Comparison of Heart Rate Variability Measured by ECG in Different Signal Lengths

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Abstract

The measurement of heart rate variability, HRV, provides a noninvasive measurement of the autonomic nervous system (ANS) activity. HRV can be measured with the variation of RR intervals exhibited in a sequence of ECG sample. For a short-term HRV, the measuring time is usually five minutes. However, there are still many expectations of shortening the measuring time to evaluate the ANS. In this paper we analyzed and compared three minute HRV measurement to five minute standard short-term HRV. In order to evaluate the measurement results based on three minute and five minute HRVs, four major measurements were calculated in this study. The first is the standard deviation of normal-beat to normal-beat intervals (SDNN). The second is the square root of the mean squared differences of successive difference normal-beat to normal-beat intervals (RMSSD). The third is the proportion of interval differences of successive normal-beat to normal-beat intervals greater than 50 ms (pNN50). The fourth is the ratio of low frequency energy to high frequency energy (LF/HF) based on Fourier analysis method. Results show that the HRV presented by both SDNN and LF/HF using the three-minute measuring data differs significantly from that using the five-minute measuring data. In addition, the characteristics of HRV under different heart rate conditions shows that faster heart rate will come out smaller HRV. In conclusion, the HRV analyzed based on three minutes measuring data would not be equaled to that of five minutes measuring data. At the same time, the conditions of heart rate need to be considered when heart rate variability was analyzed..

Keywords: Short-term HRV, Activity of autonomic Nervous system, ECG.

Introduction

The ANS comprises two basic components: the sympathetic and parasympathetic. The sympathetic influences heart rate (HR) and can be mediated by releasing s epinephrine and norepinephrine. The parasympathetic influences on heart rate, but it is mediated via the acetylcholine release from vagus nerve. The heart rate may be increased by acting sympathetic activity or decreased by acting parasympathetic activity. Changes in the balance of sympathetic/parasympathetic control of heart rate will result in measurable changes in heart rate variability, HRV. The analysis of HRV is one of the useful non-invasive tools for measuring the status of autonomic nervous system. To measure the HRV information can be obtained using the variations of heart-beat to heart-beat intervals that can be measured by any cardiac related signal such as electrocardiogram (ECG). [1]

HRV analysis has been applied widely to many clinical studies including sudden death, cardiovascular diseases, hypertension, and diabetes [2-5]. The clinical importance of HRV has been known since the publication of studies established that HRV was an independent and strong predictor of mortality after myocardial infarction [6-7]. In addition, low heart rate variability has been implicated as a risk factor for sudden death. Moreover, low parasympathetic active have an increased risk for sudden death [4]. HRV measures are usually divided into short-term and long-term recording. For short-term HRV measures, the measuring time length is five minutes which has been found valid and with clinical significance. However, in the existing studies, there is no information to show the differences of short-term HRV based on different measuring time. Actually, It is highly possible to shorten the measuring time to provide the information in understanding of autonomic nervous system status.

The purpose of this paper is to evaluate the changes of the HRV measured using three-minute measuring data to show whether that would differ significantly from the result measured by the five-minute measuring data which is regularly used for the short-term HRV analysis. In addition, features of HRV under different heart rate conditions will be analyzed and discussed in this study.

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Materials and Methods

Materials

In this paper the Normal Sinus Rhythm RR Interval Database (nsr2db) is employed [8]. The database includes annotation files of 54 long-term ECG recording of subjects in normal sinus rhythm (30 man, aged 28.5 to 76, and 24 women, aged 58 to 73). The length of each ECG recording is around 24 hours. The original ECG recordings were digitalized as 128 samples per second. Beat annotations were obtained by automatic analysis with manual review and correction. Annotations are labels that point to specific locations within a recording and describe events at those locations. The detail description about annotations can be found at [9].

Methods

HRV can be analyzed by using two major techniques. One is statistically analyzing a sequence of RR intervals of ECG in time domain. Another is analyzing the spectrum of the same RR intervals of ECG data in frequency domain.

Time domain measures of HRV based on the data of the intervals between adjacent normal QRS complex have two different approaches. One is derived from direct measurements of normal beat to normal beat, NN, intervals, which consists primarily of SDNN, the standard deviation of NN intervals. Another is derived from the difference between NN intervals and most commonly used measures include NN50, pNN50 and RMSSD. The NN50 represents the number of adjacent NN intervals pairs is greater than 50 milliseconds. The pNN50 represents the proportion derived by dividing NN50 by the total number of NN intervals. The RMSSD represents the square root of the mean squared differences of successive difference NN intervals. Some other time domain measurements of HRV can be referred to [10].

There are many different spectral methods that have been used in the analysis of the HRV [11]. The methods for computing the power spectral density (PSD) may be approached generally either by nonparametric technology (e.g. fast Fourier transform, FFT) or by parametric technology (e.g. autoregressive model approach, AR). In this paper the nonparametric method is used. The regions of each power spectrum for short-term recordings of 2 to 5 minutes is commonly divided into three frequency bands [12-13]: very low frequency (VLF) band, 0.0033-0.04 Hz, low frequency (LF) band, 0.04-0.15 Hz, and high frequency (HF) band, 0.15-0.4Hz. The ratio of LF to HF (LF/HF) was commonly used in order to represent the controlled and balanced behavior of the two branches of the ANS. For short-term recording, VLF is dubious measures and was not considered in this study.

To measure HRV based on measuring data length in both three minutes and five minutes, each ECG recording was divided into non-overlapped segments for each data of five minutes length. Each five-minute segment was divided into three sub-segments in the length of three minutes. Figure 1 illustrated the three sub-segments were from 0 to 3 minutes, 1 to 4 minutes, and 2 to 5 minutes respectively. All the HRVs were calculated by SDNN, RMSSD, pNN50, and LF/HF for comparing the changes of different measuring time lengths.

Table 1. Total counts of heart rate for all data segments.

Heart Rate (bpm)	Counts	Normalized Counts
40 to 60	1787	0.12
60 to 80	7067	0.47
80 to 100	4978	0.33
100 to 120	972	0.07
120 to 140	111	0.01
Total	14915	1.00

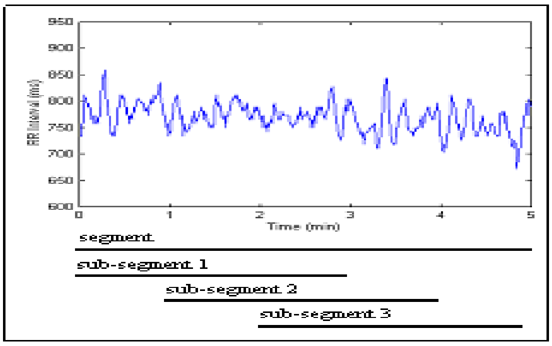

Figure 1. Five minutes data segment (RR intervals) divided into three sub-segments. The three sub-segments were from 0 to 3, 1 to 4 and 2 to 5 minutes respectively.

The paper also compares the HRV measured in three-minute data length with that in five minutes under different heart rate conditions. Based on different heart rate conditions, all segmented data could be divided into five different groups (heart rate range from 40 to 140 bpm). The grouped data are shown in Table 1. The mean and standard deviation of HRV measured by the data lengths of three minutes and five minutes were calculated, and the results were compared by the SDNN, RMSSD, pNN50, and LF/HF, four parameters. The study also employed the t-test to analyze the differences of HRVs obtained by the measuring data lengths of three and five minutes.

Results

Standard Deviation of NN intervals: SDNN

The means and standard deviations of SDNN measurement for segments and sub-segments were shown in Figure 2. The results pointed out the faster the heart rate is the smaller the SDNN measurement will be. The mean of SDNN measurement for segments is greater than three sub-segments under the same heart rate condition.

To compare SDNN measurements, the means and standard deviations of difference between segments and sub-segments were shown in Table 2. The p value of t-test is smaller than critical value 0.05 for each pair of segments and sub-segments. This indicated that SDNN measurements in three minutes differ significantly from that in five minutes.

Root Mean Square of successive difference: RMSSD

The analyzing results of RMSSD measurements were shown in Figure 3 and Table 3. The means of RMSSD

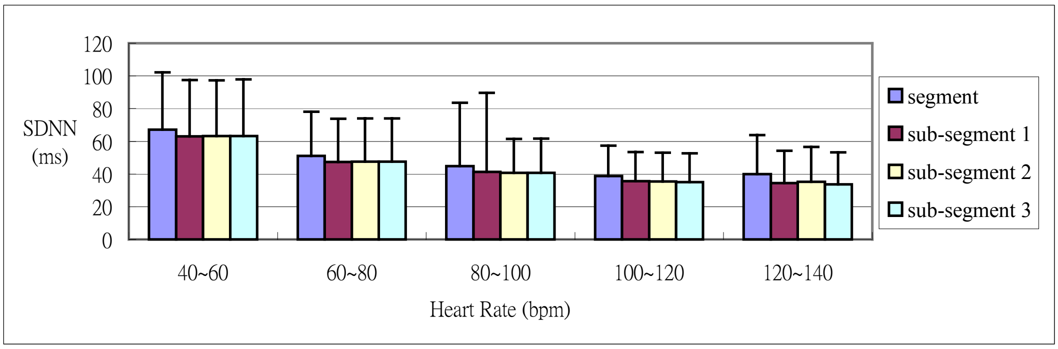

Figure 2. Means and Standard Deviations of SDNN measurement of segmentation and sub-segmentation

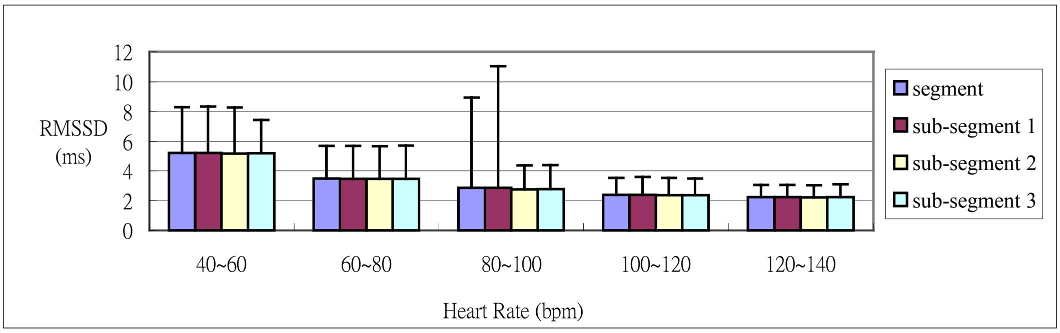

Figure 3. Means and Standard Deviations of RMSSD measurement of segmentation and sub-segmentation

Table 2. Mean and Standard Deviation of difference of SDNN between segment and sub-segments

Heart Rate (bpm)	SDNN (ms)		
	sub-segment 1	sub-segment 2	sub-segment 3
40 to60	4.15±18.66 *	4.01±15.37 *	3.95±16.55 *
60 to 80	3.72±13.22 *	3.56±10.55 *	3.51±12.32 *
80 to 100	3.52±16.07 *	4.12±33.08 *	4.04±33.62 *
100 to 120	3.16±8.81 *	3.56±7.72 *	3.76±9.54 *
120 to 140	5.31±13.75 *	4.61±7.90 *	6.13±12.74 *

*: p<0.05

Table 3. Mean and Standard Deviation of difference of RMSSD between segment and sub-segments

Heart Rate (bpm)	RMSSD (ms)		
	sub-segment 1	sub-segment 2	sub-segment 3
40 to60	0.00±3.02	-0.05±2.57	-0.04±3.02
60 to 80	0.01±2.06	-0.02±1.69	-0.04±2.08
80 to 100	0.00±1.70	-0.02±1.42	-0.02±1.70
100 to 120	-0.08±1.46	0.02±1.09	0.11±1.51
120 to 140	-0.05±1.16	-0.03±0.81	0.04±1.02

*: p < 0.05

measurement decreased when heart rate increased which could be found both at three minutes and five minutes measured. In addition, the means of RMSSD measurements of segments are approximated to three sub-segments under the same heart rate condition.

With the p-value greater than critical p value 0.05, the results pointed out that the RMSSD measurement had no significant differences in three minutes and five minutes.

Proportion of NN50: pNN50

For pNN50 measurements, the analyses results were similar to the results of RMSSD and were presented in Figure 4 and Table 4. The pNN50 measured in three minutes has no significant difference comparing to that in five minutes. This evident showed that the parameter of pNN50 measured in three minutes could be applied to as an estimator of that in five minutes. The result in figure 4 also shows that the higher heart rate data will have lower the means of pNN50.

Ratio of LF to HF: LF/HF

The spectral analysis results of the LF/HF of HRV show in Table 5 and Figure 5. The analyzing results, p value was smaller than critical value 0.05, pointed out that the measurements in three minutes differ significantly from that in five minutes. The results of the LF/HF measurements are also proportionally increased with the increased heart rate. The results also implied that the spectrum contents more LF components in the low frequency band than HF components in the high frequency band when heart rate increased.

Discussion

For SDNN measurement, the analyses results indicated that the HRV measured from the measuring data in three minutes differs significantly from that using the measuring in five minutes. One of the major reasons is to keep a stable heart rate for lasting five minutes presenting more variation than that of three minutes. In other words, sometimes heart rate varies conspicuously in five minutes as shown in Figure 6. The phenomenon will cause RR interval variation increasing,

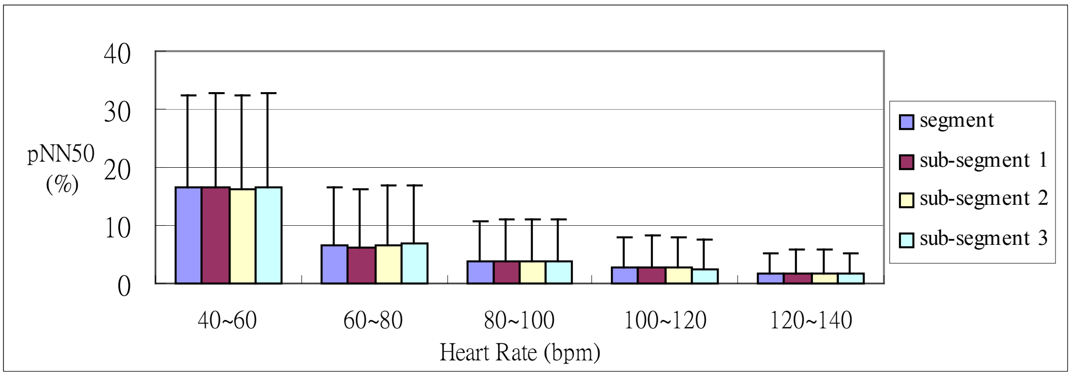

Figure 4. Means and Standard Deviations of pNN50 measurement of segmentation and sub-segmentation

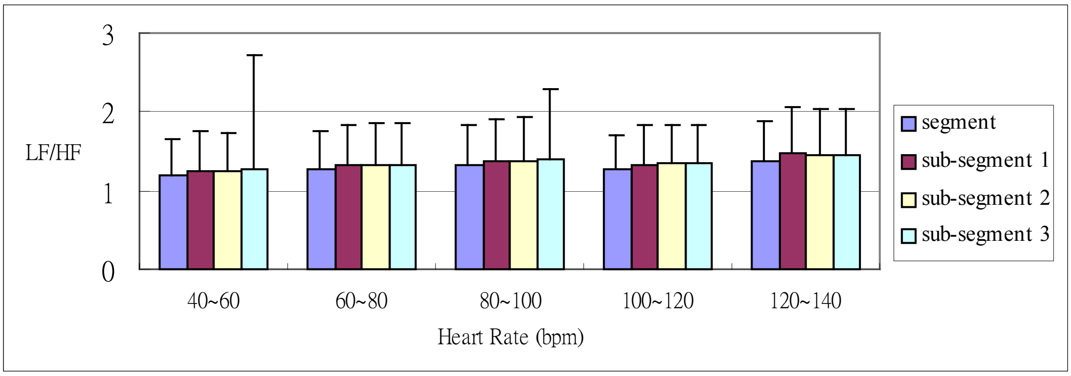

Figure 5. Means and Standard Deviations of LF/HF measurement of segmentation and sub-segmentation

Table 4. Mean and Standard Deviation of difference of pNN50 between segment and sub-segments

Heart Rate (bpm)	pNN50 (%) sub-segment 1	sub-segment 2	sub-segment 3
40 to 60	0.00±3.02	-0.05±2.57	-0.04±3.02
60 to 80	0.01±2.06	-0.02±1.69	-0.04±2.08
80 to 100	0.00±1.70	-0.02±1.42	-0.02±1.70
100 to 120	-0.08±1.46	0.02±1.09	0.11±1.51
120 to 140	-0.05±1.16	-0.03±0.81	0.04±1.02

*: p < 0.05

Table 5. Mean and Standard Deviation of difference of LF/HF between segment and sub-segments

Heart Rate (bpm)	LF/HF sub-segment 1	sub-segment 2	sub-segment 3
40 to 60	-0.05±0.21 *	-0.05±0.24 *	-0.10±1.36 *
60 to 80	-0.05±0.24 *	-0.06±0.25 *	-0.06±0.23 *
80 to 100	-0.06±0.53 *	-0.05±0.27 *	-0.06±0.74 *
100 to 120	-0.05±0.49 *	-0.06±0.23 *	-0.06±0.24 *
120 to 140	-0.08±0.58	-0.07±0.24	-0.06±0.31

*: p < 0.05

consequently results in greater SDNN measurement in five minutes than that in three minutes. In addition, the SDNN measurement is mathematically equal to total power of HRV, consequently the results of spectral analyses will be affected by this phenomenon.

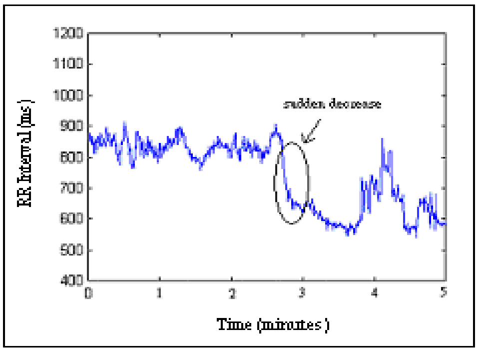

Figure 6. RR intervals of five minutes. This sample shown the RR intervals were not stable and varied conspicuously.

The analyzing results show three-minute RMSSD and pNN50 measurements are consistent with estimations of five minutes. The RMSSD and pNN50 were highly correlated to high frequency energy (HF) of HRV [10]. Thus, we conjecture that HF measurement has no significant difference between three minutes and five minutes.

For the analysis of HRV in frequency domain, the results of LF/HF measurements were correlated to SDNN. The SDNN measurement in three minutes differed from that in five minutes. The results implied that the total power distributions would be different between three minutes and five minutes. Therefore, the phenomenon that heart rate was not stable may affect the analysis results of LF/HF and even cause the significant difference between three and five-minute measuring.

The features of HRV measurements under different heart rate conditions were not the same. With the heart rate increased, the degree of heart rate variation decreased. The measurements of SDNN, RMSSD and pNN50 help to account for the result. Therefore, the heart rate needs to be considered when heart rate variability was analyzed.

Conclusion

In this paper we analyzed four measurements of HRV in three minutes and five minutes. The results indicated that the SDNN measurements differ significantly in three minutes and five minutes. It was shown that SDNN measurement in three minutes would not be equal to that of estimations in five minutes. The paper also confirmed that the characteristics of HRV measures under different heart rate conditions. The faster the heart rate is, the smaller the HRV measurements will be. The evidence could be found in analyzing the HRV based on either three or five-minute data.

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