Contemporary procedure characteristics and outcomes of accessory atrioventricular pathway ablations in an integrated community-based health care system

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Abstract

Purpose

Descriptions of large series of accessory atrioventricular pathway (AP) ablations in adults and adolescents have been limited to referral centers and published over 20 years ago. We aimed to characterize contemporary accessory AP distribution and features in a large community-based population that influence ablation outcomes.

Methods

Retrospective analysis of 289 patients (age 14–81) who underwent AP ablation from 2015–2019 was performed. Pathways were categorized into anteroseptal (AS), left freewall (LFW), posteroseptal (PS), and right freewall (RFW) locations. We analyzed patient and pathway features to identify factors associated with prolonged procedure time parameters.

Results

Initial ablation success rate was 94.7% with long-term success rate of 93.4% and median follow-up of 931 days. APs were in LFW (61.6%), PS (24.6%), RFW (9.6%), and AS (4.3%) locations. Procedure outcome was dependent on pathway location. Acute success was highest for LFW pathways (97.1%) with lowest case times (144 ± 68 minutes) and fluoroscopy times (15 ± 19 minutes). Longest procedure time parameters were seen with AS, left anterolateral, epicardial-coronary sinus, and right anterolateral pathway ablations. A novel ECG algorithm was developed to predicts AP locations and further guide procedure planning.

Conclusion

In this community-based population, majority of APs are located in the left freewall and posteroseptal region, with only retrograde conduction, and can be ablated using traditional approaches with short time parameters and high success. Using a novel ECG algorithm for pathway localization, we can predict cases with longer procedure times, higher fluoroscopy exposure, and lower acute and long-term success for manifest pathways.

Introduction

Catheter ablation using radiofrequency (RF) energy has been the cornerstone of therapy for patients with accessory atrioventricular pathways (AP) since its safety and efficacy was first described in the 1990s (1–5). These reports demonstrated high acute success and low complication rates. Early reports have also identified factors associated with failure of ablation procedures. Failure of procedures have been

attributed to technical challenges such as poor catheter stability, inaccurate mapping, failure to record AP potential, and pathway locations such as right sided, posteroseptal, and anteroseptal regions (6–8). These studies included short term follow up and have not provided important procedure characteristics such as fluoroscopy time and case times which are crucial in the procedure planning process. A study in the pediatric population examined long-term outcomes of AP catheter ablation and identified pathway features that predict ablation failure or long-term recurrence (9). Such long-term analysis of AP ablations has not been done in the adolescent and adult population. AP features may influence procedural efficiency, acute success, and long-term outcome. Identifying cases that are predicted to have poor efficiency and outcome using traditional mapping and ablation approaches, and selective use of three-dimensional mapping and transseptal left atrial access may improve overall procedural and cost efficiency.

Although various ECG classification methods for identification of pathway location are already available (10–15), there is no established single standard. We drew on previous published work to develop a novel ECG algorithm for pathway localization based on delta wave polarity and R/S wave transition across various sets of leads.

Comprehensive assessment of patient and AP features that influence procedural time parameters, acute, and long-term success has not been described in the adolescent and adult population in the modern era. In this study, we characterized patient and AP features, and identify predictors of procedural complexity, and acute and long-term success of catheter ablation in a contemporary community-based adolescent and adult population.

Methods

Patient selection and follow up protocol

We identified 289 consecutive patients ranging in age from 14 to 81, who underwent RF ablation procedures for accessory AP from 2015 to 2019 at Kaiser Medical Center, Santa Clara, California, USA. The source population included the Kaiser Permanente Northern California Heath Care System with more than 4 million members with demographics reflective of the US population (16). Patients included those with (i) ventricular pre-excitation with documentation of SVT or atrial fibrillation, (ii) asymptomatic ventricular pre-excitation, or (iii) SVT with concealed accessory AP.

A 12-lead ECG was obtained immediately post ablation and at least one-year post ablation in all patients. Patient charts were reviewed at 1-5 years post ablation. Recurrences were identified by return of ventricular pre-excitation or recurrence of documented SVT by ECG or event monitor at any point during follow up period. Intermittent pre-excitation was categorized as recurrence. All clinical encounters were reviewed within the follow up period for recurrence of ventricular pre-excitation or SVT. Patients with less than one year follow up were excluded. The study protocol including ethics review was approved by the Institutional Review Board of Kaiser Permanente.

Ablation procedure

During comprehensive electrophysiology study, recordings from the tricuspid and mitral annulus were obtained using 7 French steerable duodecapolar or decapolar catheters inserted into the coronary sinus. Recordings were also obtained from the His bundle as well as the right ventricular apex using 5-6 French quadripolar catheters. Mapping and ablation were performed using standard 4-5mm tip ablation catheters. Open-irrigated catheters, remote magnetic navigation (Stereotaxis, St. Louis, MO), and 3D mapping with Carto (Biosense Webster, Diamond Bar, CA) or Ensite (Abbott, Santa Clara, CA) mapping systems were used at the operator's discretion. In general, our institutional preference for initial ablation procedure is to use standard non-irrigated ablation catheters without 3D mapping. For left sided APs, our initial approach is generally retrograde transaortic. Use of transseptal approach is at the discretion of the operator. If transseptal approach was done, Brockenbrough needle was used with intracardiac echocardiography guidance. Irrigated catheters were used in 11% of initial ablations and 36.4% of repeat ablation procedures. 3D mapping was used in 3.9% of initial procedures and 31.8% of repeat procedures (Table 1 and Table 2).

Non-irrigated RF ablations were performed in temperature-controlled mode targeting 30-50W with temperature limit of 55-70^{o}C. Open-irrigated ablations were performed targeting 20-45W depending on the location of the AP. Power output was limited to ≤25W for ablations inside the coronary sinus. Ablations were performed in 30-60 second intervals with end point of anterograde and retrograde AP conduction block and SVT non-inducibility. Post ablation, if acutely successful, at least 30 minutes of wait period was generally included prior to termination of procedure.

Accessory pathway characteristics and ablation outcome analysis

AP ablation locations were separated into four anatomic groups, anteroseptal (AS), left freewall (LFW), posteroseptal (PS), and right freewall (RFW), as previously described (10). PS region in this study encompass all septal pathways, including mid-septal from below the His to the coronary sinus ostium and is separated into three regions, left posteroseptal (LPS), right posteroseptal (RPS), and subepicardial coronary venous system (Epi-CS). The AS group included both true para-Hisian pathways defined by the presence of a His potential recorded at the site of ablation, and right anterior pathways located within one centimeter of the His recording site as viewed in LAO 45^{o}.

ECG algorithm for AP localization

116 ECGs with baseline ventricular preexcitation were examined with an algorithm to test accuracy in predicting the known AP location based on successful ablation site. Pathways were localized based on the following 12 lead ECG characteristics:

1. Anteroseptal: Precordial R/S transition occurs relatively late at V3 or later with positive delta wave at least in leads II and aVF.

2. Left freewall: Delta wave is equiphasic or positive in V1 and are negative at least in lead aVL. As a subgroup of LFW pathways, left anterolateral (LAL) pathways, given their superior location on the mitral annulus, have positive delta waves in at least leads II and aVF.
3. Posteroseptal: Precordial R/S transition occurs early at V1-V2, with negative delta waves in at least two inferior leads, aVF and III. As a subgroup, RPS pathways have a negative or equiphasic delta in V1, with a characteristic abrupt transition to positive delta and R>S wave at V2. LPS pathways are more leftward leaning with positive delta wave at V1. The subepicardial CS venous system (Epi-CS) is a unique subset of PS pathways, which are at the most inferior aspect of the heart resulting in characteristic negative delta or Q wave in lead II.
4. Right freewall: Precordial R/S transition is late and ≥ V3. As a subgroup of RFW, right anterolateral and right anterior pathways which we group together and classify as RAL have positive delta in at least leads II and aVF.

Statistics

Statistical analysis was performed using Prism 8.4.2 software (GraphPad Software, San Diego, CA) and Microsoft Excel for Office 365 (Microsoft Corporation, Redmond, WA). Numerical data are presented as median ± interquartile range. For continuous variables, comparisons among groups were analyzed using one-way ANOVA test. To assess statistical significance of differences in frequency of dichotomous variables, contingency tables were created comparing observed frequencies to expected frequencies using Chi-square test. P-values are presented for all statistical analyses.

To compare freedom from recurrence post ablation procedures, survival data was plotted using the Kaplan-Meier method. The log rank test was used to detect statistical difference among groups.

Results

Patient and accessory pathway characteristics

During the study period (2015-2019), a total of 304 accessory AP ablation were performed. 281 of these procedures were initial ablations (Figure 1). 22 patients underwent repeat ablation which were all successful without long term recurrence except for one, for whom a third procedure was performed successfully.

The distribution of pathway locations was not uniform (Figure 2). Two groups together accounted for 83.2% of cases (LFW: 61.6% and PS: 24.6%). LFW pathways were less likely to be manifested (31.8%) compared to pathways from other locations (p=0.004; Table 1). RFW and AS pathways were relatively uncommon comprising 9.6%, and 4.3% of all cases respectively.

In our population, 80.8% of patients undergoing RF ablation had demonstrated atrioventricular reciprocating tachycardia (AVRT). Multiple accessory pathways were reported in 3.6% of cases (Table 1).

Patient characteristics such as age, sex, and left ventricular function were not statistically different among the four AP groups (Table 1).

Known major complications associated with ablations such as cerebral vascular events, cardiac perforation, tamponade, myocardial infarction or death did not occur. Two cases were complicated by AV block requiring pacemaker implants (one from LPL group and one from RPS group). One patient had a femoral arterial pseudoaneurysm (LPL group).

Initial procedure acute outcome

For left atrial and ventricular access, our initial approach was generally retrograde aortic (196 of 199 cases, 98.5%), with 173 of these cases being LFW pathway ablations. Overall use of open-irrigated catheters and 3D mapping during initial ablation was 11% and 3.9 %, which was much lower than during repeat ablations (36.4% and 31.8%, respectively). More open-irrigated catheters were used in the PS group (21.7%) with 7/15 of these cases being inside the coronary sinus system (Table 1).

Acute success was achieved in 94.7% of all initial procedures (LFW: 97.1%; PS: 95.7%; RFW: 87%; and AS: 75%) (Table 1). Median fluoroscopy time was highest in AS group (33 ± 30 min) and lowest in LFW group (15 ± 19 min). Longest ablation duration times were in AS (422 ± 318s) and RFW (519 ± 539s) groups (Table 1 and Figure 3). Total case time, as defined by time from patient arrival to exit from the EP laboratory, was longest in AS group (203 ± 77 min) and shortest in LFW group (144 ± 68 min) (Table 1 and Figure 3). Significant number of outliers were seen in each group (Figure 3).

The number and proportion of cases with prolonged procedure time parameters (fluoroscopy, ablation, and case times) for all four groups and specific locations within the groups were tabulated (Table 3). The following times were defined as prolonged: procedure time ³ 200 min, fluoroscopy time ³ 30 min, and ablation time ³ 400 sec. Anatomic locations that had a greater than 50% of cases with prolonged time parameters were highlighted. These locations consisted of AS, LAL, Epi-CS, and RAL. Common reasons cited for prolonged times were, (i) limited mapping capability, (ii) limited lesion formation, (iii) difficult ablation catheter navigation, (iv) multiple chambers mapped, and (v) incidental secondary arrhythmias requiring ablation.

Long term outcome of initial ablation procedures

With median follow up of 931 days post ablation in patients who had initial successful ablations, 93.4% remained free from recurrence of SVT or ventricular pre-excitation (Figure 4a). Long term success was lower at 75.0% for AS pathways compared with 98.2% for LFW pathways (p=0.002 log-rank test; Figure 4b). RFW and PS pathways have similar long-term outcome (90.0% and 90.8% respectively, Figure 4b). There were no statistical differences by age, sex, or ventricular pre-excitation in acute or long-term outcome (data not shown).

ECG predictors for specific pathway locations of interest

An ECG algorithm was developed based on the following rationale. Sets of leads represent planes of axis through the heart. Anterior-posterior axis is represented by the precordial leads V1-V6. Pathways which are located most anteriorly such as RAL, transitions the latest, generally with R/S = 1 at or after V3; whereas pathway farthest away from the chest wall such as LFW leads display R>S by V1 (Figure 5a). The superior-inferior axis is revealed by inferior leads II, aVF, and III. As the pathway location transitions from an inferior to a superior location, delta wave in lead II first becomes positive followed by lead aVF and then by lead III (Figure 5b). Left-right axis is represented by lateral leads I and aVL. As the pathway location transitions from right to left, lead aVL first becomes negative, then lead I (Figure 5c).

This ECG algorithm was tested on 116 ECGs with ventricular pre-excitation representing all four groups. Of special interest were specific locations within groups (AS, LAL, Epi-CS, RAL) characterized as being more difficult to ablate based on prolonged procedure time parameters (Table 3). The algorithm was validated at each pathway location for sensitivity, specificity, and negative predictive value (Figure 5d). The positive predictive value (PPV) was not utilized as it is subject to wide variations at locations with only a small number of pathways relative to adjacent locations that may have overlap in ECG characteristics. There is significant overlap with AS and RAL pathways, as precordial transition pattern does not differentiate clearly in the anterior portion of the RA shared by both pathways.

Sensitivity and specificity varied but were generally high at most individual locations. Of note, both the sensitivity and negative predictive value for AS, LAL, Epi-CS, and RAL locations were all equal to 1 (Figure 5d). There were no false negatives, suggesting that if an ECG did not display characteristics of AS, LAL, Epi-CS, and RAL pathways as described, there is extremely high likelihood (100%) that the pathway would not be localized to these specific sites. ECGs with baseline preexcitation patterns from AS, LAL, Epi-CS, and RAL pathways demonstrate characteristic patterns (Figure 6).

Discussion

Over a four-year period from 2015 through 2019, 289 patients underwent radiofrequency ablation procedures for AP in our institution. The source population included the Kaiser Permanente Northern California Health System with diverse demographics that reflect large portions of the US population. As the sole referral center for this population, 97.2% patients in this study had their first ablation at our institution. Without a referral bias towards complexity and repeat ablations, this study was able to identify all ablations derived from a large population group and was able to give an accurate picture regarding the distribution of pathway locations.

Distribution of pathway locations

Consistent with prior studies (3,4), we found that the most common location of accessory pathways was left freewall followed by posteroseptal region. There may be developmental correlates of this finding that is consistent in pediatric and now adolescent and adult populations. In the early stages of cardiac development, the developing left ventricle is continuous with the atrial myocardium including the basilar aspect of the eventual septum (17). The development of accessory muscular connections may be a

vestige of the atrial – left ventricular connection that persisted through the subsequent formation of the fibroadipose insulating tissue of the atrioventricular canal. Thus, APs would be more common along the mitral annulus. Interestingly, we also found that distinct from other locations, the majority of LFW pathways only demonstrated retrograde conduction. This may be due in part to the distinctive embryologic origin of the mitral annular to the tricuspid annular tissues. The tricuspid annular tissue derives not only from atrioventricular canal myocardium like the mitral annulus but also primary ring tissue which forms much of the normal anterograde decremental conduction system (17). In fact, this is thought to contribute to pathophysiology of unusual pathways with physiologic properties similar to AV node found along the tricuspid annulus of the RFW. Perhaps the embryologic presence of the primary ring tissue in the tricuspid annulus is more conducive to anterograde conduction when accessory AV connection are formed. Findings in this study and others suggest such correlation with the developing cardiac conduction system and pathophysiology of accessory atrioventricular pathways (18).

Outcome of ablation at different locations

Our acute procedural success (94.7%) and major complication rate (1.0%) for all ablations are in line with previous large reported series (4,19). Acute success rates varied amongst groups with highest success for LFW pathways (97.1%) and lowest success for AS pathways (75%). Lower success rate was associated with a greater degree of difficulty as measured by prolonged procedural time parameters.

We were able to make comparisons on the degree of difficulty encountered during AP ablation between major groups as well as identify specific regions within each group that were particularly more challenging to ablate. From review of the reasons for prolonged times contained in the procedure report, we surmise that transient loss of AP conduction during ablation energy delivery was the most common cause of prolonged time parameters. Inability to create an effective lesion for complete ablation of the AP may be the result of (i) poor ablation catheter contact, (ii) power output limited by temperature, (iii) limited proximity to actual site of pathway. These potential reasons for prolonged procedure time parameters were likely due to problematic pathway anatomic locations.

Difficult pathway locations for ablation

Ablations of pathways at specific locations within the anatomic groups were identified as difficult in this study. Pathways located in the LAL region can be uniquely challenging. A potential explanation is that mapping becomes more limited by the inability to employ multipole catheter recordings effectively as the coronary sinus diverges away from the mitral valve annulus as it courses more anteriorly. Catheter stability can also be limiting in this region. As a group, Epi-CS pathways are generally more difficult due to need for multi-chamber mapping. RFW pathways were also challenging with a significantly lower acute success rate (87%). The angle of entry into the RA from the IVC favors the catheter to be directed septally and requires additional manual torque for the catheter to reach and contact the lateral wall. These anatomical characteristics makes catheter maneuverability and stability more difficult, as reflected by the significantly longer ablation application time required in this group. AS pathways presented challenges due to its proximity to the AV node. Although risk of AV node injury is minimized with ablation

approached from the ventricular side (4), maneuvering the catheter to a stable position in the right ventricle is inherently difficult and accounts for highest total case times among the four groups.

Efficiency and cost saving

Our experience with employing standard techniques without 3D mapping and with retrograde aortic approach for left sided pathways as the initial strategy is unique in the current environment. We demonstrated that most of these ablations can be performed successfully with procedural and cost efficiency with standard mapping and ablation tools. Given greatly reduced use of expensive equipment, this approach is both efficient and cost-effective. Our overall use of open-irrigated catheters (11%) and three-dimensional mapping (3.9%) at the initial ablation procedure was low compared to other studies (9,20,21).

However, in specific pathway locations where anatomy and catheter access and stability present challenges leading to longer case times and fluoroscopy exposure as demonstrated in this study, supplemental tools may be helpful. 3D mapping enhances mapping accuracy in cases where multipolar mapping is not ideal such as in LAL and RAL locations. Open-irrigated ablation can also ensure more effective lesions inside the CS vein and during ablation on the ventricular side of the myocardium where close tissue contact results in limited power output limited by temperature elevations. Remote magnetic navigation may enhance maneuverability of the ablation catheter when targeting specific pathway locations (22).

An effective ECG algorithm validated in this study emphasized transition of R/S ratio and delta wave polarity as an intuitive way to use the ECG to predict pathway location, and thereby procedure degree of difficulty, and potential benefit of supplemental tools at initial approach. The algorithm emphasized areas of overlap as it is based on transitions of delta wave or R/S polarity. These overall strategy with selective use of supplemental tools based on predicted AP location may improve overall procedure planning, efficiency, cost, and outcome.

Study Limitations

AP locations were only documented as narratives in the procedure report with fluoroscopic images unavailable to verify a successful site. This could result in subjective inaccurate assignment of the pathway location. However, the inaccurate assignment would likely be to a close adjacent site and not across a major group.

Although reasons for prolonged procedure times were tabulated, their actual frequency of occurrence within a given location could not be quantified since only narrative information entered in the report at the discretion of the operator was included, with under-reporting a potential significant issue. Despite this, we were able the summarize common reasons for prolonged times within each specific site.

Abbreviations

AP = atrioventricular pathway

RF = radiofrequency

SVT = supraventricular tachycardia

TVA = tricuspid valve annulus

MVA = mitral valve annulus

AS = anteroseptal

PS = posteroseptal

RFW = right freewall

LFW = left freewall

Declarations

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Conflicts of interest/Competing interests

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethics approval

This study was approved by the Kaiser Permanente Institutional Review Board.

Consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and material

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability

Not applicable

Authors' contributions

Charlie Young MD- Concept/design, Data analysis/interpretation, Drafting article, Critical revision of article, Approval of article

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Taylor I. Liu MD, PhD- Concept/design, Data analysis/interpretation, Drafting article, Critical revision of article, Approval of article, Statistics, Funding secured by, Data collection

Disclosures

The authors have no disclosures

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References

1. Garg J, Shah N, Krishnamoorthy P, Mehta K, Bozorgnia B, Boyle NG, et al. Catheter ablation of accessory pathway: 14-year trends in utilization and complications in adults in the United States. Int J Cardiol [Internet]. 2017 Dec 1 [cited 2020 Sep 23];248:196–200. Available from: https://pubmed.ncbi.nlm.nih.gov/28712558/
2. Lesh MD, Van Hare GF, Schamp DJ, Chien W, Lee MA, Griffin JC, et al. Curative percutaneous catheter ablation using radiofrequency energy for accessory pathways in all locations: Results in 100 consecutive patients. J Am Coll Cardiol [Internet]. 1992 [cited 2020 Sep 23];19(6):1303–9. Available from: https://pubmed.ncbi.nlm.nih.gov/1564231/
3. Calkins H, Sousa J, el-Atassi R, Rosenheck S, de Buitleir M, Kou WH, et al. Diagnosis and cure of the wolff-parkinson-white syndrome or paroxysmal supraventricular tachycardias during a single electrophysiologic test. N Engl J Med. 1991 Jun 6;324(23):1612–8.

4. Jackman WM, Wang X, Friday KJ, Roman CA, Moulton KP, Beckman KJ, et al. Catheter ablation of accessory atrioventricular pathways (wolff-parkinson-white syndrome) by radiofrequency current. N Engl J Med. 1991 Jun 6;324(23):1605–11.
5. Kugler JD, Danford DA, Deal BJ, Gillette PC, Perry JC, Silka MJ, et al. Radiofrequency catheter ablation for tachyarrhythmias in children and adolescents. N Engl J Med. 1994 May 26;330(21):1481–7.
6. Twidale N, Wang X, Beckman KJ, McLelland JH, Moulton KP, Prior MI, et al. Factors Associated with Recurrence of Accessory Pathway Conduction After Radiofrequency Catheter Ablation. Pacing Clin Electrophysiol. 1991;14(11):2042–8.
7. Xie B, Heald SC, Camm AJ, Rowland E, Ward DE. Radiofrequency catheter ablation of accessory atrioventricular pathways: Primary failure and recurrence of conduction. Heart. 1997;77(4):363–8.
8. Morady F, Strickberger SA, Man KC, Daoud E, Niebauer M, Goyal R, et al. Reasons for prolonged or failed attempts at radiofrequency catheter ablation of accessory pathways. J Am Coll Cardiol [Internet]. 1996 Mar 1 [cited 2020 Sep 23];27(3):683–9. Available from: https://pubmed.ncbi.nlm.nih.gov/8606282/
9. Backhoff D, Klehs S, Müller MJ, Schneider HE, Dieks JK, Paul T, et al. Long-Term Follow-Up After Radiofrequency Catheter Ablation of Accessory Atrioventricular Pathways in Children. JACC Clin Electrophysiol. 2018 Apr 1;4(4):448–55.
10. Arruda MS, Mcclelland JH, Wang X, Beckman KJ, Widman LE, Gonzalez MD, et al. Development and validation of an ECG algorithm for identifying accessory pathway ablation site in Wolff-Parkinson-White syndrome. J Cardiovasc Electrophysiol [Internet]. 1998 [cited 2020 Sep 23];9(1):2–12. Available from: https://pubmed.ncbi.nlm.nih.gov/9475572/
11. Fitzpatrick AP, Gonzales RP, Lesh MD, odin GW, Lee RJ, Scheinman MM. New algorithm for the localization of accessory atrioventricular connections using a baseline electrocardiogram. J Am Coll Cardiol. 1994 Jan 1;23(1):107–16.
12. Giorgi C, Nadeau R, Primeau R, Campa MA, Cardinal R, Shenasa M, et al. Comparative accuracy of the vectorcardiogram and electrocardiogram in the localization of the accessory pathway in patients with Wolff-Parkinson-White syndrome: Validation of a new vectorcardiographic algorithm by intraoperative epicardial mapping and electrophysiologic studies. Am Heart J. 1990;119(3 PART 1):592–8.
13. Haissaguerre M, Marcus F, Poquet F, Gencel L, Le Métayer P, Clémenty J. Electrocardiographic characteristics and catheter ablation of parahissian accessory pathways. Circulation [Internet]. 1994 [cited 2020 Sep 23];90(3):1124–8. Available from: https://pubmed.ncbi.nlm.nih.gov/8087922/
14. Chiang CE, Chen SA, Siong Teo W, Tsai DS, Wu TJ, Cheng CC, 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 [Internet]. 1995 [cited 2020 Sep 23];76(1–2):40–6. Available from: https://pubmed.ncbi.nlm.nih.gov/7793401/

15. Takahashi A, Shah DC, Jaïs P, Hocini M, Clementy J, Haïssaguerre M. Specific electrocardiographic features of manifest coronary vein posteroseptal accessory pathways. J Cardiovasc Electrophysiol [Internet]. 1998 [cited 2020 Sep 23];9(10):1015–25. Available from: https://pubmed.ncbi.nlm.nih.gov/9817553/
16. Koebnick C, Langer-Gould AM, Gould MK, Chao CR, Iyer RL, Smith N, et al. Sociodemographic characteristics of members of a large, integrated health care system: comparison with US Census Bureau data. Perm J [Internet]. 2012 [cited 2020 Sep 20];16(3):37–41. Available from: https://pubmed.ncbi.nlm.nih.gov/23012597/
17. Anderson RH, Sánchez-Quintana D, Mori S, Lokhandwala Y, Correa FS, Wellens HJJ, et al. Unusual variants of pre-excitation: From anatomy to ablation: Part I—Understanding the anatomy of the variants of ventricular pre-excitation. J Cardiovasc Electrophysiol. 2019;
18. de Chillou C, Maria Rodriguez L, Schläpfer J, Kappos KG, Katsivas A, Baiyan X, et al. Clinical characteristics and electrophysiologic properties of atrioventricular accessory pathways: Importance of the accessory pathway location. J Am Coll Cardiol. 1992;
19. Pappone C, Vicedomini G, Manguso F, Saviano M, Baldi M, Pappone A, et al. Wolff-parkinson-white syndrome in the era of catheter ablation insights from a registry study of 2169 patients. Circulation [Internet]. 2014 Sep 2 [cited 2020 Sep 20];130(10):811–9. Available from: https://pubmed.ncbi.nlm.nih.gov/25052405/
20. Ceresnak SR, Dubin AM, Kim JJ, Valdes SO, Fishberger SB, Shetty I, et al. Success rates in pediatric WPW ablation are improved with 3-dimensional mapping systems compared with fluoroscopy alone: A multicenter study. J Cardiovasc Electrophysiol. 2015 Apr 1;26(4):412–6.
21. Kubuš P, Vít P, Gebauer RA, Zaoral L, Peichl P, Fiala M, et al. Long-term results of paediatric radiofrequency catheter ablation: A population-based study. Europace. 2014 Oct 8;16(12):1808–13.
22. Chun JKR, Ernst S, Matthews S, Schmidt B, Bansch D, Boczor S, et al. Remote-controlled catheter ablation of accessory pathways: Results from the magnetic laboratory. Eur Heart J [Internet]. 2007 Jan [cited 2020 Sep 24];28(2):190–5. Available from: https://pubmed.ncbi.nlm.nih.gov/17218451/

Tables

Table 1. Patient Characteristics

Patient and Procedure Characteristics	All Patients (N=281)	Anteroseptal (N=12)	Left Freewall (N=173)	Posteroseptal (N=69)	Right Freewall (N=27)	p-value
Female	117 (41.6%)	4 (33.3%)	70 (40.5%)	30 (43.5%)	13 (48.1%)	ns
Age (years)	38 ± 27	28 ± 22	39 ± 25	37 ± 30	32 ± 21	ns
LVEF (%)	60 ± 5	60 ± 5	60 ± 5	60 ± 5	60 ± 5	ns
Manifest pathway	116 (41.3%)	7 (58.3%)	**55 (31.8%)**	36 (52.2%)	15 (55.6%)	***0.004***
Multiple pathways	10 (3.6%)	0 (0%)	4 (2.3%)	3 (4.3%)	3 (11.1%)	ns
Secondary arrhythmia	11 (3.9%)	1 (8.3%)	5 (2.9%)	4 (5.8%)	1 (3.7%)	ns
Tachyarrhythmia:						
AF	18 (6.4%)	0 (0%)	9 (5.2%)	6 (6.9%)	3 (11.1%)	ns
AVRT	227 (80.8%)	11 (91.7%)	149 (86.1%)	**44 (63.8%)**	23 (85.2%)	***<0.001***
Open Irrigated Ablation	31 (11.0%)	1 (8.3%)	13 (7.5%)	**15 (21.7%)**	2 (7.4%)	***0.014***
3D Mapping	11 (3.9%)	2 (16.7%)	4 (2.4%)	4 (5.8%)	1 (3.7%)	ns
Fluoroscopy Time (min)	17 ± 22	**33 ± 30**	15 ± 19	19 ± 24	19 ± 26	***<0.001***
Ablation Application Duration (sec)	278 ± 330	**422 ± 318**	278 ± 398	270 ± 289	**519 ± 539**	***0.003***
Total Case Time (min)	155 ± 74	**203 ± 77**	144 ± 68	160 ± 75	155 ± 96	***<0.001***
Acute Procedure Success	266 (94.7%)	**9 (75.0%)**	168 (97.1%)	66 (95.7%)	**23 (85.2%)**	***0.001***

Table 2. Repeat Procedures

	Repeat Procedures (N= 22)
Anterior/Anteroseptal AP	2 (9.1%)
Left Freewall AP	8 (36.4%)
Posteroseptal AP	7 (31.8%)
Right Freewall AP	5 (22.7%)
First procedure at outside facility	8 (36.4%)
Open Irrigated Ablation	8 (36.4%)
3D Mapping	7 (31.8%)
Acute Success	21 (95.5%)
Long term Success	21/21 (100%)

Table 3. Cases with prolonged procedure, fluoroscopy, and ablation times

	Procedure Time ≥ 200 min.	**Fluoroscopy Time ≥ 30 min**	**Ablation Time ≥ 400 sec**
All Patients (N=281)	66 (23.5%)	76 (27.0%)	88 (31.3%)
Anteroseptal (N=12)	**8 (66.7%)**	**6 (50.0%)**	**7 (58.3%)**
Left Freewall (N=173)	29 (16.8%)	35 (20.2%)	41 (23.7%)
Left AL FW (N=7)	***6 (85.7%)***	***5 (71.4%)***	***4 (57.1%)***
Posteroseptal (N=69)	20 (29.0%)	25 (36.2%)	23 (33.3%)
Right PS (N=38)	*11 (28.9%)*	*12 (31.6%)*	*13 (34.2%)*
Left PS (N=25)	*6 (24.0%)*	*11 (44.0%)*	*7 (28%)*
Epi-CS (N=6)	***3 (50.0%)***	*2 (33.3%)*	***3 (50%)***
Right Freewall (N=27)	9 (33.3%)	10 (37.0%)	**17 (63.0%)**
Right AL FW (N=6)	***4 (66.7%)***	***3 (50.0%)***	***3 (50.0%)***

Figures

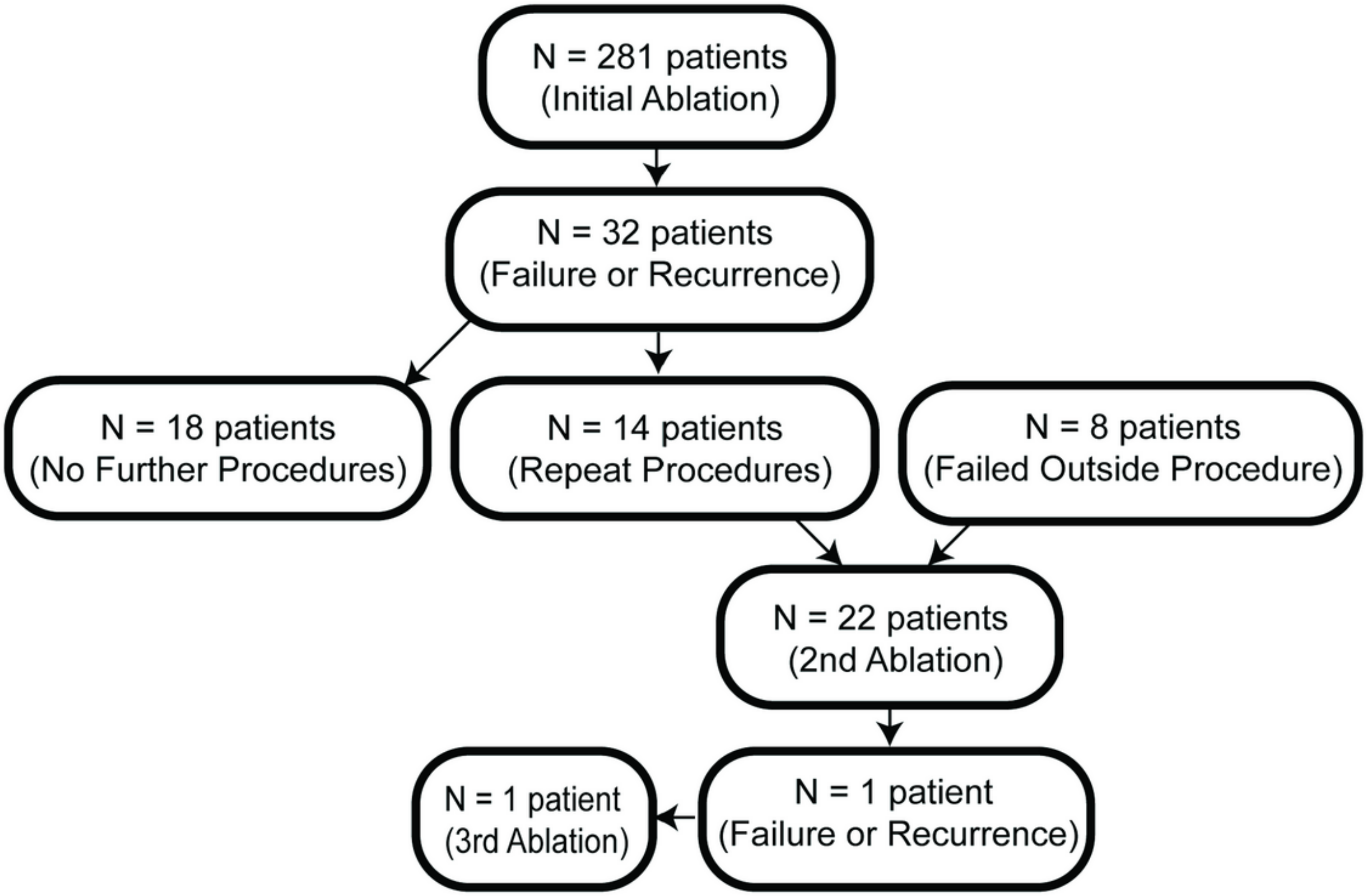


Figure 1

Study patients Number of patients in our cohort.

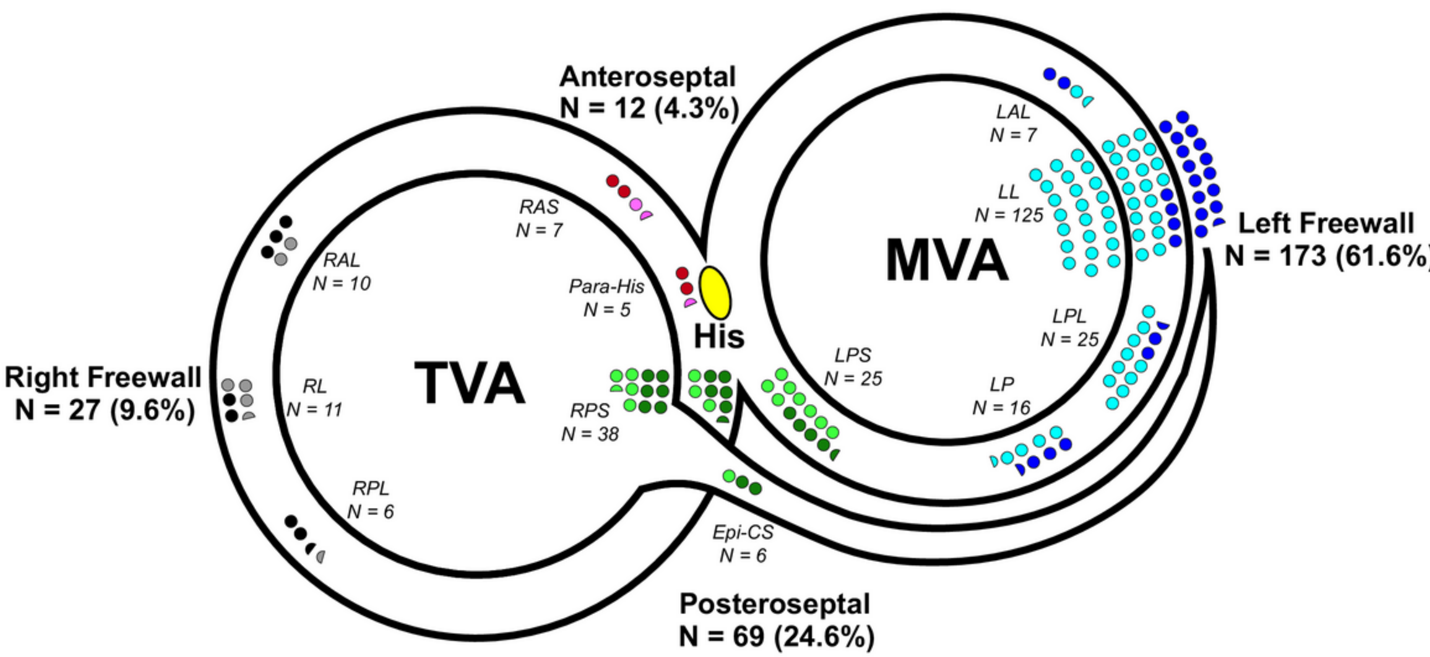


Figure 2

Distribution of accessory atrioventricular pathways The number and proportion of patients with accessory AP locations are displayed along tricuspid valve annulus (TVA) and mitral valve annulus (MVA). His bundle recording is labeled yellow. Number of patients are proportionately represented by the number of circles (each circle represents 2 patients). Anteroseptal pathways are red (manifest) or pink (concealed). Left freewall pathways are dark blue (manifest) or light blue (concealed). Posteroseptal pathways are dark green (manifest) or light green (concealed). Right freewall pathways are black (manifest) or gray (concealed). Sub-regional locations are listed. Epi-CS- epicardial-coronary sinus; LAL- left anterolateral; LL- left lateral; LP- left posterior; LPL- left posterolateral; LPS- left posteroseptal; RAL- right anterolateral; RAS- right anteroseptal; RL- right lateral; RP- right posterior; RPL- right posterolateral; RPS- right posteroseptal

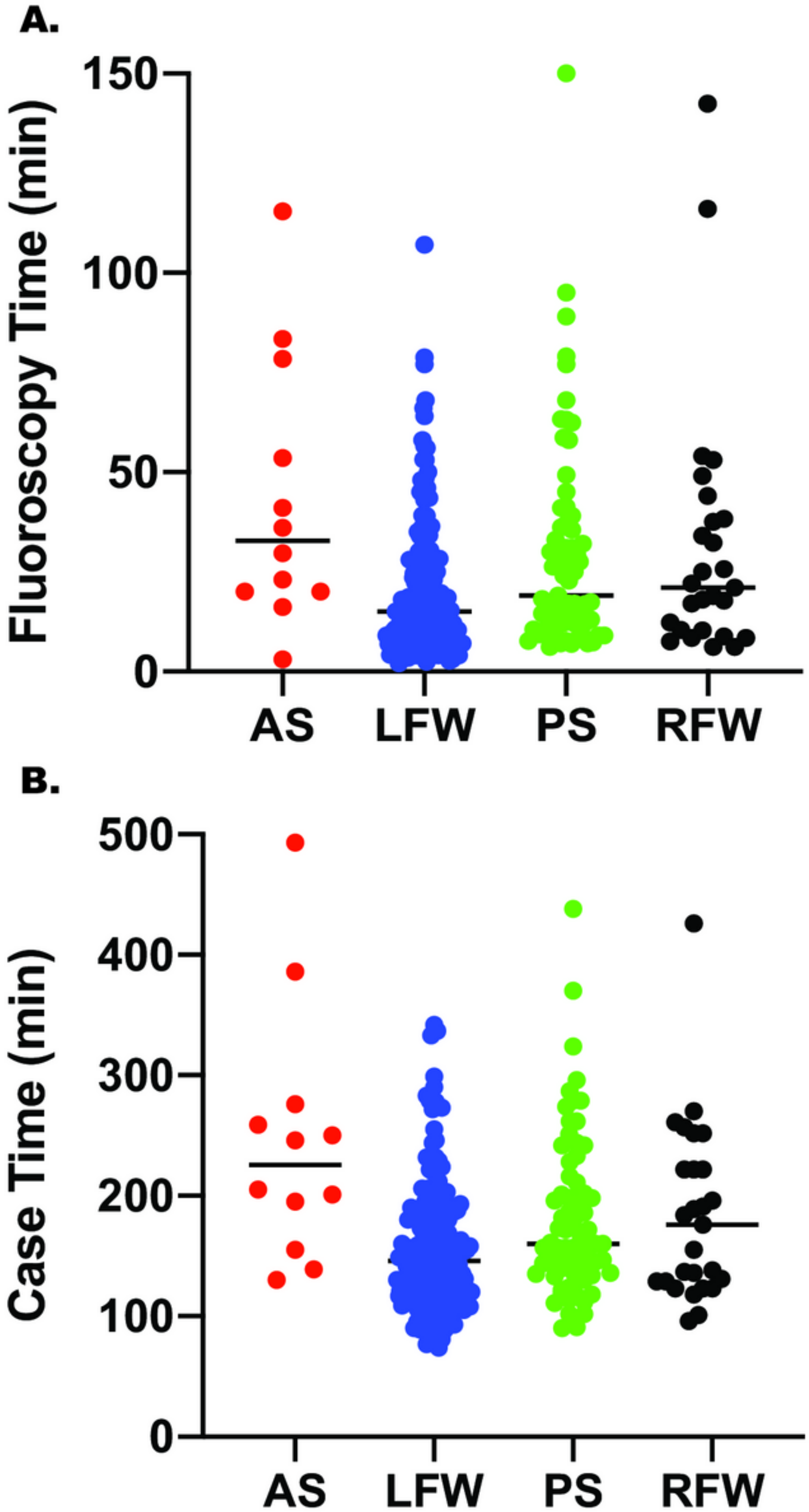


Figure 3

Case times and fluoroscopy times The total case times (A) and fluoroscopy times (B) for the initial ablation procedures are shown for each AP location group, anteroseptal (red), left freewall (blue), posteroseptal (green), and right freewall (black). Each dot represents one case. Median times are also displayed as black horizontal line.

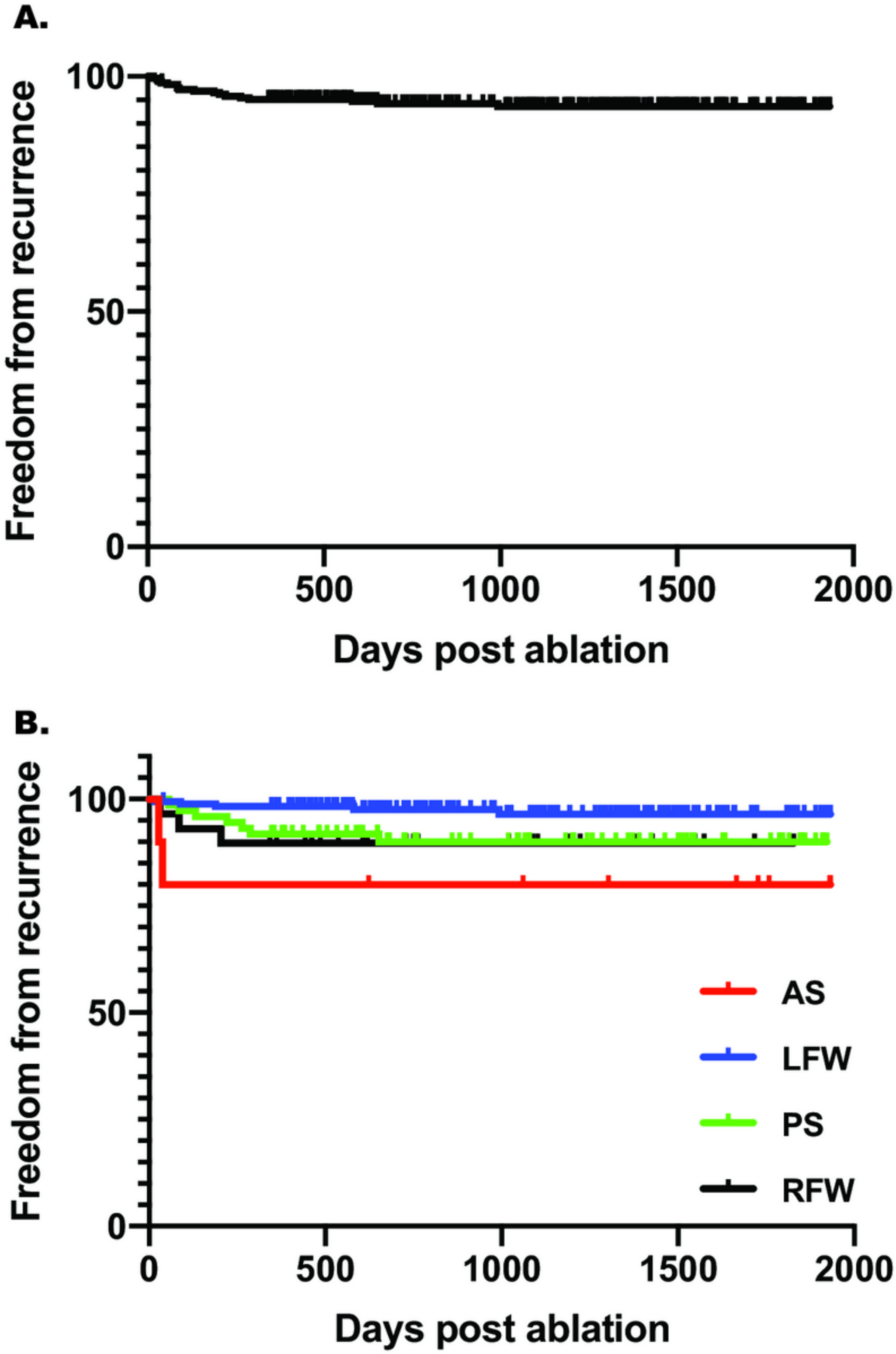
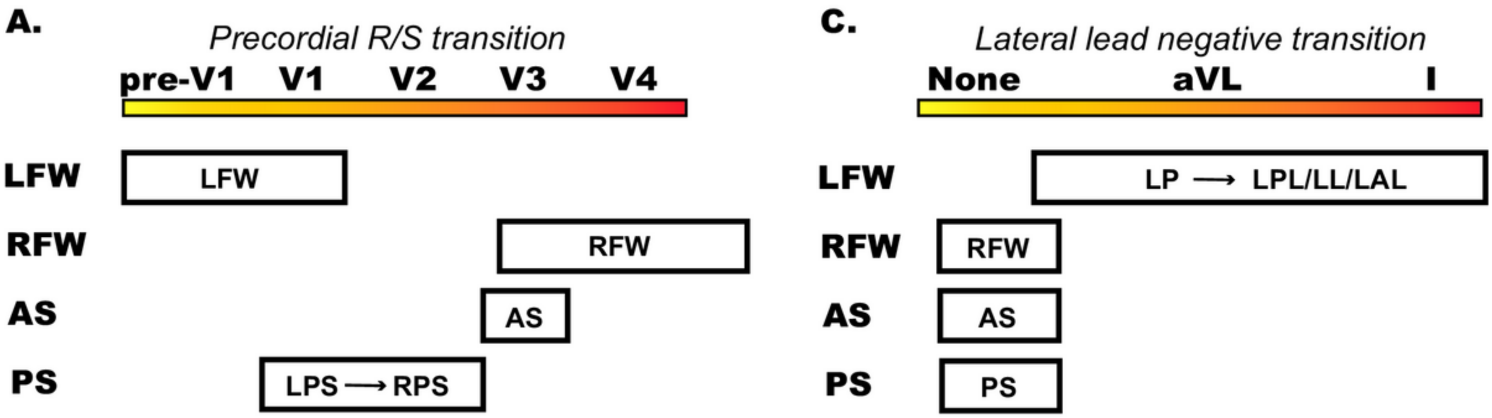
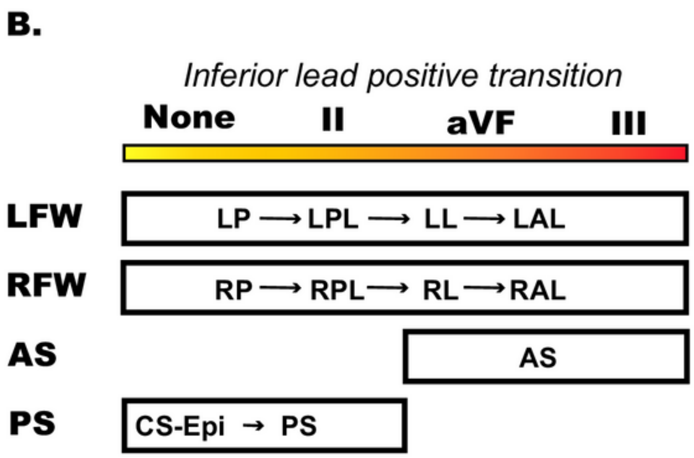


Figure 4

Freedom from recurrence post ablation Kaplan Meier curve depicting the long-term freedom from recurrence of ventricular pre-excitation or SVT in all patients (A) and (B) among patients with AP at specific location groups, anteroseptal (red), left freewall (blue), posteroseptal (green), right freewall (black).





D.

Pathway Location	Sensitivity	Specificity	NPV
LFW	0.75	1	0.81
LAL	1	0.73	1
RFW	0.6	0.97	0.94
RAL	1	0.9	1
AS	1	0.91	1
PS	0.92	0.85	0.96
RPS	0.83	0.97	0.96
LPS	0.67	0.86	0.97
CS-Epi	1	0.97	1

Figure 5

ECG localization of manifest accessory pathways AP localization algorithm for ECGs with ventricular pre-excitation is shown graphically. (A) The anterior-posterior axis is represented by precordial V1-V6 R/S transition. (B) Superior-inferior axis is represented by delta wave polarity transition in II, aVF, and III. (C) The right-left axis is represented by delta wave polarity transition in lateral leads I and aVL. (D) Sensitivity, specificity, and negative predictive values (NPV) are reported for each AP location. AS- anteroseptal; Epi-CS- epicardial-coronary sinus; LAL- left anterolateral; LFW- left freewall; LPS- left posteroseptal; PS- posteroseptal; RAL- right anterolateral; RFW- right freewall; RPS- right posteroseptal

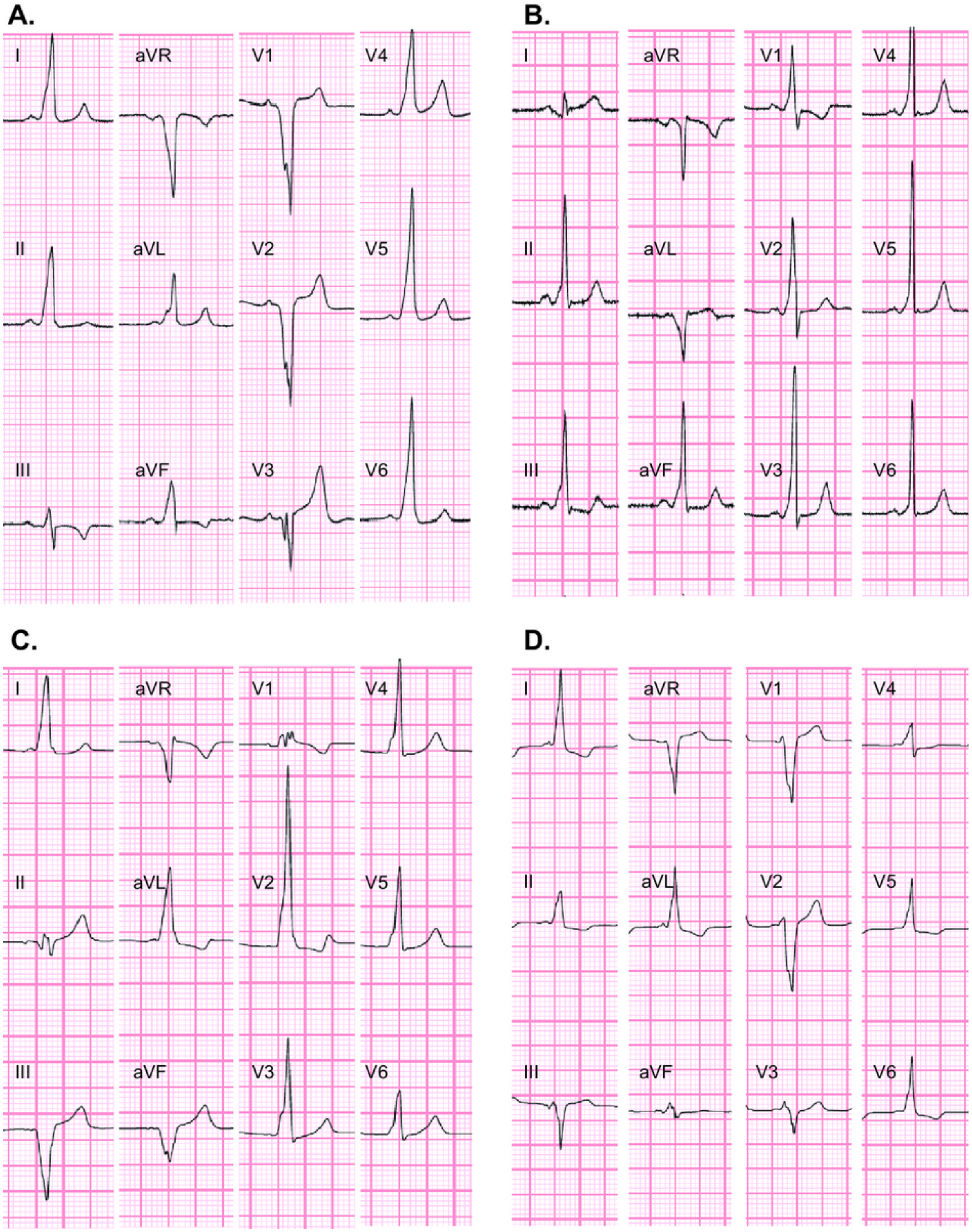


Figure 6

ECG patterns associated with accessory pathway locations Typical ECG patterns associated with (A) anteroseptal, (B) left anterolateral freewall, (C) epicardial- coronary sinus, and (D) right anterolateral pathways are shown.