## Original Article

# Electrocardiographic Criteria for Differentiating Endocardial from Epicardial Posterseptal Accessory Pathways to Guide Catheter Ablation

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## Highlights

- A negative delta wave in lead II, a positive delta wave in aVR, a positive delta wave in V1, and/or QRS notching in lead II predict an epicardial posteroseptal accessory pathway.
- A negative delta wave in V1 and/or an R/S ratio <1 in V1 predict an endocardial posteroseptal accessory pathway, with a positive delta wave in aVR and R/S <1 in V1 serving as independent predictors.
- These ECG criteria can guide preprocedural planning-redirecting roughly 25–30% of posteroseptal APs from a right endocardial to a coronary sinus approach-thereby reducing procedure time, radiation exposure, and futile ablation attempts.

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## ABSTRACT

**Background:** Radiofrequency (RF) catheter ablation is the standard treatment for symptomatic patients with Wolff-Parkinson-White (WPW) syndrome. Successful RF ablation of an accessory pathway (AP) depends on accurate localization of its site.

**Methods:** This retrospective, observational, cross-sectional study included all consecutive patients who underwent successful RF ablation of a single manifest posteroseptal AP at the Cardiac Electrophysiology Laboratory of the Cardiovascular Department, Cairo University Hospitals. Twelve-lead electrocardiograms were collected and analyzed to identify electrocardiographic criteria that differentiate epicardial from endocardial posteroseptal APs to guide mapping and ablation strategies.

**Results:** Seventy-three patients with a posteroseptal AP were included: 47 were ablated from the right posteroseptal endocardium; 6 from the left posteroseptal endocardium; and 20 were ablated epicardially (from the coronary sinus or its branches). Epicardial posteroseptal APs were predicted by a negative delta wave in lead II, a positive delta wave in lead aVR, a positive delta wave in lead V1, and/or QRS complex notching in lead II. Endocardial posteroseptal APs were predicted by a negative delta wave in lead V1 and/or an R/S ratio less than 1 in lead V1. Double QRS transition was not useful for differentiation unless combined with a Q wave or predominantly negative QRS complex in lead V1.

**Conclusion:** Epicardial and endocardial posteroseptal APs can be differentiated based on delta wave polarity in leads II, aVR, and V1; R/S ratio in lead V1; and QRS complex notching in lead II.

**Keywords:** Electrocardiogram; Catheter Ablation; Posteroseptal Accessory Pathway

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## Introduction

Radiofrequency (RF) catheter ablation is the preferred treatment for patients with Wolff-Parkinson-White (WPW) syndrome. Ablation success depends primarily on accurate accessory pathway (AP) localization. Analyzing the preexcitation pattern on the surface electrocardiogram (ECG) during sinus rhythm is the first step in AP localization.

Posteroseptal APs are the most frequently reported pathways with an epicardial course, with an incidence of 9% to 24% among all posteroseptal pathways.[1-4] Pathways in this location pose a diagnostic challenge because of the anatomical complexity of the area-at the crux of the 4 cardiac chambers-and the high risk of complications, including atrioventricular (AV) node and coronary artery injury.[5] Posteroseptal APs can be ablated from either the right or left endocardium. Nonetheless, failure of the endocardial approach often raises suspicion of an epicardial location, necessitating alternative ablation strategies.[6-10] Epicardial ablation, from within the coronary sinus (CS) or its branches, is reported for pathways refractory to endocardial ablation.[1-3,10-12] Although several studies have correlated surface ECG patterns with AP insertion sites, few have accounted for epicardial AP locations.[13]

Accurate localization of the AP site is critical for preprocedural patient counseling regarding potential risks, particularly if an epicardial location is anticipated, and for guiding the initial mapping strategy (eg, selecting the appropriate ablation catheter, such as an irrigated-tip catheter for epicardial pathways in comparison with a standard nonirrigated catheter for endocardial pathways).

The present study aimed to identify the 12-lead ECG criteria that differentiate endocardial from epicardial posteroseptal APs.

## Methods

### Patients and Study Design

This retrospective, observational, cross-sectional study included all consecutive patients who underwent an electrophysiologic (EP) study and successful RF ablation of a single manifest posteroseptal AP at the EP lab of the Cardiovascular Department, Cairo University Hospitals, between 2018 and 2024. Data were collected from the EP database using a structured extraction form. Variables included clinical data, preprocedural 12-lead ECG parameters, EP mapping findings, and successful ablation approach (endocardial vs epicardial). ECGs were recorded at a paper speed of 25 millimeters per second and a calibration of 10 mm/mV. All preprocedural ECGs were independently reviewed by 2 electrophysiologists blinded to the successful ablation site; all discrepancies were resolved by consensus.

Patients were excluded if they had known structural heart disease, a manifest pathway in a location other than the posteroseptal region based on 12-lead localization, multiple APs, a failed or aborted ablation procedure, Mahaim fibers, incomplete medical data, or no baseline ECG.

The study protocol was approved by the Institutional Review Board of Cairo University. A waiver of informed consent was granted because of the retrospective design, minimal risk to participants, and use of deidentified data, in accordance with the Declaration of Helsinki.

### Clinical Data

Detailed medical history and cardiovascular risk factors were reviewed for all eligible patients.

### ECG Selection of Posteroseptal Pathways

Among patients with manifest preexcitation, the Fitzpatrick algorithm was drawn upon to select those with a posteroseptal location. A positive QRS complex in leads I and aVL, negative delta-wave polarity in the inferior leads, and early precordial QRS transition localized the AP to the posteroseptal region.

### ECG Criteria Used for Differentiating Endocardial vs Epicardial Pathways

- **PR interval:** Measured from the beginning of the P wave to the beginning of the QRS complex.

- **Delta-wave polarity:** The initial 40 milliseconds of the preexcited QRS complex was assessed. Delta-wave polarity was classified as positive (the entire delta wave above baseline), negative (the entire delta wave below baseline), isoelectric (the entire delta wave on the baseline), or biphasic (the delta wave composed of both positive and negative components).
- **R/S ratio in frontal and precordial leads:** The R/S ratio was calculated as the sum of positive deflections divided by the sum of negative deflections. It was classified as positive (R/S ratio>1 [predominant positive QRS complex]), negative (R/S ratio <1 [predominant negative QRS complex]), or equiphasic (R/S ratio=1).
- **Precordial QRS transition:** Based on R/S amplitude, an equiphasic R and S wave at any lead indicated that QRS transition occurred at that lead. A dominant R wave in any lead indicated that QRS transition occurred before that lead, whereas a dominant S wave in any lead indicated that QRS transition occurred after that lead (eg, if the S wave was dominant in lead $V_1$ and the R wave was dominant in lead $V_2$, QRS transition occurred between $V_1$ and $V_2$).
- **Presence of double QRS transition:** The proportion of the positive QRS component increased from lead $V_1$ to $V_2$ and beyond $V_3$ but decreased between leads $V_2$ and $V_3$. Thus, the positive QRS component in $V_1$ was less than that in $V_2$ and greater than that in $V_3$.
- **Maximum QRS width**
- **Presence of QRS notching in the inferior leads**

## EP Study and Ablation

The standard protocol of the institution conducting the study was as follows. Written informed consent was obtained from all patients before the EP study and RF catheter ablation. Antiarrhythmic drugs were discontinued for a minimum of 5 half-lives before the procedure. Studies were performed under conscious sedation with midazolam and/or fentanyl. Three venous sheaths (two 6F and one 7F) were inserted percutaneously via the right femoral vein under local anesthesia. A 6F quadripolar catheter was placed at the right ventricular apex, a 6F decapolar catheter in the CS, and a 4-mm-tip ablation catheter or a 3.5-mm irrigated-tip catheter, according to the suspected location of the pathway, was placed at the His bundle for mapping and ablation. Catheter positions were confirmed by cine fluoroscopy in left anterior oblique 30°, right anterior oblique 30°, and anteroposterior views. Cine images were obtained to document catheter position and the successful ablation site. Intracardiac electrograms from bipolar electrodes and surface ECGs were continuously monitored and stored utilizing a computer-based digital amplifier-recorder system. EP studies followed standard protocols. Signals were recorded at 1000 Hz (bipolar filters, 30 to 250 Hz; 50-Hz notch filter). Measurements were performed at a sweep speed of 200 millimeters per second. The ventricular AP insertion site was mapped and ablated at the site of the earliest bipolar ventricular potential relative to delta-wave onset. Transseptal access to the left atrium was performed when mapping of the mitral annulus was required. Standard RF energy was used; irrigated-tip catheters were employed for epicardial ablation within the CS or its branches. RF applications used a power of less than or equal to 50 W and a temperature limit of 50 °C or lower during sinus rhythm and were delivered for 60 seconds. Delivery was stopped early for catheter movement or an impedance rise. Acute success required AP conduction block at RF cessation and after 30 minutes. A postablation EP study, after a 20- to 30-minute waiting period, confirmed the absence of other APs and AP recurrence and assessed AV node–His bundle conduction.

## Anatomical Localization of Posteroseptal AP

The exact AP location was determined by the successful ablation site: right posteroseptal AP-earliest ventricular activation during antegrade conduction at the posteroseptal region of the tricuspid annulus or CS ostium; ablated via a transvenous right endocardial approach. Left posteroseptal AP-earliest activation at the posteroseptal region of the mitral annulus; ablated via a transseptal left endocardial approach.

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Epicardial AP-successful ablation within the CS, middle cardiac vein, or CS diverticulum.

Patients were classified into 2 groups according to the successful ablation site: the endocardial group, including those successfully ablated at the right or left posteroseptal region, and the epicardial group, including those successfully ablated within the CS or its branches.

## Statistical Analysis

Data were coded and entered using SPSS version 28 (IBM Corp, Armonk, NY). Data were summarized using mean (SD) for quantitative variables and frequency (No.) and percentage (%) for categorical variables.

For comparisons of categorical data, the $\chi^2$ test was performed. The Fisher exact test was employed when the expected frequency was less than 5. Standard diagnostic indices-including sensitivity, specificity, positive predictive value, negative predictive value, and diagnostic efficacy-were calculated as described by Galen.[1] Interobserver agreement was assessed for different ECG variables included in the Results section (delta-wave polarity, R/S transition, QRS transition, double transition, and QRS notching). Two independent reviewers scored 120 randomly selected ECGs, and the quoted $\kappa$ equals to 0.89 reflects agreement before consensus adjudication. Discrepancies were then resolved by joint review to produce the final dataset. The multivariable logistic regression model included the following ECG variables: delta-wave polarity; R/S ratio in $V_1$; QRS precordial transition; double transition; and QRS notching. All candidate variables listed above were entered into the multivariable model simultaneously. For statistically significant associations, odds ratios (ORs) with 95% confidence intervals (CIs) were reported. A *P* value less than .05 was considered statistically significant.

## Results

A total of 215 consecutive patients with manifest APs who underwent EP study and RF ablation were screened. Of these, 86 had posteroseptal APs according to Fitzpatrick ECG criteria. Thirteen patients were excluded, and 73 patients were included in the final analysis (Figure 1). The mean age of the study population was 37.7 (10.8) years, and nearly half were male (56%). The most common comorbidity was hypertension (13.7%) (Table 1).

Patients were divided into 2 groups based on the ablation site:

**Endocardial group:** Patients who underwent successful ablation using nonirrigated catheters for a single manifest posteroseptal AP from the endocardium. This group included 2 subgroups (Figure 1).

**Epicardial group:** Patients who underwent successful ablation using irrigated-tip catheters for a single manifest AP from the epicardial venous structures of the heart. This group included 20 patients (27.4% of the study population) (Figure 1).

## ECG Criteria in the Endocardial Group vs the Epicardial Group

### Delta-Wave Polarity

Comparison of delta-wave polarity in the frontal leads (Table 2) revealed significant differences between the 2 groups in leads II, aVR, and $V_1$. A negative delta wave in lead II was observed in 85% of the epicardial group (P<.001) (Figure 2), showing 79% specificity, 85% sensitivity, and 60% positive predictive value for epicardial AP. A positive delta wave in lead aVR occurred in 60% of the epicardial group (P<.001) (Figure 2), demonstrating high specificity (98%) and positive predictive value (92%) but limited sensitivity (60%) for epicardial posteroseptal AP. A positive delta wave in lead $V_1$ was observed in 75% of the epicardial group (P< .001). It was associated with epicardial AP, with 77% specificity, 75% sensitivity, and 55% positive predictive value. A negative delta wave in lead $V_1$ occurred in 64% of the endocardial group (P< .001); it exhibited high specificity (90%) but low sensitivity (64%) for endocardial posteroseptal AP (Supplementary Table S1).

## R/S Ratio in the Precordial and Frontal Leads

A predominantly negative QRS complex in lead $V_1$ (R/S ratio <1) was observed in 91% of the endocardial group (P<.001) (Table 3,

Supplementary Table S2). This feature had high sensitivity (90%) but limited specificity (50%) for detecting endocardial AP (Figure 3). Most patients showed a negative QRS complex in the inferior leads (II, aVF); nevertheless, these features were not useful for differentiating endocardial from epicardial APs.

## QRS Transition

Both groups showed early precordial QRS transition (before $V_3$). Still, transition at $V_1$ occurred in 50% of the epicardial group compared with 9.4% of the endocardial group. Transition after $V_1$ (between $V_1$ and $V_2$ or at $V_3$) was more common in the endocardial group (88.7%) than the epicardial group (45%; P<.001) (Table 4, Supplementary Table S3).

## Double Transition

A double transition pattern was present in 43.4% of the endocardial group compared with 20% of the epicardial group (Figure 3), but this did not reach statistical significance (P=.065). Combining double transition with a Q wave in lead $V_1$ was significantly more common in the endocardial group (35.8%) than the epicardial group (5%; P=.008) (Table 4). This combination showed 95% specificity and 95% positive predictive value but low sensitivity (36%).

Combining double transition with a predominantly negative QRS complex in lead $V_1$ (R/S ratio <1) was more common in the endocardial group (41.5%) than the epicardial group (15%; P=.033) (Table 4, Supplementary Table S3). This combination was associated with endocardial AP, with 85% specificity, 41% sensitivity, and 88% positive predictive value.

## QRS Notching in the Inferior Leads

QRS notching in lead II was significantly more common in the epicardial group (70%; P=.001) (Table 4). It differentiated epicardial from endocardial posteroseptal AP with 72% specificity, 70% sensitivity, and 48% positive predictive value (Figure 2).

## Independent Predictors of the Pathway Location

Multivariable logistic regression, including the following ECG variables-delta-wave polarity, R/S ratio in $V_1$, QRS precordial transition, double transition, and QRS notching-identified independent predictors of endocardial compared with epicardial posteroseptal APs (Table 5). A positive delta wave in lead aVR was an independent predictor of epicardial AP, and an R/S ratio less than 1 in lead $V_1$ was an independent predictor of endocardial AP.

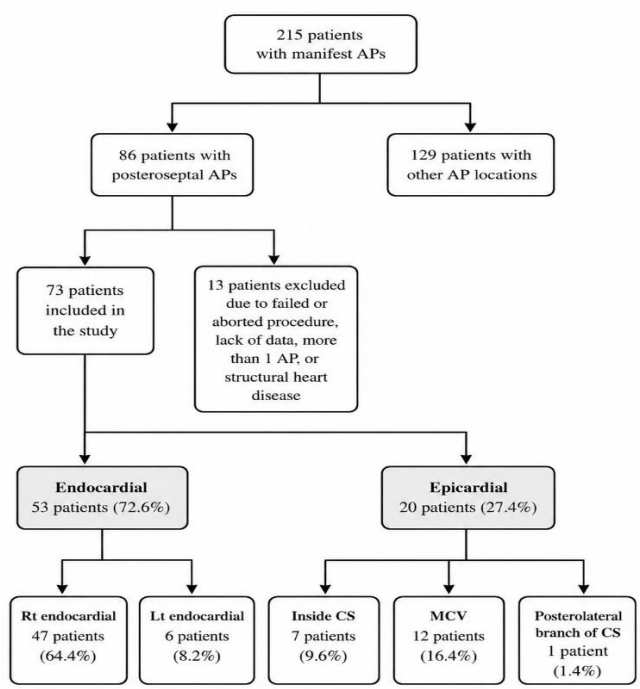



**Figure 1**. Flow chart showing the number of patients included in the study with different sites of ablation of the posteroseptal accessory pathways (APs)
AP: accessory pathway; CS: coronary sinus; MCV: Middle cardiac vein; Rt; right; Lt: left

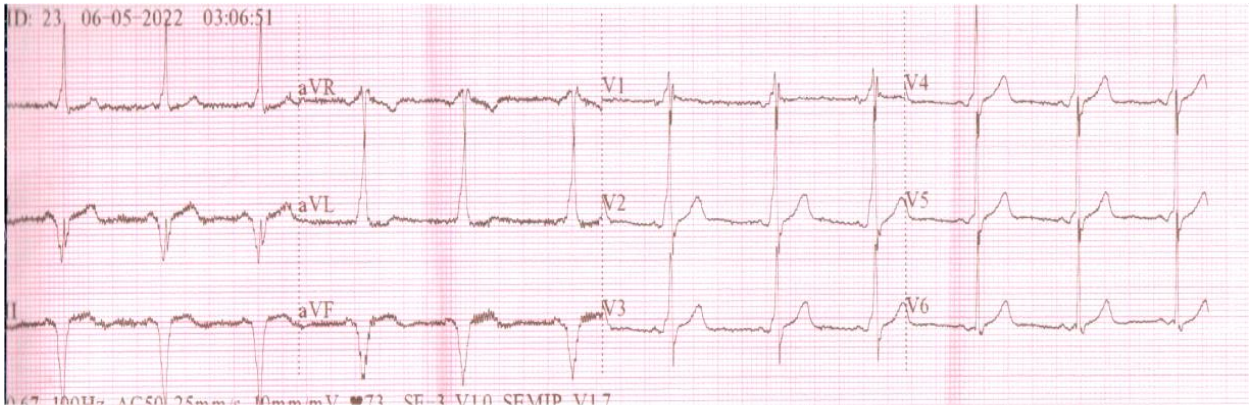



**Figure 2.** Typical electrocardiogram (ECG) from a 31-year-old man who underwent successful radiofrequency ablation of a posteroseptal accessory pathway epicardially within the middle cardiac vein. The ECG shows a negative delta wave in lead II, positive delta waves in leads aVR and $V_1$, an early precordial transition at $V_1$, and QRS complex notching in lead II.

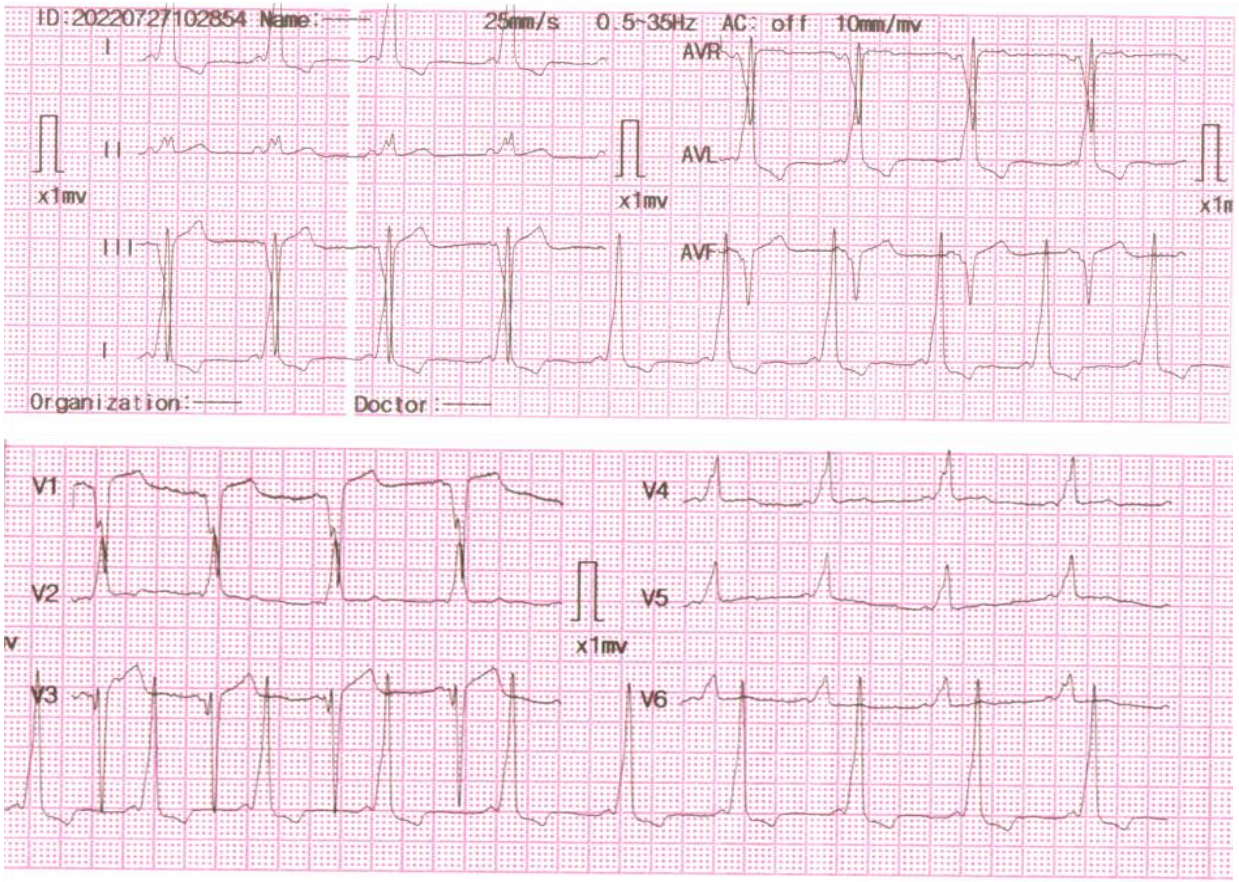



**Figure 3.** Electrocardiogram from a 19-year-old man who underwent successful radiofrequency ablation of a right endocardial posteroseptal accessory pathway. The ECG shows a positive delta wave in lead II, a negative delta wave in lead $V_1$, an R/S ratio of <1 in lead $V_1$, and precordial QRS transition between leads $V_1$ and $V_2$. The double-transition sign is also evident.

**Table 1.** Demographic data and comorbidities of the study population

| | Count (%) |
|---|---|
| Sex (male) | 41 (56.2) |
| Age (mean [SD]) | 37.7 (10.8) |
| Diabetes mellitus | 4 (5.5) |
| Hypertension | 10 (13.7) |
| Thyroid disorders | 2 (2.7) |
| Chronic kidney disease | 1 (1.4) |

**Table 2.** Delta-wave polarity in the frontal and precordial leads in both groups

| | | Epicardial Count (%) | Endocardial Count (%) | P |
|---|---|---|---|---|
| Delta-Wave Polarity in Lead II | positive | 2 (10.0) | 35 (66.0) | <.001 |
| | negative | 17 (85.0) | 11 (20.8) | |
| | Isoelecteric | 1 (5.0) | 7 (13.2) | |
| Delta-Wave Polarity in Lead aVF | positive | 0 | 5 (9.4) | .639 |
| | negative | 20 (100.0) | 46 (86.8) | |
| | isoelecteric | 0 | 1 (1.9) | |
| | biphasic | 0 | 1 (1.9) | |
| Delta-Wave Polarity in Lead aVR | positive | 12 (60.0) | 1 (1.9) | <.001 |
| | negative | 4 (20.0) | 49 (92.5) | |
| | isoelecteric | 4 (20.0) | 3 (5.7) | |
| Delta-Wave Polarity in Lead $V_1$ | positive | 15 (75.0) | 12 (22.6) | <.001 |
| | negative | 2 (10.0) | 34 (64.2) | |
| | isolecteric | 3 (15.0) | 6 (11.3) | |
| | biphasic | 0 | 1 (1.9) | |

**Table 3.** R/S ratio in precordial and frontal leads in both groups

| | | Epicardial Count (%) | Endocardial Count (%) | P |
|---|---|---|---|---|
| R/S Ratio in Precordial Lead $V_1$ | <1 | 10 (50.0) | 48 (90.6) | <.001 |
| | 1 | 7 (35.0) | 1 (1.9) | |
| | >1 | 3 (15.0) | 4 (7.5) | |
| R/S Ratio in Precordial Lead $V_2$ | <1 | 1 (5.0) | 1 (1.9) | .172 |
| | 1 | 0 | 6 (11.3) | |
| | >1 | 19 (95.0) | 46 (86.8) | |
| R/S Ratio in Limb Lead II | <1 | 14 (70.0) | 29 (54.7) | .092 |
| | 1 | 1 (5.0) | 0 (0.0) | |
| | >1 | 5 (25.0) | 24 (45.3) | |
| R/S Ratio in Limb Lead aVF | <1 | 18 (90.0) | 49 (92.5) | .663 |
| | >1 | 2 (10.0) | 4 (7.5) | |

**Table 4.** Other electrocardiographic variables between the 2 study groups

| Variable | | Epicardial Count (%) | Endocardial Count (%) | P |
|---|---|---|---|---|
| QRS Transition | At $V_1$ | 10 (50.0) | 5 (9.4) | <.001 |
| | Between $V_1$ and $V_2$ or at $V_2$ (after $V_1$) | 9 (45.0) | 47 (88.7) | |
| | between $V_2$ and $V_3$ (after $V_2$) | 1 (5.0) | 1 (1.9) | |
| Double Transition | Yes | 4 (20.0) | 23 (43.4) | .065 |
| | No | 16 (80.0) | 30 (56.6) | |
| Double Transition with Q Wave in $V_1$ | Yes | 1 (5.0) | 19 (35.8) | .008 |
| | No | 19 (95.0) | 34 (64.2) | |
| Double Transition With R/S Ratio <1 in $V_1$ | Yes | 3 (15.0) | 22 (41.5) | .033 |
| | No | 17 (85.0) | 31 (58.5) | |
| QRS Notching in Inferior Lead II | Yes | 14 (70.0) | 15 (28.3) | .001 |
| | No | 6 (30.0) | 38 (71.7) | |

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**Table 5.** Multivariate logistic regression to detect independent predictors of epicardial and endocardial accessory pathways

| | | P | OR | 95% CI | |
|---|---|---|---|---|---|
| | | | | Lower | Upper |
| Epicardial | Positive delta wave in aVR | <0.001 | 116.852 | 11.001 | 1241.186 |
| Endocardial | R/S ratio in $V_1$ <1 | 0.001 | 16.169 | 3.005 | 87.008 |

## Discussion

Ablation of posteroseptal APs poses a challenge for electrophysiologists because of the region's anatomical complexity. The present study aimed to enable preprocedural localization of posteroseptal APs drawing upon surface ECG, guide mapping strategies in the EP laboratory, reduce procedure time, and optimize procedural setup, such as using irrigated-tip catheters for epicardial APs or transseptal puncture for left endocardial posteroseptal APs.

Key ECG findings differentiating epicardial from endocardial posteroseptal APs were delta-wave polarity and QRS notching in lead II, delta-wave polarity in lead aVR, and delta-wave polarity and R/S ratio in lead $V_1$.

The present study found that a negative delta wave in lead II was more common in the epicardial group. Mechanistically, this reflects a superior-to-inferior activation vector consistent with epicardial posteroseptal activation.

Arruda et al[1] first described this pattern and developed a stepwise algorithm for AP localization. After excluding left free-wall APs based on delta-wave polarity in lead I and R/S ratio in $V_1$, they reported 100% specificity and sensitivity for epicardial AP in a small cohort (only 7 epicardial cases). A later study by Arruda's group in 171 patients with epicardial APs found lower sensitivity (70%) for a negative delta wave in lead II.[2]

Similarly, Takahashi et al[3] in 117 patients with manifest posteroseptal APs identified this finding as the most sensitive ECG feature for epicardial APs ablated in the CS or middle cardiac vein, with 79% specificity and 87% sensitivity. Haghjoo et al[4] reproduced similar results, reporting 100% sensitivity but only 20% specificity for differentiating epicardial from endocardial APs. Key differences from our study include their smaller epicardial cohort (7 patients) and different delta-wave definitions: the initial 40 milliseconds of the preexcited QRS in frontal leads and 60 milliseconds in precordial leads.

The present study found that a positive delta wave in lead aVR had high specificity for epicardial AP, reflecting rightward and anterior activation vectors characteristic of epicardial pathways. Takahashi et al[15] reported that a steep positive delta wave in aVR during maximal preexcitation had 98% specificity and 88% positive predictive value but limited sensitivity (61%) for epicardial APs. Kobza et al[17] found similar results: 100% specificity, 100% positive predictive value, and 57% sensitivity. Pascale et al[18] noted that a positive delta wave in aVR was infrequent but more common in epicardial than endocardial pathways, which indicated low sensitivity but good discriminatory value. In our cohort, it similarly demonstrated limited sensitivity but high specificity and positive predictive value. Variations in percentages likely reflect differences in pathway distribution, ECG definitions of positivity, and study populations.

In the current study, a positive delta wave in lead $V_1$ was more common in the epicardial group, whereas a negative delta wave in $V_1$ predominated in the endocardial group ($P < .001$). Takahashi et al[15] assessed the initial 40 milliseconds of the QRS complex and found a negative delta wave in $V_1$ only in right endocardial APs (28%) compared with 0% in left endocardial or epicardial APs. Similarly, Pascale et al[18] evaluated the first (0–20 ms) and second (20–40 ms) halves of the initial 40-ms QRS as the delta wave, reporting a negative initial delta wave in $V_1$ (0–20 ms) in 70% of right endocardial posteroseptal APs compared with 9% of left endocardial and 23% of epicardial APs. They identified negativity in both halves as 100% specific for right endocardial posteroseptal APs. Unlike the present study, Haghjoo et al[16] considered the delta wave as the initial 60 milliseconds of the preexcited QRS complex in the precordial leads and found that delta-wave polarity in $V_1$ could not differentiate among right endocardial, left endocardial, and epicardial

posteroseptal APs.

Chiang et al[19] used the initial 60-millisecond QRS polarity in $V_1$ in an AP localization algorithm, with positive polarity indicating left endocardial posteroseptal APs and negative polarity denoting right endocardial Aps. Epicardial APs were, however, not included.

Because of variability in delta-wave definitions, many studies have favored QRS polarity over delta-wave polarity, primarily to differentiate right from left endocardial posteroseptal APs. Unlike the present study, most have not included epicardial APs, although APs ablated within the CS often show an R/S ratio greater than or equal to 1 in $V_1$, with this finding becoming more common farther from the CS ostium and closer to the left atrial free wall.[20] In the current cohort, a predominantly negative QRS complex in $V_1$ (R/S ratio <1) was more common in the endocardial than epicardial group ($P$ < .001), particularly in right compared with left endocardial posteroseptal APs. Conversely, an R/S ratio greater than or equal to 1 in $V_1$ occurred in 50% of epicardial cases by comparison with 8.4% of endocardial cases. Notably, 50% of our limited left endocardial cases also showed this pattern.

Thus, R/S ratio in $V_1$ helps differentiate right endocardial from epicardial or left endocardial APs but not left endocardial from epicardial APs. Pambrun et al[21] employed a 4-step algorithm that incorporated $V_1$ QRS polarity to distinguish right endocardial from left endocardial/epicardial posteroseptal APs, followed by QRS notching in lead II to distinguish epicardial from left endocardial APs. Pascale et al[18] confirmed that an R/S ratio greater than or equal to 1 in $V_1$ was more common in left endocardial APs.

In the present study, double transition alone was not statistically significant for differentiating endocardial from epicardial APs (P=.065). Be that as it may, combinations improved predictive value: a Q wave in lead $V_1$ with double transition or a predominantly negative QRS complex in $V_1$ (R/S ratio <1) with double transition better predicted endocardial posteroseptal APs. A predominantly negative QRS complex in $V_1$ alone differentiated endocardial from epicardial APs with high sensitivity (90%) but limited specificity (50%), regardless of double transition. Adding double transition improved accuracy for detection of endocardial APs.

Pascale et al[18] similarly found that combining a Q wave or negative QRS complex in $V_1$ with a positive QRS component in $V_2$ greater than that in $V_1$ and $V_3$ was 100% specific for right endocardial AP, eliminating the need for left-sided or epicardial approaches. Debabrata Bera[22] described a similar "reverse pattern break": a monophasic tall R wave in $V_2$ greater than that in $V_1$ and $V_3$, plus either an R/S ratio less than 1 in $V_3$ or an S wave greater than 4 mV in $V_3$.

QRS notching in lead II was more frequent in the epicardial group and was useful for differentiating epicardial from endocardial posteroseptal APs. Pambrun et al[21] used this finding as the final step to distinguish left endocardial posteroseptal APs from epicardial APs ablated deep in the CS.

The observed variations in the sensitivity and specificity of ECG criteria for predicting posteroseptal AP location may stem from anatomical variability (the posteroseptal region extends from the triangle of Koch to the CS ostium and beyond; studies differ in the exact locations included), degree of preexcitation (marked preexcitation can obscure features such as QRS notching or alter delta-wave polarity compared with milder preexcitation), and variability in CS anatomy (variations in size, branching, and proximity to the mitral annulus affect the classification of pathways as epicardial and CS accessibility).

In our cohort, 27% (20/73) of posteroseptal APs were epicardial, requiring CS ablation. Our criteria could redirect 25% to 30% of posteroseptal APs before the procedure (from a right endocardial to a CS approach), saving time, reducing radiation exposure, and avoiding futile attempts.

## Limitations

The small sample size and marked imbalance between subgroups, particularly the very small number of left endocardial pathways, reduce the robustness of subgroup analyses, limit conclusions regarding differentiation among right endocardial, left endocardial, and epicardial pathways, and result in wide 95% CIs around diagnostic estimates. The retrospective, cross-

sectional design introduces potential selection bias because only successfully ablated pathways were included. This may have enriched the cohort with anatomically simpler cases, potentially overestimating diagnostic performance. ECG criteria were derived and tested in the same cohort without prospective or external validation, raising concerns about optimistic performance estimates.

These findings should be considered exploratory and require confirmation in larger, independent cohorts. The multivariable model requires cautious interpretation because of the small number of events.

## Conclusions

ECG criteria can predict whether posteroseptal APs are epicardial or endocardial before ablation: epicardial pathways typically show a negative delta wave in lead II combined with positive delta waves in leads aVR and/or $V_1$ (and/or QRS notching in lead II), while endocardial pathways show a negative delta wave and/or R/S ratio less than 1 in lead $V_1$ (Graphical Algorithm, Supplementary Data).

## Declarations:

## Ethical Approval

The study was approved by the Ethics Committee of Cairo University (455/19.12.2018).

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## Conflict of Interest

The authors declare that they have no conflict of interest to declare.

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