CONTEMPORARY REVIEW

How to use the 12-lead ECG to predict the site of origin of idiopathic ventricular arrhythmias

Andres Enriquez, MD,[*] Adrian Baranchuk, MD,[*] David Briceno, MD,[†] Luis Saenz, MD,[‡] Fermin Garcia, MD[†]

*From the *Division of Cardiology, Queen's University, Kingston, Ontario, Canada, †Section of Cardiac Electrophysiology, Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania, and ‡Fundación Cardioinfantil, Bogotá, Colombia.*

Idiopathic ventricular arrhythmias may arise from anywhere in the heart, and the majority of them can be effectively treated with catheter ablation. The 12-lead electrocardiogram (ECG) is the initial mapping tool to predict the most likely site of origin and is valuable to choose the appropriate ablation strategy. Crucial to ECG interpretation is understanding the attitudinal orientation of the heart within the chest and the relationship between the different cardiac structures. In this review, we provide a stepwise anatomical approach for the localization of idiopathic ventricular arrhythmias based on sequential analysis of the most relevant ECG features.

KEYWORDS Catheter ablation; Electrocardiogram; Site of origin; Ventricular arrhythmias; Ventricular tachycardia

(Heart Rhythm 2019;16:1538–1544)

Introduction

Idiopathic ventricular arrhythmias (VAs) occur in patients with structurally normal hearts. The spectrum of clinical presentation includes isolated premature ventricular contractions (PVCs), repetitive nonsustained or sustained ventricular tachycardia (VT), and PVC-triggered ventricular fibrillation. The majority originate from the outflow tract of the right ventricle (RV) and left ventricle (LV), but they may arise from anywhere in the heart. Idiopathic VAs can be effectively treated with catheter ablation, and major advances have been made in the past decade in terms of mapping tools and energy delivery.

Invasive electrophysiology has greatly benefited from a rediscovery of cardiac anatomy. The systematic study of anatomical relationships using modern techniques has helped us to understand the reasons why ablation may fail and to better approach challenging cases. The surface 12-lead electrocardiogram (ECG) is useful to localize the site of origin of VAs when catheter ablation is being considered. Several studies have enriched our understanding of the correlation between different VA sources and specific ECG patterns.

Anatomical considerations

Classical anatomy textbooks described the human heart in the "Valentine position," in which the heart stands on its apex with some rightward rotation. This description is incorrect and has been the source of confusing and inappropriate nomenclature. More recently, efforts have been made toward an anatomically correct or attitudinal description of the heart. A seminal contribution in this direction is the landmark anatomical atlas published by Wallace McAlpine in 1975.[1]

When the heart is viewed in an attitudinal perspective, the right cardiac chambers are anterior relative to the left chambers. The RV is positioned anteriorly and to the right of the LV. The LV lies obliquely in the chest, with the base located posteriorly and the apex positioned to the left. The so-called anterior interventricular sulcus in fact begins superiorly and travels to the left and slightly anteriorly, while the so-called posterior interventricular sulcus is actually positioned inferiorly.

Regarding the outflow tract region, the anatomical relationships are complex and VAs from different structures in this region may have a similar ECG appearance. The RV outflow tract (RVOT) wraps around and crosses the LV outflow tract (LVOT) anteriorly, so that the pulmonary valve lies anterior and to the left of the aortic valve (AoV). This relation is important, as the anterior aspect of the RVOT is actually the most leftward and highest outflow tract structure.

The LVOT corresponds to the elliptical opening of the LV, also termed the LV ostium by McAlpine.[1,2] This is composed by the aortic root anteriorly and by the mitral annulus posteriorly and to the left. Both valves are anatomically coupled through a band of fibrous tissue known as the aortomitral continuity (AMC), which extends between the anterior leaflet of the mitral valve (MV) and the left (LCC) and noncoronary cusp (NCC) of the AoV. The AoV occupies a central position within the heart and is composed of 3 cusps, each one with relevant anatomical

Address reprint requests and correspondence: Dr Andres Enriquez, Division of Cardiology, Queen's University, 76 Stuart St, Kingston, Ontario, Canada K7L 2V7. E-mail address: Andres.Enriquez@kingstonhsc.ca.

1547-5271/$-see front matter https://doi.org/10.1016/j.hrthm.2019.04.002

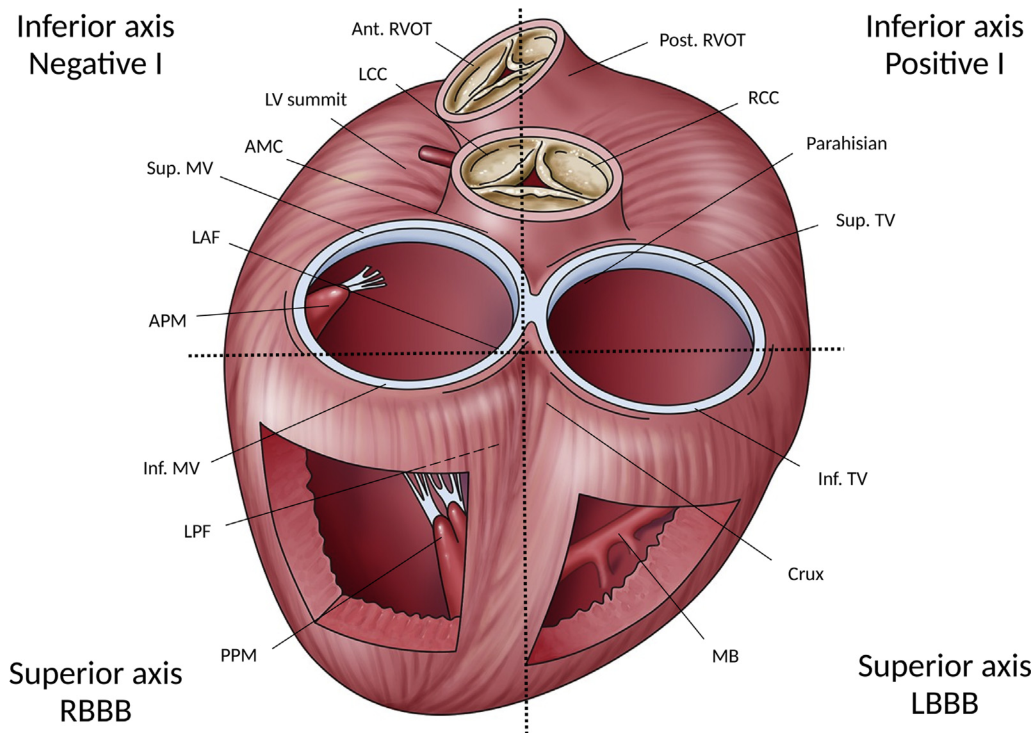

Figure 1 Anatomic approach for the regionalization of the VA site of origin based on frontal plane axis and bundle branch block pattern. AMC = aortomitral continuity; APM = anterolateral papillary muscle; Inf. = inferior; LAF = left anterior fascicle; LBBB = left bundle branch block; LCC = left coronary cusp; LPF = left posterior fascicle; LV = left ventricular; MB = moderator band; MV = mitral valve; PPM = posteromedial papillary muscle; RBBB = right bundle branch block; RCC = right coronary cusp; RVOT = right ventricular outflow tract; Sup. = superior; TV = tricuspid valve; VA = ventricular arrhythmia.

relationships. In attitudinal orientation, the right coronary cusp (RCC) is the most anterior cusp relative to the sternum, the NCC is posterior and rightward, and the LCC is posterior and leftward. The NCC is the most inferior and the LCC is the most superior in position. The RCC is in close proximity to the posteroseptal aspect of the RVOT, while the LCC is adjacent to the anterior aspect of the LV ostium, in close proximity to the left anterior descending coronary artery. Conversely, the NCC is in relationship with both the left atrium and the right atrium separated by the interatrial septum. Below the commissure between the RCC and the NCC lies the membranous ventricular septum, where the penetrating bundle of His is located.

A common site of origin of VAs is the LV summit. This corresponds to the highest portion of the LV epicardium, above the upper end of the anterior interventricular sulcus and bounded by the bifurcation between the left anterior descending and the left circumflex coronary arteries.[3] This triangular region is transected by the great cardiac vein at its junction with the anterior interventricular vein, which provides an access to map and sometimes ablate PVCs/VTs from this region.

ECG features

Several ECG features are relevant for the localization of a particular VA. The most important are (1) QRS axis, (2) bundle branch block pattern, (3) precordial transition, and (4) QRS width.

The QRS axis has both a vertical (superior-inferior) and a horizontal (right-left) dimension. The vertical dimension is reflected by QRS polarity in bipolar leads II and III. For example, all outflow tract VAs share an inferiorly directed QRS axis, with positive forces in leads II and III. The horizontal dimension is better reflected by lead I. Structures closer to the left arm will produce a deeply negative complex in lead I (rightward axis); conversely, structures closer to the right arm are strongly positive in lead I (leftward axis). Additional approximation to the horizontal dimension is given by the relative amplitude between limb leads aVR and aVL: a more positive polarity in lead aVR than in lead aVL suggests a more leftward origin; a more positive polarity in lead aVL than in lead aVR points toward a more rightward origin.

The bundle branch block pattern is related to the sequence of RV and LV activation. VAs with a right bundle branch block (RBBB) appearance typically arise in the LV, while VAs with a left bundle branch block (LBBB) appearance may arise anywhere in the RV, but also in the left side of the interventricular septum.

The precordial transition in RBBB VAs (first lead with a predominant S wave) occurs progressively earlier as the site of origin moves from the base toward the apex of the LV. In LBBB VAs, the precordial transition (first lead with a predominant R wave) occurs progressively later as the site of origin moves from the septum toward the RV free wall. Positive concordance (all positive precordial leads) is seen in VAs arising at the base of the heart, in which case ventricular activation has to move anterior and apical. Conversely, negative concordance (all negative precordial leads) is seen in VAs originating near the apex, such that electrical activity moves away from the chest wall.

Finally, septal VAs have narrower QRS durations than do VAs originating on the free wall of both ventricles because of synchronous rather than sequential ventricular activation.

Having mentioned these general rules, it should be acknowledged that the 12-lead ECG has limitations[4] and significant variation may result from several factors, such as body habitus, lead placement, and shifts in the relationship of the heart to the chest wall.

Comprehensive anatomic approach for the prediction of the site of origin

We propose an algorithm based on 4 anatomical quadrants for rapid regionalization of a particular VT/PVC (Figures 1 and 2). Once ascribed to any of these quadrants, analysis of additional ECG features, such as precordial transition, QRS duration, or specific morphology in certain leads, is helpful to postulate the most likely site of origin.

Step 1

We start looking at the superior/inferior axis, represented by polarity in leads II and III. Inferior-axis VAs (positive QRS complex in leads II and III) arise from basal areas of the heart, including the outflow tracts and the superior aspect of the atrioventricular valves, while superior-axis VAs (negative QRS complex in leads II and III) have their origin at the inferior aspect of both ventricles (Table 1). A few VAs may exhibit discordance between leads II and III (positive/negative or negative/positive). These will be discussed separately.

Step 2

Our next step is to separate VAs arising from the right or left side of the chest midline, which does not necessarily means RV vs LV, especially in the outflow tracts, where there is a significant overlap between the RVOT and the LVOT.[5]

1. For outflow tract VAs, the best single ECG discriminator is the left/right axis reflected by lead I. Rightward structures, such as the posterior aspect of the RVOT, RCC, para-Hisian region, and superior aspect of the tricuspid valve (TV), are positive in lead I, while leftward structures, such as the anterior aspect of the RVOT, LCC, AMC, anterolateral MV annulus, and LV summit, will produce a negative complex in lead I. The commissure between the RCC and the LCC, a common source of idiopathic VAs, is close to the midline, and, in our experience, arrhythmias from this area may have either a positive, a negative, or a biphasic QRS complex in lead I.[6]
2. For VAs arising from the inferior aspect of the ventricles, the most helpful element is the bundle branch block appearance, as some VAs from the septal portion of the LV may exhibit a left axis. VAs with a superior axis and LBBB appearance may arise from RV structures (inferior aspect of the TV or moderator band [MB]) or the cardiac crux. Conversely, VAs with a superior axis and RBBB pattern arise from LV structures (inferior

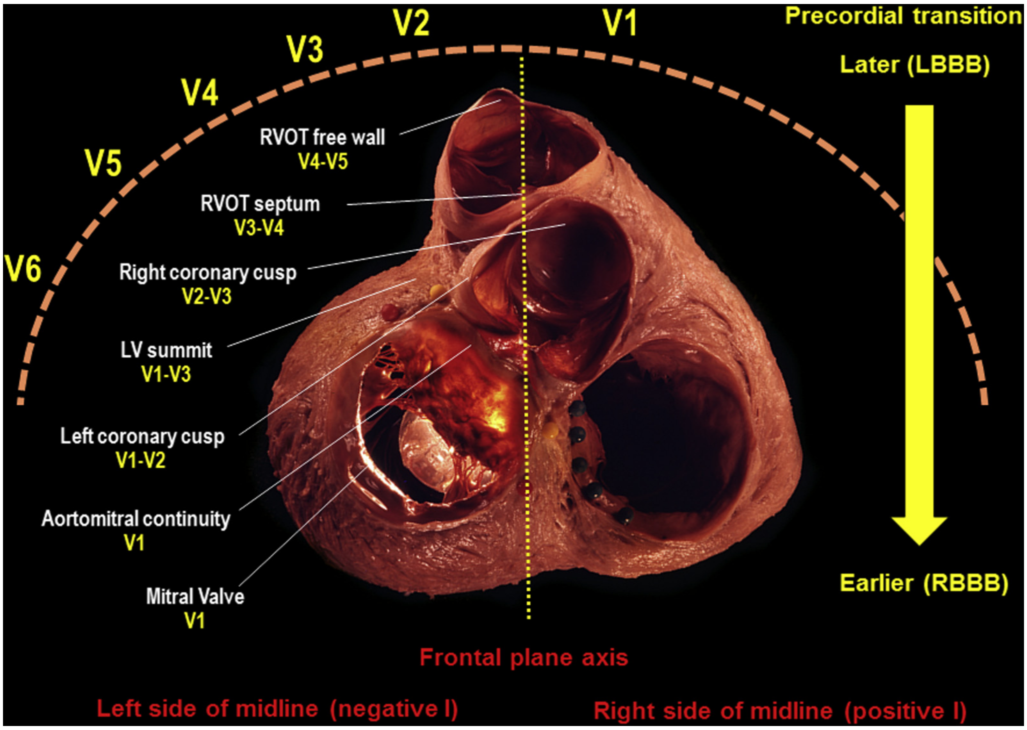

Figure 2 Anatomical schema to understand the electrocardiographic patterns of outflow tract VAs, showing the value of precordial transition and frontal plane axis. The free wall of the RVOT is the most anterior structure, and the precordial transition occurs progressively earlier as we move toward the anterolateral mitral annulus. Lead I polarity allows one to discriminate structures located leftward from the midline from those located on the right side. Note that the anterior aspect of the RVOT is actually a leftward structure while the right coronary cusp of the aortic valve is a rightward structure. Abbreviations as in Figure 1. Reproduced from Dr K. Shivkumar with permission. Copyright UCLA Cardiac Arrhythmia Center, McAlpine Collection.

Table 1 Electrocardiographic features of idiopathic VAs

A. Positive II and III: Suggests origin from the outflow tracts and top of atrioventricular valves	
Positive lead I: Structures rightward from the midline	
a. Posterior RVOT	LBBB, transition at or after V_3, QS in V_1
b. RCC	LBBB, V_2 or V_3 transition (V_2 transition ratio $\geq$0.6), QS in V_1
c. Para-Hisian	LBBB, typically V_2 or V_3 transition, QS in V_1, R in aVL (vs negative in the RVOT), III may be negative, narrow QRS
d. Top of the TV	LBBB, variable transition, QS or rS in V_1, positive aVL (vs negative in the RVOT), III may be negative
Negative lead I: Structures leftward from the midline	
a. Anterior RVOT	LBBB, transition at or after V_3, QS in V_1
b. LCC	LBBB or RBBB, V_1 or V_2 transition, rS, R, or multiphasic pattern in V_1
c. AMC	RBBB, positive concordance, qR in V_1
d. Anterolateral MV	RBBB, positive concordance, R or Rsr′ in V_1
e. LV summit	RBBB or LBBB with V_2 or V_3 transition, taller R wave in III than in II, pseudo-delta wave and/or MDI $>$ 0.55, V_2 "pattern break"
Exceptions are 2 non-outflow tract structures:	
a. Left anterior fascicle	RBBB, rsR′ in V_1, narrow QRS, right axis
b. Anterolateral PM	RBBB, R, Rsr′, or qR in V_1, late R/S transition, II may be negative
B. Negative II and III: Suggests origin from the inferior aspect of both ventricles	
LBBB pattern: RV structures or crux	
a. Inferior TV	LBBB, variable transition (V_2 through V_5), QS or rS in V_1
b. Moderator band	LBBB, late transition (V_5 or V_6), left superior axis
c. Cardiac crux	LBBB, V_2 transition, left superior axis, QS in inferior leads, pseudo-delta wave and/or MDI $>$ 0.55
RBBB pattern: LV structures	
a. Inferior MV	RBBB, positive concordance, R or Rsr′ in V_1
b. Posteromedial PM	RBBB, R $<$ S in V_5, R, Rsr′, or qR in V_1
c. Left posterior fascicle	RBBB, R $<$ S in V_5, rsR′ in V_1, narrow QRS
C. Inferior lead discordance: Suggests origin from the midcavitary structures or lateral aspect of the atrioventricular valves	
- Positive II/negative III: Lateral TV, RV intracavitary structures (moderator band), interventricular septum (parahisian)	
- Negative II/positive III: Lateral MV, anterolateral PM	

AMC = aortomitral continuity; LBBB = left bundle branch block; LCC = left coronary cusp; LV = left ventricular; MDI = maximum deflection index; MV = mitral valve; PM = papillary muscle; RBBB = right bundle branch block; RCC = right coronary cusp; RV = right ventricular; RVOT = right ventricular outflow tract; TV = tricuspid valve; VA = ventricular arrhythmia.

aspect of the MV, posteromedial papillary muscle [PPM], or left posterior fascicle).

Step 3

Once we circumscribe the likely site of origin to 1 of these 4 quadrants, a more refined localization relies in other characteristics such as precordial transition, QRS width, or QRS morphology in specific leads (Table 1 and Figure 3).

Right upper quadrant

In includes the posterior aspect of the RVOT, RCC, superior TV and para-Hisian region (Figures 4A–4E). Outflow tract VAs, in general, can be differentiated from TV and para-Hisian VAs by looking at lead aVL polarity. Lead aVL is a left sided but also a superior lead; thus, the majority of outflow tract VAs show negative deflections in lead aVL (QS waves) as well as in lead aVR. Conversely, TV and para-Hisian VAs are located more inferiorly and rightward in the chest and, therefore, usually exhibit positive deflections in lead aVL (any R or r waves).[7,8] In addition, RVOT and RCC VAs show a strong inferior axis, with tall R waves in leads II and III. In VAs from the superior TV and para-Hisian region, positive forces are less pronounced, especially in lead III, which can be even isoelectric or negative. Finally, a narrow QRS duration (usually <130 ms) is typical of para-Hisian VAs given the early engagement of this His-Purkinje system.

Differentiation between posterior RVOT and RCC VAs may be particularly challenging and has been the subject of several studies. A precordial R/S transition after lead V_3 usually suggests RVOT origin, while the transition at lead V_2 or earlier is typical of LVOT origin. Differentiation is more difficult when the transition is in lead V_3, as this pattern can be seen in both VAs from the posteroseptal RVOT and those from the RCC, and different algorithms have been proposed.[9–13] One of them compares the precordial transition during the PVC and sinus rhythm.[9] When the PVC transition occurs later than the sinus rhythm transition, the origin is the RVOT (100% specificity). If the PVC transition occurs at or earlier than the sinus rhythm transition, then the so-called V_2 transition ratio is measured (percentage R wave during the PVC divided by the percentage R wave during sinus rhythm). A ratio of ≥0.6 predicts an LVOT origin with a sensitivity of 95% and a specificity of 100%. Another ECG criterion is the

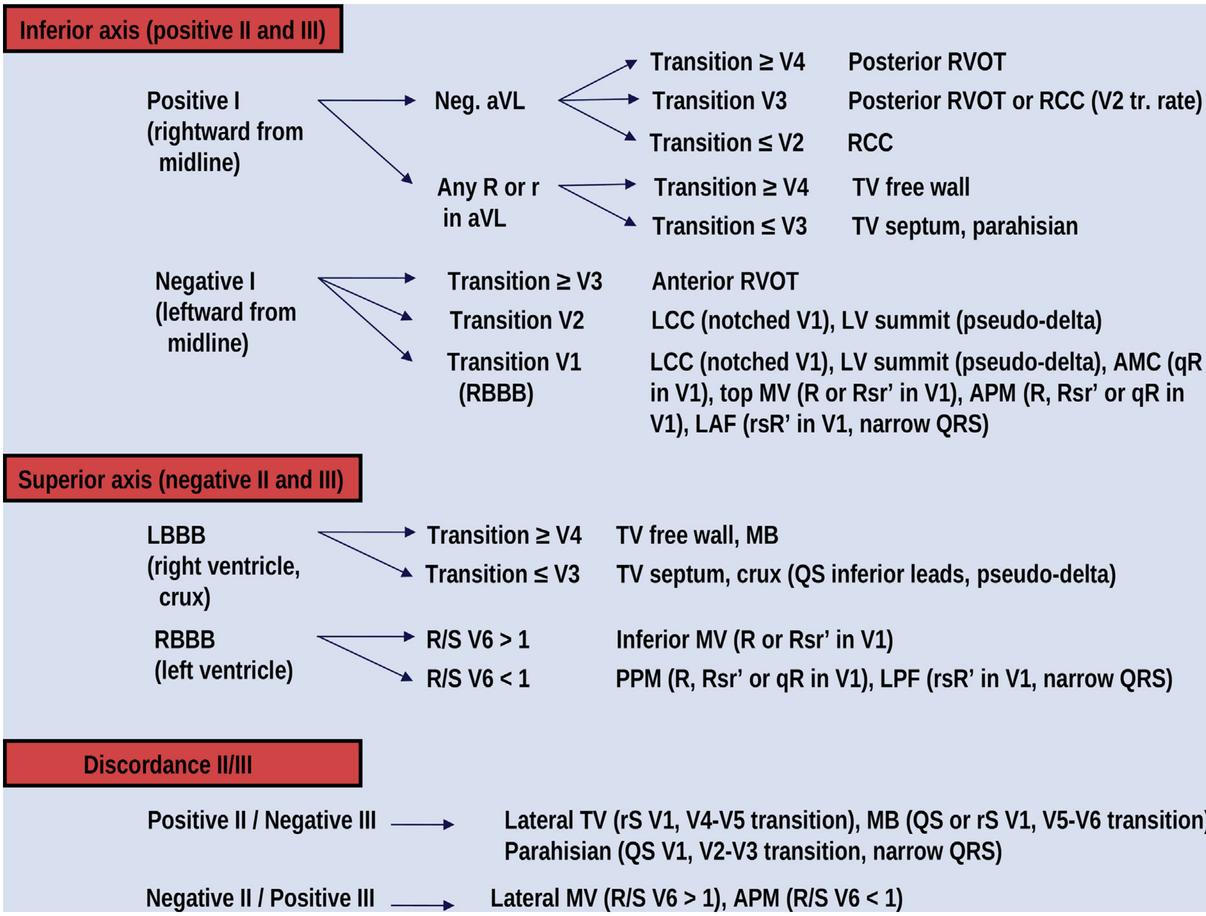

Figure 3 Stepwise electrocardiographic approach for the prediction of the VA site of origin. Abbreviations as in Figure 1.

V_2S/V_3R index, defined as the S-wave amplitude in lead V_2 divided by the R-wave amplitude in lead V_3. An index of $\leq$1.5 predicts an LVOT origin with a sensitivity of 89% and a specificity of 94%.[10]

Left upper quadrant

It includes the anterior aspect of the RVOT and most LVOT structures (excluding the RCC) (Figures 4F–4L). The precordial transition is likely the most helpful characteristic to pay attention in this group (Figure 2). As we move progressively more posterior from the RVOT free wall to the lateral mitral annulus, the precordial transition occurs progressively earlier (lead V_4 or V_5 for the RVOT free wall, lead V_3 or V_4 for the RVOT septum, lead V_1 or V_2 for the LCC) and finally transforms from an LBBB to an RBBB configuration at the AMC or the top of the MV. In addition to the bundle branch block pattern, some specific characteristics of lead V_1 may orientate to certain locations: RVOT and RCC VAs typically exhibit a QS pattern in lead V_1; a QS pattern with notching in downstroke is suggestive of VAs from the RCC/LCC commissure; LCC VAs often have a multiphasic pattern in lead V_1 (M or W pattern); a qR pattern in lead V_1 is often seen in VAs from the AMC; and VAs from the anterolateral MV annulus most often have an R pattern in lead V_1 with positive precordial concordance.

VAs arising from the LV summit may have either an LBBB pattern with lead V2 or V3 transition (septal aspect, also known as inaccessible area) or an RBBB pattern (lateral aspect or accessible area).[14,15] Attention should be paid to characteristics suggesting an epicardial origin such prominent pseudo-delta waves or maximum deflection index $>$ 0.55. In addition, a V_2 pattern break in LBBB VAs, defined as a loss of the R wave in lead V_2 compared to leads V_1 and V_3 (Supplemental Figure 1), suggests an origin near the anterior interventricular sulcus, often in close proximity to the left anterior descending coronary artery.[16]

Two non-outflow tract structures may also produce a right inferior-axis ECG pattern:

1. Left anterior fascicle: Typically characterized by a narrow QRS duration ($<$130 ms), an rsR′ pattern in lead V_1 mimicking typical RBBB, and right axis deviation.
2. Anterolateral papillary muscle (APM): Usually exhibits an RBBB pattern with a wider QRS duration, an R, Rsr′, or qR pattern in lead V_1, and late R/S transition (V3 to V5). Lead II may be negative.

Right lower quadrant

The most common sources of idiopathic VAs in this quadrant are the inferior TV annulus, the MB, and the cardiac crux

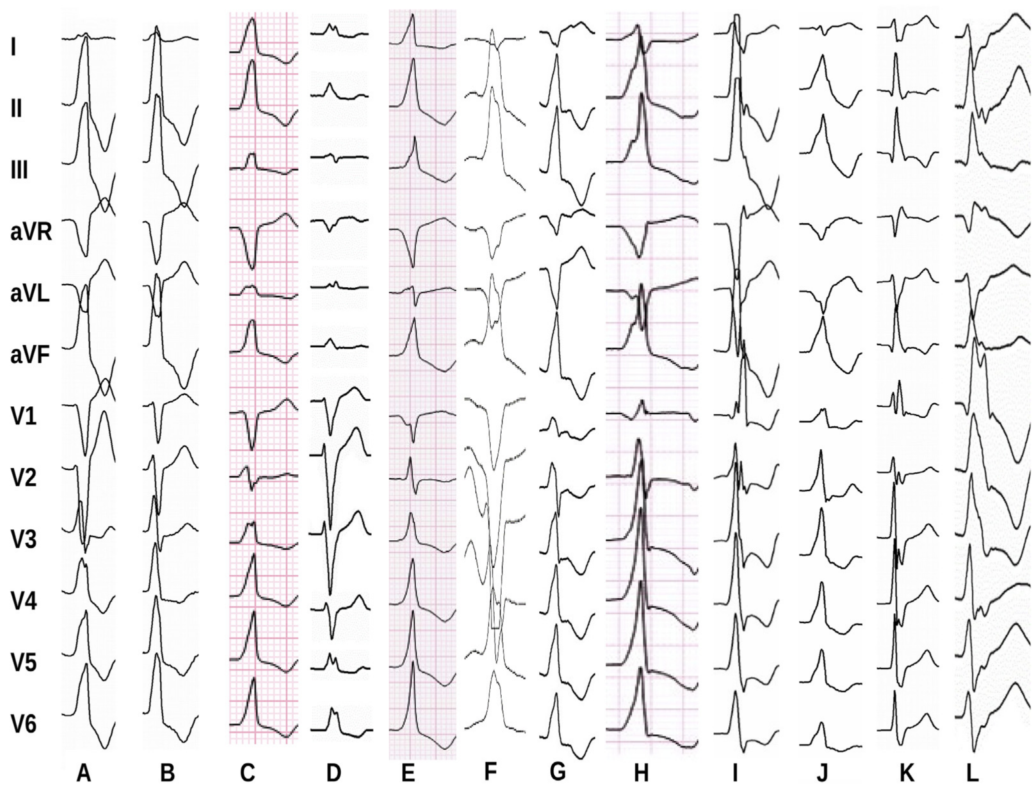

Figure 4 Inferior-axis VAs with origin at the (**A**) posterior RVOT (septal wall), (**B**) RCC, (**C**) para-Hisian region, (**D**) superior TV, (**E**) RCC-LCC commissure, (**F**) anterior RVOT, (**G**) LCC, (**H**) AMC, (**I**) anterolateral MV, (**J**) LV summit, (**K**) left anterior fascicle, and (**L**) anterolateral papillary muscle. Abbreviations as in Figure 1.

(Figures 5A–5C). The MB is a prominent muscular trabeculation that crosses from the septum to the free wall of the RV and provides support to the anterior papillary muscle of the TV. The crux of the heart is an epicardial region near the junction of the middle cardiac vein and the coronary sinus. MB VAs typically have a left superior axis and late precordial transition (later than lead V_4).[17] Conversely, crux VAs also have a left superior axis, but with early transition (lead V_2) and a QS pattern in inferior leads.[18] They may also present features suggesting an epicardial access, such a pseudo-delta wave or maximum deflection index > 0.55. TV VAs have a variable precordial transition (leads V_2 through V_5) depending on their septal or lateral origin (lead V_2 or V_3 for septal sites and lead V_4 or V_5 for free wall sites). A QS pattern in lead V_1 is recorded in the majority of VAs arising from the septal portion of the TV annulus, while most VAs from the free wall portion exhibit an rS pattern in lead V_1.

Left lower quadrant

Idiopathic VAs with RBBB and superior axis may arise from the inferior MV annulus, the left posterior fascicle, and the PPM (Figures 5D–5F). These can be differentiated on the basis of 3 main characteristics: precordial transition, QRS duration, and V_1 morphology.[19] Positive precordial concordance (R > S in lead V_6) is relatively specific of MV VAs, reflecting their more basal location. Conversely, VAs from the left posterior fascicle and PPM usually have R < S by lead V_5. A QRS duration of <130 ms is highly suggestive of fascicular VAs, reflecting the more rapid ventricular depolarization via the Purkinje system. For the same reason, fascicular VAs typically have an rsR′ (r < R′) pattern in lead V_1, mimicking typical RBBB. In comparison, PPM and MV VAs usually have an Rsr′ (R > r′), R, or qR pattern in lead V_1.

Inferior lead discordance

Inferior lead discordance reflects an opposite depolarization vector along bipolar limb leads II (from the left leg to the right arm) and III (from the left leg to the left arm).[20] This is most often observed in VAs originating from midcavitary structures (interventricular septum, MB, and APM) and sometimes from the lateral aspect of the atrioventricular valves. Positive/negative discordance (positive II/negative III) is equivalent to a frontal axis of −30° to +30°, and negative/positive discordance (negative II/positive III) is equivalent to a frontal axis of +150° to +210°. In particular, the likely sites of origin are as follows:

1. Positive/negative discordance: RV structures, including the lateral TV, MB, and interventricular septum (para-Hisian region). All these have an LBBB configuration.
2. Negative/positive discordance: LV structures, including the lateral MV and APM. These have an RBBB configuration.

Conclusion

The 12-lead ECG remains a valuable mapping tool for the determination of VA origin. Keeping in mind the attitudinal orientation of the heart in the chest and looking at a number

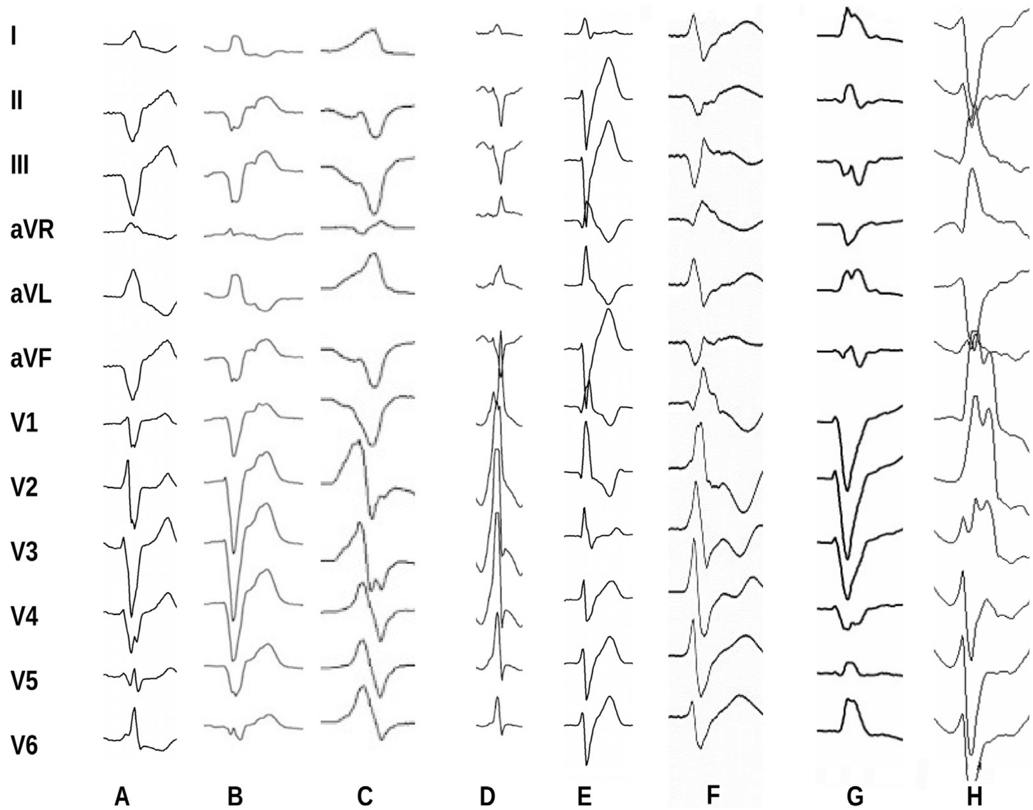

Figure 5 Superior-axis VAs with origin at the (**A**) inferior TV, (**B**) moderator band, (**C**) cardiac crux, (**D**) inferior MV, (**E**) left posterior fascicle, and (**F**) posteromedial papillary muscle. Two examples of VAs with inferior lead discordance ablated from the (**G**) moderator band and (**H**) anterolateral papillary muscle. Abbreviations as in Figure 1.

of ECG features in an organized sequence makes it possible to quickly regionalize a PVC/VT to 1 of 4 quadrants and postulate the most likely differential diagnoses for the sites of origin.

Appendix

Supplementary data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrthm.2019.04.002.

References

1. McAlpine WA. Heart and Coronary Arteries. New York: Springer-Verlag; 1975.
2. Yamada T, Litovsky SH, Kay GN. The left ventricular ostium: an anatomic concept relevant to idiopathic ventricular arrhythmias. Circ Arrhythm Electrophysiol 2008;1:396–404.
3. Enriquez A, Malavassi F, Saenz LC, et al. How to map and ablate left ventricular summit arrhythmias. Heart Rhythm 2017;14:141–148.
4. Jamil-Copley S, Bokan R, Kojodjojo P, et al. Noninvasive electrocardiographic mapping to guide ablation of outflow tract ventricular arrhythmias. Heart Rhythm 2014;11:587–594.
5. Hutchinson MD, Garcia FC. An organized approach to the localization, mapping, and ablation of outflow tract ventricular arrhythmias. J Cardiovasc Electrophysiol 2013;24:1189–1197.
6. Bala R, Garcia FC, Hutchinson MD, et al. Electrocardiographic and electrophysiologic features of ventricular arrhythmias originating from the right/left coronary cusp commissure. Heart Rhythm 2010;7:312–322.
7. Yamauchi Y, Aonuma K, Takahashi A, et al. Electrocardiographic characteristics of repetitive monomorphic right ventricular tachycardia originating near the His-bundle. J Cardiovasc Electrophysiol 2005;16:1041–1048.
8. Tada H, Tadokoro K, Ito S, et al. Idiopathic ventricular arrhythmias originating from the tricuspid annulus: prevalence, electrocardiographic characteristics, and results of radiofrequency catheter ablation. Heart Rhythm 2007;4:7–16.
9. Betensky BP, Park RE, Marchlinski FE, et al. The V_2 transition ratio: a new electrocardiographic criterion for distinguishing left from right ventricular outflow tract tachycardia origin. J Am Coll Cardiol 2011;57:2255–2262.
10. Yoshida N, Yamada T, McElderry HT, et al. A novel electrocardiographic criterion for differentiating a left from right ventricular outflow tract tachycardia origin: the V_2S/V_3R index. J Cardiovasc Electrophysiol 2014;25:747–753.
11. Ouyang F, Fotuhi P, Ho SY, et al. Repetitive monomorphic ventricular tachycardia originating from the aortic sinus cusp: electrocardiographic characterization for guiding catheter ablation. J Am Coll Cardiol 2002;39:500–508.
12. Cheng D, Ju W, Zhu L, et al. V_3R/V_7 index. Circ Arrhythm Electrophysiol 2018;11:e006243.
13. Zhang F, Hamon D, Fang Z, et al. Value of a posterior electrocardiographic lead for localization of ventricular outflow tract arrhythmias: the V_4/V_8 ratio. JACC Clin Electrophysiol 2017;3:678–686.
14. Yamada T, McElderry HT, Doppalapudi H, et al. Idiopathic ventricular arrhythmias originating from the left ventricular summit: anatomic concepts relevant to ablation. Circ Arrhythm Electrophysiol 2010;3:616–623.
15. Santangeli P, Marchlinski FE, Zado ES, et al. Percutaneous epicardial ablation of ventricular arrhythmias arising from the left ventricular summit: outcomes and electrocardiogram correlates of success. Circ Arrhythm Electrophysiol 2015;8:337–343.
16. Hayashi T, Santangeli P, Pathak RK, et al. Outcomes of catheter ablation of idiopathic outflow tract ventricular arrhythmias with an R wave pattern break in lead V_2: a distinct clinical entity. J Cardiovasc Electrophysiol 2017;28:504–514.
17. Sadek MM, Benhayon D, Sureddi R, et al. Idiopathic ventricular arrhythmias originating from the moderator band: electrocardiographic characteristics and treatment by catheter ablation. Heart Rhythm 2015;12:67–75.
18. Kawamura M, Gerstenfeld EP, Vedantham V, et al. Idiopathic ventricular arrhythmia originating from the cardiac crux or inferior septum: epicardial idiopathic ventricular arrhythmia. Circ Arrhythm Electrophysiol 2014;7:1152–1158.
19. Al'Aref SJ, Ip JE, Markowitz SM, et al. Differentiation of papillary muscle from fascicular and mitral annular ventricular arrhythmias in patients with and without structural heart disease. Circ Arrhythm Electrophysiol 2015;8:616–624.
20. Enriquez A, Pathak RK, Santangeli P, et al. Inferior lead discordance in ventricular arrhythmias: a specific marker for certain arrhythmia locations. J Cardiovasc Electrophysiol 2017;28:1179–1186.