

MORPHOLOGY EVALUATION OF HEART RATE VARIABILITY POWER SPECTRUM

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Abstract-A relatively simple feature 'fractal number' reflects adequately differences in the morphology of power spectral patterns. The spectral region area ratios are well-known estimators of the heart rate variability, but the fractal numbers are able to complementary evaluations of the particular spectral morphologies. We investigated 30 heart rate variability spectra and applied wave recognition techniques to the power density series of the R-R, Q-Q and S-S variability curves. Comparisons between spectral region area ratios and fractal number ratios showed the functionality of the morphology estimator as an appropriate complementary tool for clinical assessments of the sympatho-vagal balance at the sinus node.

INTRODUCTION

Variations of sinus rhythm heart rate reflect the interplay of numerous body subsystems, adapting to the particular conditions within their scope of functionality. The sympatho-vagal balance at the sino-atrial node greatly affects the discharge rate, thus offering valuable information about the status of the autonomic nervous system, if properly assessed. However the necessary non-invasive P-wave detection is not reliable enough and practically the P-P intervals are assumed to be closely approximated by the corresponding R-R intervals. More simple time-domain techniques, such as heart rate variance, were recently overwhelmed by the power spectrum analysis of the heart rate [1], an essential standard technique for evaluation of the heart rate variability (HRV). Appropriately handled, the frequency-domain can supply possibilities for fast-screening of the population and for categorizing cardiac, diabetic, postoperative and other patients. These possibilities are far from being exhausted. Currently Fourier Transforms and Auto-Regressive Algorithms are being widely used to obtain the HRV spectrum [2], [3]. Efforts are concentrated on linking spectral power density changes in relevant frequency ranges to their corresponding physiological counterparts. So far these significant frequency ranges are considered [4] to be: 0.0167 - 0.05 Hz, 0.05 - 0.15 Hz (L), 0.15 - 0.35 Hz (H), 0.35 - 0.50 Hz, with affiliations to the vasomotor, baroreceptor (L) and respiratory (H) activity respectively. Generally, under low frequency (L) and high frequency (H) spectral bands, the spectral band area is implied, so that the evaluation of the enormous variety of clinical spectral patterns is done mostly through ratios of L, H and L+H

areas. Although the area is a very useful general indicator, it fails to reflect the particular morphology of the concerned pattern. Clearly there is need for further pattern description parameters.

METHODS

We performed the present study evaluating the power spectra of the HRV of 30 subjects. In 20 cases there had been occasional beats of various ventricular origins, but we accepted the cases, since the goal of the study was to be able to distinguish between spectral patterns with different morphology of the spectral bands. The ECG itself had a sampling rate of 250 Hz, 2 leads, 30 minutes duration. We built a TurboC++ (Borland Int. Inc., Scotts Valley, CA, USA) custom application running under Windows 3.1 (Microsoft Corp., Redmond, WA, USA) to create a complex study environment with a sufficient number of test ECG parameters involved. We described previously [6] the Q-, R- and S-wave detection, as well as the extrasystole identification procedures in detail. The original R-R intervals were extracted after rejection of all intervals, which were connected to at least one end of a ventricular extrasystole. To be able to perform a Fast Fourier Transform (FFT) technique [5], we linearly interpolated (resampled) the original non-equidistant R-R interval sequence at 4 Hz, obtaining 1024 equidistant R-R values. We subtracted the mean and applied a Hanning window to reduce side effects. After obtaining the discrete power spectral curve with a frequency resolution of 0.0039 Hz, we computed both the conventional spectral area parameter and a simple morphology estimator 'fractal number' [6] for the L, H and L+H ranges. Fractal numbers (FN) evaluate the 'plane-filling' quality of the concerned pattern: $FN = \log(\text{Waveform_Length}) / \log(\text{Waveform_Diameter})$, thus sensitively reflecting the morphology of simple waveforms. To remove the influence of the different waveform widths and magnitudes, before each calculation of a fractal number, we uniformly normalized them to a norm. We implemented the width normalization through an equidistant linear interpolation and before the magnitude normalization we removed first the baseline trend between the onset and offset of the waveform. In this way a straight line pattern would give a FN = 1.0 and a complete 'plane-filling' curve - FN = 2.0.

RESULTS

We considered a direct assessment of the functionality of the fractal number spectral morphology estimator for a

rather subjective procedure, while the spectral area was already an established criterion. That is why we tied its performance to the area estimator through comparisons of the corresponding L/H ratios for all 30 heart rate (R-R) variability spectra. Further, we applied the same procedure to all Q-Q and S-S variability power spectra and visualized the result for functionality attestation as Fig.1. shows. We found the cross-correlation coefficient between the HRV spectral area and morphology ratio estimator series to be 0.78.

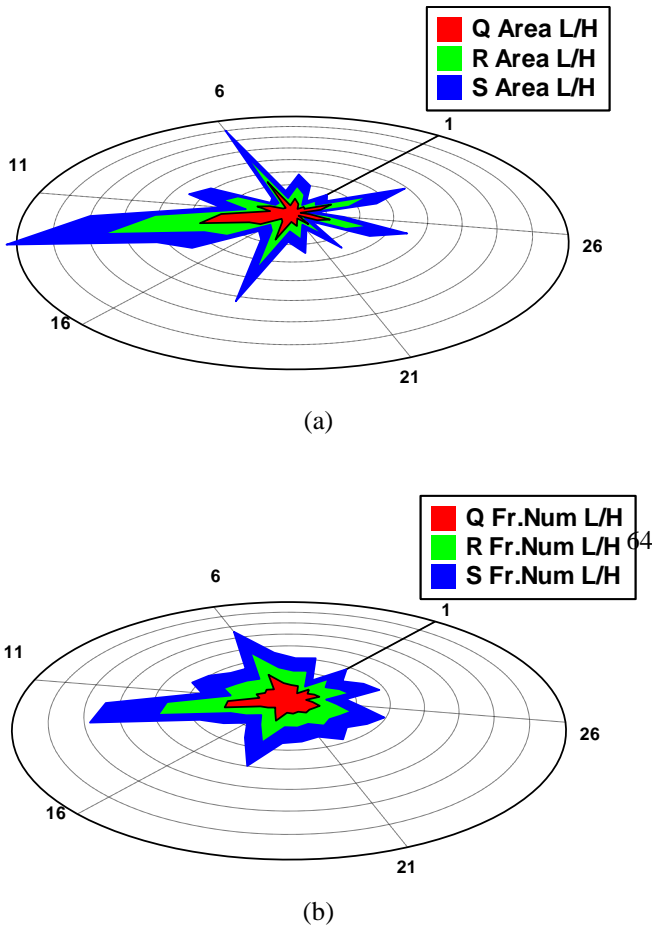


Fig.1. Qualitative comparisons through spider plots with multiple categories (a) of the power spectral L/H area ratios and (b) of the L/H fractal number ratios in the R-R, Q-Q, S-S variability power spectra. The data was taken from 30 subjects. Cross-correlation between R-R spectral area ratio and fractal number ratio series was found to be 0.78.

DISCUSSION

The main purpose of the presented study as a part of a wide-range cardiac rhythm analysis project was to facilitate the automated evaluation of heart rate variability for daily clinical use. We saw no obstacles to apply customary time-domain signal analysis procedures also to the frequency-domain, as there was a definite clinical need for a fast automated morphology evaluation aid. However we should consider some limitations of this evaluation approach. We showed that the fractal numbers of the normalized patterns correspond well even to gradual morphology changes [6], but an implication of that is that these patterns do not exceed a certain extent of complexity. Additional research

is needed on this point. Another adjustment should be done taking into account that the fractal number is not sensitive to the 'sign' of the pattern, giving equal values for patterns with the same form, but with reverse polarity. However, this 'sign' condition is relatively easy to consider during a pattern classification attempt. Another restriction is the assumption for stationarity of input data for the FFT procedure. A much better approach would be to use another spectral technique, regarding a time axis at the output. We are currently working also on that problem. Summarizing the functionality of the fractal number spectral morphology estimator, we consider its overall performance as a clinical diagnostic tool, complementary to the area estimator. While the area and morphology spectral range estimator ratios both reflect particular spectral range characteristics, they are complementary to each other, evaluating the power spectral density of the heart rate variability. We are carrying out further research to connect this result with other ECG-derived parameters, trying to achieve a more effective combination of interval and morphology analysis.

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