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Research Article

Localization of Accessory Pathway in Patients with Wolff-Parkinson-White Syndrome Using Cross-Recurrence Plot of Precordial Leads

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Abstract

The non-invasive localization of accessory pathway (AP) in patients with Wolff-Parkinson-White (WPW) syndrome is typically performed upon physicians' diagnoses based on observing their electrocardiogram (ECG) signals, which are not always the same. Therefore, a high-accuracy automatic method can help minimize this gap regarding AP localization. This study was to develop a novel semi-automatic localization of AP in patients with WPW syndrome, using features selected from the cross-recurrence plot (CRP) of consecutive precordial leads on ECG. The study participants comprised of 31 patients with WPW syndrome (aged 8-69, with a mean age of 31.19±14.69, 32.3% female), receiving successful ablation therapy during the first session. The features extracted from the CRP, including laminarity (LAM), trapping time (TT), determinism (DET), and mean length of diagonal line (L) were then analyzed. The feature reduction, the classification and the cross-validation (CV) methods were sequential forward selection (SFS), the k-nearest neighbors (KNN), and the leave-one-out (LOO) respectively. The proposed method could differentiate the right and left APs in patients with WPW syndrome with an accuracy value of 87% (sensitivity: 93.33%, specificity: 81.25%). These results were achieved by the LAM and L features from the CRP of (V1, V2) and (V3, V4), respectively.

Keywords: Wolff-Parkinson-White syndrome, Localization, Accessory pathway, Cross-recurrence plot.

Highlights

- The localization of APs with a semi-automatic approach using ECG signal was achieved non-invasively.
- The feature LAM yielded from the CRP of leads V1 and V2 was effective in the localization of APs.
- The feature L yielded from the CRP of leads V3 and V4 was effective in the localization of APs.

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1. Introduction

In Wolff-Parkinson-White (WPW) syndrome, patients have one or more accessory pathways (APs) between their atrium and ventricles. Catheter ablation and Cryoablation of the location of accessory pathways in the cross-section of atrium and ventricles are two major methods to treat these patients. In these methods, catheters are placed in the heart, and the APs are localized through intra-cardiac signals [1, 2]. In this procedure, physicians and patients are subjected to fluoroscopy X-ray. The non-invasive localization of accessory pathway (AP) in patients with Wolff-Parkinson-White (WPW) syndrome is typically performed upon physicians' diagnoses. To this end, they observe patients' electrocardiogram (ECG) signals, which are not always the same [3, 4].

The semi-automatic, non-invasive, and accurate localization of APs in patients with WPW syndrome could determine the start point of the procedure and help successful ablation. This process also reduces the disadvantages of invasive procedures for patients and physicians [5, 6].

Literature shows that the transition of the QRS complex in precordial leads could help to find the location of AP [7, 8]. Therefore, the present study aims to find out the hidden dynamic of this transition using a Cross recurrence plot (CRP).

2. Innovation and contribution

Up to now, features LAM, TT, DET, and L extracted from recurrence plots have been used to diagnose patients with atrial fibrillation and healthy subjects and to locate the atrial fibrillation driver [9, 10]. To our knowledge, these features have not been used for the localization of APs so far. The main objective of this study is to apply LAM, TT, DET and L from CRP of consecutive precordial leads, i.e., V_k and V_{k+1}, (k=1, 2, …,5) for localization of AP in WPW patients.

3. Materials and Methods

Participants included 31 WPW patients with single anterograde AP. The APs in the regions around Mitral and tricuspid valves (e.g., Left lateral, Posterolateral, Right posteroseptal, Parahisian, Left posteroseptal, Midseptal, and Right posterior Aps) were included in the study. On the other hand, patients with multiple APs, atriofascicular APs, epicardial APs, and patients with previous ablation history were excluded before starting the study [11]. data and results were assessed by a physician who was an expert in cardiac electrophysiology.

The 12 leads ECG signals in resting position before ablation (using Bard human electrophysiology) with 2 kHz in 10 s were recorded and used in MATLAB software.

Motion artifacts of ECG signals were removed from the data using a zero-phase bandpass filter with order four and a cut-off frequency of 0.5 to 100 Hz [12, 13].

The input of the feature extraction method were one segment, three concatenated segments, and 3 s of ECG signals of each participant with delta wave separately. Each segment was defined as the part of the ECG signal from the start of the P wave to the end of the T one [14].

Then, the features extracted from each input were fed to the algorithm of feature selection and classification LO-SFS and the optimum features of each classification were defined. The algorithm of LO-SFS is the combination of SFS and LOO methods. The KNN classification method [15] and the LOO cross-validation method were used in the SFS algorithm the KNN classification method [15] and the LOO cross-validation method were applied.

In this study, the LOO method was used in two stages: 1) the LOO method in an external loop (e-LOO) and 2) the LOO in an internal loop (i- LOO). In e- LOO in each iteration, the data of one individual were left out, and feature selection with the SFS method was applied for other individuals. Therefore, in each iteration, one "vector of selected features" was determined in e-LOO. The number of these iterations is the same as the number of all participants. An in i- LOO was used for providing the testing and training subsets of data for the classifier used in the SFS method.

Afterward, a histogram representing the number of occurrences of the features (across all vectors of selected features) versus the feature number was plotted. By applying this histogram, the most frequent feature/features were selected and fed to the classifier. After finding the optimum number of most frequent features and determining its related accuracy, The final accuracy was reported. The details of finding these optimum features were described in our previous study [6]. These features provide the most generalization for future testing data [6, 16].

4. Results and Discussion

Semi-automatic localization of AP from surface ECG was performed for right and left APs in three different inputs, one segment, three concatenated distinct segments, and 3 s of ECG signal with the accuracy of 87%, 84%, and 68%, respectively. The input of one segment had superiority in speed of computation and accuracy over other mentioned inputs. Here, the time of feature extraction was about 1 minute in one segment, and it was about 2.5 hours for the input of 3 s of the ECG signal. In optimum input (one segment of ECG), the feature LAM extracted from CRP of V1 and V2 leads together with the feature L extracted from CRP of V3 and V4 as features fed in KNN classifier could differentiate right and left APs with the accuracy of 87%.

5. Conclusion

The data indicated that the features extracted from the CRP of the precordial leads on ECG could differentiate right and left APs in WPW patients semi-automatically.

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7. References

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Appendix.

Table 1. Naming features extracted from CRPs of precordial leads.

	CRP(V1,V2)	CRP(V2,V3)	CRP(V3,V4)	CRP(V4,V5)	CRP(V5,V6)
LAM	P_1	P_5	P_9	P_{13}	P_{17}
TT	P_2	P_6	P_{10}	P_{14}	P_{18}
DET	P_3	P_7	P_{11}	P_{15}	P_{19}
L	P_4	P_8	P_{12}	P_{16}	P_{20}

Table 2. The result of classification using the most frequent features obtained from the histogram of Figure 1.

KNN	Feature 1	Feature 12	Features 1 and 12 together
The accuracy of the classification with k=1, 3, 5	51.61%	77.42%	87%

Table 3. The results of classification with different methods of feature reduction.

Method of feature reduction	Number of segments	Vector of features	Accuracy of the classification
Without feature reduction	1	[1, 2, 3, …, 20]	61%
Students t-test	1	[1, 2, 3, 4, 5, 7, 15, 18, 19]	66%
LO_SFS _ KNN_Ecludian distance	1	[1,12]	87%
LO_SFS_KNN_Cosine distance	1	[1, 2, 19]	84%
LO_SFS_KNN_Ecludian distance	3 concatenated segments	[1, 4, 5, 12, 13]	84%
LO_SFS_KNN_Ecludian distance	3 seconds of ECG signal	[2, 3, 5, 17, 9]	68%

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