Effect of Ectopic Beats on Heart Rate Variability Indices in Heart Failure Patients

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Abstract

Heart rate variability (HRV) provides a valuable tool for early detection of cardiovascular abnormalities. Ectopic beats have been proven to have an influence on HRV results, but the effect of different amount of ectopic beats on analysis of congestive heart failure (CHF) patient rhythms has not been quantified. In this study, we tested the commonly used HRV indices for significant differences between 5-min RR segments with and without ectopic beats. Eight long-term CHF RR interval recordings from http://www.physionet.org were studied. Each recording was divided into non-overlapping segments of 5-min RR segments without or with different numbers of ectopic beats. Two time-domain HRV indices of SDNN and RMSSD and two frequency-domain indices of normalized low frequency (LFn) and high frequency (HFn) powers were employed. Results showed that ectopic segments had significantly larger values for SDNN (39 ± 18 vs. ectopic free segments 28 ± 16 ms, $P < 0.05$), RMSSD (47 ± 29 vs. 24 ± 23 ms, $P < 0.05$) and HFn (0.66 ± 0.13 vs. 0.52 ± 0.14, $P < 0.01$), and significantly lower values for LFn (0.34 ± 0.13 vs. ectopic free segments 0.48 ± 0.14, $P < 0.01$). Compared with the indices of RMSSD and frequency-domain indices, SDNN was least affected by a relatively small amount of ectopic beats (one to six beats). Compared with the time-domain indices, the frequency-domain indices responded more quickly to the appearance of ectopic beats.

Keywords

Electrocardiographic (ECG) • Heart rate variability (HRV) • Ectopic beat • Congestive heart failure (CHF)

1 Introduction

Heart rate variability (HRV) studies the slight fluctuations in RR interval time series and has become an important tool for the assessment of cardiovascular autonomic regulation during various physiological and clinical conditions. However, ectopic beats consists in RR interval time series may cause bias in the reliable measurement of HRV [1, 2]. Researchers reported that some HRV time-domain parameters are more sensitive to the ectopic beats than others [1]. Researchers also stated that the presence of only one ectopic beat can introduce an increase in the high frequency (HF) power in HRV of around 10% [3]. The reason is that ectopic beats can induce the sudden changes in RR intervals and increase the high-frequency fluctuation in the tachogram of HRV, distorting the true measure of an HRV metric [4].

Although many detecting and editing (correcting) methods for ectopic beats have been proposed [2, 5–7], there is no agreed conclusion on which method is more efficient to handle the ectopic beats to obtain accurate HRV estimation [2, 4, 7]. Meanwhile, the effect of different amount of ectopic beats on the common time-domain and frequency-domain HRV indices for special cardiovascular disease has not been widely documented. This paper, therefore, aims to quantify the differences between ectopic-free and ectopic RR interval time series for congestive heart failure (CHF) patients and to quantify the effect of different amount of ectopic beats on the

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commonly used time-domain and frequency-domain HRV indices.

2 Methods

2.1 Database

All data used were from the PhysioNet CHF RR Interval Databases [8], a free-access, online archive of physiological signals. This database included 29 long-term RR interval records of subjects aged 34–79, with CHF. The original ECGs were digitized at 128 Hz, and the beat annotations were obtained by automated analysis with manual review and correction. A 5-min time window was used to segment the long-term RR interval records. In each 5-min RR segment, RR intervals greater than 2 s were first removed to exclude the influence from artifacts [9]. Then 5-min RR segments were classified as an ectopic segment if at least one ectopic beat was included or ectopic-free segment if no ectopic beat existed. Ectopic beats were from supraventricular or ventricular beats, depending on the localization of ectopic focus. Figure 1 shows the examples of an ectopic-free and ectopic 5-min RR segments. To exclude the record effect, only eight records with approximately equal amounts of ectopic-free and ectopic RR segments were selected for the following analysis (see Table 1).

2.2 HRV Indices

For a 5-min RR segment $x(i)$, $(i = 1, 2, \ldots, N)$, four common HRV indices were calculated in this study.

(1) Time-domain indices:
The standard deviation of 5-min RR segment (SDNN) and the square root of the mean of the sum of the squares of differences between adjacent intervals of 5-min RR segment (RMSSD) were used and were defined as:

$$\mathrm{SDNN} = \sqrt{\frac{1}{N-1}\sum\nolimits_{i=1}^{N}\left(x(i)-\bar{x}\right)^2} \quad (1)$$

$$\mathrm{RMSSD} = \sqrt{\frac{1}{N-1}\sum\nolimits_{i=1}^{N-1}\left(x(i+1)-x(i)\right)^2} \quad (2)$$

where $\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x(i)$ is the mean value of RR intervals.

(2) Frequency-domain indices:
Frequency-domain analysis provides a quantitative evaluation of sympathetic and parasympathetic activation. The low frequency (LF) component (between 0.04 and 0.15 Hz) reflects both sympathetic and parasympathetic nervous systems while the HF component (between 0.15 and 0.40 Hz) mainly reflects vagal activity [4, 10]. Burg modern spectrum estimation was used to acquire frequency parameters. The spectral powers of LF and HF were normalized using $\mathrm{LFn} = \frac{\mathrm{LF}}{\mathrm{LF}+\mathrm{HF}}$ and $\mathrm{HFn} = \frac{\mathrm{HF}}{\mathrm{LF}+\mathrm{HF}}$.

2.3 Statistical Analysis

Group *t*-student test was used to determine whether the results obtained from the ectopic-free and ectopic RR segments had significant differences. Comparisons were also performed between the ectopic-free group and the groups

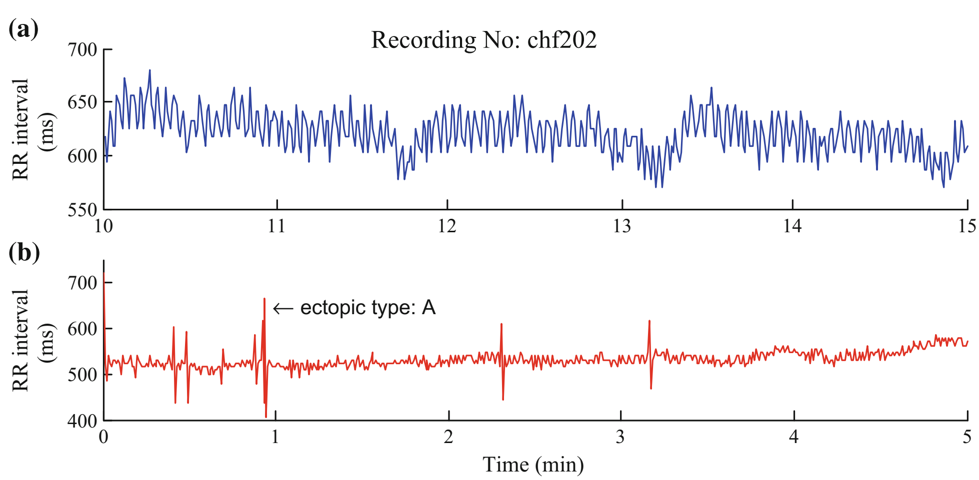

Fig. 1 Examples of 5-min RR segments: **a** ectopic-free RR segment and **b** RR segment with 'a' (atrial) type ectopic beat

Table 1 Recordings selected from the PhysioNet CHF RR interval databases

Record	# Beats			# 5-min RR segments		
	Normal	Ectopic	Total	Ectopic-free	Ectopic	Total
chf202	109,003	273	109,276	97	150	247
chf203	98,473	496	98,969	75	187	262
chf209	108,758	507	109,265	70	156	226
chf215	141,898	5,851	147,749	110	166	276
chf220	136,929	820	137,749	138	143	281
chf224	134,367	356	134,723	137	150	287
chf225	91,161	242	91,403	97	121	218
chf228	117,459	1,467	118,926	71	204	275

with different amount of ectopic beats. All statistical analyses were performed using the SPSS software (Ver. 20, IBM, USA). A statistical significance was accepted at $P < 0.05$.

3 Results

Table 2 gives the overall means and SDs of HRV indices (i.e., SDNN, RMSSD, LFn, and HFn) from both ectopic-free and ectopic 5-min RR segments. As shown in Table 2, there were significant differences in all four indices between the two groups (all $P < 0.05$). For time-domain indices, SDNN in ectopic group was significantly larger by 11 ms (39 ± 18 vs. 28 ± 16 ms, $P < 0.05$) and RMSSD was significantly larger by 23 ms (47 ± 29 vs. 24 ± 23 ms, $P < 0.05$). For frequency-domain indices, LFn in ectopic group was significantly lower by 0.14 (0.34 ± 0.13 vs. 0.48 ± 0.14, $P < 0.01$) while HFn was significantly larger by 0.14 (0.66 ± 0.13 vs. 0.52 ± 0.14, $P < 0.01$).

Then we divided the ectopic RR segments into sub-groups with different amount of ectopic beats. Figure 2 shows the distribution of RR segments classified by the number of ectopic beats. There are total 795 ectopic-free RR segments (also as shown in Table 2). For ectopic ones, there are 464, 243, 138, 81, 50 and 33 segments when ectopic beast are from one to six respectively, and there are 217 ectopic segments with ectopic beats more than six. Figure 3 shows the corresponding mean and SDs values of the four HRV indices for each RR segment group, to allow the ectopic beat number-related HRV changes to be observed and compared.

For time-domain indices, SDNN increased with increasing ectopic beat number. When compared with the ectopic-free group, statistically significant increases were observed at the group with one ectopic beat ($P < 0.01$), the group with two ectopic beats ($P < 0.01$) and the group with more than six ectopic beats ($P < 0.01$). However, the groups with three to six ectopic beats did not show the statistical significance. The reason maybe come from the small amount of RR segments. RMSSD also increased with the increase of ectopic beat number for each group. When compared with the ectopic-free group, statistically significant increases were observed for all seven ectopic groups (all $P < 0.01$).

For frequency-domain indices, LFn gradually decreased with the increase of ectopic beat number for each group. When compared with the ectopic-free group, statistically significant decreases were observed for all seven ectopic groups (all $P < 0.01$). HFn showed a reverse trend to LFn since mathematically, the sum of LFn and HFn was a constant.

For comparison of the results from time-domain and frequency-domain HRV indices, the latter responded more quickly to the appearance of ectopic beats. With the increase of ectopic beats from one to six, LFn (HFn) quickly decreased (increased) at these situations with relatively small amount of ectopic beats. When the number of ectopic beats was large and increased up to more than six, the decrease trend in LFn (increase trend in HFn) was not obvious.

Table 2 HRV results for ectopic-free and ectopic 5-min RR segments

Index	Ectopic-free	Ectopic	*P*-value
# segment	795	1277	
SDNN (ms)	28 ± 16	39 ± 18	<0.05
RMSSD (ms)	24 ± 23	47 ± 29	<0.05
LFn	0.48 ± 0.14	0.34 ± 0.13	<0.01
HFn	0.52 ± 0.14	0.66 ± 0.13	<0.01

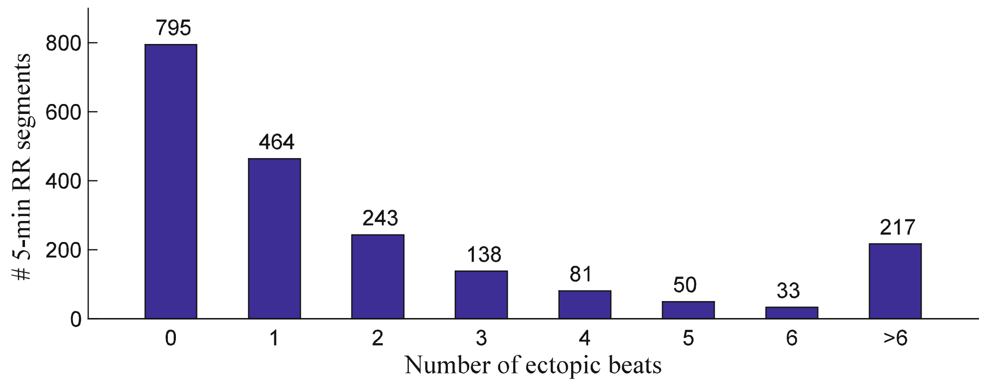

Fig. 2 Distribution of the ectopic-free and ectopic 5-min RR segments classified by the number of ectopic beats

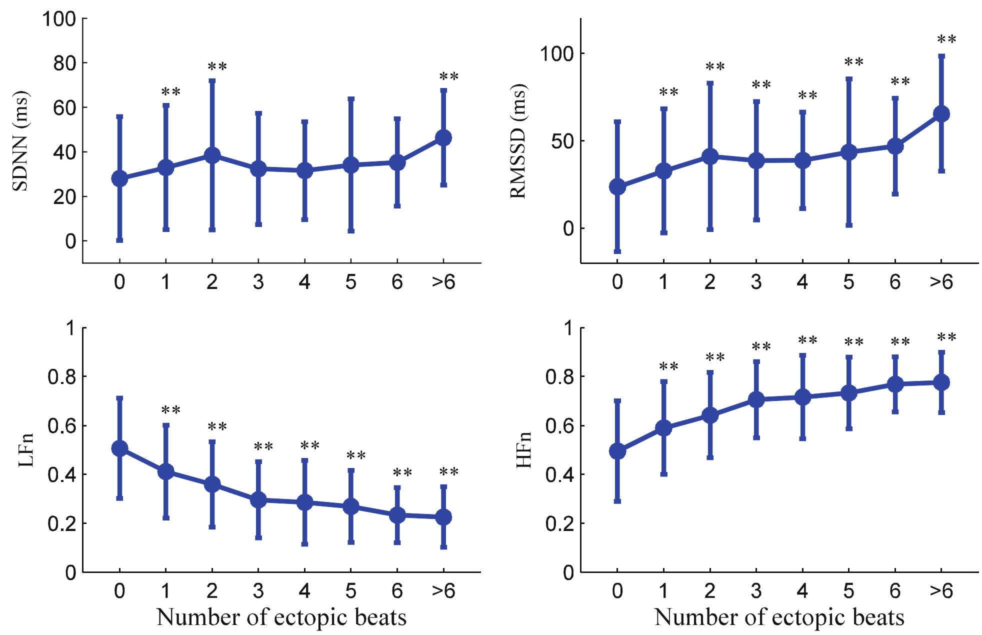

Fig. 3 Group mean and standard standards (SDs) of four HRV indices at each RR segment group with different numbers of ectopic beats. Compared with ectopic-free group, statistically significant differences at the $P < 0.01$ level are marked as '**'

However, time-domain indices showed distinct changes when applied on the RR segments with more than six ectopic beats.

4 Discussion

In this study, we quantified the effect of different amount of ectopic beats on the common time-domain and frequency-domain HRV indices for CHF patients. The results showed that the ectopic RR segments had larger SDNN, RMSSD, and HFn but lower LFn values than the ectopic-free RR segments. Compared with the indices of RMSSD and frequency-domain indices, SDNN was least affected by a relatively small amount of ectopic beats (one to six beats). Compared with the time-domain indices, the frequency-domain indices responded more quickly to the appearance of ectopic beats. The results confirmed that ectopic beats in RR segments have a significant influence on the HRV results for CHF patients.

Ectopic beats are routinely removed/edited from the RR tachogram prior to HRV analysis. Our results agreed with the previously reported works. Salo et al. found that SDNN was least affected by the editing of RR intervals, and compared with the indices of SDNN and RMSSD, frequency-domain indices were more sensitive to the editing of RR intervals and reported larger errors after the ectopic beat editing [1]. This finding was consistent with our current study, where we showed that RMSSD and frequency-domain indices were more sensitive to the appearance of a small amount of ectopic beast (one to six beats). The reason is that the ectopic beats are usually step-like shapes and can result in sudden changes in RR interval time series. This effect is significant on the transient change of HRV reflected by RMSSD and the spectral components of HRV reflected by the frequency-domain LFn and HFn indices [4].

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