pregnancy on the mother may permit a better understanding of the influence of gestation on maternal cardiovascular interactions as well as offering potential new clinical tools. Hoyer et al. [14] examine fetal heart rate dynamics on multiple time scales with different methods. With increasing gestational age, measurements of multi-scale complexity, time irreversibility, and fractal scaling show different scale-dependent complexity changes, which are compatible with the differentiation of the fetal autonomic nervous system. One factor involved in the changes of fetal HRV over gestational age is the increasing occurrence of fetal breathing movements. These can be associated with fetal respiratory sinus arrhythmia (RSA) and the algorithm proposed by Van Leeuwen et al. [15] for the automatic identification of fetal RSA enables a simple and efficient approach for the assessment of this aspect of prenatal development. Baumert et al. [16] examine the application of multiscale entropy and detrended fluctuation analysis to R–R interval and Q–T interval variability during the second half of pregnancy. These approaches quantify the information content and the pattern structure of time series of these intervals on different time scales. Their results show that these nonlinear properties are different, and that gestational age has a clear effect, primarily upon the R–R interval series. Their observations shed light on pregnancy-induced changes in autonomic control, and may thus be useful in the clinical surveillance of pregnant mothers.

This special issue demonstrates the application of modern signal processing and modeling tools for the assessment of the complex nonlinear dynamics of the human cardiovascular system. Society will benefit from the rapid application of the clinically relevant insights achieved by such work. We hope that the concepts and work appearing here will stimulate future research, improve individual diagnostics, and reduce patient risk.

References

[1] Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, Eur. Heart J. 17 (1996) 354–381.
[2] A. Porta, et al., Addressing the complexity of cardiovascular regulation, Philos. Trans. A Math. Phys. Eng. Sci. 367 (1892) (2009) 1215–1218.
[3] N. Wessel, et al., Nonlinear methods of cardiovascular physics and their clinical applicability, Int. J. Bifurcat. Chaos 17 (2007) 3325–3371.
[4] T. Buchner, et al., Complex Activity Patterns in Arterial Wall, Results from a Model of Calcium Dynamics, Comput. Biol. Med., doi:10.1016/j.compbiomed.2011.12.001, this issue.
[5] B. Schelin, et al., Are the Fractal Skeletons the Explanation for the Narrowing of Arteries Due to Cell Trapping in a Disturbed Blood Flow? Comput. Biol. Med., doi:10.1016/j.compbiomed.2011.07.002, this issue.
[6] F. Aletti, et al., Deep and Surface Hemodynamic Signal from Time Resolved Transcranial Near Infrared Spectroscopy Compared to Skin Flowmotion, Comput. Biol. Med., doi:10.1016/j.compbiomed.2011.06.001, this issue.
[7] L. Faes, et al., Non-uniform Multivariate Embedding to Assess the Information Transfer in Cardiovascular and Cardiorespiratory Variability Series, Comput. Biol. Med., doi:10.1016/j.compbiomed.2011.02.007, this issue.
[8] A. Porta, et al., Model-based Assessment of Baroreflex and Cardiopulmonary Couplings during Graded Head-up Tilt, Comput. Biol. Med., doi:10.1016/j.compbiomed.2011.04.019, this issue.
[9] T. Bassani, et al., Testing the Involvement of Baroreflex during General Anesthesia through Granger Causality Approach, Comput. Biol. Med., doi:10.1016/j.compbiomed.2011.03.005, this issue.
[10] R.E. Frye, Special issue on techniques for measuring brain connectivity: advanced anatomic, function, effective and network neuroconnectivity techniques, Comput. Biol. Med. 41 (12) (2011) 1058–1061.
[11] D. Cysarz, et al., Binary Symbolic Dynamics Classifies Heart Rate Variability Patterns Linked to Autonomic Modulations, Comput. Biol. Med., doi:10.1016/j.compbiomed.2011.04.013, this issue.
[12] U. Parlitz, et al., Classifying Cardiac Biosignals using Ordinal Pattern Statistics and Symbolic Dynamics, Comput. Biol. Med., doi:10.1016/j.compbiomed.2011.03.017, this issue.
[13] T. Penzel, et al., Effect of CPAP Therapy on Daytime Cardiovascular Regulations in Patients with Obstructive Sleep apnea, Comput. Biol. Med., doi:10.1016/j.compbiomed.2011.09.001, this issue.
[14] D. Hoyer, et al., Fetal Development assessed by Heart Rate Patterns—Time Scales of Complex Autonomic Control, Comput. Biol. Med., doi:10.1016/j.compbiomed.2011.05.003, this issue.
[15] P. Van Leeuwen, et al., Automatic Identification of Fetal Breathing Movements in Fetal RR Interval Time Series, Comput. Biol. Med., doi:10.1016/j.compbiomed.2011.05.012, this issue.
[16] M. Baumert, et al., Multiscale Entropy and Detrended Fluctuation Analysis of QT Interval and Heart Rate Variability during Normal Pregnancy, Comput. Biol. Med., doi:10.1016/j.compbiomed.2011.03.019, this issue.

N. Wessel*
AG Nichtlineare Dynamik (S)/Kardiovaskuläre Physik, Institut für Physik, Humboldt-Universität zu Berlin, Robert-Koch-Platz 4, 10115 Berlin, Germany
E-mail addresses: niels.wessel@charite.de, wessel@physik.hu-berlin.de

P. van Leeuwen
Department of Biomagnetism, Grönemeyer Institute for Microtherapy, University of Witten/Herdecke, Germany

* Corresponding author. Tel.: +49 30 2093 99181; fax: +49 30 2093 99188.