Time delay between RR and RT heart beat intervals in exercise test of normal subjects and elderly ischemic patients

Conference Paper · May 2014

DOI: 10.1109/ESGCO.2014.6847558

4 authors, including:

Camillo Cammarota
Sapienza University of Rome
50 PUBLICATIONS **299** CITATIONS

Mario Curione
Sapienza University of Rome
97 PUBLICATIONS **665** CITATIONS

Marisa Varrenti
Azienda Ospedaliera Niguarda Ca' Granda
42 PUBLICATIONS **78** CITATIONS

Time Delay between RR and RT Heart Beat Intervals in Exercise Test of Normal Subjects and Elderly Ischemic Patients

Camillo Cammarota*, Mario Curione, Andrea Quaresima and Marisa Varrenti

***Abstract*—The RR and RT time intervals extracted from the electrocardiogram measure respectively the duration of cardiac cycle and repolarization. The series of these intervals recorded during the exercise test are characterized by a global minimum. We model these series as a sum of a deterministic trend and random fluctuations, and estimate the trend using a multi scale wavelet decomposition. Data analysis performed on a group of 20 healthy subjects and 30 elderly ischemic patients provides evidence that the minimum of the RT series follows the minimum of the RR series, with a mean delay respectively of 67 and 28 beats.**

I. INTRODUCTION

From the electrocardiogram (ECG) several time intervals can be measured, revealing important informations on the heart function. The RR and QT intervals measure respectively the duration of cardiac cycle and repolarization. The existence of a time delay of QT adaptation to modifications of RR was measured in patients survivors of acute myocardial infarction using 24 hours Holter recordings [1]. The time of adaptation was estimated to be 150 beats. The effect of age on the QT-RR coupling has been recently investigated in [2]. These studies assume that the series are stationary or moderately non stationary and assume a dependence of the QT interval on the weighted mean of several previous RR intervals.

The main feature of RR and RT series recorded during the exercise test is the presence of a global minimum; the RR minimum corresponds to peak heart rate (acme). It is usual to consider as an equivalent index of repolarization, in place of QT, the duration of the RT interval, defined as the time from the R peak to the apex of T wave. This is also motivated by the fact that during the exercise, at peak heart rate, the end of T wave is not easily detectable. We address the question if the two minima occur at the same time or if a delay is observable. Our approach is independent of any assumption on the RR-RT relationship, and it is only based on the trend estimation of the two series. This report extends to a group of ischemic patients the analysis performed on healthy subjects in [3], [4].

II. DATA ACQUISITION

In multistage Bruce protocol [5] the patient on a bicycle ergometer is subjected to a workload increasing in time by steps (25 W every 2 minutes). The exercise is stopped when the heart rate reaches a maximum, usually 85% of the estimated top heart rate based on the patient's age. After achieving peak workload, the patient spends some minutes at rest on the bicycle until its heart rate recovers its basic value. The standard 12-leads ECG was recorded using the electrocardiograph PC-ECG 1200 (Norav Medical Ltd.), which provides in output digital signal with resolution of 2.441μV and 500 Hz sampling frequency. The R peak detection was performed using a derivative-threshold algorithm. The T apex was detected as the maximum of the T wave subsequent to each R peak. We have analyzed 20 normal subjects (15 males, age 38.5 ± 14.7 yr) and a group of 30 elderly ischemic patients (28 males, age 61 ± 9.0 yr) who underwent to the test in a preceding study of our group [6]. The test was performed after pharmacological wash-out. All tests of ischemic patient were negative for inducible ischemia; the ejection fraction was mildly reduced (about 45%). Analysis of raw data, R and T peak detection and subsequent computations were performed using the free statistical software R [7].

Research supported by MIUR, Italian Ministry of Education, Universities and Research;

C. Cammarota, A. Quaresima, Department of Mathematics, University of Rome, La Sapienza, Italy (*corresponding author e-mail: cammar@mat.uniroma1.it).

M. Curione, M. Varrenti, Department of Internal Medicine and Medical Disciplines, University of Rome, La Sapienza, Rome, Italy.

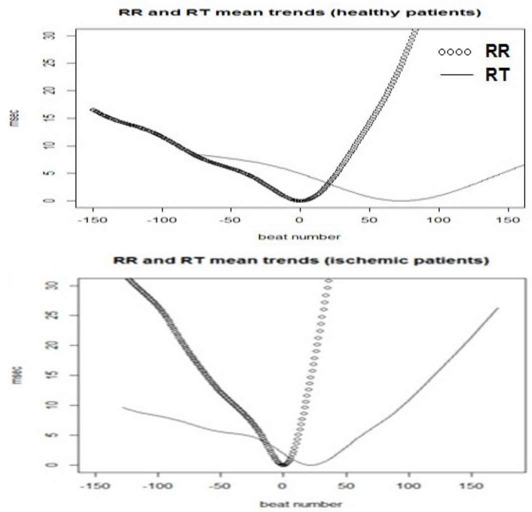

Fig. 1. Group average of RR and RT trends for normal (top) and ischemic (bottom) subjects during exercise test. The individual series are shifted horizontally and vertically in order to put the acme of RR at (0,0) and then the group average is computed.

III. TREND EXTRACTION

We assume as a model for both RR and RT series, denoted $X_t, t = 0, ..., N-1$, the following one

$$X_t = T_t + \epsilon_t \tag{1}$$

where T_t denotes a deterministic sequence (trend) and ϵ_t a sequence of random variables (noise). The extraction of the

978-1-4799-3969-5/14/$31.00 © 2014 IEEE

trend is performed using wavelets. In the notations of [8] the discrete wavelet transform (DWT) of $X = (X_0, ..., X_{N-1})$ is a vector of wavelet coefficients $(W_1, ..., W_{J_0}, V_{J_0})$, where J_0 is a suitable index such that $2^{J_0} \leq N$; each of the W_j is a vector associated with a scale 2^{j-1} and the vector V_{J_0} is associated to the scale 2^{J_0}. An analysis of variance (ANOVA, or energy decomposition) holds

$$||X||^2 = \sum_{j=1}^{J_0} ||W_j||^2 + ||V_{J_0}||^2. \quad (2)$$

We use the multiresolution analysis (MRA) of X_t, an additive decomposition in terms of the N dimensional vectors D_j (the jth level detail, $1 \leq j \leq J_0$) and S_{J_0} (the J_0th level smooth), associated with scales τ_j in case of D_j and λ_{J_0} in case of S_{J_0}. The time series is decomposed according to

$$X_t = \sum_{j=1}^{J_0} D_{j,t} + S_{J_0,t}. \quad (3)$$

We base the MRA on the non dyadic wavelet transform called 'maximal overlap' DWT (MODWT). In dyadic DWT the coefficients are computed over rigidly fixed intervals that not necessarily line up with interesting features of the time series, as the minimum. In MODWT the transform is shift invariant, which allows a optimal detection of the minimum at each scale. The wavelet filter is LA(8), Daubechies least asymmetric scaling filter with 8 coefficients, and periodic boundary conditions are used. The trend extraction method is based on the idea that the smooth S_{J_0} is associated with the trend T_t and the details D_j are associated with the noise ϵ_t; their estimators are

$$\hat{T}_t = S_{J_0,t}; \quad \hat{\epsilon}_t = \sum_{j=1}^{J_0} D_{j,t}. \quad (4)$$

In our data all the series have length greater than $N = 2^{10} = 1024$, so the range of possible scale indices J_0 goes from 1 to 10. Obviously if $J_0 = 1, 2$, the trend S_{J_0} is not sufficiently smooth and the minimum location is biased by the noise; if J_0 is large, say $J_0 \geq 7$, the trend S_{J_0} is conditioned by values that are far from the true location of the minimum. We have selected the intermediate scales $J_0 = 3, ..., 6$. These are related to the running mean filter of length $2n + 1 = 2^{J_0} + 1, J_0 = 3, 4, 5, 6$. The results are robust with respect both to these scale changes and to the wavelet filter used.

IV. RESULTS

We denote τ_{RR} and τ_{RT} the minimum locations estimated from the trends of the RR and RT series. We test the hypothesis $\tau_{RR} = \tau_{RT}$ against the alternative $\tau_{RR} < \tau_{RT}$ and we estimate a confidence interval for the delay $\tau_{RT} - \tau_{RR}$. The standard paired t-test has rejected the hypothesis of equal minimum locations, and provided evidence that the RT minimum follows the RR minimum. The mean delay of the normals is significantly larger than the one of ischemic patients. These result are summarized in the Table.

TABLE I
RR - RT DELAY

	$\tau_{RT} - \tau_{RR}$		
	Number of cases	*Mean (beats)*	*95% Conf. int. (beats)*
normal	20	67	46 - 87
ischemic	30	28	10 - 46

V. CONCLUSIONS

One of the possible explanations for the RR-RT delay is based on a compensatory mechanism. During the exercise the sympathetic system has a twofold action: 1) it increases the slope of the phase 4 of the transmembrane action potential of sinus node cells reducing the RR intervals; 2) it reduces the duration of the phase 3 of the action potential mainly on the work cells, and so reducing the RT intervals. In addition the last action allows a more rapid relaxation of myocardial fibers in protodiastole and consequently allows better ventricular filling.

Immediately after the acme the prolonged decrease of RT reflects the persistence of the sympathetic activity on ventricular relaxation, which is finalized to avoiding a sudden reduction of the cardiac output due to the sharp reduction of heart rate at the end of exercise.

In ischemic patients, as a consequence of aging and/or chronic ischemia, this compensatory mechanism is reduced, as they have a reduced ventricular responsiveness to catecolamines [9]. Further studies are needed for assessing the effect of this phenomenon on arrhythmic risk.

REFERENCES

[1] E. Pueyo, P. Smetana, P. Caminal, A. Bayes de Luna, M. Malik, and P. Laguna, "Characterization of QT interval adaptation to RR interval changes and its use as a risk-stratifier of arrhythmic mortality in amiodarone-treated survivors of acute myocardial infarction", *Biomedical Engineering, IEEE Transactions on*, 51(9):1511–1520, Sept. 2004.

[2] M. Baumert, B. Czippelova, A. Porta and M. Javorka "Decoupling of QT interval variability from heart rate variability with ageing", *Physiol. Meas.* 34, 1435171448 (2013).

[3] C. Cammarota and M. Curione, "Time delay between RR and RT heart beat intervals assessed by trend extraction of exercise test data", *Fluctuation and Noise Letters*, 11(04):1250019, 2012.

[4] S. Da Ros, A. Quaresima, M. Varrenti, S. lanna, S. Salvatore, C. Cammarota, S. Matteoli, M. Curione, "The delay of minimum R-T interval compared to minimum R-R interval assessed at the acme of stress test in normal subjects. What is the meaning of this phenomenon?", *74 SIC Congress*, Rome 2013.

[5] R. J. Gibbons and G. J. et al. Balady, "Acc/aha guideline update for exercise testing: summary article. a report of the american college of cardiology/american heart association task force on practice guidelines committee on exercise testing", *J. Am. Coll. Cardiol.*, 40:1531 – 1540, 2002.

[6] M. Curione, C. Cammarota, G. Cardarelli, S. Di Bona, T. Montesano, L. Travascio, M. Colandrea, M. Colotto, M. Ciancamerla, and G. Ronga. "QRS area monitoring during stress test: a novel index to separate normal to ischaemic patients?", *Archives of medical science*, 4:51–56, 2008.

[7] R Development Core Team, *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria, 2008. ISBN 3-900051-07-0.

[8] D.B. Percival and A.T. Walden, *Wavelet methods for time series analysis*. Cambridge University Press, 2000.

[9] S. Da Ros, A. Quaresima, M. Varrenti, S. Di Bona, S. Amato, V. Castellano, C. Cammarota, S. Matteoli, M. Curione, "Loss of physiological compensatory mechanism at the acme of stress test assessed in ischemic patients by RR, RT, QRS area time series continuous ECG recording" *74 SIC Congress*, Rome 2013.