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Comparison of Linear and Non Linear Analysis of Heart Rate Variability in Different Postures.

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ABSTRACT

Heart Rate Variability (HRV) has been used for many years as a valuable diagnostic and prognostic tool in basic and applied medicine. Alteration in the posture is a well recognized stimulus to alter the cardiovascular hemodynamics and HRV can quantify these changes. It has been realized lately that the traditional indices of heart rate variability such as time domain and spectral methods may not reflect the true dynamics of heart rate changes because these methods assume that cardiovascular function is a stationary system. Because non-linear mechanisms are also involved in the genesis of heart rate dynamics analysis of the dynamic behavior of cardiac signals has opened up a new approach towards the assessment of normal and pathological cardiovascular behavior. The analysis of such perturbations has been traditionally assessed by the spectral methods of HRV, but it was a felt need to analyze this behavior by non linear methods as well. We employed a simple, cost effective and easily reproducible method of Poincare analysis to measure the HRV and correlate with the traditional method of quantifying the variability by means of time and frequency domain. Our results show a significant increase in the sympathetic tone as measured by the time and frequency domain measures of HRV between the Lying and Head up tilt posture as well as a significant increase in the parasympathetic tone between the head up tilt and head down tilt posture. There was a trend of increase in the parasympathetic component when Lying posture was compared with the Head down tilt, but the results were not statistically significant. The changes in the HRV parameters studied were successfully detected both by linear and non linear methods. Among the parameters studied, the linear time domain measures SD, RMSSD and the Poincare measures SD1 and SD2 provided the best performance in terms of discriminative power. Most of the parameters except the ratios (LF/HF and SD1/SD2) were correlated. Our results suggest that the study of cardiovascular behavior by means of non linear method such as Poincare analysis can be a very informative and easily reproducible tool.

Keywords: Cardiovascular behavior, HRV, Postural change, Poincare analysis, Non linear method

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INTRODUCTION

The cardiovascular concept of homeostasis refers to the tendency of the organism to maintain a regular heart rate and blood pressure in the face of changing environmental conditions. However no physiological variable shows stationary or periodic behavior. Spontaneous fluctuations are observed in heart rate and blood pressure even when the environmental conditions are kept constant and there are no perturbations on the system. The importance of these fluctuations was realized and since then heart rate variability (HRV) has been widely studied. Many studies have shown that a decreased fluctuation of RR intervals implicates an increased risk of arrhythmic events and an increased mortality rate with a previous myocardial infarction [1-3]. Heart rate variability has become a very useful tool to assess the regulation of cardiovascular system [4, 5].

Traditional indices of heart rate variability such as time domain and spectral methods may not reflect the true dynamics of heart rate changes because these methods assume that cardiovascular function is a stationary system. Apart from this, the results obtained from such methods are dependent on the units and the types of analysis used. Because non-linear mechanisms are also involved in the genesis of heart rate dynamics [6,7], analysis of the dynamic behavior of cardiac signals has opened up a new approach towards the assessment of normal and pathological cardiovascular behavior. It has also been hypothesized that spontaneous fluctuations in the dynamics of cardiovascular function may protect the system in case of acute perturbations, and that abnormalities in dynamic behavior may predispose to abrupt changes in cardiovascular function [8].

HRV has been accepted as good marker of cardiac autonomic activity (Tone). Perturbations to the cardiovascular system result in restoration of original status and autonomic nervous system plays a very important role in mediating theses homeostatic responses. Cardiac autonomic activity (tone) has been shown to change during prolonged perturbations to the system. Even acute perturbations show some transient changes and they can be faithfully assessed by HRV.

The analysis of cardiovascular signals through power spectral method in general and heart rate in the form of HRV in particular is not without certain pitfalls. The studies thus far have been confounding not only because of the numerous conditioning physiological processes, but also because of the varieties of ways of quantifying HRV. Perhaps most confusing have been the claims drawn from application of power spectral analysis and non linear dynamics (Chaos Theory). In the former, this may result not only from an adequate appreciation of the mathematical requirements for spectral analysis, but also from the fact that it is generally incapable of resolving nonlinearities. Although the dynamical behavior of the cardiovascular system can be best assessed by quantitative means, given the shortcomings of the spectral analysis, a semi quantitative but qualitative assessment of this dynamical behavior can be applied.

One of the methods to analyze HRV by non-linear method is a Poincare plot. The Poincare plot is a diagram in which each RR interval is plotted as a function of the previous one. The Poincare plot gives a useful quantitative and qualitative representation of the RR data by illustrating qualitatively with graphic means the kind of RR variations included in the recording. The shape of the plot can be used to identify "attractors" [9]. The non-linear relationship and structure in the plots indicate that the process might be chaotic rather than random.

In the present study we assessed the spontaneous fluctuations in the dynamics of cardiovascular function by giving postural challenge in the form of head up tilt (70^o) and head down tilt (20^o). HRV was performed and a non-linear analysis approach in the form of Poincare plot analysis was applied to study the cardiovascular behavior during the changes in posture.

The objectives of the present study were:

- To find out the changes in the time and frequency domain measures of HR in different body postures
- To find out the correlation between the parameters of non linear HRV analysis in terms of Poincare method with the linear time and frequency measures of HRV
- The authors intended to find out whether Poincare analysis can be used as an alternative/adjunctive tool to study the dynamics of cardiovascular system, especially for Heart rate Variability.

METHODS

33 healthy adult human subjects (mean age 24 Years, 19 males and 12 females, Mean age: 28±3) underwent the study. Subjects were explained to have morning meal at least 2 hours before the testing procedure. The testing was done in a quiet room at a temperature of 25-28^{o}C. All of the subjects were healthy and had no history of major systemic illness which can either affect directly or indirectly the autonomic functions as well as hemodynamic status during the changes in the posture. A detailed medical history also made sure that the subjects included in the study were not on any pharmaceutical intervention. They were explained about the protocol of the study beforehand. Informed written consent was taken from each of the subject.and the research protocol was approved by the Institute's ethical committee.

Subjects were allowed to lie down on the tilt table (Huntleigh Akron, UK) for 10 minutes, and after the subjects were comfortable, ECG acquisition was started through DAS port Nevrokard ADC converter and software for 5 minutes. After acquiring the signal in lying posture, data was checked for any noise, artifact or ectopic beats, and only those ECG signals were kept for further analysis that were free of any artifacts or ectopic beats. After this, the table was tilted up to 70^o and immediately ECG was acquired for 5 minutes. After acquiring ECG in the head up tilt (HUT) posture, the table was brought back to horizontal position (0^o) and after giving rest for 5 minutes the table was tilted down to 20^o (HDT) and ECG was acquired for further 5 minutes. The subjects were asked to report any discomfort during the tilt and if they did experience any inconvenience, the table was brought back to the horizontal position and those subjects were excluded from the study. After acquiring the ECG signal in all the three postures the software could do analog to digital conversion of the ECG signal and the digital data was subjected to time and frequency domain analysis after applying FFT and also Poincare analysis.

Statistical analysis of the data

Data from all the three postures was analyzed among each other by applying non-parametric Wilcoxon signed rank test. Correlation between the HRV and Poincare data was done by applying Pearson's Correlation.

RESULTS

Time and frequency domain measures of HRV during different postures

Lying vs Head-up tilt (HUT)

Time domain measures of HRV showed a significant decrease in minimum RR interval [764 (580 - 988) vs 668 (230 - 918) p< 0.001], mean RR interval [911.66 (759.27 - 1091.7) vs 795.03 (678.12 - 1033.43) p< 0.001], SDSD [42.74 (13.33 - 104.06) vs 34.06 (7.83 - 92.26) p<0.03], RMSSD [42.68 (13.31- 103.93) vs 34.01 (7.82 - 92.16) p<0.03], NN50 [36 (0-116) vs 10 (0 - 89) p<0.01], pNN50 [11.34 (0.29 -74) vs 2.46 (0-27.05) p<0.01] when lying posture was compared with 70^0 head up tilt. Frequency domain analysis of HRV between these two postures resulted in significant decrease in high frequency (HF) component [52.63 (20.83 - 91.18) vs 41.63 (4.83 - 77.69) p<0.05], an increase in low frequency (LF) component [38.31 (6.14 - 75.7) vs 51.41 (18.83 - 83.59) p<0.03], and an increase in LF/HF ratio [0.8 (0.2 - 3.63) vs 1.23 (0.24 - 5.79) p<0.001]. (Table-1, 2).

Table No. 1: Lying vs Head-up tilt (HUT), Time domain analysis

	Lying Median (Range)	Head-Up Median (Range)
Max	1059 (894 - 1376)	1126 (882 - 1228)
Min	758(578 - 997)	726 (592 - 743)**
Max/Min	1.4 (1.10 - 1.83)	1.42 (1.14 - 1.99)
Range	306 (102 - 484)	312 (84 - 588)
Mean	902.453 (747.27 - 1084.7)	834.356 (712.98 - 11053.59)***
CV	4.93 (1.81 - 11.89)	5.46 (2.09 - 15.58)
Variance	2042.32 (321.53 - 8156.4)	2208.61 (606.02 - 16296.53)
Median	912 (742 - 1094)	964 (782 - 1094)
SDNN	44.855 (17.93 - 90.31)	46.99 (22.97 – 127.65)
SENN	2.45 (1.03 - 4.57)	2.66 (0.97 - 6.71)
SDSD	47.78(13.33 - 104.06)	42.96(13.60 – 182.08)*
RMSSD	42.68 (13.31 - 103.93)	39.67 (14.56- 180.73)
NN50	35.90(0 - 116)	32.64 (1 - 123)**
pNN50	10.97(0 - 29.74)	7.67 (0-19.86)**

[The data is expressed as median (range) for lying (n=33) and head up tilt (n=33). The parameters were measured in milliseconds. SDNN- standard deviations of R-R intervals, SDSD- standard deviation of successive R-R differences, RMSSD- root mean of squared successive R-R intervals, CV- coefficient of variation of R-R intervals, NN50- number of R-R interval differences equal or more than 50 milliseconds, pNN50- percentage of NN50, *= p<0.05, **= p<0.01, ***= p<0.001]

Table No. 2: Lying vs Head-up tilt (HUT), frequency domain analysis

	Lying Median (Range)	Head-Up Tilt Median (Range)
Total Power	156 (113.84 - 26)	148.08 (112.53 - 213.01)
LF	38.315 (6.14 - 75.7)	30.24 (11.23 - 62.70)*
HF	51.655 (20.83 - 91.18)	48.76 (14.39 - 73.77)*
LF/HF	0.74 (0.12 - 3.58)	0.62(0.17-5.57)**

[The data is expressed as median (range) for lying (n=33) and head up tilt (n=33) postures. The power of the given frequency band calculated as area under curve within a particular frequency band is expressed in arbitrary units. Abbreviations: LF-power of low frequency band, HF- power of high frequency band, LF/HF-ratio between LF and HF , *= p<0.05, **= p<0.01]

Lying vs Head-down tilt (HDT)

There was no significant change in both time and frequency domain measures of HRV when lying posture was compared with 20^0 head down tilt.

Head-up tilt (HUT) vs Head-down tilt (HDT)

There was a significant increase in minimum RR interval, mean RR interval, SDSD, RMSSD, NN50 & pNN50 when 70^0 head-up tilt posture was compared with 20^0 head up tilt. (Table- 3,4).

Table No. 3: Head-up tilt (HUT) vs Head-down tilt (HDT), Time domain analysis

	Head-up tilt Median (Range)	Head-down tilt Median (Range)
Max	990 (694 - 1962)	1126 (882 - 1228)
Min	668 (230 - 918)	766 (592 - 1006)*
Max/Min	1.37 (1.11 - 4.92)	1.42 (1.14 - 1.99)
Range	249 (100 - 1182)	312 (84 - 588)
Mean	795.03 (678.12 - 1033.43)	963.84 (793.37 - 1094.59)
CV	6.215 (2.29 - 10.05)	5.46 (2.09 - 15.58)
Variance	2019.975 (333.5 - 8178.3)	2208.61 (606.02 - 16296.53)
Median	794 (670 - 1034)	964 (782 - 1094)
SDNN	44.935 (18.26 - 90.43)	46.99 (22.97 – 127.65)
SENN	2.29 (0.94 - 4.98)	2.66 (0.97 - 6.71)
SDSD	34.065 (7.83 - 92.26)	49.25 (13.60 – 182.08)**
RMSSD	34.015 (7.82 - 92.16)	49.18 (13.58 – 181.83)*
NN50	10 (0.89)	45 (1 - 131)*
pNN50	2.46 (0 - 27.05)	7.76 (0-67)*

[The data is expressed as median (range) for head up tilt (n=33) and head down tilt (n=33). The parameters were measured in milliseconds. SDNN- standard deviations of R-R intervals, SDSD- standard deviation of successive R-R differences, RMSSD- root mean of squared successive R-R intervals, CV- coefficient of variation of R-R intervals, NN50- number of R-R interval differences equal or more than 50 milliseconds, pNN50-percentage of NN50*= p<0.05, **= p<0.01,]

Table No. 4: Head-up tilt (HUT) vs Head-down tilt (HDT), Frequency Domain analysis

	Head-up tilt Median (Range)	Head-down tilt Median (Range)
Total Power	159.38 (125.35 - 317.62)	128.408 (112.53 - 213.01)
LF	51.41 (18.83 -83.59)	30.24 (11.23 - 62.70)
HF	41.635 (4.83 - 77.69)	66.16 (14.39 - 73.77)
LF/HF	1.23 (0.24 - 17.29)	0.45 (0.14 - 5.55)

[The data is expressed as median (range) for head up tilt (n=33) and head down tilt (n=33) postures. The power of the given frequency band calculated as area under curve within a particular frequency band is expressed in arbitrary units. Abbreviations: LF-power of low frequency band, HF- power of high frequency band, LF/HF- ratio between LF and HF]

Correlation between linear and non linear parameters of HRV

Most of the parameters studied for linear and non linear analysis of HRV were found to be closely related. All the parameters except the ratios (LF/HF, SD1/SD2) correlated significantly with the mean RR interval. Among the parameters, the linear time domain measures (SD, RMSSD) and the non linear measures derived from Poincare method (SD1, SD2) provided the best performance in terms of discriminative power. (Table-5)

Table No. 5: Pearson's Correlation Coefficients between different HRV Parameters

Pearson's R	RMSSD	LF Power	HF Power	LF/HF	SD1	SD2	SD1/SD2
Mean RR	0.56	0.35	0.47	ns	0.53	0.54	Ns
SD		0.71	0.72	0.63	0.71	0.97	Ns
RMSSD		0.43	0.86	ns	1.00	0.57	0.54
LF Power			0.40	0.40	0.46	0.77	-0.14
HF Power				-0.12	0.90	0.56	0.30
LF/HF					ns	0.18	-0.34
SD1						0.60	0.48
SD2							-0.19

DISCUSSION

The results of the present study show that Heart Rate variability (HRV) is modified by change in posture. A decrease in HRV was observed when lying posture was compared with the Head up tilt. There was no statistically significant change when lying posture was compared with Head down tilt, although there was a trend of increase in the overall HRV. There was a significant difference in the HRV when Head up tilt posture was compared with the Head down tilt.

The findings of postural changes in the HRV are consistent with the Physiological changes expected due to the perturbations caused and the normal homeostatic mechanisms coming into play. The overall decrease in the HRV after the head up tilt denotes increased sympathetic tone which is required to restore the cardiac output by causing sympathetic stimulation ultimately resulting in an increase in the heart rate as well as blood pressure. There was a trend of a decrease in the overall HRV when the subjects were compared in head down tilt posture compared to lying, although we could not find any statistically significant change. This may be due to a lesser degree of head down tilt as prevalent literature suggests that a greater degree of head down tilt results in significant changes. We didn't employ a greater degree of tilt because of the fact that our main objective of the study was to find out the correlation between the non linear analysis of HRV and traditional HRV in these maneuvers. We observed a significant difference in the overall HRV when Head up tilt posture was compared with the Head down tilt posture.

The changes in the HRV parameters studied were successfully detected both by linear and non linear methods. Among the parameters applied, the linear time domain measures (SD, RMSSD) and the non linear methods based on the Poincare plot (SD1, SD2) provided the best performance in terms of discriminative power.

Most of the parameters studied were found to be closely correlated. In addition, all the other parameters but the ratios (LF/HF, SD1/SD2) correlated significantly with the mean RR interval. This was expected as the mean RR interval is set by the interplay of sympathetic and parasympathetic tones, while HRV is a result of the modulation of these tones [10]. This finding reinforces the fact that HRV should never be interpreted without changes in the heart rate.

Partially redundant information can be provided by different HRV parameters as is evidenced by their strong correlation, a subset of the parameters could be sufficient to depict the relevant changes in HRV during change in posture. Respiratory Sinus Arrhythmia (RSA) apart from the central modulation plays a key role in the genesis of HRV and the parameters most closely related to RSA are RMSSD, HF power and SD1, while SD, SD2 and LF power all measure slower HRV rhythms such as 10-sec rhythm [11]. Hence it might be sufficient to use only one parameter from each of these two groups. Based on the preliminary analysis presented in the present study, we think that the optimal and physiologically relevant subset would be mean RR interval, SD1 and SD2.The biggest advantage of this particular selection is that the quantitative Poincare analysis does not require pre processing or stationarity of the acquired ECG signal and the parameters SD1 and SD2 are very fast and easily computable. Although our results make us to arrive to this conclusion, but we think that a more thorough statistical analysis would be needed to make the final selection for the optimal sub set.

Traditionally HRV has been quantified by linear time domain measures such as SD, SDSD, RMSSD and CV among others as well as frequency domain measures such as Total power, LF, HF and LF/HF ratio. However in recent years it has been stressed that the autonomic Nervous System (ANS) is not a linear system and a non linear approach to study the cardiovascular autonomic behavior should be used to study them [12]. The authors with their findings from the present study conclude that Poincare analysis can be a simple and reliable tool for assessing the dynamical and non linear behavior of the cardiovascular system. To validate this, the authors have compared the changes in the autonomic tone resulting due to postural changes between the measures obtained from the time tested traditional time and frequency domain analysis of HRV and measures obtained from Poincare analysis. The findings suggest that non linear assessment of HRV in the form of Poincare analysis can be a simple and very informative tool in assessing the cardiovascular autonomic status. With their findings the authors conclude that the optimal subset to pick up relevant changes in HRV parameters due to postural challenge would be mean RR interval, SD1 and SD2.

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