Information from Graphical Analysis of Heart Rate Variability using Chaos Theory

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Abstract: ***Heart period continually varies from beat to beat as a result of autonomic effects on the sinoatrial node; these changes can be computed as heart rate variability (HRV).HRV has become a popular clinical and investigational tool. The temporal fluctuations in heart rate exhibit a marked synchrony with respiration (increasing during inspiration and decreasing during expiration – the so called respiratory sinus arrhythmia, RSA) and are widely believed to reflect changes in cardiac autonomic regulation. Additionally, following a premature ventricular beat, reproducible variations take place in RR interval as a result of baroreflex mediated autonomic effects on the sinoatrial node, which can be gauged as heart rate turbulence (HRT). Apparently, impaired autonomic task as gauged through HRV and HRT are reliable in the prediction of adverse results within clinical surroundings. The ability of decreased HRV and HRT in the prediction of adverse results has been justified by their reliance on vagal mechanisms, which are capable of echoing an improved sympathetic and a decreased sinus node's vagal modulation thereby promoting cardiac electrical instability.***

Keywords: Heart Rate Variability, Chaos Theory, Graphical analysis

1. Introduction

In 1987, HRV's spectral analysis was utilized in post-MI patients [1]. The intricacy of computation was partly compensated for through the ability of spectral method in identifying and measuring the rule of the principal rhythmic constituents hidden within the HRV signal. This revealed that autonomic modulation and, especially sympathetic together with parasympathetic outcomes were largely liable for the low-frequency (LF; ≈0.1 Hz), as well as high-frequency (HF; ≈0.25 Hz) constituents of HRV, it was likely to evaluate change within autonomic control in a range of cardiovascular diseases, especially after MI. The analysis of short-term recordings showed that two different spectral patterns were certain: firstly, in simple MI, was exemplified by a prevalent LF and a lesser HF constituent, with an LF/HF ratio >2, signifying a sympathetic activation, along with a decreased vagal tone. Secondly, in complex MI, was instead differentiated by a major decrease in total power, a tiny or absent LF constituent, and a relatively prevalent HF constituent, with >60% to 70% of control in the VLF variety. These patients' autospectrum failed in echoing the clinical image of neurohumoral sympathetic activation thereby being the same as subsequently reported in patient with congestive heart failure in the disease's most advanced levels [2].

2. Background

Study of HRV's non-linear dynamics has also been applied in illustrating the fractal like trait of the variability sign and confirmed effectual in the recognition of patients vulnerable to sudden cardiac death. In spite of the clinical authenticity of these determinations, it has also been proven that the relation linking neural input to sinus node responsiveness happens to be very intricate and variable within distinctive clinical conditions. Therefore, abnormal HRT or HRV on quantifiable Holter recordings is capable of echoing not only non-neural, but also autonomic mechanisms, something that must be considered when construing any findings. Nonetheless, under managed conditions, the calculation of the low, along with high frequency constituents of HRV and of their standardized powers or ratio appears to have the capability of giving valid information regarding sympatho-vagal balance within standard subjects, and in most patients who have a protected left ventricular function. As a result, analysis of HRV by means of the chaos theory is capable of offering a distinctive tool to explicitly measure autonomic control mechanisms alongside various perturbations. Additionally, HRV analyses are of ample utility in the identification of patients who have a greater cardiac mortality and in the evaluation of autonomic control mechanisms [3]. However, their capability of capturing specified degrees of autonomic control might be restricted to controlled laboratory researches in comparatively healthy subjects.

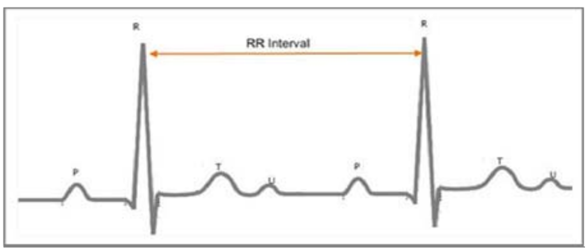

Figure 1: R Peaks and RR Intervals of an ECG Signal

There are various reports on the study of beat-to-beat gaps' spontaneous variations, which have turned out to be an essential tool, recognizable by clinical cardiologists. For instance, in 1987, there was a report explaining that decreased heart rate variability (HRV) had the capability if recognizing a subgroup of subjects that has increased cardiac mortality following myocardial infarction (MI), with its predictive significance being quite apart from habitual clinical risk-stratifying features [4]. Initially, it was recommended that decrease in HRV might echo, at the sinus node point, an autonomic inequity exemplified by improved sympathetic and decreased vagal function. This explanation was also backed by indirect findings like a tendency to quicker heart rates and a lesser day-night heart rate distinction examined in these patients.

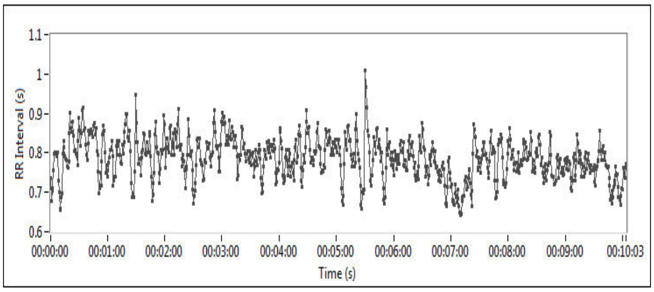

Figure 2: HRV of an Adult

Apparently, was not anticipated was the ability of HRV's time and frequency-domain computations to envisage total cardiac, as well as arrhythmic mortality to a conderably similar level, especially when the quantity of clinical and experimental proof on the proarrhythmic function of sympathetic activation and decreased vagal tone was considered. Furthermore, the interpretation of a obviously decreased LF within high-risk patients was hard to justify. These and other unrequited questions have created a new concern in the analysis of innovative R-R interval time cycles, as well as in a more inclusive appraisal of the essential and peripheral methods liable for beat-to-beat oscillations.

3. Methodology

Various methods have been utilized in demonstrating nonlinear dynamic systems through description of system trajectory within the space, through calculating fractal dimensions, or through ascertaining self-similarity features [5]. Of particular concern is the method based on the evaluation of the long-term relationship of R-R interval time cycles through ascertaining the long-range energy-law relationship. Whenever the power and regularity of HRV are outlined on a bilogarithmic level, the outline in the 10−4- to 10−2-Hz regularity range that matches with VLF is depicted by a straight line along with a −1 slope [6]. Apparently, this broadband spectrum happens to be an indication of a fractal-like procedure with a long-term reliance, proposing that fluctuations within R-R interval are connected to variations that happened hundreds of beats before and, at least within experimental animals, are reliant on baroreflex mechanisms' functional integrity [7].

$$C(r) = \log \varepsilon(r) + \frac{r}{N} \qquad (1)$$

In patients following MI, the availability of left ventricular dysfunction was connected to an extensively more negative spill of the energy-frequency relation [1]. The exponent of 1/f spill was significantly connected to level of left ventricular dysfunction rather than total energy. The other indicator of fractal factor, D2, was lesser in patients who have depressed ejection fraction as compared to control subjects. All these findings were constant with the theory that the changed HRV pattern examined in these patients, at first exemplified by a marked decrease in total power, was also connected with a loss of difficulty of the variability signal.

Apparently, the capability of energy-law regression of envisaging death following MI was initially reported by Bigger, Steinman, Rolnitzky, Fleiss, Albrecht and Cohen.[8] According to these authors, a power-law regression limit under −1.372 was significantly connected to total cardiac, as well as arrhythmic mortality, with an analytical value comparable to that of VLF and ULF power when measured individually but extensively greater when joined with zero connection energy. In the current matter of Circulation, the outcomes of a modern utilization of nonlinear dynamics to HRV signal's study in post-MI patients engaged in the DIAMOND study [9].

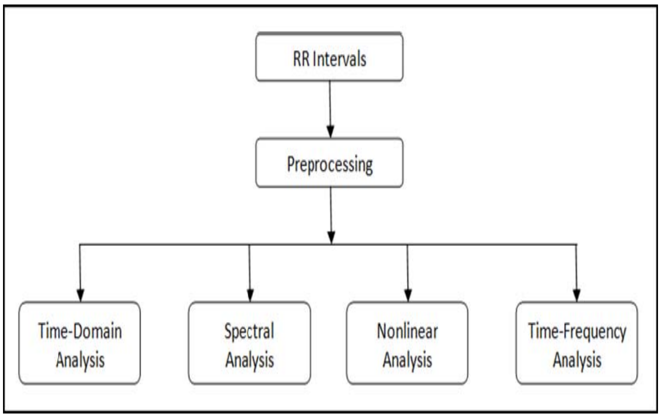

Figure 3: HRV Analysis Process

Besides 1/f slope, these authors also examined short-range association of interbeat intervals through detrended fluctuation study, that permits to calculate 2 indicators of the fractal scaling features of short (<11 beats) , as well as intermediary (>11 beats) R-R interval time cycles[3]. Throughout a follow-up period that lasted for 2 years, 114 deaths happened; 75 were categorized as arrhythmic. Conventional time- and frequency-domain limits of HRV and indicators of nonlinear dynamics fluctuated extensively between survivors along with nonsurvivors. Nonetheless, amongst all R-R interval inconsistency quantifiers, the decreased short-term scaling α1 possessed the best general independent exactness in the forecast of all-purpose mortality following alteration of other variables. Additionally, this indicator was the only quantifier that independently envisaged arrhythmic death too.[8]

After spectral study was instead used in 24-hour recordings, apparently, ≈90% of the power was available within the ultra-low frequency (ULF; <0.00033 Hz) with extremely low-frequency (VLF; 0.0033 to 0.04 Hz) variety, while the LF and HF constituents justified <10% of spectral power. Additionally, a significant decrease in total and fractional power differentiated patients having increased cardiac mortality apart from those whose prognosis was better.

Nonetheless, the sensitivity, specificity, as well as the positive analytical value of spectral parameters turned out to be the same as those of the SD of the standard R-R interval (SDNN) or even triangular index (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1056).
This early study was followed by various reports whereby HRV's geometric indices or time-domain parameters quantified on Holter recordings, turned to be effective in the identification of post-MI patients with improved cardiac mortality. [10] When sensitivity along with specificity were ascertained, unfortunately, their value turned out to be less than anticipated, with a positive analytical value <30%. Apparently, the confounding outcome of the range of computation methodologies found within commercial instrumentation also played a role in the limited utilization of this method within routine clinical procedure [10].

4. Chaos theory and Non-linear dynamics

According to a 24-hour tachogram, heart period fluctuates while responding to environmental factors like posture or physical activity, as well as in stationary situations. This rhythmicity that might have numerous interfaces with other physiological rhythms like respiration might also be influenced by small perturbations (such as atrioventicular block or premature ventricular contractions). Consequently, the time series is inconsistent with time; it fails in showing regular periodicity, and is unexplainable through a linear method. A nonlinear deterministic method seems like being more appropriate in explaining more complicated phenomena, indicating that evidently; erratic behavior is capable being created even through a simple deterministic system that has nonlinear structure.[5]

$$y_n^{calc} = a_0 + a_1 y_{n-1} + a_2 y_{n-2} + \ldots + a_\kappa y_{n-\kappa} + a_{\kappa+1} y_{n-1}^2 + a_{\kappa+2} y_{n-1} y_{n-2} + \ldots + a_M y_{n-\kappa}^d = \sum_{m=0}^{M-1} a_m z_m(n) \qquad (2)$$

Therefore, it is not a wonder that certain nonlinear dynamics subtype, chaos theory, together with fractals, has of late been utilized in studying HRV signal. At first, it was presumed that chaotic fluctuations might describe cardiac electrical function in ventricular or atrial fibrillation. Later on, it was recommended that the heartbeat fluctuations in normal sinus rhythm can be partly credited to deterministic anarchy and that a reduction in this kind of nonlinear variability can be seen in distinctive cardiovascular diseases and prior to ventricular fibrillation.[6]

5. Results and Analysis

These results fuel new concern in the analysis of HRV; firstly, they show that it is impossible to completely extract the quantity of information concealed in the variability signal with a single approach. Certainly, the duration of recordings, as well as the specified pattern of fluctuations available in the variability signal could deserve distinctive modalities of study. Whenever HRV is decreased, as is the case of high-danger post-MI patients, linear constituents of the variability signs are nearly undetectable, as specified by the lack or marked decrease of the LF constituent and through the steeper rise of the energy-frequency connection in the VLF level. The current results consent to this hypothesis: lesser estimates of the short leveling exponent (<11 beats) denote loosing short-term connection the R-R interval properties within the same time level that relate to LF fluctuation periodicity. Therefore, the variation of autonomic control system, which exemplifies acute MI, might span from a tiny decrease in HRV with a prevalence of LF on HF to a marked decrease of rhythmic fluctuations with a loss of long, as well as short-term connection of interbeat intervals.

Additionally, the data imply that a deficit of short-term connection is capable of predicting total cardiac, as well as arrhythmic mortality [9]. Therefore, there is a possibility that in high-stake patients, a constant sympathetic activation along with a decreased vagal tone might ascertain a marked decrease in dynamic difficulty of heart rate oscillations that would cause heart period to be less flexible and less capable of coping with the necessities of a constantly changing environment [6].

$$\varepsilon(\kappa, d)^2 = \frac{\sum_{n=1}^{N}\left(y_n^{calc}(\kappa, d) - y_n\right)^2}{\sum_{n=1}^{N}\left(y_n - \mu_y\right)^2} \qquad (3)$$

Another advantage of this approach happens to be the possibility of carrying out analysis on raw data exclusive of the need for time-consuming and in most case, disputable editing. Unfortunately, this model does not seem to be easily translated into clinical practice whereby frequency area is still almost hasty. Nonetheless, only a mechanism based on an integrated study of linear, as well as nonlinear dynamics of interbeat oscillation seems to be ample to properly examine the HRV signal, while at the same time better recognizing patients at risk [5].

6. Conclusions

In conclusion, HRV's time and frequency domain study has been turned out to be effectual in the evaluation of autonomic tone of the sinus node, as well as in the stratification of patients following MI. The marked decrease in HRV examined in high-risk patients appears to be connected with a significant decrease of the linear along with rhythmic constituents of HRV. Therefore, a nonlinear method based on the analysis of long and short term connection of interbeat intervals appears to be more effective in the detection of abnormal model of R-R fluctuations available in these patients and possible to echo an abnormal autonomic modulation.

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