A Novel Heart Rate Variability Index for Evaluation of Left Ventricular Function Using Five-Minute Electrocardiogram

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Abstract

In this paper, we introduce a new index based on the frequency-domain analysis of heart rate variability, or more precisely, the power spectrum of the instant heart rate signal. This index, called VHFI, is defined as the very high frequency component of the power spectrum normalized to represent its relative value in proportion to the total power minus the very low frequency component. We tested VHFI on patients with known reduced left ventricular function and found that this index has the potential to be a useful tool for quick evaluation of left ventricular function.

1.   Introduction

The autonomic nervous system (ANS) is the part of the peripheral nervous system that acts as a control system, maintaining homeostasis in the body. One of these maintenance activities which are mainly performed without conscious control or sensation is heart rate. Therefore, it is possible to analyze heart rate variability (HRV) for quantitative assessment of ANS. Estimation of HRV is based on the analysis of consecutive sinus rhythm R-R intervals. The clinical relevance of HRV has been known since 1965 [1] but its importance became appreciated in the late 1980s, when it was confirmed that HRV was a strong predictor of mortality after an acute myocardial infarction [2]. It is now well known that HRV has the potential to provide valuable information about physiological and pathological conditions.

HRV analysis can be done on both short-term (2 to 5 minutes) and long-term (24 to 48 hours) ECG recordings. Several measures of HRV have been proposed which can basically be divided into time-domain and frequency-domains. There are also methods to analyze dynamics of the heart rate with respect to respiratory phase which are referred to as phase-domain approaches. Because of both mathematical and physiological relationship, many time-, frequency-, and phase- domains are strongly correlated.

Nevertheless, usually frequency-domain approaches are used to analyze short-term ECG recordings. One reason is that more experience and theoretical knowledge exist on physiological interpretation of the frequency-domain analysis of stationary short-term recordings [3]. Another reason is that commonly used time-domain measures such as SDNN (the standard deviation of N-N intervals), pNNx (the fraction of N-N intervals that differ by more than x ms from the previous N-N interval), and RMSSD (the root-mean-square of successive differences of N-N intervals) offer only a limited view of HRV. They do not capture any information about the order of the intervals, except for pair-wise coupling. Such information can be obtained by using frequency-domain methods.

In frequency-domain analysis of HRV, one usually estimates the power spectral density (PSD) of the instantaneous heart rate (IHR) signal using proper mathematical algorithms. PSD basically provides information of how power distributes as a function of frequency.

In section 2, we introduce a new index based on frequency-domain analysis of HRV for quick evaluation of left ventricular function by analysing five-minute ECG recordings. In section 3, we show the results of testing our method on patients with reduced left ventricular function. We discuss the results in section 4 and derive the conclusion in section 5.

2.   Methods

We collected five-minute 12-lead ECGs at 500 samples-per-second (sps) using a Philips PageWriter Touch electrocardiograph (which has five-minute ECG storage) and annotated them using Philips Holter analysis program (2010W). Using the 2010W algorithm we distinguished normal sinus beats from ectopic beats and erroneous measurements, and extracted the N-N intervals.

We then calculated the reciprocal of each N-N interval in minute to derive the IHR signal for each record in beats per minute (bpm). Since IHR signal obtained this

way is sampled at non-uniform intervals, we had to either resample it at uniform intervals and replace the unusable samples or use methods which estimate PSD directly from irregularly sampled time series. One such method is the Lomb algorithm [4] which involves least squares fitting the time domain data points to sine/cosine series. We note that in studying HRV, the matter of interest is actually the non-uniformity of IHR. This plus the fact that the Lomb algorithm avoids all the complications and pitfalls of resampling and replacement of outliers, and introduces no drawbacks of its own [5], convinced us to choose the Lomb algorithm to estimate the PSD.

The main spectral components which have been extensively studied for short term ECG analysis are very low frequency (VLF), low frequency (LF), and high frequency (HF). It is known that VLF assessed from short-term recordings ($\leq$ 5 minutes) is a dubious measure and should be avoided when the PSD of short-terms ECGs is interpreted [3]. This is basically because the major constituent of VLF is the non-harmonic component which does not have coherent properties and is affected by algorithms of baseline or trend removal. The measurement of VLF, LF, and HF power components could be made either in absolute value of power (milliseconds squared) or in normalized units. The normalized values for LF and HF represent the relative value of each power component in proportion to the total power minus the VLF component. Nevertheless, none of these common PSD components was useful for our purpose and hence, we defined and used the Very High Frequency (VHF) component. Based on VHF, we defined an index VHFI as

$$VHFI = \frac{VHF}{TP - VLF} \times 100, \qquad \text{(Equation 1)}$$

where TP is the total power of IHR signal for the five-minute ECG record. In section 3, we show that VHFI has the potential to be a useful tool for quick evaluation of left ventricular function.

Table 1 shows the frequency domain measures we selected for HRV. Figure 1 and Figure 2 show IHR and PSD for a 5-minute ECG record, respectively.

Table 1. Selected frequency domain measures for HRV

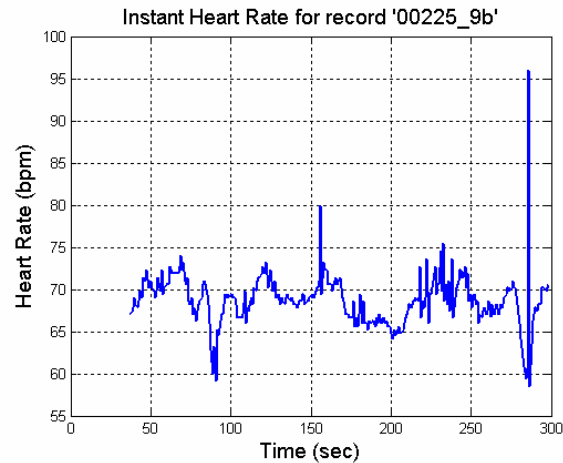| Variable	Description	Frequency Range
5-min Total Power (TP)	The variance of N-N intervals over the temporal segment	≤ 0.5 Hz
VLF	Power in VLF range	≤ 0.05 Hz
LF	Power in LF range	0.05-0.15 Hz
HF	Power in HF range	0.15-0.4 Hz
VHF	Power in VHF range	0.4-0.5 Hz

Figure 1. IHR signal for a 5-minute ECG record, calculated as the reciprocal of each N-N interval.
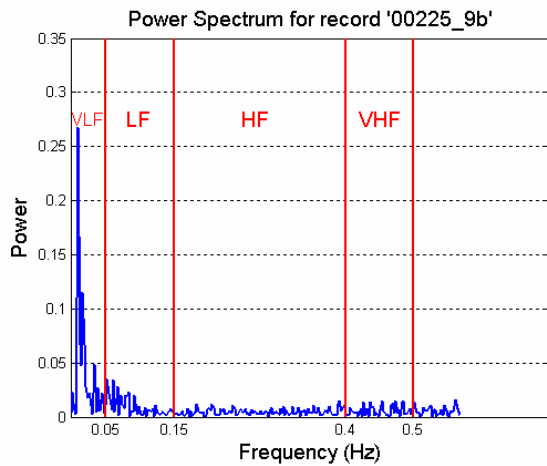

Figure 2. PSD for IHR signal of the 5-minute ECG record shown in Figure 1, calculated by the Lomb algorithm.

3. Results

Patients (n = 168) who were admitted to Ruijin Hospital due to suspicious coronary heart disease (CHD) were randomly selected for the study. The study group (n = 67) consisted of post myocardial infarction (post-MI) or dilated cardiopathy patients with decreased left ventricular systolic function. Their left ventricular ejection fraction (LVEF) was between 21 to 49.5 percent with the average of 40.5±7.1%. Patients selected to the control group (n = 101) had normal heart function by echocardiogram; their LVEF varied between 55 and 76 percent with the average of 68.0±4.2%. They also were without any severe coronary artery stenosis (<30%) by coronary angiography. Hypertension and diabetes mellitus were not excluded.

Five-minute 12-lead ECGs at 500 sps were recorded using a Philips PageWriter Touch electrocardiograph, and

annotated using the Philips 2010W Holter analysis program. We then estimated the heart rate PSD using the Lomb algorithm, and calculated VHFI as presented in Equation 1. To make the data format recorded by PageWriter Touch suitable for the 2010W algorithm, we chose the three ECG channels I, aVF, and V2 from the 12-lead record and down-sampled them to 200 sps.

VHFI is a continuous index and its limits can be set at any level depending on the population. We defined the positive test as VHFI $\geq$ 11 and negative test as VHFI < 8. Note that the positive test here means that the patient should belong to the study group while the negative test means that the patient should belong to the control group. Consequently, false positive is defined as a positive test for a patient in the control group and false negative is defined as a negative test for a patient in the study group. For those patients whose VHFI is greater than or equal 8 but less than 11, the test is considered inconclusive. Table 2 summarizes the performance of using the test measure VHFI.

Table 2. Performance of using VHFI to distinguish between the control and study groups

VHFI	Control Group	Study Group
< 8	76	16
$\geq$ 8 & < 11	13	7
$\geq$ 11	12	44

Unclassified	11.9%
Sensitivity	73.3%
Specificity	86.4%

4. Discussion

One reason for low specificity could be inclusion of hypertension and diabetes mellitus patients in the control group which may result in false positives. One reason for low sensitivity could be including the patients with frequent premature ventricular contraction (PVC) beats in the study group. For these patients there are very few normal sinus beats in the ECG record. Therefore, the IHR signal is sparse, and hence, that would not be possible to accurately estimate its PSD with the Lomb algorithm or any other spectrum estimation algorithm for that matter. Figure 3 shows an ECG record with many PVC beats in it. For this record, there are only 37 N-N intervals to derive the IHR signal from in the whole five minutes of recording. The IHR signal is shown in Figure 4. This small number of points is hardly enough to estimate an accurate PSD. Therefore, the PSD shown in Figure 5 is not reliable and should not be used for any kind of interpretation.

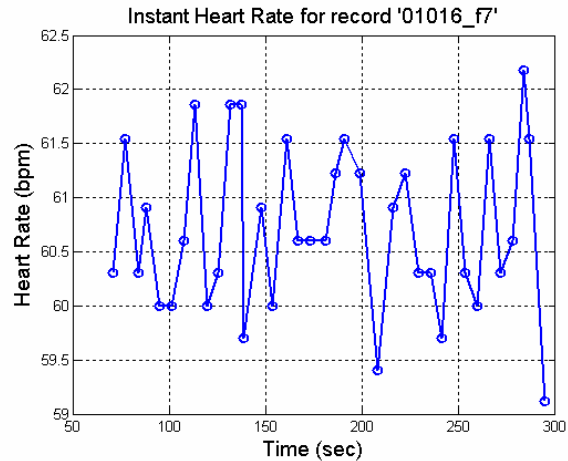Figure 3. ECG record with many PVC beats.

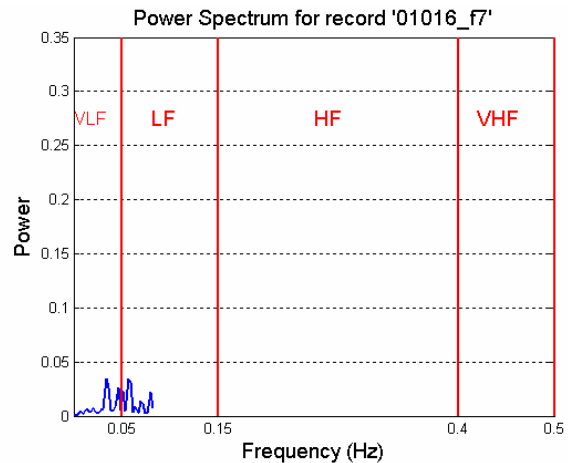Figure 4. IHR signal for the record shown in Figure 3. It has only 37 points.

Figure 5. PSD for the IHR signal shown in Figure 4, calculated by the Lomb algorithm. Because of the very small number of available points, this PSD is not accurate and should not be used for any kind of interpretation.

Another type of arrhythmia for which VHFI should not be used (and we excluded them from study group) is atrial fibrillation (Afib). This is because if the whole ECG record (which is only 5 minutes long) is Afib, heart rhythm is irregularly irregular, and hence, the PSD of IHR does not contain any useful information about the left ventricular function. Figure 6 shows the ECG record for a 78 year old male with hypertension, diabetes mellitus, and Afib. Figure 7 and Figure 8 show the IHR and PSD for this record, respectively. One observes that for this record the IHR signal is very erratic and its power is distributed almost uniformly across the whole frequency range. In this case, VHFI is not a reliable measure and should not be used to make a decision about the left ventricular function.

Figure 6. ECG record for a 78 year old male with hypertension, diabetes mellitus, and Afib.
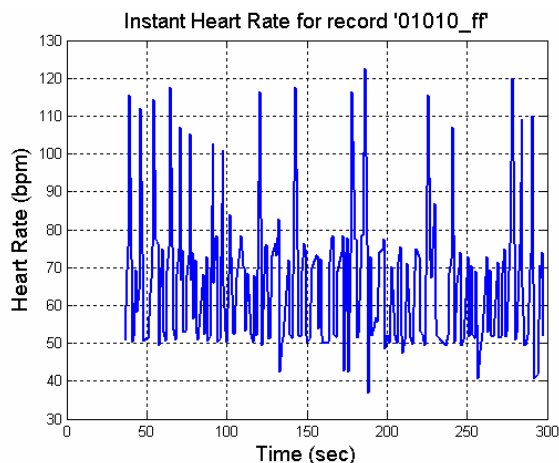

Figure 7. IHR signal for the record shown in Figure 6. Since the rhythm is irregular due to Afib, the IHR signal has a very erratic shape.
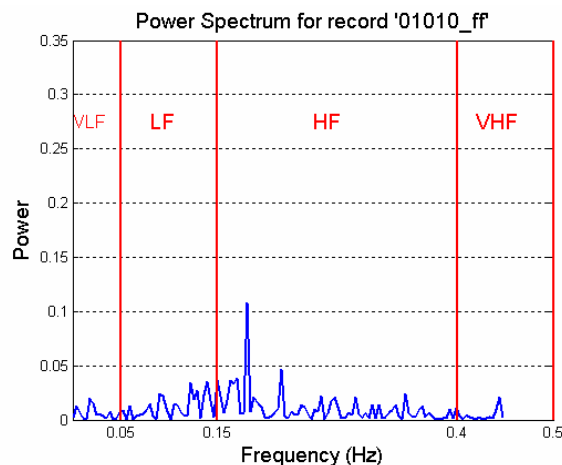

Figure 8. PSD for the IHR signal shown in Figure 7, calculated by the Lomb algorithm.

5.   Conclusion

Based on the results shown in Table 2 we believe the new index VHFI has potential for fast assessment of severe left ventricular dysfunction. Calculating this index needs only five minutes of ECG which can be recorded easily in virtually any environment.

We plan to further enhance the algorithm efficiency by combining VHFI with other ECG analysis indices.

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