A New Method to Detect Erratic Sinus Rhythm in RR-Interval Files Generated from Holter Recordings

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Abstract

Episodes of erratic sinus rhythm (ESR), assumed to be as a high-degree of non-respiratory sinus arrhythmia with normal p-waves, are seen on Holter recordings in the elderly and cardiac patients. ESR increases heart rate variability (HRV) and may confound its predictive value. We hypothesized that a triplet of normal-to-normal (NN) intervals represented by ($N_1N_2N_3N_4$) is ESR if N_1N_2/N_2N_3 and N_2N_3/N_3N_4 are both outliers in the distribution of NN-interval ratios. The time spent in ESR in each ten-minute segment was visually estimated using a heart-rate tachogram of NN intervals (HRTACH) and compared with the calculated values. A total of 858 ten-minute segments in six randomly selected 24-Hour recordings of older adults were examined. A qualitative test of the algorithm yielded a positive predictive value of 0.83 and a negative predictive value of 0.87 for 552 positive tests. Results suggest that the method can identify subjects with and without ESR in RR-interval files.

1. Introduction

Standard time and frequency domain HRV performs calculations on each NN interval or relative differences in two NN intervals over a time series of RR intervals. Frequency domain HRV, which involves spectral analysis of a series of NN intervals, has been found to provide a window onto autonomic nervous system function [1]. A relatively low value of the standard deviation of NN intervals in a 24-hour RR-interval file predicts mortality in post-MI patients [2]. In addition, relatively low values of standard HRV, measured shortly after MI, are associated with increased risk of mortality independent of other risk factors [3,4,5]. Low standard HRV predicts poor cardiac health and abnormal cardiac autonomic modulation.

Investigators from the Zutphen study reported that relatively high values of standard HRV that did not appear to reflect respiratory modulation of heart rate were also associated with increased mortality in older adults [6]. In elderly subjects and cardiac patients, we have also observed relatively high values of standard HRV from abnormal power spectral plots associated with an erratic sinus rhythm that does not reflect respiratory modulation. We have speculated that this increased standard HRV, which does not apparently reflect normal cardiac autonomic modulation, may confound the relationship between HRV and cardiac health. It is therefore extremely important to develop a method to identify and possibly eliminate epochs in which this rhythm is present.

Such episodes of high HRV may occur in disjoint time periods with a duration of as little as 0.1 minutes to many hours. On a HRTACH, i.e. a plot of heart rate determined from NN intervals *vs.* time, ESR is visibly different from normal respiratory sinus arrhythmia (RSA). The irregular oscillatory rhythm often appears black on the HRTACH shown in Figure 1 as result of the frequency of the variation of the heart rate in time. This rhythm also causes changes in the appearance of spectral plots, manifested as additional power in the various power bands. A marked blurring of the peak in the high frequency power band during sleep also suggests the presence of ESR.

Standard time domain HRV variables that compare relative differences in duration in two NN intervals do not adequately identify periods of ESR. Large and small NN interval ratios observed in ESR are not necessarily different from those observed in RSA. In an attempt to not include high values of normal HRV while detecting ESR, the proposed method was developed to utilize 4 successive normal beats or 3 NN intervals.

The ultimate goal of this preliminary work is to develop an algorithm that can automatically detect and quantify all episodes of ESR. With this, ESR may be excluded from RR-interval files in order to determine if ESR confounds the relationship between HRV and cardiac health, and if the presence or degree of ESR predicts poor cardiac health.

2. Subjects

Six randomly selected Holter recordings were obtained from our database of Holter recordings of older adults. There were three males and three females between 66 and 77 years old. Three were healthy, and three had heart disease.

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3. Methods

3.1. Holter recording tape analysis

Holter recordings were processed by research Holter technicians at the Washington University School of Medicine Heart Rate Variability Laboratory, using a Marquette MARS 8000 Holter analyzer (GE-Marquette, Milwaukee, WI). The two-channel analog signals were digitized at 128 Hz. All Holter analyses were reviewed in detail by one of us (PKS). After editing, the labeled-QRS binary file was transferred to a Sun workstation (Sun Microsystems, Palto Alto, CA) for conversion to a RR-interval text file containing a header followed by a list of beat labels and associated RR-intervals with units of milliseconds.

3.2. Heart rate tachogram analysis

The HRTACH has one hour of data plotted in 6 ten-minute segments in landscape mode on 8.5 inches by 11 inches plain letter paper. The start time of each segment is indicated in the left margin. Segments are arranged in descending order from top to bottom. The mean heart rate of each ten-minute tachogram is also plotted on the HRTACH. Tic marks are placed every 0.5 minutes on the top and bottom borders of the page. Figure 1 provides an example of a HRTACH with a considerable amount of ESR.

ESR is measured visually with the assistance of the scale provided on the upper and lower borders of the tachogram. Disjoint intervals of beat-to-beat rapid, irregular oscillatory changes in heart rate indicate ESR. The error in a measurement is about 5%.

3.3. Erratic sinus rhythm detection algorithm

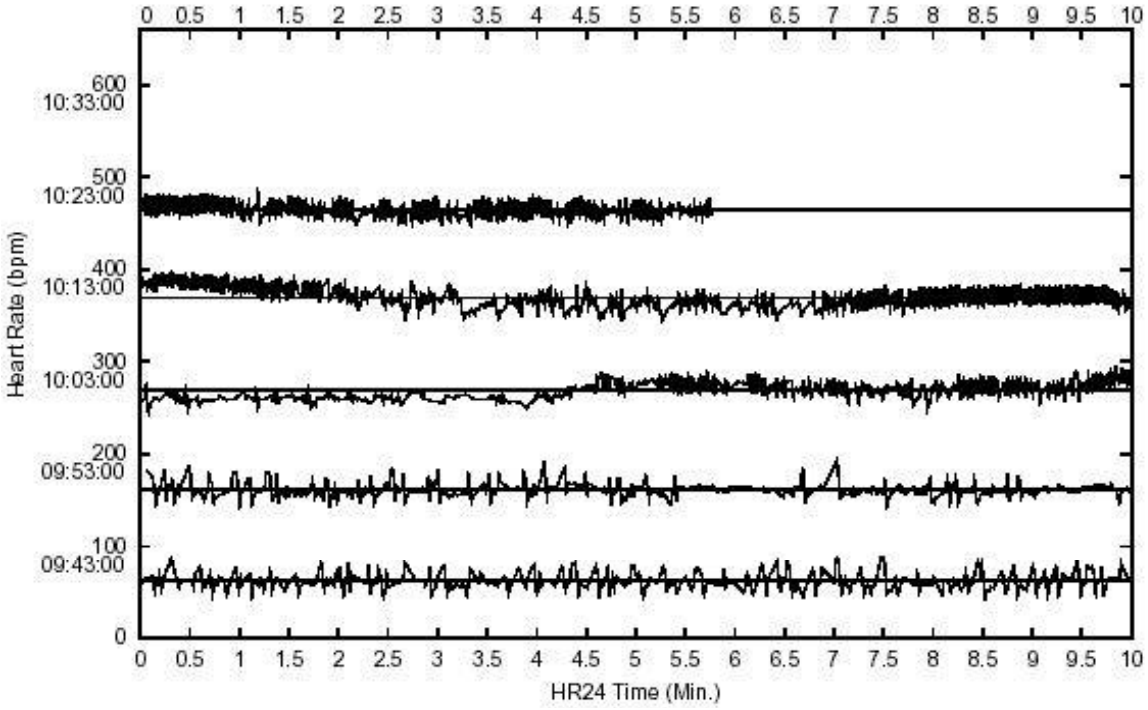

Figure 1. A Heart rate tachogram with ESR. Heart rate in beats per minute is plotted against time in minutes during the last hour of a 24-hour Holter recording. Since the tape ends at 10:29 A.M., some data are missing. Several uninterrupted periods of ESR can be observed from 10:08 A.M. to 10:29 A.M.

This algorithm performs the test for ESR in the RR-interval file beat-by-beat in sequence. The beat labels and RR intervals are rewritten as binary files so that the C program may access both randomly. The previous beat, the current beat, and the next two beats must all be normal before the tests on NN interval ratios can be applied. If a triplet of NN intervals is erratic, the program outputs the beat number, NN interval duration, and time for each member of the triplet. The information for each NN interval is listed in one row so that a unique numerical sort of the final output file allows for an easy determination of the time spent in ESR for each ten-minute segment. If a triplet of NN intervals is not erratic, the program skips to the next beat and applies the ESR test again.

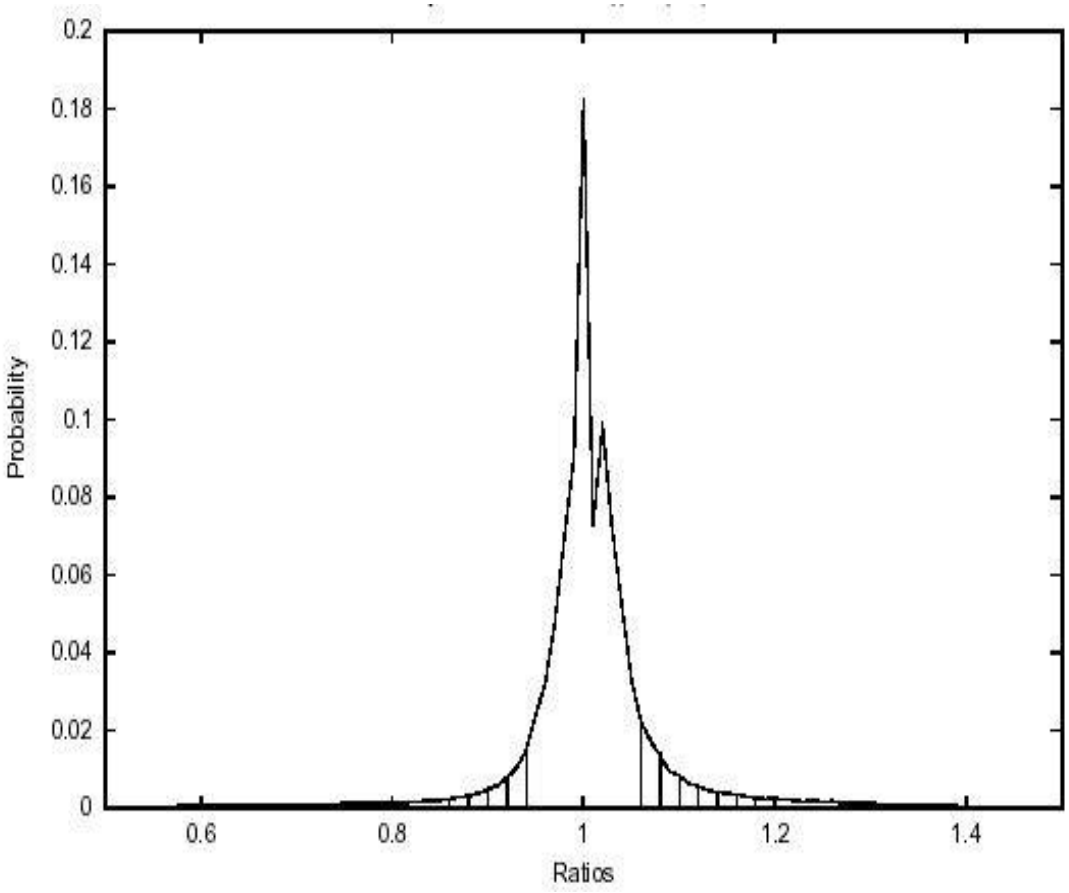

Figure 2. The probability distribution of NN-interval ratios for the RR-interval file whose last hourly tachogram is illustrated in Figure 1. The left and right areas of the distribution marked with vertical lines separated by 2 bin widths indicate low and high NN-interval ratios, respectively, for this subject. The two innermost vertical lines under the dis tribution curve specify the location of the cut points.

The ESR algorithm must not detect sleep apnea, normal heart rate arousals during sleep or activity, and RSA. Hence the algorithm excludes certain triplets of NN intervals. If, within the next 6 NN intervals in the RR-interval file, a monotonically increasing or decreasing run of 3 or more NN intervals is detected, the algorithm skips to the next beat. In the case of sleep apnea, this portion of the algorithm is apparently successful. In an ECG recording of about 4 hours of continuous sleep apnea, the maximum time spent in ESR in a ten-minute segment was calculated to be less than 0.24 minutes. The average time spent in ESR per ten-minute segment was about 0.1 minutes. Therefore, this portion of the algorithm helps to exclude intervals of the HRTACH where the heart rate is changing rapidly but is not ESR. If the test over 6 NN intervals fails because there are no such runs or not all 7 beats are normal, the NN interval ratio test over 3 NN intervals proceeds as usual.

The test for ESR involves the determination of cut points from the probability distribution of NN interval ratios, determined separately for each subject. All of the NN interval ratios are placed in 500 bins of width 0.01 from 0.2 to 5.2 and normalized by dividing the frequency of occurrence in each bin by the total number of NN-interval ratios found in the RR-interval file. The first bins that contain more than 2.9% of the data when approached from the left and right of the distribution define the left and right NN-interval-ratio cut points, respectively. An example is provided in Figure 2.

With lower (CL) and upper cut points (CU), and 3 NN intervals formed by the four normal beats N_1, N_2, N_3, and N_4, the test for ESR is: ($N_1N_2/N_2N_3 < CL$ or $N_1N_2/N_2N_3 > CU$) and ($N_2N_3/N_3N_4 < CL$ or $N_2N_3/N_3N_4 > CU$). If this test is satisfied, then the triplet is erratic. The total time spent in ESR in a ten-minute segment is $N_1N_2 + N_2N_3 + N_3N_4$ for each erratic triplet of NN intervals where each NN interval is counted only once.

4. Results

The visual and numerical determinations of ESR were carried out for 858 10-minute segments in 6 RR-interval

files generated from 24-hour Holter recordings. Calculated results were rounded off to the nearest tenth of a minute.

A qualitative test of the algorithm was made by assuming that any value of time spent in ESR greater than 0.1 minutes provided by both measurement and calculation was a positive test. In this case, with 552 positive tests, the positive predictive value of the test was 0.83 and the negative predictive value of the test was 0.87.

The absolute value of the difference between the measured and calculated values was less than 0.5 minutes for 67% of the 10-min segments and less than one minute for 81% of the segments. Hence, the algorithm provides a good indication of the presence of ESR.

In Figure 1, the calculated values of the time spent in ESR for the 10-minute segments beginning at 09:43, 09:53, 10:03, 10:13, and 10:23 are 1.0, 1.3, 4.1, 6.1, and 4.3 minutes, respectively. Note that the fairly smooth and rapid heart rate changes in the segments at 09:43 and 09:53 are not labeled as ESR by the algorithm. The algorithm underestimates the amount of time spent in ESR by about 25% in the segments at 10:13 and 10:23.

By changing the label of the 3rd normal beat to a unclassified beat label in the RR-interval file for each recognized erratic triplet of NN intervals while running the ESR program, one may remove most of the ESR detected by the method. Repeating this process on the modified RR-interval file removes all detectable ESR. Hourly plots of 2-minute averaged power spectral density (PSD) of the modified RR-interval files have better defined peaks in the high frequency band at night during sleep, and the abnormal power distribution is markedly reduced. This result is due primarily to the exclusion of all 2-minute PSD's with less than 80% NN intervals.

5. Discussion

Results indicate that this method can qualitatively detect the presence of rapidly fluctuating ESR in ten-minute segments very well. The calculation is not dependent on the segment length though. Quantitatively, the algorithm gives reasonable agreement to within one minute, but requires further development before it is implemented in this manner. A limitation is that the presence of high- and low-amplitude ESR in the same RR-interval file may prevent the detection of low-amplitude ESR.

The detection and exclusion of time intervals containing ESR using this method may improve the ability of HRV to identify subjects at risk for mortality. However, an accurate exclusion of epochs of ESR is not yet possible using this method. Further research is required in order to accurately quantify ESR so that all epochs of ESR and no epochs of normal high standard HRV are excluded.

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