

Recurrence Quantification Analysis of Heart Rate and Blood Pressure Variability in Obese Children and Adolescents

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Abstract

Obesity is a rapidly growing complex medical problem and increasingly occurs already in childhood. The change in the autonomic nervous system activity is an important factor contributing to initiation and progression of various cardiovascular complications of obesity. The aim of this study was to detect the presence of cardiovascular dysregulation using novel nonlinear measures and compare their performance with linear heart rate and blood pressure variability (HRV and BPV) analysis. We examined 40 obese children and adolescents (age 14.2 [13.1–16.1] (median [interquartile range]) years) and 40 age and gender matched control subjects. Continuous finger arterial blood pressure (FinometerPro, FMS, Netherlands) and ECG signal recorded from bipolar thoracic lead (Cardiofax ECG-9620, NihonKohden, Japan) were measured in supine position. HRV and BPV time series (2000 heart beats length) were analysed using linear analysis and using nonlinear recurrence quantification analysis (RQA). Only RQA measures in HRV analysis were able to detect a reduction in cardiovascular control complexity associated with obesity. We conclude that RQA is a sensitive method to detect subtle abnormalities in heart rate dynamics associated with obesity.

1. Introduction

Obesity is a rapidly growing complex medical problem having a pandemic characteristics nowadays. Obesity increasingly occurs already in childhood – in the last twenty years the percentage of obese children in developed countries increased three times. Until recently, it was assumed that obesity in childhood brings only the risk of its persistence to adulthood. Today, it is proved that the obesity associated complications described traditionally only in adults (dyslipidemia, atherosclerotic changes, hypertension, etc.) occur even in obese children and adolescents [1]. The change in the autonomic nervous system (ANS) activity and dysbalance of its main

components – parasympathetic and sympathetic nervous systems – are important factors contributing to initiation and progression of various cardiovascular complications of obesity [2]. Analysis of spontaneous oscillations of cardiovascular parameters – heart rate and

blood pressure variability (HRV and BPV) – provides important information on the autonomic control of circulation. Since HRV originates predominantly from oscillations in parasympathetic nervous traffic and blood vessels are predominantly under sympathetic nervous system control, beat-to-beat analysis of simultaneously obtained heart rate and blood pressure signals may provide information about both branches of cardiovascular control [3]. The aim of this study was to compare HRV and BPV in young obese subjects with control group and to analyse the performance of various linear and nonlinear HRV and BPV indices in detection of autonomic dysregulation in this future high risk group.

2. Methods

2.1. Study protocol

We have noninvasively recorded continuous finger blood pressure (FinometerPro, FMS, Netherlands) and ECG (bipolar thoracic lead; Cardiofax ECG-9620, NihonKohden, Japan) signals in 40 obese children and adolescents (25 female, 15 male) aged 14.2 [13.1 – 16.1] years (range: 9.9 – 18.2 years) and 40 age and gender matched control subjects 14.5 [13.1 – 16.2] years (range: 10.7 – 18.4 years). All subjects were examined over 60 min under standardized conditions in a quiet room from 8 to 12 AM. The subjects were instructed to lie comfortably in the supine position and not to speak or move unnecessarily.

2.2. Data analysis

Heart rate variability and systolic blood pressure variability (SBPV) analysis was performed off-line on 2000-beats long time series segments of beat-to-beat RR intervals and systolic blood pressure values. HRV and

SBPV were analysed using standard linear time and frequency domain analysis and by method derived from nonlinear dynamics – Recurrence Quantification Analysis.

2.3. Linear analysis

Time domain analysis

We computed the three most commonly used measures:

- MeanRR – mean RR interval duration
- SDRR – the standard deviation of RR intervals reflecting the overall HRV magnitude
- RMSSD – the root-mean-square of successive beat-to-beat differences reflecting the average magnitude of the changes between two consecutive beats that is usually regarded as a marker of vagal heart rate control

Frequency domain analysis

We computed spectral powers in two frequency bands associated with different physiological rhythms:

- Low frequency band (LF: 0.04 – 0.15 Hz) reflecting the baroreflex mediated heart rate oscillations.
- High frequency band (HF: 0.15 – 0.4 Hz) determined by the respiratory sinus arrhythmia which is regarded as a marker of the cardiac vagal control.

2.4. Recurrence quantification analysis

First, a multidimensional state space was reconstructed from the one-dimensional time series (RR intervals or SBP oscillations), applying the time delay embedding method [4]. Each point in the reconstructed phase space represents the state of the system at a given time and is determined by m coordinates (m corresponds to the embedding dimension; according to previous studies we chose $m = 10$ [5,6]). The coordinates are determined by the original time series' values delayed by selected time interval τ . The embedding time delay (τ) was set individually for each recording as the first minimum of the mutual information function. Next, the distances between individual points (a point in ten dimensional space corresponds to a state of the system at a given time) at times i and j were calculated using the Euclidean norm. When the distance between points was lower than a given threshold (tolerance), a recurrence point was plotted in the recurrence plot (RP) with the coordinates $[i, j]$ [7]. The tolerance level was selected individually for each recording giving the fixed percentage of recurrence points set to 5%. This procedure also minimizes the influence of HRV magnitude on RQA parameters and thus renders RP to provide hidden information on control system dynamics [8]. The most important structures for RQA are diagonal and vertical lines in RP. Diagonals reflect the repetitive occurrence of similar sequences of states in the system dynamics and express the similarity of system

behavior in two distinct time sequences. Verticals result from a persistence of one state during some time interval. In our study we computed the following measures:

- %Det (percentage of determinism) – the percentage of recurrence points forming diagonals from all recurrence points;
- L_{max} – maximal length of a diagonal;
- trapping time (TT) – mean length of the vertical lines;
- laminarity (Lam) – proportion of recurrence points forming verticals;
- V_{max} – maximal length of a vertical.

Low TT , Lam and V_{max} values imply high complexity in the system's dynamics, because the state of the system stays only for a short time in a state similar to the previously occurring state.

2.5. Statistics

Non-parametric tests were used to take into account the non-Gaussian distribution of the HRV and SBPV parameters. Between-groups comparisons (obese vs. control group) were performed with Kruskal-Wallis test. Results are presented as median [interquartile range]. A value of $p < 0.05$ was considered statistically significant.

3. Results

Time domain HRV and SBPV analysis. No significant between-groups differences were found in MeanRR ($p = 0.206$) SDRR ($p = 0.427$) and RMSSSD ($p = 0.444$). Similarly, for SBPV no significant between-groups differences were found in linear measures reflecting overall (SD SBP: $p = 0.847$) and beat-to-beat variability (RMSSD SBP: $p = 0.150$) variability, although MeanSBP tended to be slightly higher in obese group compared to control group ($p = 0.051$).

Frequency domain HRV and SBPV analysis. We have found no significant between-groups differences in both frequency bands for HRV (LF HRV; $p = 0.237$) and HF HRV; $p = 0.371$). After decomposing the systolic blood pressure time series into spectral components, we have found that the power of high frequency oscillations was significantly higher in obese patients (HF SBPV; $p = 0.019$) (Figure 1). The power of low frequency oscillations of SBPV was not different between obese patients and control group (LF SBPV; $p = 0.9$).

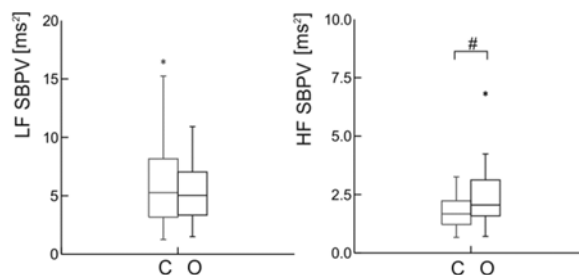


Figure 1. Box plots of frequency domain SBPV indices – spectral powers in low and high frequency bands (LF SBPV and HF SBPV) # denotes significant between groups difference (obese group – O vs. control group - C). Circles and asterisks correspond to outliers.

RQA of heart rate oscillations (Figure 2). No significant between-groups differences were found in RQA measures based on diagonals (%Det: $p = 0.885$; Lmax: $p = 0.806$). However, using RQA measures derived from vertical lines, significant differences in TT and Vmax were detected. Both TT and Vmax were significantly higher in obese patients compared to control group pointing towards complexity loss and simplification of heart rate (TT: $p = 0.028$; Vmax: $p = 0.019$). No significant difference in laminarity was found ($p = 0.637$).

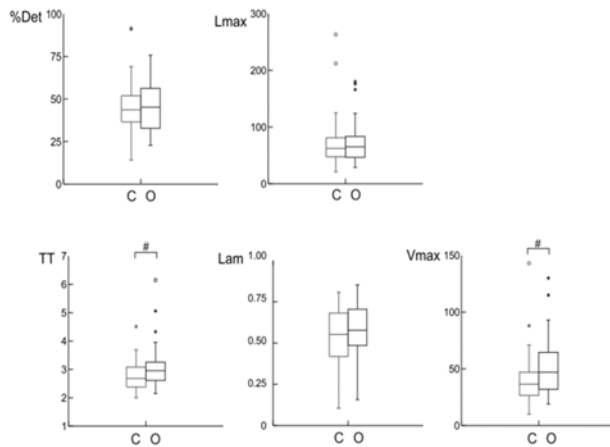


Figure 2. Box plots of RQA indices – recurrence plots were constructed from RR intervals. # denotes significant between groups difference (obese group – O vs. control group - C). Circles and asterisks correspond to outliers.

RQA of systolic blood pressure oscillations. There were no significant between-groups differences in any RQA measure derived from systolic blood pressure oscillations (%Det: $p = 0.788$; Lmax: $p = 0.754$; TT: $p = 0.897$; Vmax: $p = 0.413$; Lam: $p = 0.637$).

4. Discussion

The major findings of our study include relatively well preserved heart rate and blood pressure control in young obese subjects and the higher sensitivity of recurrence plot related measures to detect subtle abnormalities in cardiac autonomic control in obese subjects.

ANS plays an important role in the pathogenesis of cardiovascular complication related to obesity. In previous studies, a decreased parasympathetic activity in obese adults [9] and children [10] was demonstrated by a reduced high frequency power of HRV. The results from the analysis of low frequency heart rate oscillations are

more variable – an increase, no difference or even a decrease in LF power were observed [11]. We have not found any significant difference in linear HRV measures in time and frequency domains between our groups of 40 obese and 40 age and gender matched control children and adolescents. Our findings are in accordance with the studies where no significant effect of obesity on linear HRV measures was observed [10,1].

The effect of obesity on blood pressure variability in humans was analysed only rarely. While preserved LF and HF powers in BPV were found previously in moderately obese subjects, increased overall BPV magnitude was found in massively obese adults [12]. We have observed significant increase in HF power in SBPV signal in obesity. High frequency oscillations in SBPV result from the heart rate – blood pressure interaction and mechanical effect of breathing on venous return. Our results indicate increased mechanical effect of ventilation on blood pressure changes in obese subjects. We speculate that it can be the result of the changed magnitude of intrathoracic pressure oscillations caused by increased thoracic mass.

HR and BP signals are traditionally analysed by linear data analysis tools (time and frequency domain). However, these methods are not sufficient to characterize the complex dynamics of cardiovascular system. Analysis methods derived from nonlinear systems theory have opened up a new perspective for studying and understanding the characteristics of cardiovascular dynamics. Nonlinear measures describe qualitative features rather than the magnitude of the signal. We hypothesized that obesity should be accompanied by a decreased complexity of cardiovascular oscillations in accordance with the concept of complexity loss as a generic feature of pathologic dynamics [13]. RQA measures trapping time and Vmax calculated from recurrence plot constructed from spontaneous heart rate oscillations were significantly higher in obese group. This finding reflects the longer persistence of the given dynamical system state in obese subjects indicating a mild decrease of control system complexity. Our results suggest the subtle shift in sympathovagal balance – parasympathetic inhibition and/or sympathetic activation in obese group because the qualitatively similar changes in RQA measures – although with markedly higher magnitude – were associated with active orthostasis [8]. Our results point towards the importance of various signal properties quantification to better describe cardiovascular control. The inherent nonlinearity of analysed system in accordance with our results point towards the application of nonlinear methods to more properly characterize cardiovascular control and its potential impairment associated with obesity. Our results indicate the higher sensitivity of novel nonlinear methods to detect cardiovascular autonomic control changes as recently demonstrated in several other pathological conditions

including diabetes mellitus, posttrauma patients, chronic heart failure patients, etc. [14,5].

The important contribution of ANS dysbalance to the development of cardiovascular complications of obesity stress the importance of its early detection. Interestingly, several studies have found an improvement of cardiovascular autonomic control in obese subjects associated with lifestyle changes [15]. We assume that early detection and grading of high risk subjects based on HRV and BPV measures could help in administration of proper lifestyle changes to improve the prognosis of obese patients.

5. Conclusion

We conclude that cardiovascular autonomic control is relatively well preserved in obese children and adolescents. Recurrence plot analysis can reveal subtle changes in heart rate dynamics associated with obesity and possibly detect subjects with the higher risk of cardiovascular complications development.

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References

- [1] Vanderlei LC, Pastre CM, Freitas Junior IF, Godoy MF. Analysis of cardiac autonomic modulation in obese and eutrophic children. *Clinics (Sao Paulo)* 2010;65:789-792.
- [2] Ito H, Ohshima A, Tsuzuki M, Ohto N, Yanagawa M, Maruyama T, Kaji Y, Kanaya S, Nishioka K. Effects of increased physical activity and mild calorie restriction on heart rate variability in obese women. *Jpn Heart J* 2001;42:459-469.
- [3] Eckberg DL. Physiological basis for human autonomic rhythms. *Ann Med* 2000;32:341-349.
- [4] Takens F. Detecting strange attractors in turbulence. In: *Dynamical systems and turbulence*. Warwick 1980: Springer,1981:366-381.
- [5] Javorka M, Trunkvalterova Z, Tonhajzerova I, Lazarova Z, Javorkova J, Javorka K. Recurrences in heart rate dynamics are changed in patients with diabetes mellitus. *ClinPhysiol Funct Imaging* 2008;28:326-331.
- [6] Mestivier D, Dabire H, Chau NP. Effects of autonomic blockers on linear and nonlinear indexes of blood pressure and heart rate in SHR. *Am J Physiol Heart Circ Physiol* 2001;281:H1113-1121.
- [7] Marwan N, Carmen Romano M, Thiel M, Kurths J. Recurrence plots for the analysis of complex systems. *Phys Rep* 2007;438:237-329.
- [8] Javorka M, Turianikova Z, Tonhajzerova I, Javorka K, Baumert M. The effect of orthostasis on recurrence quantification analysis of heart rate and blood pressure dynamics. *Physiol Meas* 2009;30:29-41.
- [9] Rissanen P, Franssila-Kallunki A, Rissanen A. Cardiac parasympathetic activity is increased by weight loss in healthy obese women. *Obes Res* 2001;9:637-643.
- [10] Paschoal MA, Trevizan PF, Scodeler NF. Heart rate variability, blood lipids and physical capacity of obese and non-obese children. *Arq Bras Cardiol* 2009;93:239-246.
- [11] Rabbia F, Silke B, Conterno A, Grosso T, De Vito B, Rabbone I, Chiandussi L, Veglio F. Assessment of cardiac autonomic modulation during adolescent obesity. *Obes Res* 2003;11:541-548.
- [12] Piccirillo G, Vetta F, Viola E, Santagada E, Ronzoni S, Cacciafesta M, Marigliano V. Heart rate and blood pressure variability in obese normotensive subjects. *Int J Obes Relat Metab Disord* 1998;22:741-750.
- [13] Goldberger AL, Peng CK, Lipsitz LA. What is physiologic complexity and how does it change with aging and disease? *Neurobiol Aging* 2002;23:23-26.
- [14] Ho YL, Lin C, Lin YH, Lo MT. The prognostic value of non-linear analysis of heart rate variability in patients with congestive heart failure--a pilot study of multiscale entropy. *PLoS One* 2011;6:e18699.
- [15] Nagai N, Moritani T. Effect of physical activity on autonomic nervous system function in lean and obese children. *Int J Obes Relat Metab Disord* 2004;28:27-33.

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