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Original article

Nonlinear analyses of heart rate variability in hypertension

Analyse non linéaire de la variabilité du rythme cardiaque en hypertension artérielle

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Abstract

Objective. – The autonomic nervous system plays an important role in blood pressure regulation and in the development of hypertension. Heart rate variability (HRV) may be of importance in identifying subjects at higher risk of developing hypertension. In the present study, comparative analysis of HRV for normal and hypertension subjects using nonlinear indices has been carried out.

Patients and methods. – We analyzed the data from 24 patients with essential hypertension aged 45–55 (HG). All the subjects in this group had a confirmed diagnosis of the first- or second-stage essential hypertension. The control group for these subjects included 32 healthy volunteers of the same age group (CG). We analyzed the whole 5 minutes of the ECG recording. Nonlinear indices D_2, K_2 and lagged Poincaré plot indices were calculated.

Results. – Values of D_2 and K_2 in hypertension state is statistically significantly lower than in healthy. Poincaré plot indices SD1 and SD2 in healthy volunteers are statistically higher than in hypertensive patients for all lags ($P < 0{,}05$). *SD1/SD2* ratio is also higher in healthy subjects, but the difference is statistically significant only for $l = 5$ and 6.

Conclusion. – The heart rhythm in groups with hypertension is more regular, its dynamics are less complex and less "chaotic," compared to healthy ones. This is expressed in lower values of entropy and correlation dimension. The HR stabilization is observed at both short and long time intervals, but mainly due to the decrease in the difference of the "neighboring" *R-R* intervals.

Keywords: Hypertension; Autonomic nervous system; Heart rate; Nonlinear analyses; Lagged Poincaré plot

Résumé

But de l'étude. – Le système nerveux autonome joue un rôle important dans la régulation de la pression artérielle et dans le développement de l'hypertension. La variabilité de la fréquence cardiaque (VFC) peut être importante pour identifier les sujets à risque plus élevé d'hypertension. Dans la présente étude, une analyse comparative de la VFC pour les sujets normaux et hypertendus utilisant des indices non linéaires a été effectuée.

Patients et méthodes. – Nous avons analysé les données de 24 patients atteints d'hypertension essentielle âgés de 45–55 ans (HG). Tous les sujets de ce groupe avaient un diagnostic confirmé d'hypertension essentielle de grade 1 ou 2. Le groupe témoin comprenait 32 volontaires sains du même groupe d'âge (GC). Nous avons analysé les 5 minutes entières de l'enregistrement ECG. Les indices non linéaires D_2, K_2 et les indices de tracé de Poincaré décalés ont été calculés.

Résultats. – Les valeurs de D_2 et K_2 des sujets du groupe HG sont significativement plus faibles comparées au groupe CG. Les indices de placette de Poincaré SD1 et SD2 chez les volontaires sains sont significativement plus élevés que chez les patients hypertendus pour tous les retards ($p < 0{,}05$). Le rapport SD1/SD2 est également plus élevé chez les sujets sains, mais la différence n'est statistiquement significative que pour $l = 5$ et 6.

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Conclusion

Le rythme cardiaque dans le groupe hypertendu est plus régulier, sa dynamique est moins complexe et moins « chaotique » que dans le groupe témoin. Ceci est exprimé dans des valeurs plus faibles de l'entropie et de la dimension de corrélation. La stabilisation de la fréquence cardiaque est observée à des intervalles de temps courts et longs, mais principalement en raison de la diminution de la différence des intervalles R-R « voisins ».

Mots clés : Hypertension ; Système nerveux autonome ; Fréquence cardiaque ; Analyses non linéaires ; Parcelle de Poincaré retardée

1. Introduction

Recent studies in the literature [1] indicate that hypertension is one of the major causes of mortality in old-age people [2] and workload stressed middle-aged group [3,4]. The major causes of hypertension are heredity, stress, exercise, alcohol intake, smoking. There is considerable evidence to suggest that the autonomic nervous system plays an important role in blood pressure regulation and in the development of hypertension. Heart rate variability (HRV) analysis is being considered as a popular diagnostic tool in cardiology to assess the activities of the autonomic nervous system, and has been used for many years for its simplicity, accuracy, and non-invasive application. HRV may be of importance in identifying subjects at higher risk of developing hypertension, so the integrity of autonomic modulation of heart rate is evaluated by using linear and nonlinear analyzing of HRV.

The sympatho-vagal balance is altered in numerous pathophysiological processes. It is the case of essential hypertension, even in the presence of arterial pressure values still in the high normal range [5]. The ability of decreased heart rate variability to predict incident hypertension has not been well studied, and there are no studies of whether hypertension leads to changes in heart rate variability [6].

Some authors have assessed the relationship between hypertension and HRV [7–9]. Linear methods, including time- and frequency-domain analysis, were used in these studies. Actually, nonlinear phenomena involved in the genesis of HRV are determined by complex interactions of hemodynamic, electrophysiological and humoral variables, and also by autonomic and central nervous regulations. It has been speculated that analysis of HRV based on the methods of nonlinear dynamics might elicit valuable information for the physiological interpretation of HRV and for the assessment of the risk of sudden death [10]. These methods may provide information beyond the conventional time and frequency domain methods [11,12].

Both linear and nonlinear methods are used to analyze heart rate in healthy subjects and patients with different pathology. The nonlinear methods usually supplement the linear ones [13–17]. Many authors claim the prognostic value of nonlinear analysis [18–21].

Additional clinical validation of existing novel methods is needed to define their clinical predictive value as well as their robustness in relation to reproducibility and widespread clinical use [22].

For example, the correlation dimension D_2 gives the information about the number of independent functional components necessary to describe the underlying system and the degree of non-linear coupling between these components. In biological systems, the higher the D_2 the more degrees of freedom the system has and, therefore, the greater range of possible adaptive responses. The correlation dimension is usually calculated through the correlation integral using the algorithm of Grassberger and Procaccia [23]. There has been a lot of research lately on dimension of heart rhythm. The authors focused on investigating dimension of normal sinus rhythm, including the effect of circadian rhythms, influence of autonomous nervous system, rhythm after heart transplants and in different pathologic conditions.

The correlation integral is also used to calculate the correlation entropy K_2. Meanwhile, the correlation entropy describes the behavior of a system in terms of randomness, and quantifies information about underlying dynamics. It is a dynamic measure and represents the rate at which information needs to be created as the chaotic system evolves in time. Entropy refers to system randomness, regularity, and predictability and allows systems to be quantified by rate of information loss or generation. Traditionally, K_2 has been much less popular compared to D_2 as a discriminating statistic in analyzing time series in practice. However, K_2 has a significant and more relevant status, especially in the context of colored noise contamination, as indicated by many authors [24].

One method of HRV analysis is the Poincaré plot, which takes a sequence of intervals and plots each interval against the following interval. It is a representation of a time series into a phase space, where the values of each pair of successive elements of the time series define a point in the plot. The Poincaré plot is a very simplified two-dimensional phase space with delay or lag of 1 to 10 beat. A quantitative analysis of the this plot can be made by using three parameters: SD1–variance of *R-R* intervals in a short time scale, SD2–variance of *R-R* intervals in a long time scale, and the ratio SD1/SD2 [25].

Poincaré plots have been successful in characterizing abnormal cardiac function and proved to become an integral part of HRV analysis [26,27]. It is shown to provide prognostic information in myocardial infarction, chronic heart failure, and sudden infant death syndrome. It also predicts mortality risk of life-threatening ventricular arrhythmias in cardiac surgery patients [28,29].

The main aim of this study was to ascertain how and which of the variability and complexity parameters of the heart rate variability are different in hypertensive patients compared to