Original Article

A simple algorithm for localizing accessory pathways in patients with Wolff-Parkinson-White syndrome using only the R/S ratio

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ABSTRACT

Background: Several algorithms for localizing accessory pathways (APs) are based on the delta wave morphology, R/S ratio, and QRS polarity. However, they are somewhat complicated, and an accurate determination of the delta wave morphology is occasionally difficult. The aims of this study were to develop a simple algorithm for localizing APs using only the R/S ratio, and to test the accuracy of the algorithm prospectively.
Methods: We studied 142 patients with a single anterogradely conducting AP on a 12-lead ECG. R/S ratios were analyzed in leads V1, V2, and aVF (R/S-V1, R/S-V2, and R/S-aVF). AP locations were divided into five regions based on fluoroscopic anatomy.
Results: A new algorithm was developed by correlating R/S-V1, R/S-V2, and R/S-aVF with successful ablation sites in 88 initial consecutive patients. All 55 patients with left free wall APs showed R/S-V1 ≥ 0.5, and 47 (98%) of 48 patients with left anterior or lateral APs showed R/S-aVF ≥ 1. In contrast, all seven patients with left posterolateral or posterior APs showed R/S-aVF < 1. All nine patients with right-and-left midseptal or posteroseptal APs showed R/S-V1 < 0.5 and R/S-V2 ≥ 0.5. Of 12 patients with right anterior, lateral or anteroseptal APs, 10 (83%) showed R/S-V1 < 0.5, R/S-V2 < 0.5 and R/S-aVF ≥ 1. Finally, nine (75%) of 12 patients with right posterolateral or posterior APs showed R/S-V1 < 0.5, R/S-V2 < 0.5, and R/S-aVF < 1. Then this algorithm was tested prospectively in 54 patients. Overall, the sensitivity was 94%, and the specificity was 98%.
Conclusions: This ECG algorithm provides a simple and accurate way to identify the AP localization.

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1. Introduction

Radiofrequency catheter ablation has been established as an effective and curative therapy for Wolff-Parkinson-White Syndrome [1–4]. Therefore, prediction of the precise location of an accessory pathway (AP) prior to the ablation procedure is of clinical importance. Several algorithms have been published to localize the AP on a surface 12-lead electrocardiogram (ECG) [5–8]. Most of them are based on analysis of delta wave morphology. However, they are somewhat complicated, and an accurate determination of the delta wave morphology is occasionally difficult. On the other hand, some algorithms based on the QRS polarity have been reported [9,10], but their accuracy is still limited. The aims of this study were to develop a simple and

highly accurate algorithm for localizing APs using only the R/S ratio, and to test the accuracy of the algorithm prospectively.

2. Material and methods

2.1. Study population

The study population consisted of 144 consecutive patients who underwent successful catheter ablation of the manifest AP at the Nagoya University Hospital between August 2000 and February 2013. One patient with prior myocardial infarction and another with multiple anterogradely conducting APs were excluded from analysis. We studied 142 patients (94 men, 48 ± 18 years) with a single, anterogradely conducting AP. None of the patients had cardiac abnormalities, such as Ebstein anomaly, that could affect the QRS morphology. Each patient gave written, informed consent, and all anti-arrhythmic drugs were discontinued for at least five half-lives before the study.

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2.2. Study design

This study was conducted in two parts: (1) a retrospective review of the preablation ECGs and successful ablation sites in 88 consecutive patients between August 2000 and December 2008, in order to develop the ECG algorithm; and (2) a prospective assessment of the algorithm on a second group of 54 consecutive patients between January 2009 and February 2013.

2.3. Electrophysiologic study and radiofrequency catheter ablation

Quadripolar catheters with a 5-mm interelectrode distance were introduced from the right femoral vein and positioned in the high right atrium and the right ventricle. A decapolar catheter was introduced from the right femoral vein and placed across the tricuspid valve to record His bundle activation. A decapolar catheter with a 5-mm interelectrode distance was introduced from the left subclavian vein and placed in the coronary sinus with the proximal electrode at the ostium. The presence and location of the AP, as well as the involvement of the AP in tachycardia, were determined by a previously described method [3]. In addition to standard fluoroscopy, a 3-dimensional electroanatomic mapping system (CARTO®, Biosense Webster, Diamond Bar, CA) was used to localize the anatomic position of the ablation catheter. Radiofrequency energy was delivered using a 4-mm-tip nonirrigated ablation catheter

(Navi-Star™, Biosense Webster, Diamond Bar, CA) with a target temperature of 55 °C, and a maximum power output of 35 W, or a 3.5-mm-tip irrigated catheter (NAVISTAR® THERMOCOOL®, Biosense Webster, Diamond Bar, CA) with a maximum power output of 35 W. The radiofrequency energy was delivered for up to 60 s, but was usually discontinued after 15 s if no loss of AP conduction was observed. If the AP conduction was still present, the catheter was repositioned and the procedure was repeated. The location of the ablation catheter was recorded in every radiofrequency delivery by multiplane fluoroscopy. The surface 12-lead ECG and intracardiac electrogram were displayed on a monitor using an EP-WorkMate system (St. Jude Medical, St. Paul, MN).

2.4. Anatomic locations of the accessory pathway

The AP locations were identified according to the successful ablation sites confirmed by multiplane fluoroscopy, and were divided into five main regions: (1) left anterior (LA) and left lateral (LL); (2) left posterolateral (LPL) and left posterior (LP); (3) right-and-left midseptal (MS) and posteroseptal (PS); (4) right posterolateral (RPL) and right posterior (RP); and (5) right anteroseptal (RAS), right anterior (RA), and right lateral (RL). The anatomic definition of each AP location is shown schematically in Fig. 1. The anatomic regions of the successful ablation sites were analyzed by two independent observers. In case of any disagreement between the two observers, a third independent observer decided which of the suggested anatomic regions should be chosen.

2.5. Electrocardiographic analysis

In all patients, standard 12-lead ECGs were recorded during sinus rhythm at a paper speed of 25 mm/s, one day prior to the ablation procedure. During sinus rhythm, the following measurements were obtained: (1) the peak amplitude of the R- and S-waves in leads V1, V2, and aVF; and (2) the R/S ratio, calculated as the R-wave amplitude divided by the S-wave amplitude in each lead. If there was no visible S wave, the S-wave amplitude was defined as 0.1 mV.

2.6. Statistical analysis

We used a Bayesian analysis with standard definitions for sensitivity, specificity, positive predictive value, and negative predictive value. The overall accuracy of the algorithm was calculated as a weighted average.
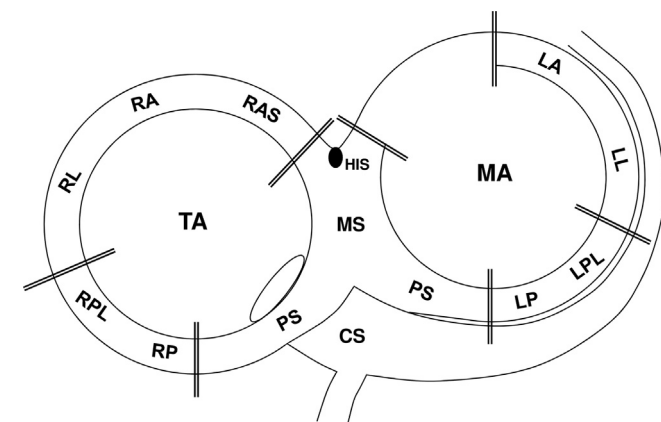

Fig. 1. Anatomic definition of accessory pathway location. A schematic diagram of the heart from the left anterior oblique projection shows the relation among the tricuspid annulus (TA), mitral annulus (MA), His bundle (HIS), coronary sinus (CS), and the anatomic locations of the accessory pathways. Accessory pathway locations are divided into five main regions, which are defined by double lines. Abbreviations: LA: left anterior; LL: left lateral; LP: left posterior; LPL: left posterolateral; MS: midseptal; PS: posteroseptal; RA: right anterior; RAS: right anteroseptal; RL: right lateral; RP: right posterior; and RPL: right posterolateral.
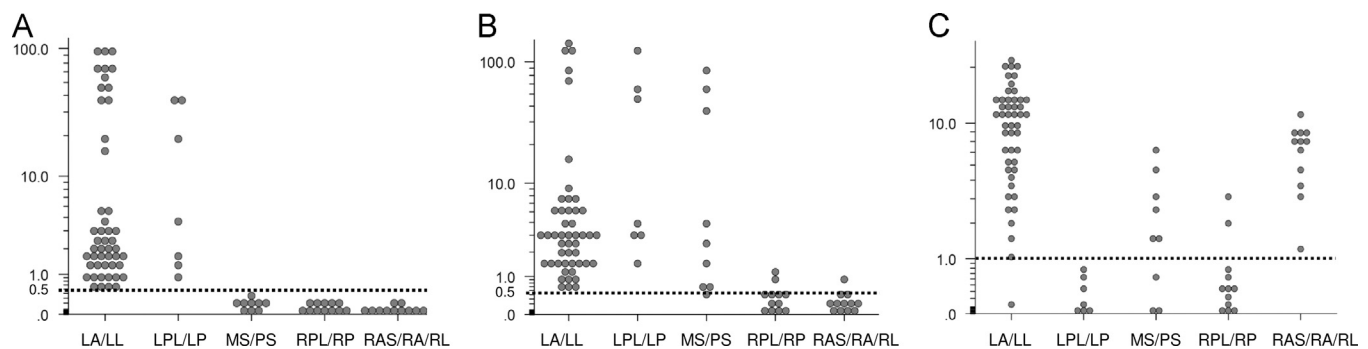

Fig. 2. Dot-plots showing R/S ratios of the initial 88 patients in each accessory pathway location. The dotted lines indicate the optimal cut-off value of the R/S ratio in each lead. (A) The LA/LL and LPL/LP regions were associated with an R/S ratio ≥ 0.5 in lead V1. (B) The LA/LL, LPL/LP, and MS/PS regions were associated with an R/S ratio ≥ 0.5 in lead V2. (C) The superior portion of the free wall APs (LA/LL and RAS/RA/RL regions) was associated with an R/S ratio ≥ 1 in lead aVF. On the other hand, the inferior portion (LPL/LP and RPL/RP regions) was associated with an R/S ratio < 1 in lead aVF. Abbreviations are the same as in Fig. 1.

3. Results

3.1. Accessory pathway locations

AP locations were determined based on successful ablation sites. Of the initial 88 patients, 48 were classified as being within the LA/LL region, seven within the LPL/LP region, nine within the MS/PS region, 12 within the RPL/RP region, and 12 within the RAS/RA/RL region. Of the nine patients classified within the MS/PS region, one was right midseptal, four were right posteroseptal, and four were left posteroseptal. There were no oblique accessory pathways crossing the anatomic regions defined in this study.

3.2. ECG algorithm development

The R/S ratios in leads V1, V2, and aVF were examined in each successful ablation site. There was considerable overlap in the R/S ratios between some contiguous sites, including LA and LL; LPL and LP; MS and PS; RPL and RP; RAS, RA, and RL. For this reason, pairs of contiguous successful ablation sites were grouped together into five main regions in the analysis. Dot-plots of the R/S ratios in leads V1, V2, and aVF are shown in Fig. 2. Among the initial 88 patients, all 55 with left free wall APs including the LA/LL and LPL/LP regions had an R/S ratio ≥ 0.5 in lead V1. Of the 48 patients classified as LA/LL region, 47 (98%) had an R/S ratio ≥ 1 in lead aVF. On the other hand, all seven patients classified as LPL/PL region had an R/S ratio < 1 in lead aVF. All nine patients classified as right-and-left MS/PS region had an R/S ratio < 0.5 in lead V1, and ≥ 0.5 in lead V2. Of 12 patients classified as RAS/RA/RL region, 10 (83%) had R/S ratios < 0.5 in leads V1 and V2, and ≥ 1 in lead aVF. Finally, nine (75%) of 12 patients classified as RPL/PL region

had R/S ratios < 0.5 in leads V1 and V2, and < 1 in lead aVF. Based on these results, a new ECG algorithm was developed using only the R/S ratios in leads V1, V2, and aVF, and is shown schematically in Fig. 3. The distribution of the AP locations and the accuracy of this ECG algorithm in each region are summarized in Table 1. This ECG algorithm correctly identified the AP locations in 82 (93%) of the 88 patients, and is described as follows:

Step 1: The R/S ratio in lead V1 is examined. If the R/S ratio in lead V1 is 0.5 or more, the AP is located in the free wall region of the mitral annulus (LA/LL or LPL/LP region). Proceed to Step 2.
If the R/S ratio in lead V1 is less than 0.5, the AP is located in the free wall region of the tricuspid annulus or septum. Proceed to Step 3.
Step 2: The R/S ratio in lead aVF is examined. If the R/S ratio in lead aVF is 1 or more, the AP is located in the LA/LL region. If it is less than 1, the AP is located in the LPL/LP region.
Step 3: The R/S ratio in lead V2 is examined. If the R/S ratio in lead V2 is 0.5 or more, the AP is located in the left or right MS/PS region. If the R/S ratio in lead V2 is less than 0.5, the AP is located in the RAS/RA/RL region or the RPL/RP region. Proceed to Step 4.
Step 4: The R/S ratio in lead aVF is examined. If the R/S ratio in lead aVF is 1 or more, the AP is located in the RAS/RA/RL region. If it is less than 1, the AP is located in the RPL/RP region.

Representative 12-lead ECGs of the five main regions are shown in Fig. 4.

3.3. ECG algorithm validation

The ECG algorithm was prospectively tested in 54 consecutive patients to assess its accuracy in predicting the successful ablation site. There were no oblique accessory pathways crossing the anatomic regions defined in this study. The distribution of the AP locations in these patients and the relationship between the predicted location and the actual location are shown in Table 2. The ECG algorithm correctly identified the AP locations in 51 (94%) of the 54 patients (sensitivity: 94%, specificity: 98%, positive predictive value: 92%, and negative predictive value: 98%).

4. Discussion

4.1. Main findings

In this study, we analyzed R/S ratios in only three leads (V1, V2, and aVF), and developed a simple ECG algorithm which could localize the APs in the five regions (LA/LL, LPL/LP, MS/PS, RPL/RP,
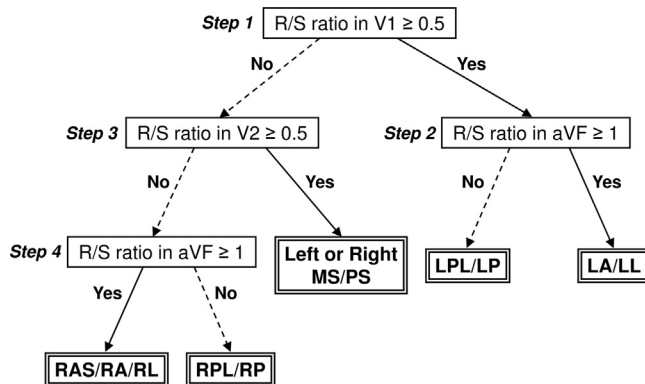

Fig. 3. Stepwise ECG algorithm for the determination of accessory pathway location. Abbreviations are the same as in Fig. 1.

Table 1
Correlation between the predicted accessory pathway location (ECG algorithm) and the actual location based on ablation site.

Ablation site	*n*	Predicted location					Accuracy			
		LA/LL	**LPL/LP**	**MS/PS**	**RPL/RP**	**RAS/RA/RL**	**Sens (%)**	**Spec (%)**	**PPV (%)**	**NPV (%)**
LA/LL	48	47	1				98	100	100	98
LPL/LP	7		7				100	99	88	100
MS/PS	9			9			100	95	69	100
RPL/RP	12			2	9	1	75	100	100	96
RAS/RA/RL	12			2		10	83	99	91	97
Total	88						93	99	95	98

LA: left anterior; LL: left lateral; LPL: left posterolateral; LP: left posterior; MS: midseptal; PS: posteroseptal; RPL: right posterolateral; RP: right posterior; RAS: right anteroseptal; RA: right anterior; RL: right lateral; Sens: sensitivity; Spec: specificity; PPV: positive predictive value; and NPV: negative predictive value.
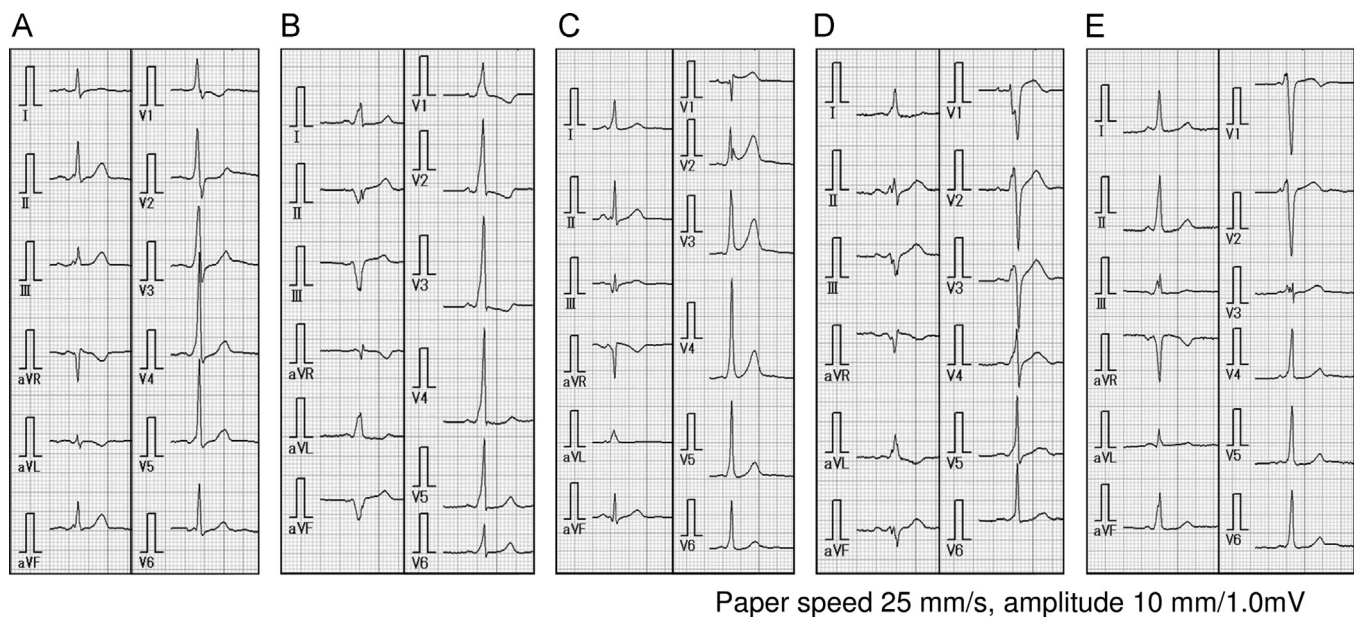
Paper speed 25 mm/s, amplitude 10 mm/1.0mV

Fig. 4. Representative 12-lead ECGs of the different accessory pathways. (A) In a case with the LA/LL accessory pathway, the R/S ratios were 0.5 or more in lead V1, and 1 or more in lead aVF. This case was successfully ablated in the LL region. (B) In a case with the LPL/LP accessory pathway, the R/S ratios were 0.5 or more in lead V1, and less than 1 in lead aVF. This case was successfully ablated in the LPL region. (C) In a case with the MS/PS accessory pathway, the R/S ratios were less than 0.5 in lead V1, and 0.5 or more in lead V2. This case was successfully ablated in the left PS region. (D) In a case with the RPL/RP accessory pathway, the R/S ratios were less than 0.5 in leads V1 and V2, and less than 1 in lead aVF. This case was successfully ablated in the RPL region. (E) In a case with the RAS/RA/RL accessory pathway, the R/S ratios were less than 0.5 in leads V1 and V2, and 1 or more in lead aVF. This case was successfully ablated in the RAS region. Abbreviations are the same as in Fig. 1.

Table 2
Correlation between the predicted accessory pathway location (ECG algorithm) and the actual location based on ablation site.

Ablation site	n	Predicted location					Accuracy			
		LA/LL	LPL/LP	MS/PS	RPL/RP	RAS/RA/RL	Sens (%)	Spec (%)	PPV (%)	NPV (%)
LA/LL	22	21	1				95	100	100	97
LPL/LP	10		10				100	95	83	100
MS/PS	11		1	10			91	98	91	98
RPL/RP	7				7		100	98	88	100
RAS/RA/RL	4				1	3	75	98	75	98
Total	54						94	98	92	98

Data were obtained from 54 patients (prospective analysis).
LA: left anterior; LL: left lateral; LPL: left posterolateral; LP: left posterior; MS: midseptal; PS: posteroseptal; RPL: right posterolateral; RP: right posterior; RAS: right anteroseptal; RA: right anterior; RL: right lateral; Sens: sensitivity; Spec: specificity; PPV: positive predictive value; and NPV: negative predictive value.

and RAS/RA/RL). The ECG algorithm was 93% accurate in the retrospective analysis, and 94% accurate in the prospective assessment. Therefore, this ECG algorithm can provide a rapid and accurate assessment of the AP locations as one follows a simple flowchart.

4.2. Localization of the left free wall, right free wall and septal accessory pathways

In previous studies [5,9,10] positive QRS polarity or an R/S ratio ≥ 1 in lead V1 was used for identifying left free wall APs. However, we found that there were nine (16%) cases with an R/S ratio < 1 in lead V1 among the 55 patients with left free wall APs of the retrospective group. Therefore, we used the optimal cut-off value of an R/S ratio ≥ 0.5 in lead V1, which yielded 100% sensitivity in both, the retrospective and prospective groups.

The R/S ratio in lead V2 also had an essential role in differentiating the midseptal and posteroseptal APs from the right free wall and right anterior septal APs in this study. Chiang et al. [11] previously reported that an R/S ratio ≥ 1 in lead V2 was a useful marker for identifying the right and left posteroseptal APs, and left

free wall APs. Iturralde et al. [9] and d'Avila et al. [10] also reported that the right posteroseptal APs were associated with positive QRS polarity in lead V2. However, we found one right posteroseptal and two left posteroseptal cases with an R/S ratio < 1 in lead V2 in the retrospective group. Therefore, we used the optimal cut-off value of an R/S ratio ≥ 0.5 in lead V2 for differentiating the midseptal and posteroseptal APs from the right free wall and right anterior septal APs, and this yielded 100% sensitivity in both, the retrospective and prospective groups.

Anatomically, the location of the tricuspid annulus is more anterior to, and to the right of the mitral annulus. In addition, the right free wall aspect of the tricuspid annulus is more anterior to, and to the right of the atrioventricular septum. A possible reason for the larger R/S ratio in lead V2 of the midseptal and posteroseptal APs was the more posterior location of the atrioventricular septum, and the larger R/S ratio in lead V1 of the left free wall APs was due to the more posterior location of the left free wall aspect of the mitral annulus.

In this study, the R/S ratio in lead aVF was useful for differentiating the anterior and lateral APs from the posterolateral and posterior APs in both, right and left free wall APs.

4.3. Comparison with the algorithm based on the delta wave morphology

Delta wave morphology reflects the ventricular attachment site of the AP, and the R/S ratio also depends on the AP location. The R/S ratio can change with the timing differences between AP conduction and atrioventricular nodal conduction, so that the analysis of delta wave morphology may identify the AP location more accurately. However, because there were very few cases with impaired atrioventricular node conduction, the region-specific R/S ratios could be obtained constantly in this study. As it is occasionally difficult to accurately determine the delta wave morphology, we believe that the algorithm based on the R/S ratio may be more convenient.

4.4. Clinical implications

This ECG algorithm allows rapid assessment of the AP locations by following a simple flowchart and it will help in the development of a strategy for catheter ablation.

4.5. Study limitations

A limitation of this study is that the sample size in the prospective assessment was small. Therefore, further prospective investigation is needed to fully determine the reliability of this new algorithm. Another limitation of this ECG algorithm is the difficulty of differentiating the detailed AP localization around the paraseptal regions. Although we tried to develop an algorithm that could subdivide the paraseptal regions into the detailed septal regions, it was impossible to do so using only the R/S ratios.

Another limitation is that the accuracy of this algorithm may be affected by the magnitude of the delta wave, cardiac rotation, bundle branch block, and axis deviation. Of the nine mispredicted patients, three patients had counter-clockwise cardiac rotation, two had left axis deviation, and one had incomplete right bundle branch block in the post-ablation ECG. The remaining three patients had no ECG abnormality in the post-ablation ECG (data not shown). We speculate that the presence of counter-clockwise cardiac rotation and right bundle branch block are associated with greater R/S ratios in lead V1 and V2 in the preablation ECG. On the other hand, clockwise cardiac rotation and left bundle branch block may be associated with smaller R/S ratios in leads V1 and V2. Left axis deviation may be associated with a smaller R/S ratio in lead aVF. However, it is difficult to know these ECG abnormalities prior to successful ablation.

5. Conclusion

We present a simple ECG algorithm that can rapidly identify the AP localization with high sensitivity and specificity.

Conflict of interest

The authors declare that there were no conflicts of interest. No financial support was received for this study.

References

[1] Jackman WM, Wang XZ, Friday KJ, et al. Catheter ablation of accessory atrioventricular pathways (Wolff-Parkinson-White syndrome) by radiofrequency current. N Engl J Med 1991;324:1605–11.

[2] Warin JF, Haissaguerre M, D'Ivernois C, et al. Catheter ablation of accessory pathways: technique and results in 248 patients. Pacing Clin Electrophysiol 1990;13:1609–14.

[3] Kay GN, Epstein AE, Dailey SM, et al. Role of radiofrequency ablation in the management of supraventricular arrhythmias: experience in 760 consecutive patients. J Cardiovasc Electrophysiol 1993;4:371–89.

[4] Iesaka Y, Takahashi A, Chun YH, et al. Radiofrequency catheter ablation of atrioventricular accessory pathways in Wolff-Parkinson-White syndrome with drug-refractory and symptomatic supraventricular tachycardia—its high effectiveness irrespective of accessory pathway location and properties. Jpn Circ J 1994;58:767–77.

[5] Arruda MS, McClelland JH, Wang X, et al. Development and validation of an ECG algorithm for identifying accessory pathway ablation site in Wolff-Parkinson-White syndrome. J Cardiovasc Electrophysiol 1998;9:2–12.

[6] Fitzpatrick AP, Gonzales RP, Lesh MD, et al. New algorithm for the localization of accessory atrioventricular connections using a baseline electrocardiogram. J Am Coll Cardiol 1994;23:107–16.

[7] Lindsay BD, Crossen KJ, Cain ME. Concordance of distinguishing electrocardiographic features during sinus rhythm with the location of accessory pathways in the Wolff-Parkinson-White syndrome. Am J Cardiol 1987;59:1093–102.

[8] Milstein S, Sharma AD, Guiraudon GM, et al. An algorithm for the electrocardiographic localization of accessory pathways in the Wolff-Parkinson-White syndrome. Pacing Clin Electrophysiol 1987;10:555–63.

[9] Iturralde P, Araya-Gomez V, Colin L, et al. A new ECG algorithm for the localization of accessory pathways using only the polarity of the QRS complex. J Electrocardiol 1996;29:289–99.

[10] d'Avila A, Brugada J, Skeberis V, et al. A fast and reliable algorithm to localize accessory pathways based on the polarity of the QRS complex on the surface ECG during sinus rhythm. Pacing Clin Electrophysiol 1995;18:1615–27.

[11] Chiang CE, Chen SA, Teo WS, et al. An accurate stepwise electrocardiographic algorithm for localization of accessory pathways in patients with Wolff-Parkinson-White syndrome from a comprehensive analysis of delta waves and R/S ratio during sinus rhythm. Am J Cardiol 1995;76:40–6.