Quantitative Poincare Plots Analysis Contains Relevant Information Related to Heart Rate Variability Dynamics of Normal and Pathological Subjects

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Abstract

Poincarè plots (PPlots) analysis of RR time series allows a beat-to-beat approach to HRV, detecting patterns associated with non linear processes. Aim of this study was to assess the discriminating power of this method over fifty 24-hours Holter recordings of normal, hypertensive, post-MI, chronic heart failure and transplanted subjects. The analysis was performed by nine novel computer-generated quantitative descriptors of main 2D and 3D morphological characteristics of PPlots.

A forward stepwise discriminant analysis showed that four variables, provided independent and significant contribution to the overall discrimination with a 82% total classification function's score between different pathological conditions. Although further investigations should be provided, this results clearly indicate that PPlots analysis contains relevant information related to different HRV dynamics of normal and cardiac patients.

1. Introduction

The analysis of heart rate variability (HRV) is a well recognized non-invasive tool to investigate the autonomic cardiac control [1] and recently, definitive evidence has been provided on the prognostic value of HRV for cardiac mortality independently of others risk stratifiers [2].

It has been speculated that nonlinear analysis of HRV might provide more valuable information for the physiological interpretation of heart rate fluctuations and for the risk assessment in cardiac patients [1] and, among these techniques, Poincarè's plots (PPlots) analysis of RR time series is one of the few methods that have been tested in the clinical setting [3,4].

Profound abnormalities in autonomic control, characterized by sympathetic hyperactivity and parasympathetic withdrawal, have been widely demonstrated in cardiac patients.

It has been shown that PPlots of HRV allows quantitative display of parasympathetic nervous activity [5] and that quantitative descriptors of PPlots are better predictors of mortality in heart failure patients than time-domain conventional indexes [6].

Several PPlots analysis' methods have been proposed in literature, but it has clearly been shown [7] that most of them bring back to existing linear measure of HRV and only nongeometric techniques, such as scanning parameters [8], allow to detect patterns resulting from non-linear processes that cannot be detectable by time- and frequency-domain analysis.

The aim of this study was to assess the discriminating power of PPlots analysis by nine novel computer-generated quantitative descriptors of main 2D and 3D maps among different pathological conditions and to identify the most meaningful morphological indexes of these plots.

2. The Noltisalis database

The study population was extracted from the Noltisalis database, collected by the cooperation of several university departments and rehabilitation clinics in Italy (see the acknowledgements).

The acronym Noltisalis stands for "**No**n**L**inear **Ti**me **S**eries **A**na**l**ys**is**" and highlights the objectives of the multicentric project: to study the nonlinear nature of the HRV signal from a time series perspective [9].

The database consisted of 50 RR series extracted from 24-hours Holter recordings, obtained using different Holter devices. The assumption of nonlinearity for the HRV signals of Noltisalis data has already been verified in a previous paper [10].

The data set consisted of five groups of subjects, corresponding to different physiopathological conditions. (Table 1)

Table 1. Structure of Noltisalis database.

Population	Code	#	Age
Normal	NR	10	42 ± 6
Hypertension	HY	10	41 ± 1
Post-myocardial infarction	MI	10	50 ± 10
Heart failure	HF	10	54 ± 11
Heart transplanted	TR	10	45 ± 15

3. Poincarè plot analysis

The PPlots technique is based on the analysis of the maps constructed by plotting each RR interval against the preceding one. Usually bi-dimensional (2D) PPlots are visually classified into three typical patterns [3]: a comet-shaped pattern (C), with an increasing HRV at lower heart rates, a torpedo-shaped pattern (T), with a reduced heart rate dispersion on the whole distribution, and a fan-shaped pattern (F), with a great dispersion in a narrow range of frequencies. One major limitation of this visual classification is the subjective evaluation of the plots.

To overcome this problem, the automatic quantification of morphological characteristics of 2D and three-dimensional (3D) PPlots have been recently proposed by our group. A dedicated software developed by the authors allowed to automatically calculate the main morphological parameters characterizing Poincarè maps. Technical details on the procedure have been described elsewhere and excellent reproducibility of obtained indexes has been previously demonstrated [8,11].

Only normal classified QRS complexes were considered in the analysis, excluding RR intervals preceding or following not-normal beats and plotting only time-closed RR couples.

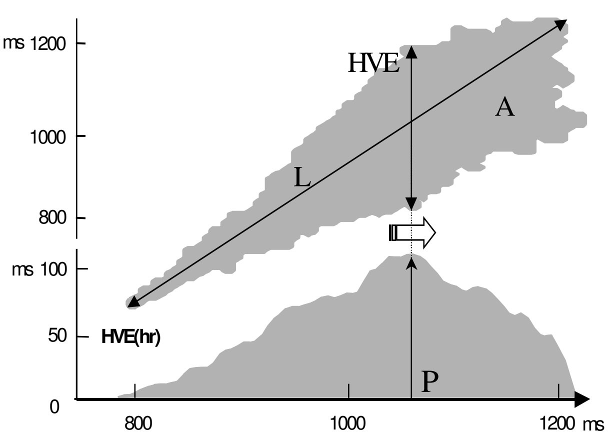

Figure 1. 2D Poincarè plots parameters

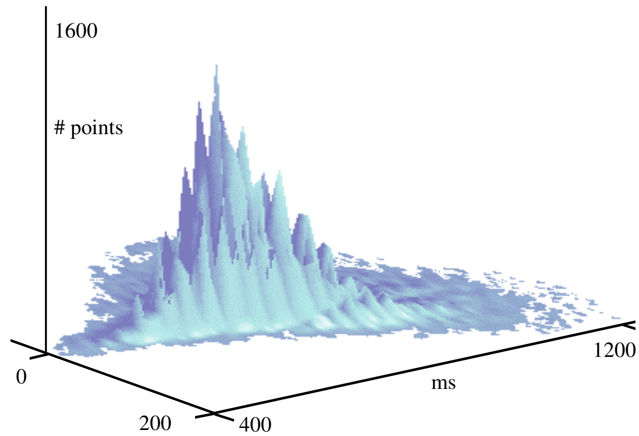

Figure 2. 3D Poincarè plots analysis

The most meaningful parameters extracted from 2D PPlots are measures of the extension and dispersion of the ellipsoidal cloud of points around the bisecting line, namely the length (L), the area (A), the highest variability extension (HVE), that can be obtained scanning the plot with a vertical line and generating a curve which represent the measure of scatterplot width at different RR intervals, and percentage of length which corresponds the maximum plot wideness (P) (Figure 1).

The most interesting parameters extracted from 3D PPlots are measures related to the plot's height, taking into account the RR couples' repetition number, namely the peaks' number (Np), the mean peaks' distance from the bisecting line (Dp), and the length of the three radii of of inertia (ρx, ρy, ρz) of the semi-ellipsoidal three-dimensional cloud of points (Figure 2).

4. Results

As shown by the 2D and 3D mean values of the Poincarè's plots parameters in tables 2 and 3 for the five studied populations, there is a direct relationship between the increasing impairment in the autonomic cardiac control and the progressive collapsing both in 2D and 3D maps.

In the 2D maps it can be appreciated a significant reduction of the area with a contraction of the length and a shortening of the width of the plots passing from normal to transplanted subjects (Table 2).

Similarly in the 3D maps it is evident a decreasing of peaks' number and of the ρy and ρz values with an increasing of the ρx, relating to a worsening autonomic cardiac control (Table 3).

Table 2. Mean and SD of the 2D PPlots parameters.

	L	HVE	P	A
NR	803±108	228±74	62±06	16894±6357
HY	801±138	233±70	60±13	17393±6425
MI	640±112	176±42	62±15	10513±2870
HF	540±113	144±66	55±12	7969±4427
TR	360±096	118±40	50±17	4424±1504

Table 3. Mean and SD of the 3D PPlots parameters.

	Np	Dp	Px	Py	Pz
NR	44±21	5±2	39±05	137±20	135±21
HY	25±08	1±1	41±03	140±37	137±39
MI	37±19	5±3	42±11	110±13	103±18
HF	16±12	3±2	50±09	100±14	88±19
TR	6±04	1±1	76±23	107±18	71±27

Entering all the nine quantitative descriptors of PPlots as candidates variables in a multivariate discriminat analysis (stepwise method), four variables, L, Dp, Np and Py provided independent and significant contribution to the overall discrimination between the five different pathological conditions considered in the study (Tab. 4 column 1).

In order to assess how these four variables discriminate between the different groups, we performed a canonical analysis. The chi-square test identified two significant roots of the canonical analysis (P<0.05).

The first discriminant function was weighted most heavily by L and Np, while the second one discriminant function by Dp (Tab. 4 columns 2 and 3 respectively).

The scores of the classification functions showed a total percentage of correctly classified cases of 82% (80%, 90%, 50%, 90, 100% for normal subjects, hypertensive, post-MI, chronic heart failure and transplanted patients respectively).

Table 4. Discriminant analysis results: p values of the variables in the model (column 1) and standardized coefficients for canonical variables (columns 2 and 3).

	p-level	std. coeff. root 1	std. coeff. root 2
L	<0.001	-1.128	0.201
Dp	<0.001	0.193	-1.033
Np	0.005	-0.650	0.195
Py	0.044	0.374	0.265

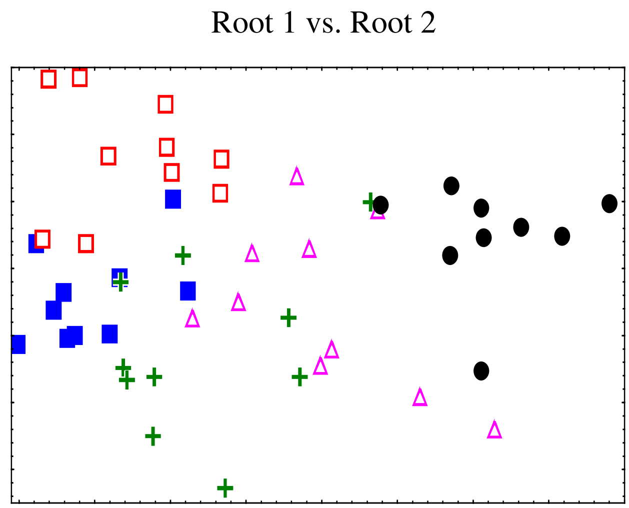

Figure 3. Scatterplot of canonical scores of root 1 vs. root 2. ■ Normal, □ Hypertension, + Post myocardial infarction, Δ Heart failure and ● Transplanted subjects.

In the determination of the nature of the discrimination for each canonical root, it can be shown that (see the above Figure 3) the root 1, along the x-axis, gives the best discrimination between the four groups of NR, MI, HF and TR subjects, while the root 2, along the y-axis, is the only one able to discriminate between NR and HY patients.

5. Discussion and conclusions

The first major finding of the study is that the parameters derived from 2D and 3D quantitative analysis of PPlots contain relevant information related to different HRV dynamics of normal and cardiovascular disease patients.

The technique is able to discriminate between the different HRV dynamics of all the five population studied with very high scores of the classification functions.

The second major finding is that, although a large number of indexes have been used in literature to quantify Poincarè maps, most of the discriminative information is contained in four of the nine indexes studied.

Indeed there are links and correlations between the indexes describing the morphological characteristics of the plots and, especially for statistical data analysis, it can be very useful to compact their information in the smallest and more significant data set possible.

The third consideration is that, although the 2D plot's length appeared as an important parameter, the other variables entered in the discriminat functions were 3D indexes.

Many authors that used Poncarè plots technique just paid their attention to the 2D indexes of the maps.

Depending on the different estimation's methods, this class of parameters can be related to existing linear measures of HRV, hence the intrinsic ability of Poincarè's plot to identify non-linear beat-to-beat structure is not completely exploited by 2D maps alone.

On the other hand the 3D maps and, more in general higher-order Poincarè plots, allow to better describe non-linear beat-to-beat pattern dynamics.

These considerations are not totally unexpected, completing and confirming the findings of a previous study of our group [12], addressing the prognostic value of Poincarè plot indexes in chronic heart failure patients.

Indeed in that study we found that just four out of six parameters were significantly associated with cardiac mortality and only a 3D parameter, Py, maintained statistical significance when adjusted for the others.

Finally it has to be pointed out that, we did not validate our results in an independent sample of patients (validation data set). Therefore the discriminative power of Pplots in this study has to be viewed as optimistic.

So, although these preliminary data clearly support the discriminating power of quantitative Poincarè plots indexes among different pathological conditions, further investigations are needed to validate the results of this study.

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References

[1] Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophisiology. Heart Rate Variability – Standard of Measurement, Phisiological Interpretation and Clinical Use. Circulation 1996;93:1043-1065.

[2] La Rovere MT, Pinna GD, Maestri R, et al. Short-term heart rate variability strongly predicts sudden cardiac death in chronic heart failure patients. Circulation 2003;107: 565-570.;

[3] Woo MA, Stevenson WG, Moser DK, Trelease RB, Harper RM. Patterns of beat to beat hearth rate variability in advanced hearth failure. Am Heart J 1992;123:704-10.

[4] Huikuri HV, Seppanen T, Koistinen MJ, Airaksinen J, Ikaheimo MJ, Castellanos A, Myerburg RJ. Abnormalities in beat-to-beat dynamics of heart rate before the spontaneous onset of life-threatening ventricular tachyarrhythmias in patients with prior myocardial infarction.. Circulation. 1996 May 15;93(10):1836-44.

[5] Kamen PW, Krum H, Tonkin AM. Poincare plot of heart rate variability allows quantitative display of parasympathetic nervous activity in humans. Clin Sci (Lond). 1996 Aug;91(2):201-8.

[6] D'Addio G., Pinna GD, La Rovere MT, Maestri R, Furgi, G, Rengo F. Prognostic Value Of Poincarè Plot Indexes In Chronic Heart Failure Patients J. Am. Coll. Cardiol.2002; 39(9B):49B.

[7] Brennan M, Palaniswami M, Kamen P. Do existing measures of Poincare plot geometry reflect nonlinear features of heart rate variability? IEEE Trans Biomed Eng. 2001 Nov;48(11):1342-7.

[8] D'Addio G, Acanfora D, Pinna GD, Maestri R, Furgi G, Picone C, Rengo F. Reproducibility of Short- and Long-Term Poincarè Plot Parameters Compared with Frequency- Domain HRV Indexes in Congestive Hearth Failure. In Computers in Cardiology 1998, IEEE Computer Society Press, 1998:381-384.

[9] Sassi R, "Analysis of HRV complexity through fractal and multivariate approaches" Ph.D Thesis, Politecnico di Milano, Italy, 2000.

[10] Signorini MG, Sassi R, Cerutti S. Working on the noltisalis database: measurement of nonlinear properties in heart rate variability signals. Proc. of the 23th Annual Conf. of the IEEE-EMBS, 2001.

[11] D'Addio G, Pinna GD, Acanfora D, Maestri R, Picone C, Furgi G, Rengo F. Reproducibility and correlation between power-law behavior and Poincarè plots of heart rate variability in congestive heart failure patients. European Heart Journal Vol 21, 2000:229.

[12] D'Addio G, Pinna GD, La Rovere MT, Maestri R, Furgi G, Rengo F. Prognostic Value Of Poincarè Plot Indexes In Chronic Heart Failure Patients Computers in Cardiology 2001; 28: 57-60. IEEE Computer Society Press

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