

Instantaneous beat-to-beat variability reflects vagal tone during hyperbaric hyperoxia

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Lund V, Laine J, Laitio T, Kentala E, Jalonen J, Scheinin H. Instantaneous beat-to-beat variability during HBO₂ –Undersea Hyperb Med 2003; 30(1):28-35 - Hyperbaric hyperoxia affects heart rate variability (HRV) by increasing parasympathetic activity. The purpose of this study was to evaluate the applicability of instantaneous beat-to-beat variability (SD1 of Poincaré plot analysis) in detecting changes in vagal tone and to evaluate possible changes in the fractality of heart rate dynamics (α_1 of detrended fluctuation analysis) during hyperbaric hyperoxia. Continuous three-lead ECG recordings were taken in ten divers who were treated at 2.5 ATA with air (PO₂ 47 kPa) and oxygen (PO₂ 235 kPa) for 60 min. Power spectral analysis, Poincaré plot analysis and α_1 were analyzed before compression, after 30 min and after 55 min at 2.5 ATA. Correlations between the variables were calculated after 55 min exposure. SD1 and high frequency (HF) power increased significantly but α_1 decreased during hyperbaric hyperoxia (PO₂ 235 kPa). HF power and SD1 also correlated significantly. However, HF power and SD1 correlated inversely with α_1 . During hyperbaric hyperoxia, SD1 reflects vagal activity and can be used instead of HF power, if stationary conditions cannot be achieved. The decreasing α_1 indicates more random heart rate dynamics during hyperbaric hyperoxia.

Hyperbaric oxygen, instantaneous beat-to-beat variability, power spectral analysis

INTRODUCTION

Increased partial pressure of oxygen during hyperbaric oxygen therapy has been shown to increase parasympathetic activity in the regulation of the heart (1,2). According to the recommendations of the international Task Force (3) the principal reference method in assessing the balance between sympathetic and parasympathetic activities in the regulation of the heart is power spectral analysis of heart rate variability (HRV). In power spectral analysis total HRV (power spectrum of the duration of the RR intervals) is divided to high frequency (HF power, 0.15-0.40 Hz), low frequency (LF Power, 0.04-0.15 HZ) and very low frequency (VLF power, < 0.04 Hz) variability bands and each band is quantified. Physiologically, HF power reflects autonomic vagal activity and LF power has both parasympathetic and sympathetic components. The physiological role of VLF power is not clearly defined. The ratio of LF and HF powers (LF/HF) is thought to reflect sympathovagal balance (3).

Power spectral analysis, however, has some methodological limitations including demand for stationary RR interval data and need to standardize breathing (3). Also, it has recently been

found in healthy subjects that the length of consecutive RR-intervals follows non-linear random-like dynamics rather than a regular linear model (4). On the other hand, recently developed non-linear dynamic methods do not require presumptions of stationary RR intervals or standardization of breathing frequency during data acquisition (4). Of these methods, instantaneous beat-to-beat variability (SD1 of Poincaré analysis) has a strong correlation with HF power and reflects vagal tone during rest, exercise and various cardiologic disorders (5-9). Another index, short term scaling exponent α_1 of the detrended fluctuation analysis (DFA) quantifies fractal correlation properties, i.e. each RR interval is partially dependent on every other previous RR-interval in the time series. Decreased α_1 means increased random dynamics, i.e. length of RR-intervals cannot be predicted, and increased α_1 reflects strongly correlated RR interval dynamics (10,11). α_1 changes similarly with LF/HF ratio and inversely with normalized HF power during passive tilt test and exercise, indicating increased correlation properties of RR interval data during vagal withdrawal and concomitant enhanced sympathetic outflow (12).

The main purpose of this study was to evaluate the applicability of SD1 of Poincaré analysis as an index of vagal outflow during hyperbaric hyperoxic conditions. Also, α_1 was analyzed to evaluate possible parallel changes in RR interval correlation properties during vagal tone induced by hyperbaric hyperoxia.

MATERIAL AND METHODS

The continuous ECG recordings (Holter) used in this study were recorded during the same hyperbaric sessions as the periodic 5 min recordings of our previous study (2). The volunteers gave a written informed consent, and the study was performed according to the Declaration of Helsinki and after approval by the Joint Ethics Committee of University of Turku and Turku University Hospital.

Compression procedures

Ten professional divers were studied during two separate 60 min hyperbaric sessions: 1) at 2.5 ATA oxygen (PO₂ 235 kPa, OXY) in a monoplace hyperbaric chamber (Oxycom, Rauma Oceanics, Finland), and 2) 2.5 ATA air (PO₂ 47 kPa, AIR) in a multiplace hyperbaric chamber (Rauma Oceanics, Finland). During the exposures, the volunteers breathed atmospheric gas in the chamber and remained in the supine position. Breathing was not standardized during the recordings (in contrast to our previous report, where the subjects breathed 15 breaths per min). The compression to 2.5 ATA took 10-15 min and the pressure was kept at 2.5 ATA for 60 min. Decompression was made according to the US Navy decompression table for 18 meters seawater (2.8 ATA).

Data acquisition and analysis

A three-lead continuous ECG-recording (Holter) was started 10 min before the compression to 2.5 ATA and recording was continued until returning to 1.0 ATA. The Holter recordings were analyzed using a commercial software package (HEARTS, Heart Signal Co., Kempele, Finland). Three separate 5-min time windows were used in the statistical analysis: 1) baseline measurement immediately before compression, 2) after 30 min stay at 2.5 ATA and 3) after 55 min at 2.5 ATA. The following dynamic measures of HRV were used: Poincaré plot analysis (SD1, SD2, SD1/SD2) and short term scaling component α_1 of the DFA parameters. Poincaré plot is a graphical analysis method in which each RR interval is plotted as a function of

the previous one. Mathematically, SD1 (instantaneous beat-to-beat variability) is defined as the standard deviation from the points of the ascending 45 degree line that is drawn through the centroid of the plot and SD2 (continuous long term variability) of the points from the line that is orthogonal to the 45 degree line (9,10). α_1 represents the slope of the line that is formed by calculating the root-mean-square fluctuation of detrended and integrated data in different sizes of observation windows of a tachogram and plotted against the size of the window in log-log scale (12). Power spectral analysis of HRV was made using modified covariance autoregressive modeling with a model order selection using Akaike Information Criterion (3,13).

Statistical analysis

The HRV variables from 5-min time windows were compared using 2-way analysis of variance (ANOVA; SYSTAT 5.01/1992 for Windows). A logarithmic transformation was made for HF, LF and Poincarè plot data (SD1, SD2). For correlation analysis, Pearson's correlation coefficients between the linear and dynamic parameters were calculated after maximal oxygen exposure (100% oxygen at 2.5 ATA, 55 min measurement occasion). Statistical significance was confirmed if $p < 0.05$.

RESULTS

Mean heart rate decreased 16% after 30 min and 18% after 55 min at 2.5 ATA during OXY and 12% and 8% during AIR (Table 1). The difference between the treatments was statistically significant ($p=0.019$).

Mean SD1 increased 3 % after 30 min and 50 % after 55 min during OXY but did not change significantly during AIR. The difference between the treatments was statistically significant ($p= 0.002$). SD2 and SD1/SD2 ratio did not differ statistically significantly between the treatments. α_1 decreased 26 % from the baseline after 30 min and 29 % after 55 min at 2.5 ATA during OXY but did not change during AIR. The difference between the treatments was statistically significant ($p=0.001$). Mean HF power increased significantly more during OXY than during AIR ($p=0.001$). Mean LF/HF ratio decreased significantly more during OXY than AIR ($p=0.007$). (Fig. 1, Table 1).

Mean HF power correlated significantly with SD1 ($p < 0.001$, Fig. 2) and inversely with decreased LF/HF ratio ($p=0.006$). Both HF power and SD1 correlated inversely with α_1 ($p=0.005$ and $p=0.038$, respectively, Table 1). The LF/HF ratio correlated significantly with α_1 ($p=0.006$) (Table 2).

DISCUSSION

The main finding of this study was that Holter-recorded instantaneous beat-to-beat variability (SD1) seems to function as an index of increased vagal activity in a comparable way with HF power during hyperbaric hyperoxia (PO₂ 235 kPa). Secondly, decreasing α_1 (short time

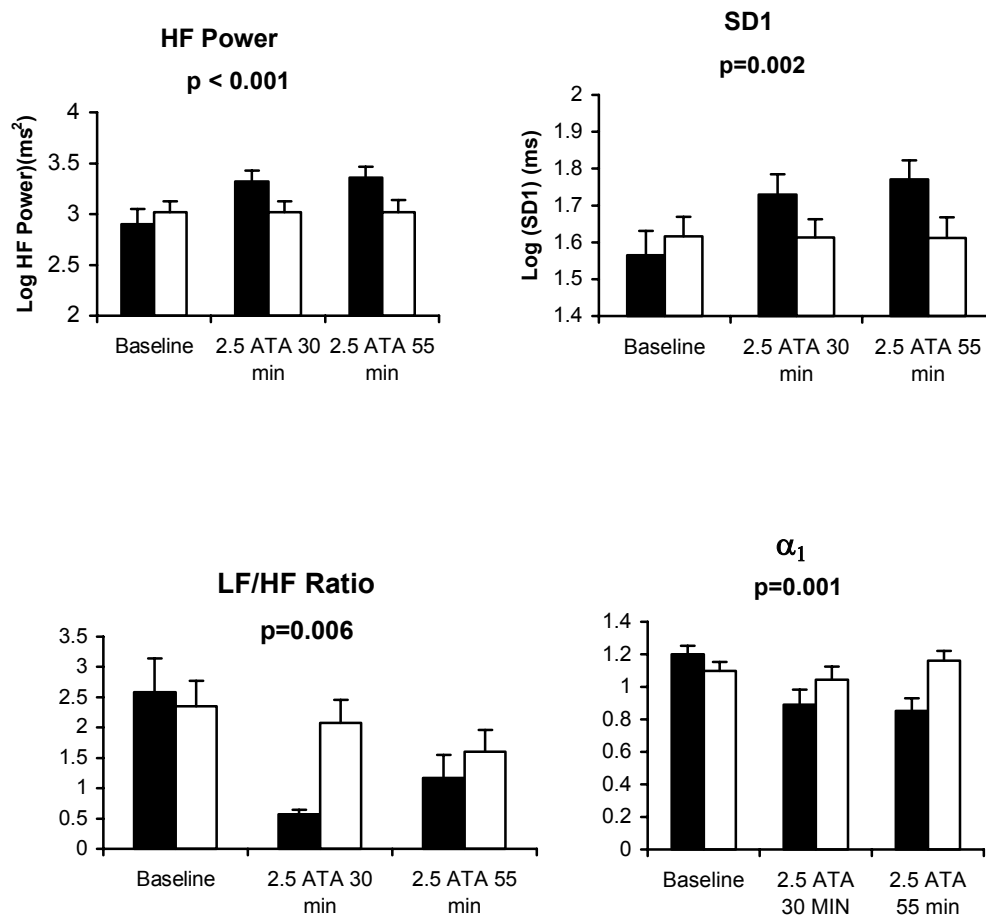


Figure 1. HF power (log), SD1 (log), LF/HF ratio and α_1 : Averages and standard errors of mean (SEM) at baseline (1), after 30-min exposure (2) and after 55-min exposure (3) at 2.5 ATA. Black bars refer for treatment with hyperbaric oxygen (OXY) and light bars for hyperbaric air (AIR). The increase of HF power and decrease of α_1 during hyperbaric hyperoxia (PO_2 235 kPa; OXY) were statistically significantly greater than during hyperbaric air (PO_2 47 kPa; AIR). In addition, LF/HF ratio and α_1 decreased significantly more during OXY. See text for details.

scaling exponent, 4-11 beats) revealed a trend towards decreased short-term correlation and thus more random RR-interval dynamics during hyperbaric hyperoxia-induced increased vagal outflow.

Parasympathetic activity increases during hyperbaric oxygenation as shown previously using frequency domain analysis of HRV (1,2). In the present study, HF power increased statistically significantly more during hyperbaric hyperoxia (PO_2 235 kPa) than during hyperbaric air (PO_2 47 kPa, (Fig. 1, Table 1), reflecting more pronounced vagal activity during hyperoxia than hyperbaria alone. SD1 showed similar trend as HF power, and it also correlated with HF power significantly (Tables 1,2). This concordance supports the idea of usefulness of SD1 as an index of vagal activity during hyperbaric oxygenation.

Table 1. Mean absolute values (SD) of heart rate, HF power, SD1, LF/HF and α_1 .

		Heart Rate	HF Power (ms ²)	SD1 (ms)	LF/HF Ratio	α_1
AIR	Baseline	57.5 (5.0)	1449 (1323)	44.6 (19.0)	2.35 (1.42)	1.10 (0.18)
	2.5 ATA 30 min	50.7 (4.9)	1474 (1489)	44.1 (19.3)	2.08 (1.26)	1.04 (0.30)
OXYGEN	2.5 ATA 55 min	53.1 (3.2)	1620 (1860)	45.0 (23.2)	1.60 (1.21)	1.16 (0.20)
	Baseline	60.9 (6.3)	1553 (2213)	42.1 (27.1)	2.58 (1.85)	1.20 (0.17)
	2.5 ATA 30 min	50.9 (4.1)	3078 (3388)	58.6 (29.3)	0.57 (0.25)	0.89 (0.31)
	2.5 ATA 55 min	50.2 (4.1)	3034 (2479)	63.1 (24.2)	1.17 (1.23)	0.85 (0.26)

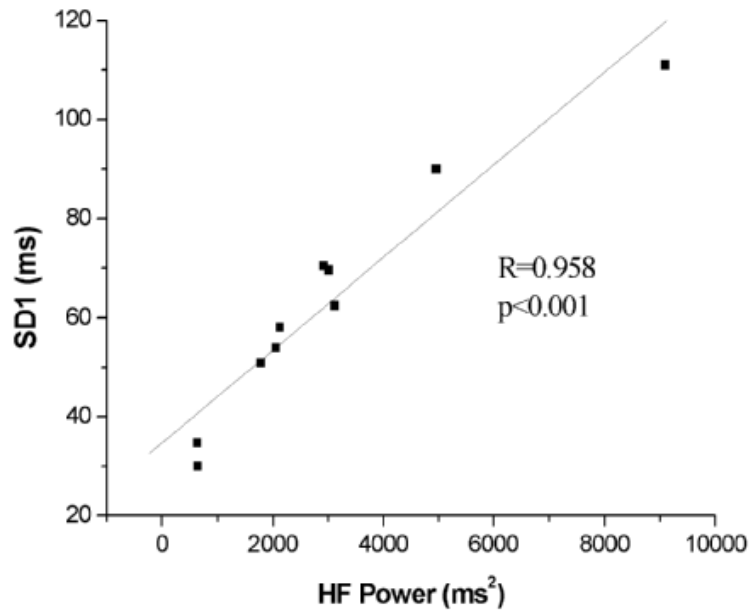


Figure 2. Correlation between HF power and SD1 after 55 min at 2.5 ATA during 100% oxygen.

Table 2. Pearson's correlation coefficients between linear and dynamic parameters after 55 min exposure at 2.5 ATA during 100% oxygen.

Air/Oxygen	HF	LF	LF/HF	SD1	SD2	SD1/SD2	α_1
HF	1	0.115 (NS)	-0.794 (**)	0.939 (***)	0.200 (NS)	0.624 (NS)	-0.806 (**)
LF		1	0.393 (NS)	0.369 (NS)	0.830 (**)	-0.503 (NS)	0.224 (NS)
LF/HF			1	-0.624 (NS)	0.176 (NS)	-0.854 (**)	0.794 (**)
SD1				1	0.467 (NS)	0.442 (NS)	-0.661 (*)
SD2					1	-0.442 (NS)	0.224 (NS)
SD1/SD2						1	-0.915 (***)
α_1							1

Statistical analysis: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, NS=not significant.

The main advantage of SD1 over HF power is that hyperventilation and changing from spontaneous to fixed breathing frequency affect HF power but do not influence SD1 to the same degree (8). In the present experiment, breathing frequency was not controlled as in our previous studies, but SD1 still correlated strongly with HF power. HF power but not SD1 demands stationarity of RR intervals in analysis (3,8). In the present study, a stationary RR interval was defined using a sequence free from ectopic beats in the frequency domain analysis. In clinical situations, control of breathing frequency and pattern may sometimes be difficult to achieve. Therefore, SD1 could be a useful alternative for HF power in situations when vagal activity is measured during non-standardized conditions.

Mean scaling exponent α_1 showed normal fractal-like ($\alpha_1 \approx 1.0$) heart rate dynamics before both interventions. Fractal-like time series exhibits both random (i.e. RR-intervals have no correlation between each other) and highly correlated RR intervals (i.e. a long RR-interval is more likely to be followed by long interval and vice versa) (4,11). Interestingly, heart rate dynamics during hyperbaric hyperoxic (PO₂ 235 kPa) showed a statistically significant change toward less fractal-like and more random dynamics. In a previous study, HF power decreased and α_1 increased during passive tilt test and moderate exercise, indicating increased RR interval correlation during vagal withdrawal and concomitant sympathetic activation (12). In this study, the decreased correlation properties (i.e. decreased α_1) were probably due to the accentuated parasympathetic drive to the heart during hyperbaric hyperoxia without concomitant enhanced sympathetic outflow, since HF power increased and LF power remained relatively stable. The negative correlation between α_1 and HF power and SD1 found in this study is thus supported by the previous findings (12).

To our knowledge, the effects of hyperbaric oxygenation on the regulation of the heart have not been studied in cardiac patients. Decreased heart rate together with increased parasympathetic activity during hyperbaric oxygen treatment is probably beneficial for patients with coronary artery disease. However, patients with variant (Prinzmetal) angina may not benefit from increased vagal activity because of increased risk of coronary spasm with increased

parasympathetic tone (19). The observed trend of α_1 towards more random type dynamics may also have clinical implications. In various heart disorders such as myocardial infarction and congestive heart failure, low values (< 0.5) of α_1 have indicated increased risk for further cardiac events (14-18).

CONCLUSION

In conclusion, SD1 of Poincaré analysis can be used as an index of parasympathetic activity during hyperbaric conditions, especially if all methodological demands of power spectral analysis are not achieved. Secondly, decreasing α_1 indicates a trend towards random heart rate dynamics during hyperbaric hyperoxia in healthy professional divers, probably induced by enhanced vagal outflow.

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