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Original Article

The clinical significance of Lorenz scatter plots in detecting ventricular parasystoles

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Abstract: Objective: To identify and diagnose ventricular parasystole (VP) early and correctly with a 24 h dynamic electrocardiogram (24-h Holter) and to analyze the characteristics of Lorenz scatter plots. Methods: From May 2017 to June 2019, 32 cases of VP, 75 cases of simple premature ventricular beat (PVB), and 80 cases of sinus rhythm (SR) who underwent physical examinations and were diagnosed in our hospital were retrospectively reviewed. The characteristics of the Lorenz scatter plots, the average heart rates, and the heart rate variability (HRV) indexes were analyzed. Results: The participants in the three groups were comparable in terms of gender and age (P>0.05), but there were no significant differences in the average heart rates, the average daytime heart rates, or the average nighttime heart rates (P>0.05). The Lorenz scatter plots of the physical examination subjects in the VP group showed triangle and inverted Y shapes, which appeared during the whole process, in both the daytime and at nighttime, but the other two groups had no such phenomenon. The HRV indexes, which included the average PVB, the standard deviation of all normal-to-normal RR intervals (SDNN), the standard deviation of the average normal-to-normal intervals (SDANN) and the proportion of the number of pairs of adjacent normal-to-normal intervals by more than 50 ms (PNN50), were all significantly higher in the VP than in the other two groups (all P<0.05). Compared with the routine electrocardiogram (ECG), the patients in the PV group who underwent dynamic ECG presented higher accuracy (P<0.05). Conclusion: The use of dynamic ECG can screen out triangle and inverted Y shapes, so it has a good application value because it can improve the diagnosis rate of VP while providing multiple indexes of HRV to assist in quantitative evaluations.

Keywords: Dynamic electrocardiogram, ventricular parasystole, Lorenz scatter plots, heart rate variability

Introduction

Ventricular parasystole (VP) is a common ventricular ectopic pacemaker, which is a manifestation of increased excitability at low pacemaker. It is found not only in asymptomatic physical examination patients, but also in those with dominant organic heart disease, such as ischemic cardiomyopathy, dilated cardiomyopathy, hyperthyroid cardiomyopathy, hypertension, diabetes and heart failure, conditions which are often the early warning signals of heart disease, and has an important predictive value for poor clinical prognosis in long-term follow-up cases [1, 2]. Therefore, the early and accurate identification of VP is vital for determining high-risk patients.

Dai et al. pointed out that the whole-course Lorenz scatter plots of VP are mainly inverted Y-shaped, a few of which are triangle or butterfly-shaped, but the common feature is that Lorenz scatter plots have inverted Y shapes in different periods, accompanied by changes of several heart rate variability (HRV) indexes, which are related to organic heart disease [3]. However, according to the big data of Lorenz scatter plots, Xiang et al. revealed that the VP is dominated by triangles, and the sides of the triangles are the boundary lines of rhythm, but the inverted Y shape is rare [4]. At present, there are mushrooming studies on Lorenz scatter plots based on dynamic electrocardiogram (ECG) in the early diagnosis of multiple ectopic heart rhythms, particularly in the early diagnosis of VP. However, due to factors such as the number of samples included, the disease characteristics of the sample population, and the length of the data collection, the results of the different studies vary and even contradict [5, 6]. Therefore, an in-depth analysis of the causes of the differences is of great significance in improving the accuracy of the clinical diagnosis of VP.

Owing to the presence of ectopic pacemakers and their own efferent and afferent block effects, the RR interval between normal and ectopic pacemakers is unstable with the longest and shortest RR intervals, which is closely related to the refractory period of normal pacemakers and the excitability of ectopic pacemakers. However, routine ECG is difficult to distinguish from simple premature ventricular beat (PVB), which is also the main reason for the application of dynamic ECG. Meanwhile, according to the heart rate and cardiac pacing data collected in the daytime, at nighttime, in different time periods or during the whole course, the Lorenz scatter plots drawn by dynamic ECG can show different image characteristics, providing richer information for VP [7].

Based on this, this study applied 24-h Holter to correctly identify and diagnose the early VP and analyzed the characteristics of Lorenz scatter plots, providing an important basis for improving the early diagnosis of such diseases.

Materials and methods

Research participant data

From May 2017 to June 2019, 32 cases of VP, 75 cases of simple PVB, and 80 cases of SR who underwent physical examination and were diagnosed in The First Affiliated Hospital of Fujian Medical University were reviewed retrospectively. Inclusion criteria: 1) Patients between 18 and 75 years old; 2) Patients without other organic diseases, such as lung, liver, kidney, or brain function abnormalities; 3) Patients without dominant atrial arrhythmia, ventricular tachycardia, etc.; 4) Patients who were able to consistently complete the 24-h Holter monitoring; 5) Patients with complete clinical data. This study was conducted with the approval of the Medical Ethics Committee of The First Affiliated Hospital of Fujian Medical University, with written informed consent obtained from the participants or their family members. Exclusion criteria: 1) Patients with a previous history of surgery, chemoradiotherapy or malignant tumors; 2) Patients with hyperthyroidism, abnormal endocrine function, or autoimmune diseases; 3) Lactating or pregnant women.

Research methods

The Lorenz scatter plot characteristics and the average heart rate and HRV were analyzed. The specific operation steps were as follows: The Holter BI6812 (Boying Medical Instrument Technology Co., Ltd., Shenzhen, China) was adopted, and the method of wearing it and the precautions were explained in detail to remind the research participants to wear it correctly. The research participants were supposed to work and live normally during the wearing period, but they were asked to pay attention to avoiding active areas of strong magnetic and electric fields, minimizing intense activities and stretching the limbs, and suspending all heart-related drugs such as β-blockers and ACEI/ARB drugs while wearing the device. After they correctly began wearing the device, the total time started to count for 24 hours, with 07:00-22:59 indicated as daytime and 23:00-06:59 as nighttime. In cases when the ECG data were unsatisfactory during the wearing period, or when arrhythmia occurred outside of the wearing time, the device could be re-started for 24 hours. After wearing the device, the Holter was removed by the professional staff, and all the data recorded during the wearing time were extracted. A combination of manual and computer methods was used to find the PVB, the calculate the number of occurrences, occurrence times, and corresponding RR intervals. The computer software automatically drew the Lorenz scatter plots of the whole course and the different time periods, and the calculated the related HRV indexes, including the standard deviation of all the normal-to-normal RR intervals (SDNN), the standard deviation of the average normal-to-normal intervals (SDANN), and the proportion of the number of pairs of adjacent normal-to-normal intervals by more than 50 ms (PNN50).

The judgment basis of the ventricular parallel rhythm: the ectopic beat intervals of the ventricular plane were different, so each ectopic beat interval had a maximum common divisor, and there was a ventricular fusion wave [8].

Statistical methods

SPSS 20.0 was employed for the statistical analysis. The measurement data were expressed as the mean ± standard deviation, and the comparisons among three groups were analyzed using one-way ANOVA, and the com-

Table 1. Comparison of the baseline data ($\overline{x}$ ± sd, n)

	VP group (n=32)	PVB group (n=75)	SR group (n=80)	F/χ^2	P
Male/female	18/14	40/35	42/38	0.130	0.937
Age (year)	55.6±9.8	55.3±7.7	55.2±6.9	0.463	0.521
Smoking	7	18	25	1.505	0.471
Hypertension	6	13	20	1.482	0.477
Diabetes mellitus	4	9	10	0.010	0.995
LVEF (%)	58.2±3.4	58.5±3.9	57.9±3.5	0.632	0.359
LVEDD (mm)	47.2±2.3	47.1±2.1	46.9±2.5	0.721	0.256

Note: VP, ventricular parasystole; PVB, premature ventricular beat; SR, sinus rhythm; LVEF, left ventricular ejection fraction. LVEDD, left ventricular end diastolic diameter.

Table 2. Comparison of the heart rates ($\overline{x}$ ± sd, time/min)

	VP group (n=32)	PVB group (n=75)	SR group (n=80)	F	P
Total average heart rates	72.5±4.6	73.3±4.9	71.8±4.5	0.563	0.624
Average daytime heart rates	78.9±5.2	78.5±5.3	78.6±5.4	0.465	0.659
Average nighttime heart rates	70.6±4.3	71.2±4.4	70.3±4.2	0.765	0.321

Note: VP, ventricular parasystole; PVB, premature ventricular beat; SR, sinus rhythm.

parisons between two groups were tested using the LSD-t method. The counting data were represented by the number of cases (%), and the comparisons between groups were conducted using χ^2 tests. P<0.05 indicated that the difference was statistically significant.

Results

Comparison of the baseline data

There were no significant differences in terms of gender, age, smoking, hypertension, diabetes, left ventricular ejection fraction (LVEF), or left ventricular end-diastolic diameter (LVEDD) among the three groups (P>0.05; **Table 1**).

Comparison of the heart rates

There were no marked differences in the average heart rate, average daytime heart rate, or the average nighttime heart rate among the three groups (P>0.05; **Table 2**).

Features of the Lorenz scatter plots

The Lorenz scatter plots from the physical examination subjects in the VP group showed triangle and inverted Y shapes, which appeared during the whole process, during the daytime and at nighttime, but the other two groups had no such phenomenon (**Figures 1-3**).

Comparison of the HRV indexes

The HRV indexes, including the average PVB, SDNN, SDANN, and PNN50, were significantly higher in the VP group than in the other two groups (P<0.05; **Table 3**).

The accuracy of dynamic ECG and routine ECG in the diagnosis of VP

The accuracy of the dynamic ECG was higher than the accuracy of the routine ECG in the VP group (P<0.05; **Table 4**).

Discussion

VP is the co-existence of normal sinus pacemakers and low ventricular pacemakers, which means that after ventricular pacing, it not only has an efferent function, that is, to cause part of electrocardiographic QRS wave effect, but it also has its own blocking function, namely to not trigger the QRS effect, specifically depending on the refractory relationship between the ventricular pacemakers and the normal SR [9]. If the ventricular pacing happens just at the end of the refractory period, the corresponding ventricular QRS wave can be generated, at which time, the shortest RR interval will be produced. On the contrary, if a ventricular QRS wave is generated immediately before the refractory period, the longest RR interval will be

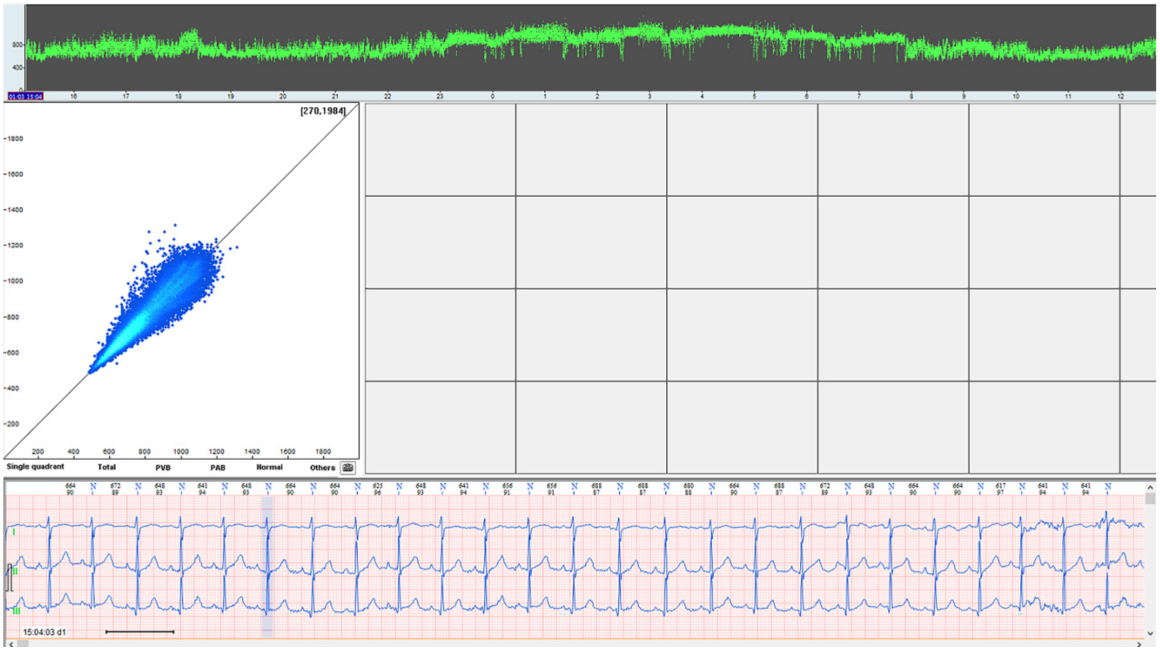

Figure 1. Representative scatter plot of the sinus rhythm: A child's normal dynamic electrocardiogram. PVB, premature ventricular beats; PAB, premature atrial beat.

generated. In the longest and shortest RR intervals, the RR intervals are automatically calculated by the dynamic ECG and computer software, that is, an RR scatter map (Lorenz scatter map) of the long time period and different time periods is formed [10].

The Lorenz scatter plot is an ideal tools for studying the inner regularity between RR periods, which can find and provide an important method to distinguish VP from simple PVB. And integrated reverse technology with Lorenz scatter plots can realize a playback control function, find typical or atypical image features, and comprehensively and accurately provide VP diagnostic information [11, 12]. Although some studies have discussed the application of Lorenz scatter plots in the recognition of ectopic rhythm, there is little research on its role in VP, and the results are not completely consistent. As a type of ventricular ectopic pacing, it is easy to confuse VP with simple ventricular pacing at a rapid heart rate. Therefore, it is necessary to determine whether there is a difference between the two in the Lorenz scatter plot, and it is of great clinical significance to screen typical patterns with big data to distinguish VP earlier and more accurately.

This study found that there were no significant differences in the average heart rate, average daytime heart rate, or average nighttime heart rate among the three groups of patients, suggesting that VP has little effect on the overall heart rate. In addition, the Lorenz scatter plots of the participants in the VP group were displayed as triangle and inverted Y-shaped patterns, which could be seen during the whole process, during the daytime and at nighttime, but not in the other two groups. The results of present study are basically consistent with those of Xiang, except that Xiang only provided three typical cases, but here we retrospectively summarized more samples and conducted an inter-group analysis, which is more convincing [4]. Apart from that, Wu et al. also proposed the atypical manifestations of VP in Lorenz scatter plots, such as the detection rates of the leaf-shaped, triangle and complex distributed images, which were 69.56%, 100.00%, and 50.00%, respectively, which also indicated that the overall detection rate of the triangles in the Lorenz scatter plots was still high [13].

All the shortest RR intervals transmitted under sinus heart rate domination constitute a boundary on the Lorenz scatter plot that is basically parallel to the Y axis and formed a triangle, indicating that the shortest refractory period of ventricular muscle does not vary significantly with sinus heart rate, while the intermediate

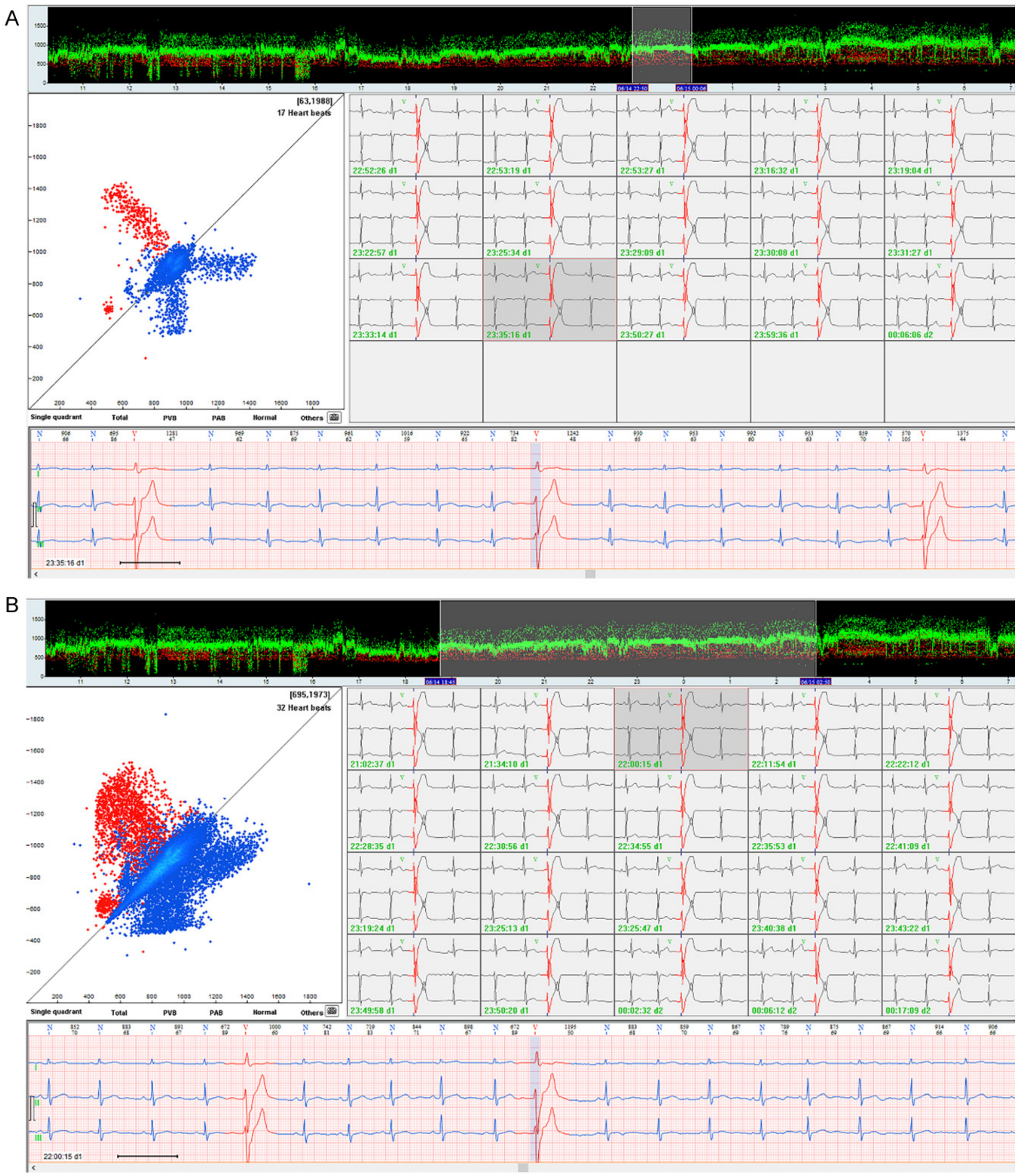

Figure 2. Representative scatter plots of VP. Typical case 1: A 55-year-old female. PVB and VP can be seen in the routine ECG, with unequal RR intervals. The dynamic ECG Lorenz scatter plot is triangle-shaped during the whole course, and inverted Y-shaped at nighttime (A). Typical case 2: 63-year-old male. VP and PVB are observed in the routine ECG, with varying RR intervals. The Lorenz scatter plot of the dynamic ECG is inverted Y-shaped during the whole course, and triangle-shaped at nighttime (B). The change rule of the real-time RR interval can be seen through a scatter plot analysis of the time RR interval. PVB, premature ventricular beat; PAB, premature atrial beat; VP, ventricular parasystole; ECG, electrocardiogram.

region represents all the VP during the shortest and longest RR intervals [14]. The degree of tilt indicates the degree of change in the shortest refractory period. Usually, the change is small, which indicates that the shortest refractory period of the ventricular muscle changes little. The line perpendicular to 45° indicates the isoline of the maximum heart rate, that is, the scatter point set of the slowest sinus rate of VP, and no VP will occur below this sinus rate. The

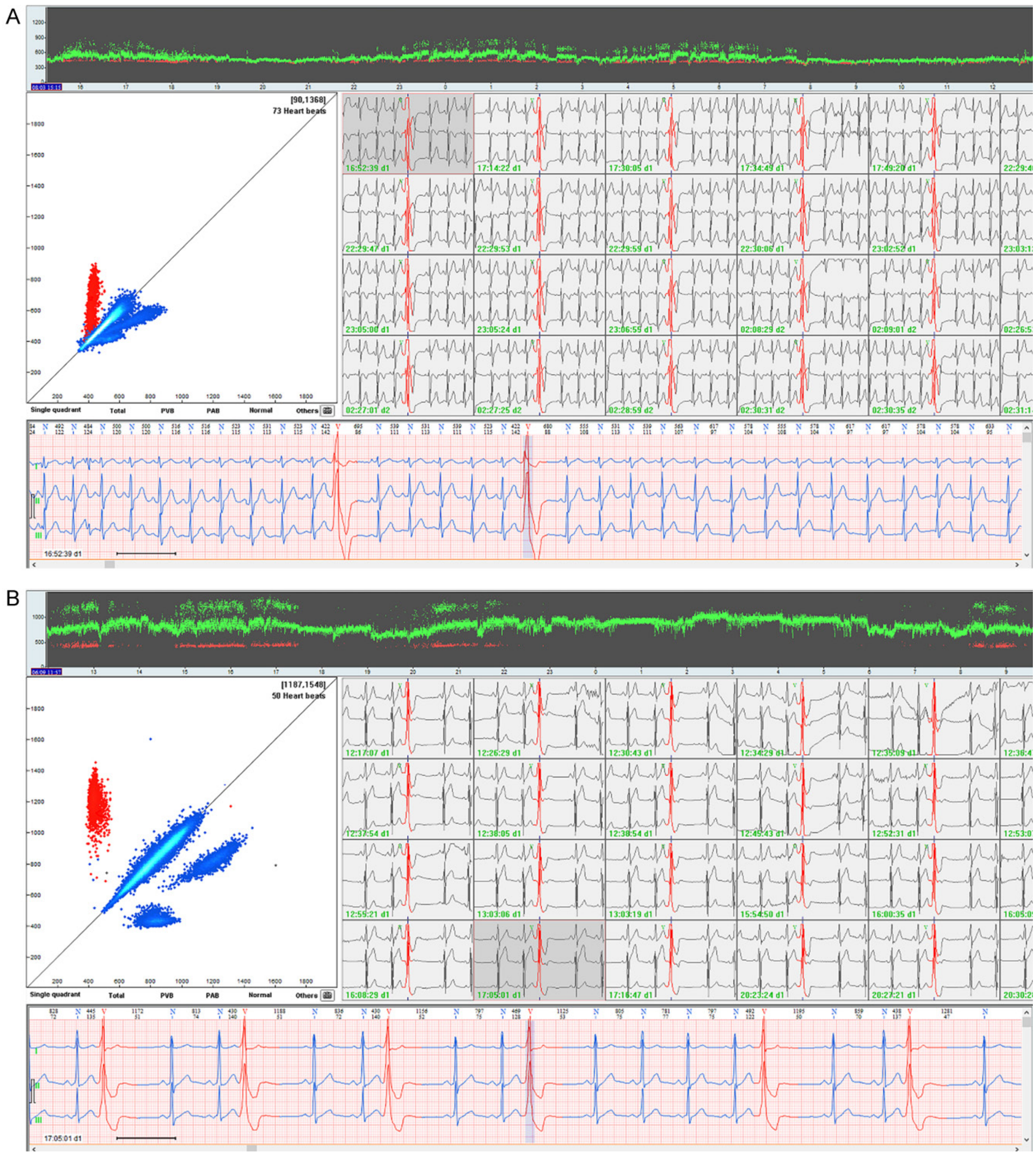

Figure 3. Representative scatter plot of PVB. Typical case: 58-year-old male. PVB can be seen in the routine ECG, with equal RR intervals. The dynamic ECG Lorenz scatter plot is leaf-shaped during the whole course (combined A and B) and at nighttime (A), without triangle or inverted Y-shaped patterns. An analysis of the time RR interval scatter plot shows that the change rule of real-time RR intervals is consistent with the graph characteristics of the whole course and divided periods. PVB, premature ventricular beat; PAB, premature atrial beat; ECG, electrocardiogram.

line that coincides with or that is parallel to 45° represents the set of equal points between the early ventricular coupling interval and the compensation interval, indicating the boundary of the maximum coupling interval [15, 16]. However, instead of the point set features mentioned above, the inverted Y shape will show in the case of divided periods, or when the sample size is small and the acquisition time is short [17].

What's more, this study determined that the HRV indexes in the VP group were significantly higher than those in the other two groups, and the results are inconsistent with those of Dai [8]. The reason behind the difference may be

Table 3. Comparison of the heart rate variability indexes ($\overline{x}$ ± sd)

	VP group (n=32)	PVB group (n=75)	SR group (n=80)	F	P
Average number of VPB	125.6±32.4[a,b]	62.3±12.4	60.5±11.7	56.234	0.000
SDNN (ms)	135.6±42.8[a,b]	82.5±23.6	80.6±18.7	123.236	0.000
SDANN (ms)	42.3±13.5[a,b]	20.5±9.8	18.7±7.6	42.632	0.000
PNN50 (%)	13.2±5.6[a,b]	5.2±1.3	5.0±1.4	10.236	0.000

Note: VP, ventricular parasystole; PVB, premature ventricular beat; SR, sinus rhythm. SDNN, standard deviation of all normal-to-normal RR intervals; SDANN, standard deviation of the average normal-to-normal RR intervals; PNN50, percent of the number of times that the difference between adjacent normal RR intervals is greater than 50 ms in the total number of NN intervals. Compared with the PVB group, [a]P <0.05; compared with the SR group, [b]P <0.05.

Table 4. Accuracy of dynamic ECG and routine ECG in the diagnosis of VP (n, %)

	Positive cases	Positive rate (%)
Dynamic ECG (n=32)	30	93.75
Routine ECG (n=32)	24	75.00
χ^2		4.267
P		0.039

Note: The undetected positive result of dynamic ECG is that the disease attack is not captured, and a single routine ECG can be used to diagnose the disease attack. ECG, electrocardiogram; VP, ventricular parasystole.

that the HRV reflects the balance of the cardiac autonomic nervous system including sympathetic and vagus nerve activities under different conditions in vivo and in vitro. When vagus nerve activity decreases or sympathetic nerve activity increases, HRV decreases [18]. Dynamic ECG can provide real-time HRV and is an important tool to reflect the activity and balance of the cardiac autonomic nerve. However, VP, an important manifestation of cardiac autonomic nervous dysfunction, is also a vital risk factor for a variety of organic heart diseases [19, 20]. In this study, the accuracy of dynamic ECG is higher than the accuracy of routine ECG in the VP group, suggesting that the former has important application value in the early identification and correct diagnosis of VP [21, 22].

However, there are also some shortcomings in this study, such as the small sample size and the short total recording time of the heart rhythm. With the increase in the recording and the preservation time of heart rhythm, as well as the accumulation of larger sample data in the future, it will be possible to find more values from Lorenz scatter plots in the early diagnosis of ectopic heart rhythm.

In conclusion, the early use of dynamic ECG to screen out VP triangle and inverted Y-shaped patterns, an important potential risk factor of organic heart diseases, enjoys a better application value for improving the accurate diagnosis rate, with a higher accuracy compared with routine ECG, while providing multiple HRV indexes for auxiliary quantitative evaluation.

Disclosure of conflict of interest

None.

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