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Poincaré Plot of RR-Interval Differences (PORRID)
A New Method for Assessing Heart Rate Variability

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ABSTRACT

Interaction of sympathetic and parasympathetic nervous systems result in variation of RR interval (variation of heart rate) appeared significantly and related to physiological (or pathological) conditions. Heart rate variabiliy (HRV) is a non-invasive index of the neural control of the heart. The control of heart rate has mainly involve nonlinear mechanism so that the application of non linear techniques seems more suitable for HRV analysis. Poincaré plot is one of the non linear techniques used for ascertaining the HRV, which in turn is a marker of the activity of the autonomic system. Analysis of a conventional Poincaré plots that use only successive RRI duplets will underestimate the ability of heart beats to influence a train of succeeding beats. A new method for assessing HRV has developed, namely Poincaré Plot of RR Interval Differences (PORRID). PORRID is a graphical representation of the variation of RR intervals difference (ΔRRI) that form a pattern around the origin. The PORRID provide more information regarding the dynamics of heart rate regulation compared with the conventional RRI Poincare plot, and result significantly different patterns between normal and abnormal subjects. PORRID for normal subject result a circular pattern and for abnormal subject result a non circular pattern.

KEYWORDS: Poincare Plot of RR Interval Differences, PORRID, RR interval, RR interval difference, sympathetic, parasympathetic.

INTRODUCTION

Heart beats are caused by electrical depolarization of the cardiac muscle cells. The electrical depolarization can be observed on an electrocardiogram (ECG) as P, Q, R, S, and T waves. The number of heart beats for one minute is known as heart rate. The heart rate value can be obtained from the interval between successive heart beats that usually referred to as *RR* interval (RRI), and is measured as the distance between the *RR* waves [1]. The RRI (or heart rate) is not completely regular. Variation of the RRI is based in part on the autonomic innervation of the sinus node. RR interval is influenced by the autonomic nervous system via the sympathetic and parasympathetic nervous systems. Parasympathetic increase the RR interval (decrease the heart rate) through the media release of acetylcholine by the vagus nerve. Sympathetic decrease the RR interval (increase the heart rate) through the release of epinephrine and norepinephrine media [2]. Interaction of the sympathetic and parasympathetic result in variation of the RR interval (heart rate variation). This variation appeared significantly and is related to physiological (or pathological) conditions [3]. The heart rate variability (HRV) is a non-invasive index of the neural control of the heart [4]. HRV is a reliable reflection of the many physiological factors modulating the normal rhythm of the heart, and provide a powerful means of observing the interplay between the sympathetic and parasympathetic nervous systems [5].

HRV analysis is based on the concept that fast fluctuations may specifically reflect changes of sympathetic and parasympathetic activity [6]. The HRV can be analyzed in the time domain, frequency domain, and by using nonlinear parameters [7]. The heart rate control involve nonlinear mechanism so that application of non linear techniques seems more suitable [8, 9, 10]. One of the non linear techniques is Poincaré plot.

Poincaré plot is a technique used for HRV analysis, which further as a marker of autonomic system activity [11]. Poincaré plot represents the temporal correlations within the RR intervals obtained from the ECG [12]. Each RR interval in this plot is a function of the preceding RR interval. The Poincaré plot can be obtain by defining an N length data vector [11],

$$\overline{RRI} = \left(RRI_1,\ RRI_2, \ldots., RRI_N\right) \qquad (1)$$

and two auxiliary vectors,

$$\overline{RRI}_n = \left(RRI_1,\ RRI_2, \ldots., RRI_{N-1}\right) \qquad (2)$$

$$\overline{RRI}_{n+1} = \left(RRI_2,\ RRI_3, \ldots., RRI_N\right) \qquad (3)$$

The Poincaré plot consists of all the ordered pairs of:

$(RRI_n\ ,\ RRI_{n+1})$

that corresponds to two successive RR interval. The current RR interval (RR_n) is represented on the x axis, and the following RR interval (RR_{n+1}) on the y axis. This (conventional) RRI Poincaré plots use successive RRI

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duplets only, with the implicit assumption that the current beat is affected by the immediately preceding beat [13]. But in fact, the heart rate affects not only the beat immediately following it, but also up to 6–10 beats downstream [14]. Thus, analysis of a Poincaré plots that use only successive RRI duplets will underestimate the ability of heart beats to influence a train of succeeding beats [13]. This paper proposed a Poincaré plot of RRI Differences (PORRID) that uses successive RRI triplets to overcome the limitations of Poincaré plot that uses successive RRI druplets. It is hypothesized that the PORRID would provide more informations regarding the dynamics of heart rate regulation compared with the conventional RRI Poincare plot, and result significantly different patterns between normal and abnormal subjects. The aim of this paper is to describe different approaches of HRV assessment using the PORRID.

MATERIALS AND METHODS

This study used the RRI data derived from MIT-BIH database of ECG records, ie MIT-BIH Normal Sinus Rhythm (NSR) Database, MIT-BIH Sudden Cardiac Death (SCD) Holter Database, BIDMC Congestive Heart Failure (CHF) Database, and MIT-BIH Arrhythmia Database [15]. These RRI sequences used to provide 3 vectors as mentioned in Eq 1 to Eq 3. Substracting $\overline{RRI}_{n+1}$ of Eq 3 with the $\overline{RRI}_n$ of Eq 2 result:

$$\overline{RRI}_{n+1} - \overline{RRI}_n = \left(RRI_2 - RRI_1,\ RRI_3 - RRI_2, ...,\ RRI_N - RRI_{N-1}\right) \qquad (4)$$

Equation (4) represents a sequence of values of two adjacent RR interval differences, which then be written as:

$$\overline{\Delta RRI} = \left(\Delta RRI_1, \Delta RRI_2, ..., \Delta RRI_M\right) \qquad (5)$$

with: M = N-1.

From Eq (5) we obtain Eq (6) and Eq (7) as follow:

$$\overline{\Delta RRI}_n = \left(\Delta RRI_1, \Delta RRI_2, ..., \Delta RRI_{M-1}\right) \qquad (6)$$

$$\overline{\Delta RRI}_{n+1} = \left(\Delta RRI_2, \Delta RRI_3, ..., \Delta RRI_M\right) \qquad (7)$$

with: n = 1, 2, ..., M-1.

Equation (6) and (7) then is used to create a Poincaré plot of the points that are pairs of ΔRRI_n and ΔRRI_{n+1} as:

$$P_n = \left(\Delta RRI_n, \Delta RRI_{n+1}\right) \qquad (8)$$

that corresponds to variations of three successive RR intervals. This ploting was named as Poincaré Plot of RR Interval Differences, shortened as PORRID. The PORRID was observed to find the information contained in it and the pattern differences between the normal and abnormal subjects.

RESULTS AND DISCUSSION

Points in the PORRID describe the variation of RR interval differences. The RR interval differences, ΔRRIs, have three possible values that are ΔRRI<0, ΔRRI=0, or ΔRRI>0. The ΔRRI<0 indicates that there have been a decrease in the RR interval values (ie $RRI_{n+1}<RRI_n$), ΔRRI=0 indicates that no changes in the RR interval values (ie $RRI_{n+1}=RRI_n$), and ΔRRI>0 indicates that there have been a rise in the RR interval values (ie $RRI_{n+1}>RRI_n$). Variability of the heart rate may be categorized as absolut and relatif variability as follow.

A. Absolut Variability

Location of each point in the PORRID may be represented in polar coordinat system as:

$$P_n = R_n \angle \theta_n \qquad (9)$$

where: P_n = point ploted in the PORRID

$$R_n = \sqrt{(\Delta RRI_n)^2 + (\Delta RRI_{n+1})^2} \qquad (10)$$

θ_n = phase angle

$$\theta_n = \tan^{-1}\left(\frac{\Delta RRI_{n+1}}{\Delta RRI_n}\right) \qquad (11)$$

A point in PORRID describe variation of three successive RRI, or two successive ΔRRI. If there is no variation in the three RRI value then both ΔRRI_n and ΔRRI_{n+1} equal to zero, which place the plotting point at the origin. Thus, the point in the origin describes that absolutely there is no variation in the three successive RRI or in two successive ΔRRI. Therefore the R_n represents the absolute variability in every successive RRI triplets. Absolute variability describes the power (or speed) of autonomic activity.

B. Relative Variability

The angle θ_n describes the relative variation in each successive RRI triplets, comparing between current and the following variations. Relative variability indicates the comparison between the power (or speed) of current and the following autonomic activities, that describes as follow.

a. Points Located in Quadrant 1

Points located in Quadrant 1 of PORRID have $\Delta RRI_n>0$ and $\Delta RRI_{n+1}>0$, indicating variations of three RRIs that increase then increased again. Points located in Quadrant 1 indicate the dominance of parasympathetic activity against the sympathetic. Relative variability in Quadrant 1 is indicated by θ_n value in the range of $0<\theta_n<90$ degrees. Relative variability indicated by $\theta_n=45^o$ represent that the following increase in RRI is equal to the current increase, describing that the power of following parasympathetic activity is equal to the current power of parasympathetic activity. Relative variability indicated by $0<\theta_n<45^o$ describes that the following power of parasympathetic activity is weaker than current power of parasympathetic activity, and $45^o<\theta_n<90^o$ describes that the following power of parasympathetic activity is stronger than current power of parasympathetic activity.

b. Points In Quadrant 2

Points in Quadrant 2 have $\Delta RRI_n<0$ and $\Delta RRI_{n+1}>0$, indicating that variations of the RR intervals are decrease then increase. Points located in Quadrant 2 indicate the change from sympathetic to parasympathetic activity. The value of relative variability is in the range of $90^o<\theta_n<180^o$. Relative variability indicated by $\theta_n=135^o$ describes that the power of following parasympathetic activity is equal to the current power of sympathetic activity. Relative variability indicated by $90<\theta_n<135^o$ describes that the following power of parasympathetic activity is stronger than current power of sympathetic activity, and $315^o<\theta_n<360^o$ describes that the following power of parasympathetic activity is weaker than current power of sympathetic activity.

c. Points Located in Quadrant 3

Points in Quadrant 3 have $\Delta RRI_n<0$ and $\Delta RRI_{n+1}<0$, indicating that variations of RR intervals are decrease then decrease again. Points located in Quadrant 3 indicate the dominance of sympathetic activity against the parasympathetic. The value of relative variability is in the range of $180^o<\theta_n<270^o$. Relative variability indicated by $\theta_n=225^o$ describes that the power of following sympathetic activity is equal to the current power of sympathetic activity. Relative variability indicated by $180<\theta_n<225^o$ describes that the following power of sympathetic activity is weaker than current power of sympathetic activity, and $225^o<\theta_n<270^o$ describes that the following power of sympathetic activity is stronger than current power of sympathetic activity.

d. Points Locatde in Quadrant 4

Points in Quadrant 4 have $\Delta RRI_n>0$ and $\Delta RRI_{n+1}<0$, indicating that the RR interval variations are increase then decrease. Points located in Quadrant 4 indicate the change from parasympathetic to sympathetic activity. The value of relative variability is in the range of $270^o<\theta_n<360^o$. Relative variability indicated by $\theta_n=315^o$ describes that the power of following sympathetic activity is equal to the current power of parasympathetic activity. Relative variability indicated by $270<\theta_n<315^o$ describes that the following power of sympathetic activity is stronger than current power of parasympathetic activity, and $315^o<\theta_n<360^o$ describes that the following power of sympathetic activity is weaker than current power of parasympathetic activity.

e. Points Located At the Origin O(0,0)

Points located at the Origin O(0.0) have $\Delta RRI_n=0$ and $\Delta RRI_{n+1}=0$, indicating the lack of variations in the three consecutive RR interval triplets. Points at the origin indicate the equilibrium between sympathetic and parasympathetic activities during three cardiac cycles.

f. Points Located on the +Y Axis

Points located on the +Y axis have $\Delta RRI_n=0$ and $\Delta RRI_{n+1}>0$, indicating that variations of the RR intervals are equal then increase. Points on the +Y axis describes the change in autonomic activity from equilibrium state to parasympathetic activity.

g. Points Located on +X axis

Points located on the +X axis have $\Delta RRI_n>0$ and $\Delta RRI_{n+1}=0$, indicating that variations of the RR intervals are increas then equal. Points on the +X axis describes the change from parasympathetic activity to the equilibrium state.

h. Points Located on -Y Axis

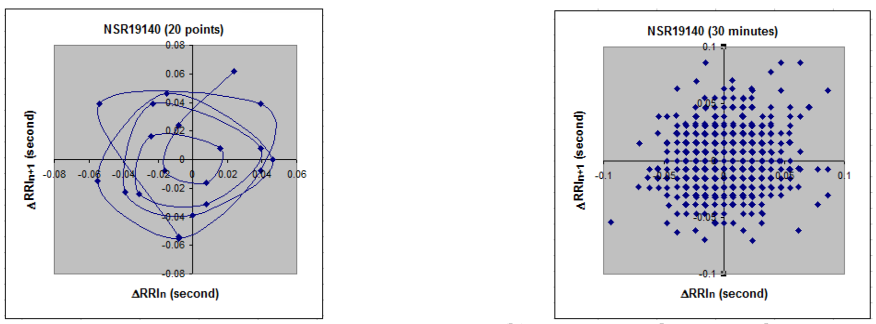
Points located on -Y axis have $\Delta RRI_n=0$ and $\Delta RRI_{n+1}<0$, indicating that variations of the RR intervals are equal then decrease. Points on the –Y axis describes the change from equilibrium state to sympathetic activity.

i. Points Located on –X Axis

Points located on –X axis have $\Delta RRI_n<0$ and $\Delta RRI_{n+1}=0$, indicating that variations of the RR interval are decrease then equal. Points on the –X axis describes the change from sympathetic activity to the equilibrium state.

PORRIDs of normal and abnormal subjects are shown in Fig 1 to Fig 4. The left panels of each figure are short term plotting (20 points) with a trace curve between two successive points. The right panels are long term plotting (about 30 minutes) of the same subjects as in the left panels but without trace curve.

PORRIDs of a subject with normal sinus rhythm in Fig 1 show a clockwise spiral trajectory around the origin in Fig 1(a) and an almost circular pattern with small radius in Fig 1(b). Small value of absolut variability shown by smal value of radius (about 0.05 second) indicates smooth variations of heart rate, that means smooth interaction between the sympathetic and parasympathetic activities. Large value of relative variability shown by the circular pattern and spiral trajectory indicates a stable interaction between the sympathetic and parasympathetic activities.

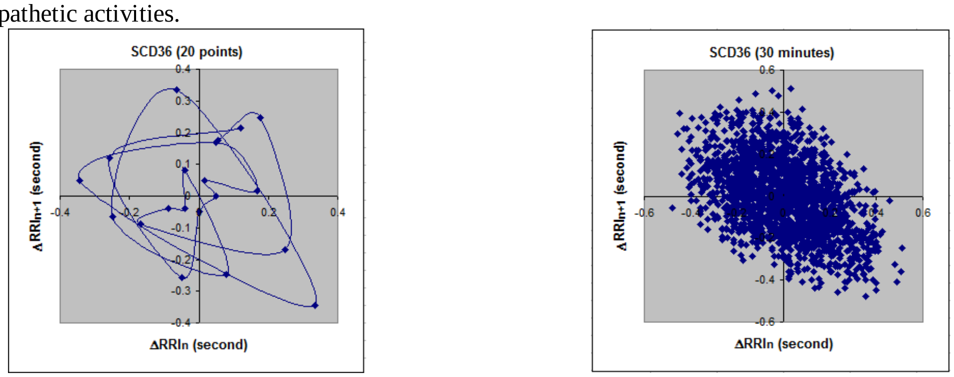


(a) Short term ploting of several ΔRRIs with trace curve between each successive point

(b) Long term plotting without trace curve

Fig 1. PORRIDs of normal subject

PORRIDs of subject ended with SCD in Fig 2 show a non spiral trajectory in Fig 2(a), and an elliptical pattern with a large values of ΔRRIs in Fig 2(b). The major axis of the ellips lies in Quadrant 2 and Quadrant 4, and the minor axis lies in Quadrant 1 and Quadrant 3. The ellips pattern and large values of absolut variability shown by large value of the major axis indicates the unstable and rough interaction between the sympathetic and parasympathetic activities.

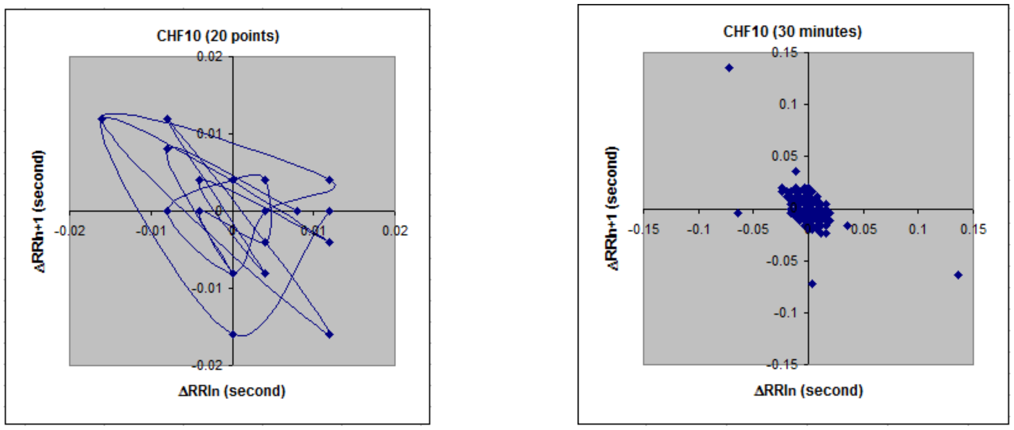


(a) Short term ploting of several ΔRRIs with trace curve between each successive point

(b) Long term plotting without trace curve

Fig 2. PORRIDs of subject ended with SCD

PORRIDs of subject with CHF in Fig 3 show a non spiral trajectory in Fig 3(a) and a small elliptical pattern around the origin in Fig 3(b). The small ellips pattern indicate the smooth but unstable interaction between sympathetic and parasympathetik. The instability is evident when an increase in sympathetic activity occur (shown by a point which the coordinat is (0.004,-0.072)), which then gets an exaggerated response of the parasympathetic shown by a point with (-0.072,0.136) coordinat. The exaggerated response of the parasympathetic shown by the large absolut variability then gets a smoother response of the sympathetik indicated by the points which the coordinats are (0.136,-0.064) and (-0.064,-0.004) .

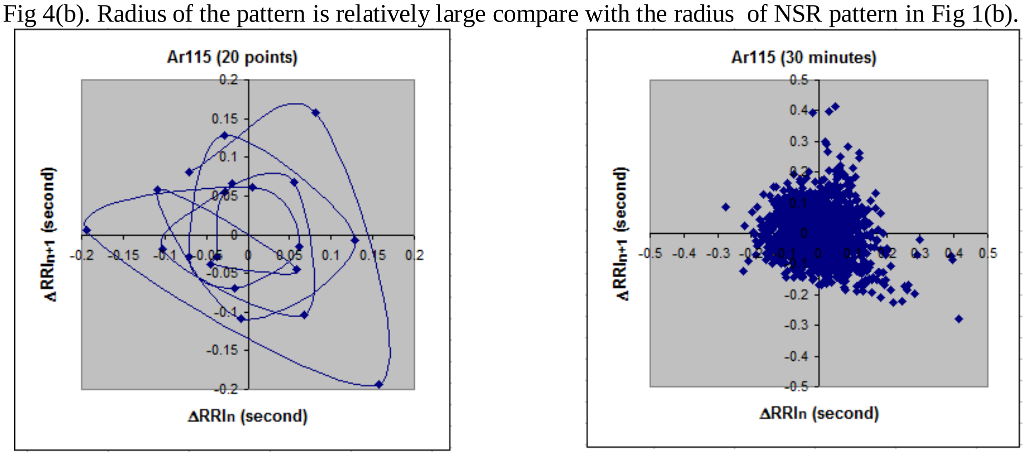


(a) Short term ploting of several ΔRRIs with trace curve between each successive point

(b) Long term plotting without trace curve

Fig 3. PORRIDs of a subject with CHF.

PORRIDs of subject with Arrhythmia in Fig 4 show a spiral trajectory in Fig 4(a) and a circular pattern in Fig 4(b). Radius of the pattern is relatively large compare with the radius of NSR pattern in Fig 1(b).



(a) Short term ploting of several ΔRRIs with trace curve between each successive point

(b) Long term plotting without trace curve

Fig 4. PORRIDs of subject with arrhythmia.

Analysis of Poincaré plot may use both of a qualitative technique that use the human eye's ability to recognize patterns, and a quantitative technique that introduces various parameters (called descriptors) which quantify the information contained in a Poincaré plot [12, 16]. A qualitative analysis of PORRID have demonstrated significantly different patterns between normal and abnormal subjects. A quantitative analysis to find PORRID descriptor is an issue for further research.

CONCLUSION

A new method for assessing heart rate variability named as Poincare Plot of RR Interval Differences (PORRID) has been developed. The PORRID provide more information regarding the dynamics of heart rate regulation than the conventional RRI Poincare plot, and result significantly different patterns between normal and abnormal subjects. The informations are described by the absolut and relative variabilities. Absolut variability is indicated by the distance (radius) from the origin to the plotted point, and describes the power (or speed) of autonomic activity. Relative variability is indicated by phase angle of the point, and describes the relative power (or speed) between the next and current autonomic activities. Qualitative analysis on PORRID of normal and abnormal subjects was performed using RR intervals derived from the MIT-BIH database. The analysis result that the PORRID of the normal subject showed a circular pattern, an elliptical pattern for subject ended with SCD, a small elliptical pattern for subject with CHF and a relatively large circular pattern for arrhytmia subject.

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