New algorithm using only lead aVR for differential diagnosis of wide QRS complex tachycardia

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BACKGROUND We recently reported an ECG algorithm for differential diagnosis of regular wide QRS complex tachycardias that was superior to the Brugada algorithm.

OBJECTIVE The purpose of this study was to further simplify the algorithm by omitting the complicated morphologic criteria and restricting the analysis to lead aVR.

METHODS In this study, 483 wide QRS complex tachycardias [351 ventricular tachycardias (VTs), 112 supraventricular tachycardias (SVTs), 20 preexcited tachycardias] from 313 patients with proven diagnoses were prospectively analyzed by two of the authors blinded to the diagnosis. Lead aVR was analyzed for (1) presence of an initial R wave, (2) width of an initial r or q wave >40 ms, (3) notching on the initial downstroke of a predominantly negative QRS complex, and (4) ventricular activation–velocity ratio (vi/vt), the vertical excursion (in millivolts) recorded during the initial (vi) and terminal (vt) 40 ms of the QRS complex. When any of criteria 1 to 3 was present, VT was diagnosed; when absent, the next criterion was analyzed. In step 4, vi/vt >1 suggested SVT, and vi/vt ≤1 suggested VT.

RESULTS The accuracy of the new aVR algorithm and our previous algorithm was superior to that of the Brugada algorithm (P = .002 and P = .007, respectively). The aVR algorithm and our previous algorithm had greater sensitivity (P < .001 and P = .001, respectively) and negative predictive value for diagnosing VT and greater specificity (P < .001 and P = .001, respectively) and positive predictive value for diagnosing SVT compared with the Brugada criteria.

CONCLUSION The simplified aVR algorithm classified wide QRS complex tachycardias with the same accuracy as standard criteria and our previous algorithm and was superior to the Brugada algorithm.

KEYWORDS Wide QRS complex tachycardia; Brugada criteria; Ventricular tachycardia; Supraventricular tachycardia

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Introduction

Despite the publication of numerous algorithms and criteria, relatively few improvements have been made in the ECG differential diagnosis of wide QRS complex tachycardia since the landmark 1978, 1988, and 1991 publications of Wellens et al,1 Kindwall et al,2 and Brugada et al.3 Thus, making an accurate rapid diagnosis in patients with wide QRS complex tachycardia remains a significant clinical problem. Using all reported traditional ECG criteria1–14 may yield an accurate diagnosis in approximately 90% of wide QRS complex tachycardias.5,6,9 However, many of these criteria are complicated, or they are not applicable in a large proportion of cases and thus are not useful in an urgent setting. Brugada et al3 stated that their algorithm had higher sensitivity and specificity than the traditional criteria, but they did not provide a true head-to-head comparison with other methods used in their study. We recently proposed a new simplified four-step decision treelike algorithm to distinguish between regular monomorphic wide QRS complex tachycardias caused by supraventricular ventricular tachycardia (SVT) and ventricular tachycardia (VT), which proved to be superior to the Brugada algorithm.15 Two new criteria were incorporated in the recent algorithm, which required knowledge only of typical bundle branch and fascicular block patterns, and eliminated some of the complicated morphologic criteria used in the final (fourth) step of the otherwise simple Brugada algorithm. However, in most cases, application of our recent algorithm required more time than did the Brugada algorithm. Therefore, we sought to further simplify and improve our recent algorithm. To this end, another four-step, decision treelike algorithm was devised that completely eliminated the complicated morphologic criteria and limited analysis to a single lead (aVR) while preserving our two previous new criteria. Lead aVR was chosen because we hypothesized that it might be more sensitive than the other leads in differentiating wide QRS complex tachycardias because, in normal sinus rhythm and SVT, the
ventricular activation wavefront proceeds in a direction away from aVR, typically yielding a QS complex in aVR. In the present study, the overall test accuracy, sensitivity, specificity, and predictive values of the new aVR algorithm were compared with those of our previous algorithm as well as the Brugada algorithm.

Methods
A different set of patients from that used to test the already established algorithm was used to devise the algorithm. To devise an optimal algorithm, we retrospectively used 103 wide QRS complex tachycardias available from the database of Indiana University. The recordings were obtained from 69 patients with proven electrophysiologic diagnoses in whom wide QRS complex tachycardia was induced during electrophysiologic study. To test the established algorithm, 483 regular wide QRS complex tachycardia ECGs (351 VTs, 112 SVTs, 20 preexcited tachycardias) recorded from 313 consecutive patients were prospectively analyzed by two of the authors (observer 1 = AV; observer 2 = GD) blinded to the electrophysiologic diagnosis and the patients’ clinical data. ECGs were obtained from June 1998 to June 2005 at Indiana University during electrophysiologic studies at which the arrhythmia diagnosis was proven. In this study, 453 of the 483 wide QRS complex tachycardia ECGs used were identical to those analyzed in our previous study.15 Wide QRS complex tachycardia tracings from patients with preexciting bundle branch block or idiopathic VTs and/or from patients taking either class I antiarrhythmic drugs or amiodarone (144, 38, and 158 tracings, respectively) were also included in this study. The 38 idiopathic VTs analyzed consisted of 11 fascicular VTs, 14 right ventricular outflow tract VTs, and 13 VTs of other types. An informed consent exemption was obtained from the Indiana University Institutional Review Board for analysis of a de-identified dataset. The observers were given complete 12-lead standard ECGs recorded during tachycardia for analysis. The ECG leads were in standard positions, with the possible exception of leads V₃ to V₅, which were often displaced one interspace due to the placement of defibrillator pads. This exception was noted to not make much difference compared with ECGs obtained using standard chest lead location. Wide QRS complex tachycardia was defined as a rhythm with a rate ≥100/min and QRS duration ≥120 ms. Only monomorphic wide QRS complex tachycardias were analyzed using the following criteria in lead aVR: (1) presence of an initial R wave, (2) presence of an initial r or q wave with width >40 ms, (3) notching on the descending limb of a negative onset and predominantly negative QRS in lead aVR, suggested VT. We also hypothesized that $v_i/v_t > 1$ suggested SVT and $v_i/v_t ≤ 1$ indicated VT. The four criteria of the new aVR algorithm were organized in a stepwise, decision-tree format similar to that of the Brugada algorithm and our previous algorithm. When any of the first three criteria of the algorithm was met, a diagnosis of VT was made, and the analysis was stopped at that step. In the last step, $v_i/v_t ≤ 1$ was considered diagnostic for VT, and $v_i/v_t > 1$ was considered diagnostic for SVT. Figure 1 shows the new aVR algorithm, our previous algorithm, and the Brugada algorithm. and Figures 2, 3, and 4 show examples of how the new aVR algorithm was applied.

Statistical analysis
Occurrence of true as well as false-positive and negative results, as well as sensitivity and specificity, were compared between two algorithms by first constructing 2×2 crosstables demonstrating where the two algorithms agreed or disagreed. Thereafter, the nonparametric McNemar test was used to compare two related proportions and determine which algorithm was better. SPSS for Windows (version 13, SPSS Inc., Chicago, IL, USA) was used for statistical analysis. $P < 0.05$ value was considered significant. The method described was not suitable for comparison of predictive values because the denominators for the two algorithms differ (unlike specificity and sensitivity, in which the denominators are the same). Lacking an entirely appropriate statistical method for comparing predictive values, these values are presented simply with 95% confidence intervals (CI) without statistical comparison. A significant between-groups difference in algorithms is indicated by disjoint (nonoverlapping) confidence intervals. Some patients are present in the dataset more than once (several VTs with different morphology were induced in some patients, whereas a few patients had wide QRS complex tachycardias due to both SVT and VT during the same electrophysiologic study). Because these episodes behaved as independent unrelated events, they were analyzed as different wide QRS complex tachycardia tracings in the study.

The $\kappa$ statistic was used to quantify overall interobserver agreement using the SAS statistical software package (SAS/STAT Software Release 6.12, SAS Institute). Overall interobserver agreement was defined as good if $\kappa > 0.6$, moderate if $0.6 > \kappa > 0.4$, and poor if $\kappa < 0.4$. 

Because three channels were recorded simultaneously on the ECG tracings, the onset and end of the QRS were defined by the earliest and latest ventricular depolarization, respectively, among the three simultaneously recorded augmented limb leads (aVR, aVL, aVF). We hypothesized that the presence of an initial dominant R wave (such as R or RS complex, but not rS complex) or an initial r or q wave >40 ms, or a notch on the downslope of a negative onset and predominantly negative QRS in lead aVR, suggested VT. We also hypothesized that $v_i/v_t > 1$ suggested SVT and $v_i/v_t ≤ 1$ indicated VT. The four criteria of the new aVR algorithm were organized in a stepwise, decision-tree format similar to that of the Brugada algorithm and our previous algorithm. When any of the first three criteria of the algorithm was met, a diagnosis of VT was made, and the analysis was stopped at that step. In the last step, $v_i/v_t ≤ 1$ was considered diagnostic for VT, and $v_i/v_t > 1$ was considered diagnostic for SVT. Figure 1 shows the new aVR algorithm, our previous algorithm, and the Brugada algorithm. and Figures 2, 3, and 4 show examples of how the new aVR algorithm was applied.

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New aVR algorithm

In lead aVR:

Step 1. Presence of an Initial R wave?
- No
- Yes
  VT diagnosed

Step 2. Presence of an Initial r or q wave >40 ms?
- No
- Yes
  VT diagnosed

Step 3. Presence of a notch on the descending limb of a negative onset and predominantly negative QRS?
- No
- Yes
  VT diagnosed

Step 4. \( V_1/V_1 \leq 1 \)?
- No
- Yes
  SVT diagnosed  VT diagnosed

Our previous algorithm

Step 1. A-V dissociation present?
- No
- Yes
  VT diagnosed

Step 2. Initial R wave in aVR present?
- No
- Yes
  VT diagnosed

Step 3. QRS morphology unlike BBB or FB?
- No
- Yes
  VT diagnosed

Step 4. \( V_1/V_1 \leq 1 \)?
- No
- Yes
  SVT diagnosed  VT diagnosed

Brugada algorithm

1. Absence of an RS complex in all precordial leads?
- yes
  VT diagnosed
- no

2. The longest R to S interval >100 ms in any precordial lead?
- yes
  VT diagnosed
- no

3. A-V dissociation?
- yes
  VT diagnosed
- no

4. Morphology criteria for VT present both in leads \( V_{1,2} \) and \( V_6 \)?
- yes
  VT diagnosed
- no
  SVT diagnosed

Figure 1  The new aVR algorithm, our previous algorithm, and the Brugada algorithm. BBB = bundle branch block; FB = fascicular block; SVT = supraventricular tachycardia; VT = ventricular tachycardia.
Results

Patient characteristics
The patient groups differed in that the preexcited tachycardia and SVT groups had younger patients, more female patients, fewer patients with a history of prior myocardial infarction or dilated cardiomyopathy, and far more patients without structural heart disease than the VT group (Table 1).

Overall test accuracy
Results are given in Table 2. The new aVR algorithm was not applicable in only 1 (0.2%) of 483 wide QRS complex tachycardias because of an isoelectric lead aVR in this tracing. In order to compare the results in an identical sample size, this wide QRS complex tachycardia was excluded from the analysis. The new aVR algorithm correctly classified 441 of 482 wide QRS complex tachycardias (91.5% overall test accuracy), which was similar to our previous algorithm [437/482 wide QRS complex tachycardias (90.7% overall test accuracy)]. Both were superior (P = .002 and P = .007, respectively) to the Brugada algorithm [412/482 (85.5% overall test accuracy)]. There was no difference in the overall test accuracy of the new aVR algorithm and our previous algorithm. The first step (initial R wave in aVR) correctly diagnosed VT in 98.6% of cases in which it was positive, whereas a correct diagnosis was made by the second, third, and fourth criteria in 87.8%, 86.4%, and 89.3% of applicable cases, respectively. The overall test accuracy of the first Brugada criterion was significantly (P = .0308) lower than that of the first criterion of the new aVR algorithm (93.3% vs 98.6%) as well as that of the fourth Brugada criterion (71% vs 89.3% for the new aVR algorithm and 82.8% for our previous algorithm; P = .005 and P = .0136, respectively) compared with that of the v/vt index criterion in the fourth step of the new aVR and our previous algorithms. The second criterion of our previous algorithm had a significantly (P = .0363) higher overall test accuracy than did the second Brugada criterion (97.7% vs 92.4%). Thus, the superiority of the two new criteria (initial R wave in lead aVR and v/vt index) to their counterparts in the same ordinal rank in the Brugada algorithm is responsible for the superior overall test accuracy of the new aVR and our previous algorithms compared with that of the Brugada algorithm.

We also evaluated a modified five-step aVR algorithm, in which the first step was AV dissociation and the next four steps were identical to the new aVR algorithm. This yielded the correct diagnosis in only one other case, when compared to the four-step aVR algorithm (442/482 vs 441/482 cases).

Fifteen wide QRS complex tachycardia episodes were misclassified by both the new aVR and Brugada algorithms. These episodes were mostly SVTs misdiagnosed as VT [12/15 (80%)], and two thirds [10/15 (67%)] of them were present with a right bundle branch block pattern. No other common characteristics of the ECGs misclassified by both the new aVR and Brugada algorithms were identified. The two observers produced very similar results. Interobserver variability was nonsignificant, as was the difference between the misclassified ECGs using all three algorithms between the two observers. Therefore, only results from observer 1 are published and used for analysis. Figure 5
shows the numbers of VT and SVT true and false-positive diagnoses made in each step of the new aVR algorithm.

Because the second criterion of the aVR algorithm might be affected by antiarrhythmic drug treatment, the second criterion was also evaluated separately in wide QRS complex tachycardia tracings recorded from patients with and without antiarrhythmic medication. From a total of 158 wide QRS complex tachycardia tracings recorded from patients receiving antiarrhythmic drug treatment in this study, the first criterion of the aVR algorithm was positive in 75 wide QRS complex tachycardia tracings; therefore, 83 tracings remained for application of the second criterion. Among wide QRS complex tachycardias obtained from patients taking antiarrhythmic medication, the second criterion was positive in 24 (29%) of 83. In all 24 cases the criterion was true positive; thus, antiarrhythmic drug treatment did not affect the performance of the second criterion. All nine false-positive cases (Figure 5) during application of the second criterion occurred in wide QRS complex tachycardias obtained from patients without antiarrhythmic drug treatment, simply because false positivity of the second criterion means that the patient had SVT, and the great majority (96%) of SVT patients did not receive antiarrhythmic medication. Our new aVR and previous algorithms, as well as that of the Brugada algorithm and traditional morphologic ECG criteria, are unable to reliably differentiate VTs from preexcited tachycardias in most wide QRS complex tachycardia cases. One possible exception may be the presence of an initial R wave in lead aVR, when using the new aVR algorithm, which seems to exclude preexcited tachycardia (with possible exception of the rare preexcited tachycardias using epicardial left-sided paraseptal or infero-posterior bypass tracts). In fact, none of our 20 preexcited tachycardias had an initial R wave in lead aVR; however, this suggestion requires further testing (for further discussion, see Vereckei et al15). Thus, the final diagnosis of VT using the new aVR algorithm also included preexcited tachycardias.

Sensitivity, specificity, and predictive values
Because only two final diagnoses (VT or SVT) were possible with the algorithms used, the specificity and positive predictive value for VT diagnosis were the same as the sensitivity and negative predictive value for SVT diagnosis.

Figure 3 Use of $v_i/v_t$ criterion in the fourth step of the new aVR algorithm. In both panels, the crossing points of the vertical lines with the QRS contour in lead aVR show the onset and end of the QRS complex in lead aVR. The crossing points and initial and terminal 40 ms of the chosen QRS complex are marked by small crosses. Left: During the initial 40 ms of the QRS, the impulse traveled vertically 0.15 mV; therefore, $v_i = 0.15$. During the terminal 40 ms of the QRS, the impulse traveled vertically 0.6 mV; therefore, $v_t = 0.6$. Thus, $v_i/v_t < 1$ yields a diagnosis of ventricular tachycardia (VT). Right: $v_i = 0.4$ and $v_t = 0.2$, determined the same way as in the left panel; thus, $v_i/v_t > 1$ suggests a diagnosis of supraventricular tachycardia (SVT).
Inversely, the sensitivity and negative predictive value for VT diagnosis were the same as the specificity and positive predictive value for SVT diagnosis, respectively. For this reason, only data for VT diagnosis are reported, which can be applied accordingly for the appropriate parameters in SVT diagnosis (Table 3). The new aVR algorithm as well as our previous algorithm had greater sensitivity for VT diagnosis than did the Brugada algorithm (96.5% and 95.7% vs 89.2%, \( P < .001 \) and \( P = .001 \), respectively). Likewise, the negative predictive values of the new aVR and our previous algorithms were better than the Brugada algorithm (86.6% and 83.8% vs 67.2%). The \( \nu/v_i \) criterion applied in the fourth step of the new aVR and our previous algorithms had a significantly greater sensitivity for VT diagnosis (90.7% and 69.8%) compared with the fourth Brugada criterion (45.2%; \( P < .001 \) and \( P = .007 \), respectively) as well as negative predictive value for VT diagnosis (87.5% and 83.8% vs 67.2%). The sensitivity for VT diagnosis of the \( \nu/v_i \) criterion applied in the fourth step of the new aVR algorithm was superior to that of the \( \nu/v_i \) criterion applied in the fourth step of our previous algorithm (90.7% vs 69.8%, respectively, \( P = .005 \)). Compared with the first Brugada criterion, the first criterion of the new aVR algorithm had greater sensitivity (38.9% vs 22.4%, \( P < .001 \)) and specificity (98.2% vs 94.6%, \( P = .0088 \); these significance data are not shown in Table 3). When all criteria were combined, there was no significant difference in any studied parameter between the greatly simplified new aVR and our previous algorithm. The overall test accuracy of the new aVR and our previous algorithm was on par with the use of all published, difficult-to-recall traditional ECG criteria.6,9

**Table 1** Clinical characteristics of the patients

<table>
<thead>
<tr>
<th></th>
<th>Supraventricular tachycardia (n = 112)</th>
<th>Ventricular tachycardia (n = 350)</th>
<th>Preexcited tachycardia (n = 20)</th>
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</thead>
<tbody>
<tr>
<td>Age (yr; mean ± SD)</td>
<td>44 ± 20</td>
<td>58 ± 18</td>
<td>35 ± 17</td>
</tr>
<tr>
<td>Female/male (%)</td>
<td>44/56</td>
<td>16/84</td>
<td>35/65</td>
</tr>
<tr>
<td>History</td>
<td></td>
<td></td>
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<tr>
<td>Postmyocardial infarction (%)</td>
<td>4</td>
<td>61</td>
<td>0</td>
</tr>
<tr>
<td>Dilated cardiomyopathy (%)</td>
<td>1</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>No structural heart disease (idiopathic) (%)</td>
<td>93</td>
<td>11</td>
<td>100</td>
</tr>
</tbody>
</table>

**Discussion**

**Major findings**

The new aVR algorithm is based solely on the principle of differences in the direction and velocity of the initial and terminal ventricular activation during wide QRS complex tachycardia due to VT and SVT. Our study shows that both our new aVR algorithm and the previous algorithm devised for differential diagnosis of wide QRS complex tachycardias have superior overall test accuracy and greater sensitivity and negative predictive value in VT diagnosis compared with the Brugada algorithm. This superiority is mainly due to the two new incorporated criteria. There was no significant difference in any studied parameter between the greatly simplified new aVR and our previous algorithm. The overall test accuracy of the new aVR and our previous algorithm was on par with the use of all published, difficult-to-recall traditional ECG criteria.6,9

**New concepts in the aVR algorithm**

Although the new aVR algorithm does not contain any fundamentally new criteria, it is based on three novel con-
cepts: (1) selection of lead aVR exclusively for differential diagnosis of wide QRS complex tachycardias; (2) classification of VTs into two main groups—(a) VTs arising from the inferior or apical region of the ventricles yielding an initial R wave in lead aVR, and (b) VTs arising from other regions and lacking an initial R wave in aVR but with slowing of the initial part of the QRS complex (this is in contrast to SVTs that show more rapid initial QRS forces); and (3) elimination of the AV dissociation criterion and complex morphologic criteria used by all prior algorithms and traditional criteria.

Choice of lead aVR and classification of VTs into two main forms
During SVT with bundle branch block, both the initial rapid septal activation (which can be either left to right or right to left) and the later main ventricular activation wavefront proceed in a direction away from lead aVR, yielding a negative QRS complex in lead aVR (Figure 5). An exception to this generalization occurs in the presence of an inferior myocardial infarction. An initial r wave (rS complex) may be seen in lead aVR during normal sinus rhythm or SVT due to loss of initial inferiorly directed forces. An rS complex also may be present as a normal variant in lead aVR, with R/S >1. With these considerations, an initial dominant R wave should not be present in SVT with bundle branch block.16,17

Because an initial dominant R wave in aVR is incompatible with SVT, its presence suggests VT, typically arising from the inferior or apical region of the ventricles yielding an initial R wave in lead aVR, and (b) VTs arising from other leads in distinguishing VT from VT (Figure 6). We also hypothesized that lead aVR is more sensitive than other leads in detecting VTs originating from sites other than the inferior or apical wall of the ventricles, but not showing an initial R wave in aVR. We hypothesized that

| Table 2 Percentage of correct diagnoses (test accuracy) made by different ECG criteria* ,*** ,# ,### ,§§§ |
| Criterion | Correct diagnosis |
| First new aVR algorithm criterion (initial R wave) | 144/146 [98.6% (96.7–100.5)] |
| Second new aVR algorithm criterion (r or q wave >40 ms) | 65/74 [87.8% (80.4–95.3)] |
| Third new aVR algorithm criterion (notch) | 32/37 [86.5% (75.5–97.5)] |
| Fourth new aVR algorithm criterion (v/v) | 201/225 [89.3% (85.3–93.4)] |
| New aVR algorithm, all criteria | 441/482 [91.5% (89–94)] |
| First criterion of our previous algorithm (AV dissociation) | 43/43 [100% (100–100)] |
| Second criterion of our previous algorithm (initial R wave in aVR) | 130/133 [97.7% (95.2–100.3)] |
| Third criterion of our previous algorithm (bundle branch block, fascicular block criterion) | 145/162 [89.5% (84.8–94.2)] |
| Fourth criterion of our previous algorithm (v/v) | 120/145 [82.8% (76.6–88.9)] |
| Our previous algorithm, all criteria | 437/482 [90.7% (88.1–93.3)] |
| First Brugada criterion (absence of RS) | 83/89 [93.3% (88.8–98.5)] |
| Second Brugada criterion (RS >100 ms) | 208/225 [92.4% (89.5–99)] |
| Third Brugada criterion (AV dissociation) | 6/6 [100% (100–100)] |
| Fourth Brugada criterion (morphology in V1,2 and V6) | 115/162 [71% (64–78)] |
| Brugada algorithm, all criteria | 412/482 [85.5% (82.3–88.6)] |

Numbers represent number of correct diagnoses/total number of tracings investigated with the criterion [percentage = test accuracy (95% confidence intervals)]. The overall (both for ventricular tachycardia [VT] and supraventricular tachycardia [SVT] diagnoses) test accuracy of all four criteria of the new aVR, our previous algorithm, and the Brugada algorithm was compared statistically. In addition, the overall test accuracy of each step of all three algorithms was compared with that of their counterparts in the same ordinal rank in the other algorithm separately.

*P < .05, **P < .01, ***P < .001 vs all criteria of the new aVR algorithm.

#P < .05, ##P < .01, ###P < .001 vs all criteria of our previous algorithm.

§P < .05, §§P < .01, §§§P < .001 vs the Brugada criterion at the same step of the Brugada algorithm.

The inferior or apical region of the ventricles yielding an initial R wave in lead aVR, and (b) VTs arising from other regions and lacking an initial R wave in aVR but with slowing of the initial part of the QRS complex (this is in contrast to SVTs that show more rapid initial QRS forces); and (3) elimination of the AV dissociation criterion and complex morphologic criteria used by all prior algorithms and traditional criteria.

Choice of lead aVR and classification of VTs into two main forms
During SVT with bundle branch block, both the initial rapid septal activation (which can be either left to right or right to left) and the later main ventricular activation wavefront proceed in a direction away from lead aVR, yielding a negative QRS complex in lead aVR (Figure 5). An exception to this generalization occurs in the presence of an inferior myocardial infarction. An initial r wave (rS complex) may be seen in lead aVR during normal sinus rhythm or SVT due to loss of initial inferiorly directed forces. An rS complex also may be present as a normal variant in lead aVR, with R/S >1. With these considerations, an initial dominant R wave should not be present in SVT with bundle branch block.16,17

Because an initial dominant R wave in aVR is incompatible with SVT, its presence suggests VT, typically arising from the inferior or apical region of the ventricles yielding an initial R wave in lead aVR, and (b) VTs arising from other leads in distinguishing VT from VT (Figure 6). We also hypothesized that lead aVR is more sensitive than other leads in detecting VTs originating from sites other than the inferior or apical wall of the ventricles, but not showing an initial R wave in aVR. We hypothesized that

![Figure 5 Numbers of ventricular tachycardia (VT) and supraventricular tachycardia (SVT) and true and false-positive diagnoses made in each step of the new aVR algorithm. WCT = wide QRS complex tachycardia.](image-url)
downstroke of the QRS, or a slower ventricular activation
initial r or q wave with width
of the QRS in lead aVR should be less steep ("slow") due to
VT without an initial R wave in lead aVR, the initial part
values (#vs all criteria of the new aVR algorithm, ¶vs all criteria of our previous algorithm, afourth Brugada criterion vs fourth step of new aVR algorithm,
(Figure 6). Another critical difference between VT and
a totally or predominantly negative QRS in lead aVR
the main vector in these VTs points downward, yielding
size pointing toward lead aVR (absent in SVT), even if
yield a slow, initial upward vector component of variable
sites of the interventricular septum or free wall) should
these VTs (except for VT arising from the most basal
sites of the interventricular septum or free wall) should
yield a slow, initial upward vector component of variable
size pointing toward lead aVR (absent in SVT), even if
the main vector in these VTs points downward, yielding
a totally or predominantly negative QRS in lead aVR
(Figure 6). Another critical difference between VT and
SVT, which is also the rationale of v_i/v_1 criterion, is that
in VT with bundle branch block the initial activation is
rapid, and the width of the QRS is caused by delay in the
mid to terminal part of the QRS. In contrast, during VT,
the initial ventricular activation is as slow or slower than
the terminal activation due to an initial slower muscle-
to-muscle spread of activation until the impulse reaches
the His–Purkinje system, after which the rest of the
ventricular muscle is more rapidly activated.15 Thus, in
VT without an initial R wave in lead aVR, the initial part
of the QRS in lead aVR should be less steep ("slow") due to
the slower initial ventricular activation having an initial
upward vector component, which may be manifested as an
initial r or q wave with width >40 ms, a notch on the
donstake of the QRS, or a slower ventricular activation
during the initial 40 ms than during the terminal 40 ms of
the QRS (v_i/v_1 ≤ 1) in lead aVR. In contrast, in VT with
bundle branch block, the initial part of the QRS in lead aVR
is steeper ("fast") due to the invariably rapid septal
activation going away from lead aVR, resulting in a narrow
(≤40 ms) initial r or q wave and v_i/v_1 > 1.

Table 3  Sensitivity, specificity, and positive and negative predictive values of different ECG criteria for differential diagnosis of wide
QRS complex tachycardia

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Sensitivity VT diagnosis</th>
<th>Specificity VT diagnosis</th>
<th>PPV VT diagnosis</th>
<th>NPV VT diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>First new aVR algorithm (initial r or q wave)</td>
<td>38.9 (34.4–43.9)</td>
<td>98.2 (95.8–100.7)</td>
<td>98.6 (96.7–100.5)</td>
<td>32.7 (27.7–37.8)</td>
</tr>
<tr>
<td>Second new aVR algorithm (r or q wave &gt;40 ms)</td>
<td>28.8 (22.9–34.7)</td>
<td>91.8 (86.7–96.9)</td>
<td>87.8 (80.4–95.3)</td>
<td>38.5 (32.7–44.4)</td>
</tr>
<tr>
<td>Third new aVR algorithm (notch)</td>
<td>19.9 (13.7–26)</td>
<td>95 (90.8–99.8)</td>
<td>86.5 (75.5–97.5)</td>
<td>42.7 (36.2–49.1)</td>
</tr>
<tr>
<td>Fourth new aVR algorithm (v_i/v_1)</td>
<td>90.7 (85.7–95.7)</td>
<td>87.5 (80.9–94.1)</td>
<td>90.7 (85.7–95.7)</td>
<td>87.5 (80.9–94.1)</td>
</tr>
<tr>
<td>New aVR algorithm, all criteria</td>
<td>96.5 (94.6–98.4)</td>
<td>75 (82.9–96)</td>
<td>92.7 (90.1–95.3)</td>
<td>86.6 (79.8–93.4)</td>
</tr>
<tr>
<td>First criterion previous algorithm (AV dissociation)</td>
<td>11.6 (8.4–14.9)</td>
<td>100 (100)</td>
<td>100 (100)</td>
<td>25.5 (21.4–29.6)</td>
</tr>
<tr>
<td>Second criterion previous algorithm (initial R in aVR)</td>
<td>39.6 (34.3–44.9)</td>
<td>97.3 (94.3–100.3)</td>
<td>97.7 (95.2–100.3)</td>
<td>35.5 (30.2–40.9)</td>
</tr>
<tr>
<td>Third criterion previous algorithm (bundle branch block, fascicular block criterion)</td>
<td>73.2 (67.1–79.4)</td>
<td>84.4 (77.6–91.2)</td>
<td>89.5 (84.8–94.2)</td>
<td>63.4 (55.6–71.3)</td>
</tr>
<tr>
<td>Fourth criterion previous algorithm (v_i/v_1)</td>
<td>69.8 (57.5–82.2)</td>
<td>90.2 (84.1–96.3)</td>
<td>80.4 (69.9–91.9)</td>
<td>83.8 (76.6–91.1)</td>
</tr>
<tr>
<td>Previous algorithm, all criteria</td>
<td>95.7 (93.6–97.7)</td>
<td>74.1 (66–82.2)</td>
<td>92.4 (89.8–95.1)</td>
<td>83.8 (76.6–91.1)</td>
</tr>
<tr>
<td>First Brugada criterion (absence of RS)</td>
<td>22.4 (18.2–26.7)</td>
<td>94.6 (90.5–98.8)</td>
<td>93.3 (88–98.5)</td>
<td>27 (22.6–31.4)</td>
</tr>
<tr>
<td>Second Brugada criterion (RS &gt;100 ms)</td>
<td>72.5 (67.3–77.6)</td>
<td>84 (77–90.9)</td>
<td>92.4 (89.9–95.9)</td>
<td>53 (45.4–60.5)</td>
</tr>
<tr>
<td>Third Brugada criterion (AV dissociation)</td>
<td>7.6 (3.4–44.9)</td>
<td>100 (100–100)</td>
<td>100 (100–100)</td>
<td>59.2 (52–66.4)</td>
</tr>
<tr>
<td>Fourth Brugada criterion (morphology in V_1 and V_2)</td>
<td>45.2 (33.8–56.6)</td>
<td>92.1 (86.5–97.7)</td>
<td>82.5 (70.7–94.3)</td>
<td>67.2 (58.9–75.5)</td>
</tr>
<tr>
<td>Brugada algorithm, all criteria</td>
<td>89.2 (86.4–92.4)</td>
<td>73.2 (65–81.4)</td>
<td>91.7 (88.8–94.5)</td>
<td>67.2 (58.9–75.5)</td>
</tr>
</tbody>
</table>

Because only two final diagnoses (ventricular tachycardia [VT] or supraventricular ventricular [SVT]) were possible with the algorithms used, the specificity and positive predictive value (PPV) for VT diagnosis were taken as the same as the sensitivity and negative predictive value (NPV) for VT diagnosis (respectively). Inversely, the sensitivity and NPV for VT diagnosis were the same as the specificity and PPV for SVT diagnosis, respectively. Therefore, only the sensitivity, specificity, and predictive values for VT diagnosis are shown. Numbers represent percentage values; numbers in parentheses are 95% confidence intervals. The sensitivity, specificity, and predictive values of all four criteria of the new aVR, our previous algorithm, and the Brugada algorithm were compared statistically; those of the fourth step of all three algorithms were compared separately. A significant between-groups difference in predictive values (❯vs all criteria of the new aVR algorithm, ◀vs all criteria of our previous algorithm, *fourth Brugada criterion vs fourth step of new aVR algorithm, #fourth Brugada criterion vs fourth step of our previous algorithm) is indicated only by disjoint (nonoverlapping) 95% confidence intervals.

For sensitivity and specificity: *P <.05, **P <.01, ***P <.001 vs all criteria of the new aVR algorithm.

*P <.05, **P <.01, ***P <.001 vs all criteria of our previous algorithm.

*P <.05, **P <.01, ***P <.001 vs all criteria of our previous algorithm.

*P <.01, ***P <.001 vs all criteria of our previous algorithm.

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Our previous algorithm was inherently limited to the His–Purkinje system (for detailed discussion, see Vereckei et al.\textsuperscript{15}) and was less time consuming than that of our previous algorithm and approximately as fast as that of the Brugada algorithm. However, the traditional ECG criteria, other authors,\textsuperscript{3,8,19,20} similar to us, reported lower sensitivity and much lower specificity of the Brugada algorithm than originally reported,\textsuperscript{2} although they still found the Brugada algorithm useful. Thus, the superiority of the new aVR and our previous algorithm to the Brugada algorithm does not mean that our two algorithms should be used to the exclusion of other methods for evaluation of wide QRS complex tachycardia.

Another limitation of our study is the relatively small number of cases of VT occurring in the absence of structural heart disease. These VTs often are more narrow than those in patients with myocardial disease and more easily confused with VT when applying other differentiating algorithms. It is possible that the new aVR algorithm is not as successful in this group as among VTs related to structural heart disease.

The inability of the aVR algorithm to differentiate preexcited tachycardias from VTs (with the possible exception of the presence of initial R wave in lead aVR) is a limitation of the algorithm. However, the traditional ECG criteria, VT, and SVT involving an atriofascicular accessory pathway that are associated with typical bundle branch block pattern indistinguishable from SVT with bundle branch block,\textsuperscript{3,4,8,18} unless AV dissociation was present in the first two arrhythmias. Because these rhythm disorders might give rise to an initial upward vector component, the new aVR algorithm might be able to correctly classify bundle branch reentry and fascicular VT as VT; however, this possibility requires further testing. Subgroup analysis investigating how preexistent bundle branch block, class I and III antiarrhythmic drug treatment, and idiopathic VT influenced the diagnostic accuracy of our previous and Brugada algorithms was performed in our previous study.\textsuperscript{15} Because the wide QRS complex tachycardia ECGs analyzed in this study are almost identical to those used in the previous study, no similar subgroup analysis was performed in order to avoid duplication of results. Although Brugada et al.\textsuperscript{2} believed that their algorithm was superior to the traditional criteria, other authors,\textsuperscript{3,8,19,20} similar to us, reported lower sensitivity and much lower specificity of the Brugada algorithm than originally reported,\textsuperscript{2} although they still found the Brugada algorithm useful. Thus, the superiority of the new aVR and our previous algorithm to the Brugada algorithm does not mean that our two algorithms should be used to the exclusion of other methods for evaluation of wide QRS complex tachycardia.

Figure 6  Explanation for ECG patterns in lead aVR with different causes of wide QRS complex tachycardia. In each example, left and right ventricles are depicted with corresponding pattern in aVR. Solid lines with arrows represent initial rapid vectors. Wavy lines and arrows signify slower impulse propagation. In the box, right bundle branch block (RBBB) and left bundle branch block (LBBB) aberration patterns are shown. Initial rapid septal activation is followed by slower activation of the “blocked” ventricle. Figures outside the box show actual aVR patterns during ventricular tachycardias (VTs) arising from (clockwise from top right): left ventricular apex; basal lateral left ventricle; midinferior wall; basal inferior wall; basal septum; and right ventricle (RV). VTs arising from near the ventricular apex or inferior or lateral ventricular wall are causing an initial R wave in lead aVR. VTs arising from other sites have a common feature. They result in a predominantly negative resultant main ventricular activation vector that yields a totally or predominantly negative QRS complex in lead aVR, with either slowing or widening of the initial part or notching on the downstroke of the QRS due to an initial upward vector component and/or a slower muscle to muscle spread of activation. SVT = supraventricular tachycardia.

Advantages and limitations of the new aVR algorithm

Advantages

The new aVR algorithm is well suited for emergency situations (e.g., patient presenting with wide QRS complex tachycardia) because the algorithm is accurate, reasonably fast, and easy due to the total elimination of complicated traditional morphologic criteria and the simple requirement to evaluate only lead aVR. Although the actual time needed for application of the three algorithms was not measured in the study (which is a limitation of the study), the definite impression of both observers 1 and 2 was that application of the new aVR algorithm was less time consuming than that of our previous algorithm and approximately as fast as that of the Brugada algorithm.

Study limitations

The limitations of the new aVR algorithm derive partly from conditions that may influence $v_h/v_c$. These conditions are anterosепal myocardial infarction, scar at a late activated ventricular site, fascicular VT, and VT exit site close to the His–Purkinje system (for detailed discussion, see Vereckei et al.\textsuperscript{15}). Our previous algorithm was inherently unable to recognize bundle branch reentry VT, fascicular VT, and SVT involving an atriofascicular accessory pathway that are associated with typical bundle branch block pattern indistinguishable from SVT with bundle branch block,\textsuperscript{3,4,8,18} unless AV dissociation was present in the first two arrhythmias. Because these rhythm disorders might give rise to an initial upward vector component, the new aVR algorithm might be able to correctly classify bundle branch reentry and fascicular VT as VT; however, this possibility requires further testing. Subgroup analysis investigating how preexistent bundle branch block, class I and III antiarrhythmic drug treatment, and idiopathic VT influenced the diagnostic accuracy of our previous and Brugada algorithms was performed in our previous study.\textsuperscript{15} Because the wide QRS complex tachycardia ECGs analyzed in this study are almost identical to those used in the previous study, no similar subgroup analysis was performed in order to avoid duplication of results. Although Brugada et al.\textsuperscript{2} believed that their algorithm was superior to the traditional criteria, other authors,\textsuperscript{3,8,19,20} similar to us, reported lower sensitivity and much lower specificity of the Brugada algorithm than originally reported,\textsuperscript{2} although they still found the Brugada algorithm useful. Thus, the superiority of the new aVR and our previous algorithm to the Brugada algorithm does not mean that our two algorithms should be used to the exclusion of other methods for evaluation of wide QRS complex tachycardia.

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![Figure 6](https://example.com/figure6.png)

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![Figure 7](https://example.com/figure7.png)

Figure 7  Representative examples of the most common lead aVR ECG patterns taken from real tracings recorded from patients with wide QRS complex tachycardias due to ventricular tachycardia (VT) and supraventricular tachycardia (SVT) superimposed on a grid (small box = 40 ms). Descriptions are given to the left of each QRS complex. Patterns seen in VT cases are shown on the left; SVT examples are at right. “Notched,” “slow,” and “rapid” refer to the type of descent of the initial portion of the QRS complex from onset to nadir.
with the exception of the presence of AV dissociation and other criteria suggested by Antunes et al., which are infrequently present, also are unable to differentiate VTs from preexcited tachycardias. Preexcited tachycardias constitute such a small proportion of wide QRS complex tachycardias in all series (4.1% in our study) that the inability to distinguish them from VTs is relatively insignificant.

**Conclusion**

Our new aVR algorithm proved to be a reasonably rapid, easy, and accurate means for obtaining the correct diagnosis in the differential diagnosis of wide QRS complex tachycardias. We found the algorithm be superior to the relatively simple Brugada algorithm and at least as accurate as the more complicated traditional morphologic criteria. Therefore, our new algorithm seems to be well suited for application in typically stressful clinical circumstances in which wide QRS complex tachycardias is encountered. However, using any published criteria or algorithm, the true cause of regular wide QRS complex tachycardias still is misdiagnosed in up to 10% of cases. A reasonable course of action is to treat all sustained regular wide QRS complex tachycardias as VT unless the diagnosis of SVT can be definitely established. It is far better to be wrong with a few cases of VT treated as VT than the reverse situation, because treating a VT as SVT may result in potentially disastrous consequences (e.g., intravenous verapamil injection causing severe hypotension and/or VT acceleration and ventricular fibrillation).

**References**