Accuracy of Ultra-Short Heart Rate Variability Measures

Tran Thong[1], Kehai Li[1], James McNames[2], Mateo Aboy[2], Brahm Goldstein[3]
[1]Department of Biomedical Engineering, OGI School of Science & Engineering, Oregon Health & Science University, Beaverton, OR, USA
[2]Biomedical Signal Processing Laboratory, Department of Electrical & Computer Engineering, Portland State University, Portland, OR, USA
[3]Department of Pediatrics, Oregon Health & Science University, Portland, OR, USA

Abstract—**Heart rate variability (HRV) measures have been used to assess autonomic cardiac regulation. The standard lengths used in HRV analyses are 5 minutes and 24 hours. In this paper we investigated the accuracy of three HRV measures for ultra-short record length, 10 seconds, which is the length of standard electrocardiograms. The measures chosen were: Standard Deviation Normal– Normal (SDNN), Root Mean Square of Successive Differences (RMSSD), frequency of the peak of the high-frequency (HF) spectra derived using a non-parametric spectrum method. Our analyses indicated that the RMSSD(10)s would be consistent estimates of the 5 minute RMSSD(300)s. The SDNN(10)s were found not to be accurate in our analyses. The HF peak, while promising, would require further studies.**

Keywords—**Heart rate variability (HRV), electrocardiogram (ECG)**

I. Introduction

Heart rate variability (HRV) has been used to assess the level of autonomic cardiac regulation[1]. The recommended lengths used in HRV analyses are 5 minutes and 24 hours. The longer records are obtained from Holter monitors that are worn by subjects for a period of one to two days. 5 minutes is a standard for short-term HRV analysis.

The standard 12-lead electrocardiograms (ECG) that are routinely collected in most cardiology laboratories are only 10 second long, as illustrated in Fig. 1 [2]. A large number of these 10 s ECG strips are routinely collected in large demographic studies over a period of time, such as in the Dutch Zutphen [3] study and the on-going Women Health Initiative study [4]. Using the 10 s ECGs collected in the Zutphen study, a low value of Standard Deviation of all NN intervals (SDNN) was predictive of mortality, suggesting that HRV is an indicator of compromised health [4].

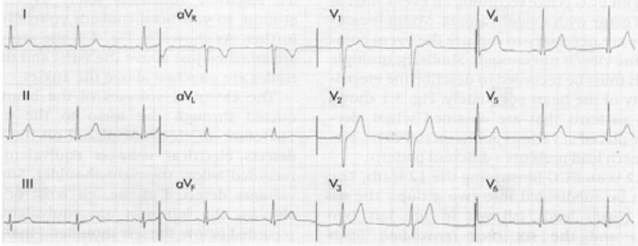

Fig.1. 10 second strip of 12 lead electrocardiogram.

Our goal in this paper is to evaluate the accuracy of HRV measures that may be applicable to ultra-short 10 s records, in comparison to the corresponding measures at 300 s. This could then be used in multi-year population studies in lieu of the longer records, which are not available.

II. HRV Measures

A list of the standard time domain HRV measures is presented in Table I [1]. Since we have only from 8 (50 beats per minute, bpm) to 15 (90 bpm) normal to normal (NN) intervals during the 10 s of recording, a large number of the measures are not applicable. The following ones were considered: SDNN, RMSSD, SDSD. SDNN has been reported to increase with the length of the analyzed recording [5]. SDSD is somewhat redundant with the RMSSD. Thus, for time domain measures we elected to study the SDNN and the RMSSD. These two measures

Table I
HRV Time Domain Measures

Variable	Units	Description
Statistical Measures		
SDNN	ms	Standard deviation of all NN intervals
SDANN	ms	Standard deviation of the averages of NN intervals in all 5-minute segments
RMSSD	ms	Root mean square of successive differences
SDNN index	ms	Mean of the standard deviation for all 5-minute segments
SDSD	ms	Standard deviation of successive differences
NN50 count		Number of pairs of adjacent NN intervals differing by more than 50 ms
pNN50	%	NN50 count divided by the total number of NN intervals.
Geometric Measures		
HRV triangular index		Total number of NN intervals divided by the height of the histogram of all intervals using 7.8125ms bins.
TINN	ms	Baseline width of minimum square difference triangular interpolation of the highest peak of the histogram
Differential index	ms	Difference between the widths of the histogram of differences between adjacent NN intervals measured at selected heights (e.g. 1000 and 10000 samples)
Logarithmic index		Coefficient a of the negative exponential curve $k.e^{-at}$, which is the best approximation of the histogram of absolute differences between adjacent NN intervals

potentially have the property that, provided they proved to be stationary, an equivalently longer duration and more accurate measure can be built up from short segments of heart rhythm. The SDNN correlates to the total HRV power. The RMSSD is related to the high-frequency (HF) energy in the band from 0.15 Hz to 0.4 Hz. The HF band represents the respiratory sinus arrhythmia due to parasympathetic cardiovascular activity [1]. The other measures in Table I would require segments longer than 10 s to be meaningful.

Since most of the 10 s ECG strips are recorded while the subject is in a supine position, we expect parasympathetic activity, also referred to as vagal activity, to dominate. Diminished vagal activity has been associated with cardiac disease [1].

With regard to spectral measures, Table II shows the standard frequency segmentation [1] used in HRV analyses. With just 10 s of recording, only coarse information about the HF band is possible. The respiratory rate for most adults is 8-12 breaths per minute (0.13 – 0.2 Hz). Thus any power measurement in this bandwidth in 10 s recordings would be inaccurate. The only information that appeared to be consistent for these short record lengths was the frequency of the peak of the HF, if one existed. Thus, we decided to investigate the accuracy of the HF peak.

III. Database and Tools

The Physionet [6] 2001 Computer in Cardiology (CinC) Challenge [7] database was used. From this database, only the subset identified to be from normal patients was selected. It consists of 25 record sets, with 2 records in each set. The data available for each record consists of 30 minutes of two-channel ECG recordings from a Holter monitor and associated automatic R-wave detection times. We only used the R-wave detection times.

As the data were obtained from Holter recordings, there was no specific restriction on the activities of the subject. As a result the heart rate was variable throughout the record and a large number of premature events, both of atrial and ventricular origins, could be observed. To simulate the recordings that would have been obtained from subjects at rest in a supine position, the following filtering was performed:

- If the current R-R interval was within 50 ms from the previous interval, accept the interval.
- If the current R-R interval differed from the previous one by more than 50 ms, an 11 point median filter centered on the current R-R interval was used to evaluate a replacement value for the current R-R interval. The median filter allowed for slow trend changes while replacing intervals with premature complexes by normal intervals. We believed this to be a better strategy than excluding these intervals altogether [3] since the substitute intervals would be close to the intrinsic intervals masked by the premature events. Any record with a large number of bigeminies was also excluded.

TABLE II
HRV FREQUENCY SEGMENTATION

VLF	≤ 0.04 Hz
LF	0.04 – 0.15 Hz
HF	0.15 – 0.4 Hz

The initial analyses were carried out using the Heart Rate Variability Analysis tool from the University of Kuopio (UKu), Finland [8]. Data detrending used the "Smooth Priors" option of the package with the "Eye" model and an Alpha value of 1000. For more extensive SDNN and RMSSD analyses, MATLAB programs were written. For detrending, a centered 21 point moving average was used to compute the average heart interval, which was subtracted from the current R-R interval.

IV. Results

A. SDNN

For each of the 50 records of the database, 300 s segments were chosen with SDNN(300)s (SDNN for a length of 300 s) of less than 30 ms as representative of periods when the subject is resting. From the 50 records, 208 non-overlapping segments met this SDNN(300) condition. For each segment the SDNN(n)s, where n is the time in units of seconds from 10 s to 300 s in steps of 10 s, were computed. The results, normalized with the respective SDNN(300)s are shown in Fig. 2. The means and standard deviations of the normalized SDNNs are shown in Table III.

For each 300 s segment, the SDNN(10)s of the thirty non-overlapping 10 s segments were computed, then normalized with respect to the corresponding SDNN(300). To assess the accuracy of the SDNN(10) measures a two way analysis of variance [9] (ANOVA) was performed. The results are shown in Table IV. The F value of the means of the 300 s groups, 1.37, was greater than the

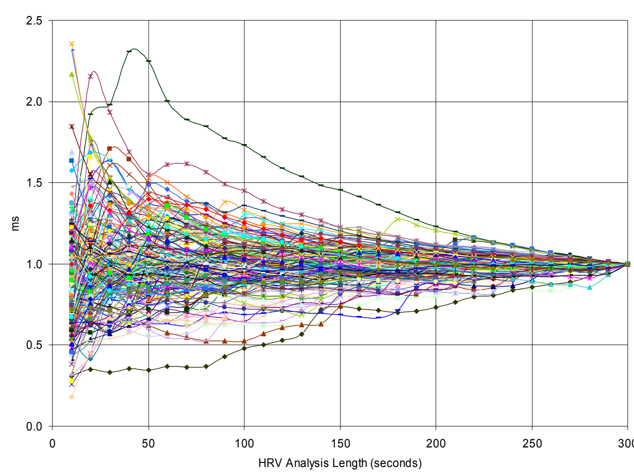

Fig. 2. Normalized SDNNs.

TABLE III
STATISTICS OF SELECTED NORMALIZED SDNNs

	Mean (normalized unit)	Standard Deviation (n.u.)
SDNN(10)	0.906	0.329
SDNN(20)	0.977	0.294
SDNN(30)	0.999	0.264
SDNN(60)	1.007	0.207
SDNN(120)	0.993	0.131

critical F value of 1.17 (P=0.05). This indicated that the means of SDNN(10)s in the 300 s groups were not consistent with the corresponding SDNN(300) resulting in an inaccurate normalization. Thus we confirmed that SDDN(10) would not be a good estimate of SDNN(300) [1].

B. *RMSSD*

Similar analyses were performed for the RMSSD. The results are shown in Fig. 3, Tables V and VI.

With F values less than the respective critical F values, no underlying inconsistency was detected for the RMSSD(10)s measures. These results tended to suggest that RMSSD(10) may be used as an estimate of RMSSD(300).

C. *HF Peak*

For each of the 50 records, a relatively stable 600 s interval was chosen and the Welch periodograms (2 Hz resampling, 256 point FFT with zero fill, 128 point overlap) were computed for segment lengths of 10 s, 20 s, 30 s, 60 s, 120 s, 300 s, 600 s with the UKu HRV Analysis package. The frequencies of the largest 2 peaks of each spectrum were recorded.

Of the 50 records, only 14 records exhibited a large single peak in the HF band in the 300 s spectra, as illustrated in Fig. 4. The other 300 s spectra did not have any peak in the HF zone or had a multitude of peaks. We confined our analyses to those records with a large single peak in the HF band at 300 s. For the spectra of the shorter analysis lengths, the peak closer to the peak of the 300 s segment was kept. The results are summarized in Fig. 5. The statistics of the normalized HF peaks are shown in Table VII.

TABLE IV
ANOVA OF NORMALIZED SDNN(10)s

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit (P=0.05)*
Between 300s Groups	30.0	207	0.145	1.37	0.000369	1.17
Within 300 s Groups	3.38	29	0.117	1.11	0.313	1.47
Error	631	6003	0.105			
Total	665	6239				

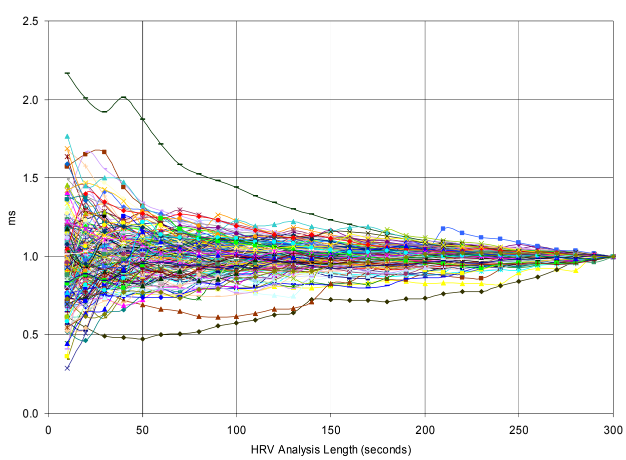

Fig. 3. Normalized RMSSDs.

TABLE V
STATISTICS OF SELECTED NORMALIZED RMSSDs

Analysis Length (s)	Mean (n.u.)	Standard Deviation (n.u.)
10	0.96	0.274
20	0.99	0.227
30	1.00	0.168
60	1.01	0.135
120	1.00	0.088

TABLE VI
ANOVA OF NORMALIZED RMSSD(10)s

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit (P=0.05)*
Between 300s Groups	4.68	207	0.0226	0.300	1	1.17
Within 300s Groups	2.83	29	0.0976	1.30	0.133	1.47
Error	452	6003	0.0753			
Total	460	6239				

V. DISCUSSION

A. *SDNN(10)*

The ANOVA analysis of the normalized SDNN(10)s revealed that the means of the SDNN(10)s within a 300 s segments do not correlate well with the SDNN(300). This is caused by the low and very low frequency components of HRV [1], [5] which were not removed by the 21 point moving average detrending filter from SDNN(300).

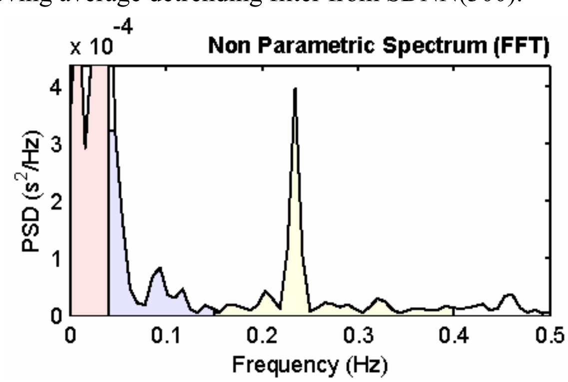

Fig. 4. 300s spectrum with strong HF peak.

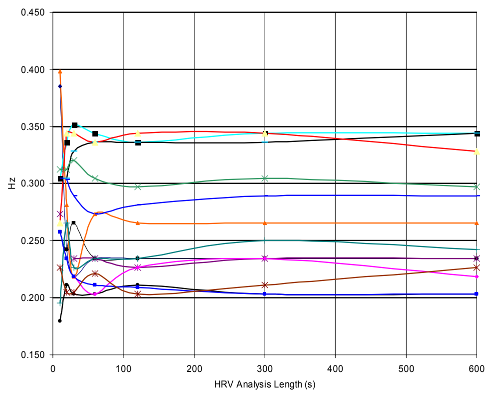

Fig. 5. Location of HF peak as a function of analysis record length.

TABLE VII
STATISTICS OF SELECTED HF PEAKS NORMALIZED FREQUENCIES

Analysis Length (s)	Mean (normalized)	Standard Deviation
10	1.10	0.27
20	1.03	0.060
30	0.99	0.076
60	0.99	0.047
120	0.99	0.027
600	1.00	0.033

B. *RMSSD(10)*

The RMSSD(10) measures did not suffer from the inconsistencies of the SDNN(10) measures, even though the same rhythm segments were used. Thus, RMSSD(10) could be used as an estimate of RMSSD(300).

One of the properties mentioned in Section II that led to the selection of the RMSSD measure is its ability to be improved by combining disjoint records, i.e. combining a number of RMSSD(10)s, for example 6, to obtain the equivalent of an RMSSD(60). Combining the RMSSD(10)s of Table VI, the equivalent normalized RMSSD(60) standard deviation was reduced to 0.125, vs. 0.271.

C. *HF Peak*

The frequencies of the HF peaks at 10 s were found not to be reliable estimates of the frequencies of the HF peaks at 300 s. From Fig. 5, at 60 s the frequencies of the peaks appeared to converge to the peaks at 300 s.

D. *Multiplicative Model*

In this paper we chose to use a multiplicative model for the relationship between the time domain measures at 10 s and the standard measures at 300 s, instead of an additive model. This selection was driven by the observation that the Poincaré plots of the R-R intervals of normal subjects tended to be fan shaped [10]. This indicated increased next interval difference for long R-R intervals relative to short ones, and by extension for large SDNNs and RMSSDs relative to small ones. With an additive model, the conclusions did not change, even though the F values in Tables IV and VI were slightly larger.

E. *Statistical Correlation*

In our analyses, the thirty 10 s segments in a 300 s interval used were adjacent. Statistical correlation between segments could be an issue. Using every other 10 s segments, the analysis was repeated with fifteen 10 s segments per 300 s intervals. The ANOVA results were essentially the same. For analyses with every fourth segments there was only a slight degradation of the results, namely RMSSD "Between 300 s groups" P-value was reduced to 0.94.

VI. Conclusion

In this paper we studied three candidate HRV measures for ultra-short (10 s) records with the goal to use them as samples of the corresponding standard 300 s values. The RMSSD(10) was found to correlate with the standard RMSSD(300).

In the WHI [3] study, ECGs of the 67,000 women enrolled will be collected at baseline, 3 years and 6 years. This database may yield valuable population heath/disease statistics with the appropriate measures. The RMSSD(10) may be such a measure. The accuracy of future recordings may be enhanced by averaging multiple successive to yield an improved RMSSD measure.

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