ORIGINAL RESEARCH CONTRIBUTION

Comparison of the "Real-life" Diagnostic Value of Two Recently Published Electrocardiogram Methods for the Differential Diagnosis of Wide QRS Complex Tachycardias

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Abstract

Objectives: The diagnostic values of the aVR lead or "Vereckei algorithm," and the lead II R-wave peak time (RWPT) criterion, recently devised for the differential diagnosis of wide QRS complex tachycardias (WCTs), were compared.

Methods: A total of 212 WCTs (142 ventricular tachycardias [VTs], 62 supraventricular tachycardias [SVT], and eight preexcitation SVTs) from 145 patients with proven electrophysiologic diagnoses were retrospectively analyzed by seven examiners blinded to the electrophysiologic diagnoses.

Results: The overall test accuracy of the Vereckei algorithm was superior to that of the RWPT criterion (84.3% vs. 79.6%; p = 0.0003). The sensitivity of the Vereckei algorithm for VT diagnosis was greater than that of RWPT criterion (92.4% vs. 79.1%; p < 0.0001). The negative predictive value (NPV) for the Vereckei algorithm was also greater (77.8%; 95% confidence interval [CI] = 73.6% to 82.1%) than that of the RWPT criterion (61.6%; 95% CI = 57.6% to 65.6%). The specificity of the Vereckei algorithm was lower than that of the RWPT criterion (64.7% vs. 80.9%; p < 0.0001). The positive predictive value (PPV) was also lower for the Vereckei algorithm (86.4%; 95% CI = 84.4% to 88.4%) than for the RWPT criterion (90.9%; 95% CI = 89.1% to 92.8%). Incorrect diagnoses made by the Vereckei algorithm were mainly due to misdiagnosis of SVT as VT (65.7% of cases), and those made by the RWPT criterion were due to the more dangerous misdiagnosis of VT as SVT (72.5% of cases).

Conclusions: The Vereckei algorithm was superior in overall test accuracy, sensitivity, and NPV for VT diagnosis and inferior in specificity and PPV to the RWPT criterion. All of these parameters were lower in "real life" than those reported by the original authors for each of the particular electrocardiographic methods.

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E lucidation of the mechanism of sustained, monomorphic wide QRS complex tachycardia (WCT) is a common diagnostic dilemma for the emergency physician. When confronted with the 12-lead WCT electrocardiogram (ECG), a correct diagnosis is vital not only for acute dysrhythmia treatment, but for further prognosis and subsequent work-up, as well as management. Because ventricular tachycardia (VT) and supraventricular tachycardia (SVT) with aberrant intraventricular conduction account for the vast majority of WCTs (80 and 15% to 20%, respectively), the clinically relevant problem is the distinction of VT from SVT with aberrant intraventricular conduction (SVT-A) in the differential diagnosis of WCTs. Other rare causes of WCT, such as SVT with anterograde conduction over an accessory pathway (preexcitation SVT), drug toxicity, electrolyte disorders (hyperkalemia), ventricular paced rhythm, or ECG artifact, account for only a small

minority (1% to 5%) of WCTs.[1–5] However, these numbers reflect the relative frequency of underlying causes of WCT obtained from studies of consecutive patients with WCT referred to electrophysiologic testing centers. Thus, the great preponderance of VT as the underlying cause of WCT might reflect the bias of difficult cases referred to electrophysiologic testing centers. According to some observations, the emergency physician might encounter VT less frequently and more commonly encounter other underlying causes of WCT in the emergency department.[6]

The ECG remains the cornerstone of distinguishing SVT-A from VT. Numerous ECG criterion and algorithms have been published for the differential diagnosis of WCTs, including the landmark publications of Sandler and Marriott,[7] Swanick et al.,[8] and Marriott and Sandler,[9] in 1965, 1966, and 1972; Wellens et al. in 1978[10]; Coumel et al. in 1984[11]; Kindwall et al. in 1988[12]; and Brugada et al. in 1991[13]; as well as the most recent publications of Vereckei et al.[14,15] and Pava et al.[16] Using all of these ECG methods, an accurate diagnosis is now possible in about 90% of WCTs.[17–19] A certain ECG diagnosis of the WCT mechanism obviates the need for a subsequent expensive and invasive electrophysiologic study. However, overreliance on ECG algorithms and criteria may be potentially dangerous, because they still misdiagnose the underlying cause of WCTs in up to 10% of cases. It seems prudent to consider and treat all sustained, regular WCTs as VT unless the diagnosis of SVT can be definitely established, because it is far better to be wrong with a few cases of SVT treated as VT than the reverse situation,[1,14] since treating a VT as SVT may result in potentially disastrous consequences (e.g., intravenous [IV] verapamil injection may cause severe hypotension and/or VT acceleration and ventricular fibrillation[20,21]). When ECG methods for WCT differentiation were applied by physicians, the reported diagnostic accuracy of a particular ECG method is usually lower than that reported by the original authors.[22–27] Therefore, we sought to compare the diagnostic value of two recently published simple ECG methods, the aVR lead "Vereckei algorithm,"[15] and the lead II R-wave peak time (RWPT) criterion,[16] for differential diagnosis of WCTs in "real life."

Figure 1 shows the lead aVR Vereckei algorithm, which contains two new criteria: 1) the v_i/v_t criterion based on the estimation of initial (v_i) and terminal (v_t) ventricular activation velocity ratio (v_i/v_t) and 2) the presence of an initial R wave in lead aVR.

The rationale behind the v_i/v_t criterion is that during WCT due to SVT, the initial activation of the septum (occurring either left-to-right or right-to-left) should be invariably rapid over the normal His-Purkinje system, and the intraventicular conduction delay causing the wide QRS complex occurs in the mid to terminal part of the QRS, thus the $v_i/v_t > 1$ during SVT. During WCT due to VT, however, an initial slower muscle-to-muscle spread of activation occurs until the impulse reaches the His-Purkinje system, after which the rest of the ventricular muscle is more rapidly activated, thus, the $v_i/v_t \leq 1$ during VT. This assumption should hold true regardless of the mechanism of VT or presence or absence of structural heart disease.
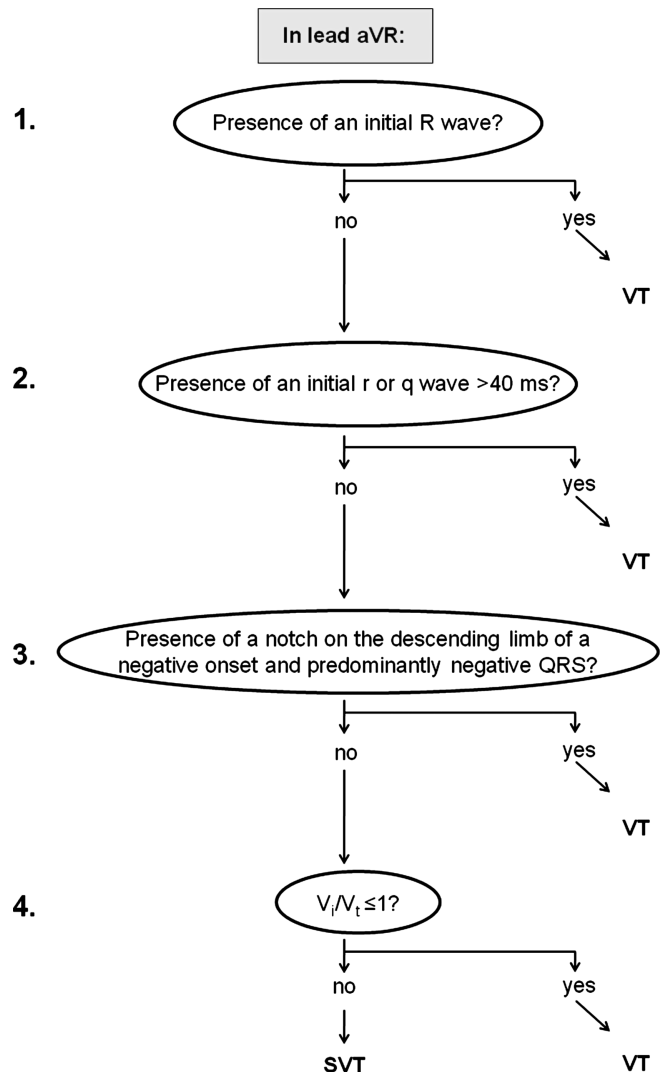

Figure 1. The aVR Vereckei algorithm. SVT = supraventricular tachycardia; VT = ventricular tachycardia.

The presence of an initial R wave in lead aVR is similar to the traditional northwest axis criterion, which suggests VT, but is not the same, because the range of the resultant QRS vector that yields an initial R wave in lead aVR is between –60 and +120 degrees. The initial ventricular activation wavefront during SVT and sinus rhythm should go away from lead aVR, yielding a negative QRS complex (an rS complex in lead aVR may be present as a normal variant or in patients with inferior myocardial infarction due to loss of initial inferiorly directed forces, but with an R/S ratio < 1). Thus, an initial dominant R wave (such as R or Rs complex) in lead aVR should not be present in SVT-A and suggests VT.

The principle on which the lead II RWPT criterion is based is that most VTs (myocardial VTs) are associated with slow initial ventricular activation close to the site of origin due to slow muscle-to-muscle conduction, resulting in a more significantly prolonged QRS duration or time to the intrinsicoid deflection when the mechanism of WCT is VT versus SVT.

METHODS

Study Design

This was a retrospective cohort study, in which 12-lead ECG tracings of WCTs from patients with proven electrophysiologic diagnosis were analyzed by board-certified cardiologists and emergency physicians as well as internal medicine, emergency medicine, and cardiology residents blinded to the electrophysiologic diagnoses and the patients' clinical data. The study complies with the Declaration of Helsinki. An informed consent exemption was obtained from the Indianapolis University Institutional Review Board for this analysis of a deidentified data set.

Study Setting and Population

A subset of 12-lead ECGs (212 tracings out of the total 483 tracings) recorded from consecutive patients during electrophysiologic studies conducted from June 1998 to June 2005 at Indiana University (those with clearly established electrophysiologic diagnoses) were evaluated. The same recordings were used in our previous studies.[14,15] The 12-lead ECG printouts were sent to us in series (series "A," "B," "C," etc.) during the study and we selected two series (series "B" and "C") containing sufficient tracings (the chosen 212 tracings that were recorded from consecutive patients) for this study. A total of 212 regular WCT ECGs (142 VTs, 62 SVTs, and eight preexcitation SVTs), recorded from 145 consecutive patients out of the total 287 consecutive patients, were retrospectively analyzed by seven observers blinded to the electrophysiologic diagnoses and patients' clinical data.

Study Protocol

WCT was defined as a rhythm with a rate of ≥100 beats/min and a QRS duration of ≥120 milliseconds. Only regular, monomorphic WCTs were analyzed. Despite the fact that preexcitation SVT is an SVT by mechanism, preexcitation SVT behaves as a VT originating from the base of the ventricles both electrophysiologically and regarding its ECG morphology. For this reason, and because neither of the two ECG methods used in this study, nor other ECG methods for WCT differentiation, are able to differentiate preexcitation SVT from VT unless atrioventricular dissociation is present, when the mechanism of WCT was preexcitation SVT, we considered a final VT diagnosis correct and an SVT diagnosis incorrect.[15,28]

The reviewers were given complete 12-lead standard ECGs obtained during tachycardia for analysis. The WCT ECG tracings were obtained from all kinds of patients with and without structural heart disease, preexistent bundle branch block, or antiarrhythmic drug treatment. Before examiners started to evaluate the study ECGs, they all were provided with copies of the published articles about the two ECG methods to be used and received brief training on a different set of 30 ECGs to elucidate the potential pitfalls and caveats in the application of the two ECG methods. The distribution of the seven examiners was the following: two board-certified cardiologists, two board-certified emergency physicians, one emergency medicine resident, one internal medicine resident, and one cardiology fellow who recently finished residency in internal medicine and started fellowship in cardiology.

The aVR Vereckei algorithm arrived at a diagnosis of VT and the analysis was stopped if any of the following criteria was met in lead aVR: 1) an initial R wave was present, 2) the QRS started with an r or q wave of >40 millisecond width, or 3) there was a notch on the downsloping limb of a predominantly negative QRS with a negative onset. When none of the first three criteria were met, in the fourth step we estimated the initial (v_i) and terminal (v_t) ventricular activation velocity ratio (v_i/v_t) by measuring the distance in mV the impulse traveled vertically during the initial (v_i) and terminal 40 milliseconds (v_t) of the QRS complex. In the fourth step, when the v_i/v_t was ≤1 the diagnosis of VT was made and if the v_i/v_t was >1 the diagnosis of SVT. Figures 2 and 3 show examples of how to apply the aVR Vereckei algorithm. For more details see the original publication.[15] The RWPT criterion suggested VT if the interval from the QRS onset to the peak of the first positive or negative wave was ≥50 milliseconds in lead II, and it suggested SVT if the interval was <50 milliseconds (see Figures 4 and 5). For further details see the original publication.[16] The accurate determination of the onset and end of the QRS complex is very important for the proper application of the ECG methods. The onset and end of the QRS were defined by determination of the earliest and latest ventricular depolarization, respectively, in the three simultaneously recorded limb leads (aVR, aVL, aVF; or I, II, III).

Data Analysis

Occurrence of true as well as false-positive and -negative results, as well as sensitivity and specificity, were compared between two ECG methods by first constructing 2 × 2 tables demonstrating where the two ECG methods agreed or disagreed. Thereafter, the nonparametric McNemar's test was used to compare two related proportions, to determine which ECG method was better. SPSS 13 for Windows software package (IBM SPSS, Armonk, NY) was used for statistical analysis. A p < 0.05 value was considered statistically significant. The type I error rate was not adjusted for multiple testing of the same variables. The above-described method was not suitable for the comparison of the predictive values, because the denominators for the two ECG methods differ (unlike specificity and sensitivity, in which the denominators are the same). Lacking an entirely appropriate statistical method to compare the predictive values, these are presented simply with 95% confidence intervals (CIs) without statistical comparison. A significant between-groups difference in ECG methods is suggested by disjoint (nonoverlapping) CIs. Some patients are in the data set more than once (several VTs with different morphology were induced in some patients, while a few had WCTs due to both SVT and VT during the same electrophysiologic study). Because these episodes behaved as independent, unrelated events, they were analyzed as different WCT tracings in the study.

The kappa statistic was performed to determine interobserver agreement using the SAS statistical software package (SAS Software Release 6.12, SAS Institute
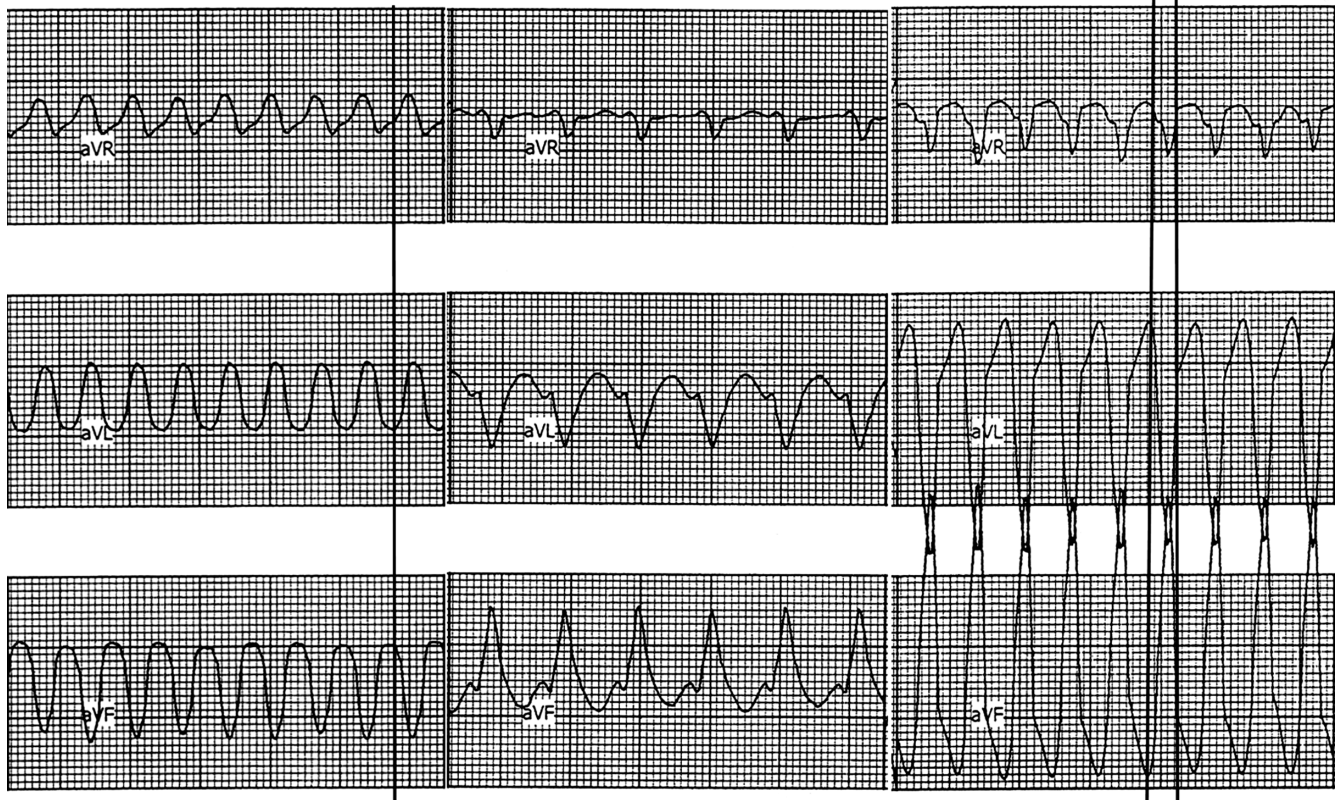
Figure 2. Examples for the positivity of the first three steps of the new aVR algorithm. The figure demonstrates three different wide QRS tachycardia WCT ECGs where one of the first three steps of the new aVR algorithm was positive (i.e., suggested a diagnosis of VT). Only the simultaneously recorded leads aVR, aVL, and aVF are shown from each 12-lead ECG. In the left panel an initial R-wave is present in lead aVR; thus the first step suggests VT. The crossing point of the vertical line with the contour of the last QRS denotes the onset of the QRS. In the middle panel an rS complex is seen in lead aVR, with an R-wave width of 70 milliseconds; therefore, the second step of the algorithm suggests VT. The right panel displays a notch on the downstroke of a negative onset and predominantly negative QRS; thus VT is diagnosed in the third step. The crossing points of the two vertical lines with the contour of the sixth QRS complex mark the onset and end of the QRS. Reproduced, with permission, from Vereckei A, Duray G, Szénási G, Altemose GT, Miller JM. A new algorithm using only lead aVR for the differential diagnosis of wide QRS complex tachycardia. Heart Rhythm 2008;5:89–98.[15] ECG = electrocardiogram; SVT = supraventricular tachycardia; VT = ventricular tachycardia; WCT = wide QRS complex tachycardia.

Inc., Cary, NC). Overall interobserver agreement was defined as near complete if $\kappa > 0.8$, good if $\kappa = 0.61$ to 0.8, moderate if $\kappa = 0.41$ to 0.6, fair if $\kappa = 0.21$ to 0.4, and poor if $\kappa < 0.2$.[29]

RESULTS

Patient Characteristics
The patients were younger in the preexcitation SVT and SVT groups than in the VT group, and far more patients had structural heart disease and histories of prior myocardial infarction or cardiomyopathy in the VT group than in the preexcitation SVT and SVT groups (see Table 1). No patient in the preexcitation SVT group and fewer patients in the SVT group took antiarrhythmic drugs than in the VT group. There were more females in the SVT group than in the two other groups, and 20% to 30% of the baseline ECG tracings showed pre-existing bundle branch block in both the SVT and VT groups.

Overall Test Accuracy
The results are shown in Table 2. The seven examiners together correctly classified 1,251 of 1,484 (84.3%) WCT

tracings using the aVR Vereckei algorithm and 1,182 out of 1,484 (79.6%) WCT tracings with the lead II RWPT criterion. The mean overall test accuracy of the aVR Vereckei algorithm was superior to that of the lead II RWPT criterion (p = 0.0003). In a post hoc analysis, the seven observers were divided into subgroups of experienced observers (four board-certified physicians) and inexperienced observers (three residents). The experienced observers achieved a significantly better mean overall test accuracy with the aVR Vereckei algorithm than with the lead II RWPT criterion (738 of 848, or 86.6% vs. 671 of 848, or 79.1%; p < 0.001), while the inexperienced observers obtained similar mean overall test accuracy with the two ECG methods (517 of 636, or 81.3% vs. 511 of 636, 80.3%, p = 0.68). The mean overall test accuracy obtained by the seven observers with the aVR Vereckei algorithm was lower in the current study than in the original article (84.3% vs. 90.3%). Overall test accuracy was not published for the lead II RWPT criterion in the original article.

The incorrect diagnoses (233 of 1,484; 15.7%) were mostly due to SVTs misdiagnosed as VTs (153 of 233; 65.7%) by the seven observers together using the aVR Vereckei algorithm. In contrast, the incorrect diagnoses
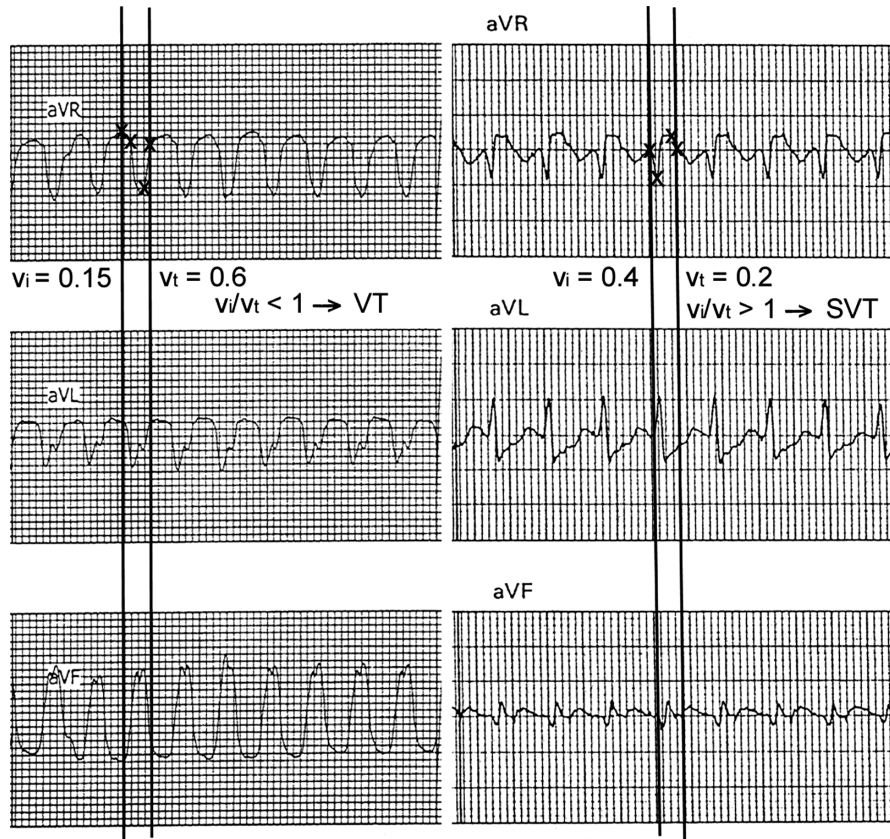
Figure 3. The use of v_i/v_t criterion in the fourth step of the new aVR algorithm. In both panels the crossing points of the vertical lines with the QRS contour in lead aVR show the onset and end of the QRS complex in lead aVR. The crossing points and initial and terminal 40 milliseconds of the chosen QRS complex are marked by small crosses. In the left panel, during the initial 40 milliseconds of the QRS the impulse traveled vertically 0.15 mV; therefore, the $v_i = 0.15$ and during the terminal 40 milliseconds of the QRS the impulse traveled vertically 0.6 mV; therefore, the $v_t = 0.6$, and thus the $v_i/v_t < 1$ yields a diagnosis of VT. In the right panel the $v_i = 0.4$ and $v_t = 0.2$ determined the same way as in the left panel, and thus $v_i/v_t > 1$ suggests a diagnosis of SVT. Reproduced, with permission, from Vereckei A, Duray G, Szénási G, Altemose GT, Miller JM. A new algorithm using only lead aVR for the differential diagnosis of wide QRS complex tachycardia. Heart Rhythm 2008;5:89–98.[15] VT = ventricular tachycardia; SVT = supraventricular tachycardia; WCT = wide QRS complex tachycardia.
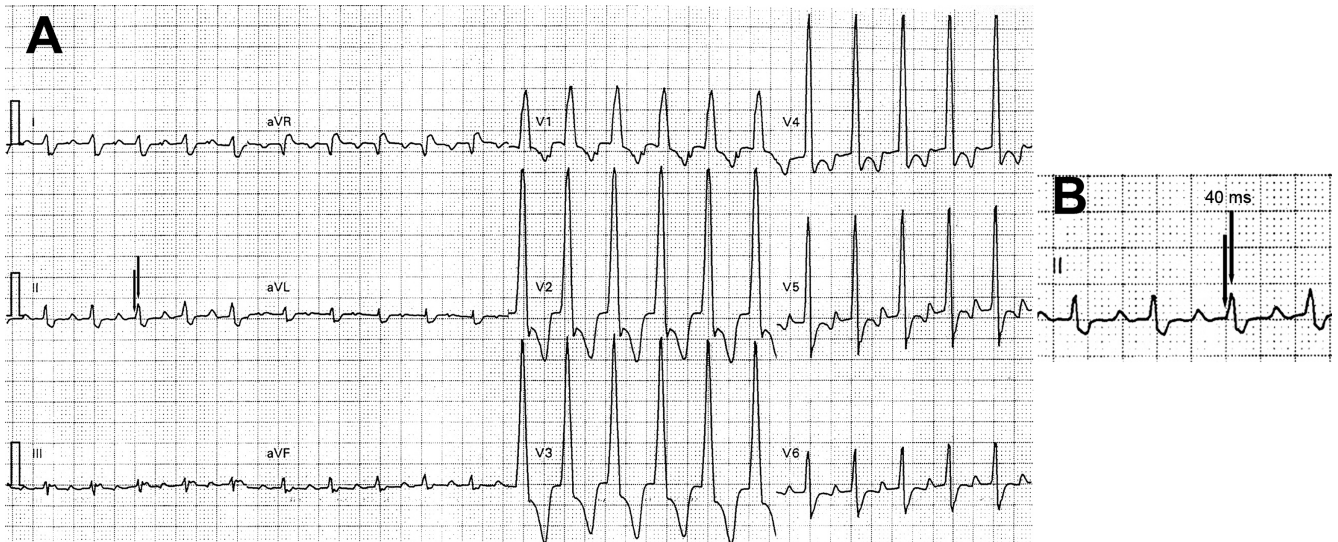

Figure 4. The use of the lead II RWPT criterion. (**A**) Twelve-lead WCT tracing recorded from a patient with SVT and a right bundle branch block pattern. (**B**) Magnified view of lead II from **A**. The RWPT, which is the interval between the two vertical arrows, was <50 milliseconds; thus SVT diagnosis was made with the lead II RWPT criterion. RWPT = R-wave peak time; SVT = supraventricular tachycardia; WCT = wide QRS complex tachycardia.

Figure 5. The use of the lead II RWPT criterion. (**A**) Twelve-lead WCT tracing recorded from a patient with VT and left bundle branch block pattern. (**B**) Magnified view of lead II from **A**. The RWPT, which is the interval between the two vertical arrows, was ≥50 milliseconds; thus VT diagnosis was made with the lead II RWPT criterion. RWPT = R-wave peak time; VT = ventricular tachycardia; WCT = wide QRS complex tachycardia.
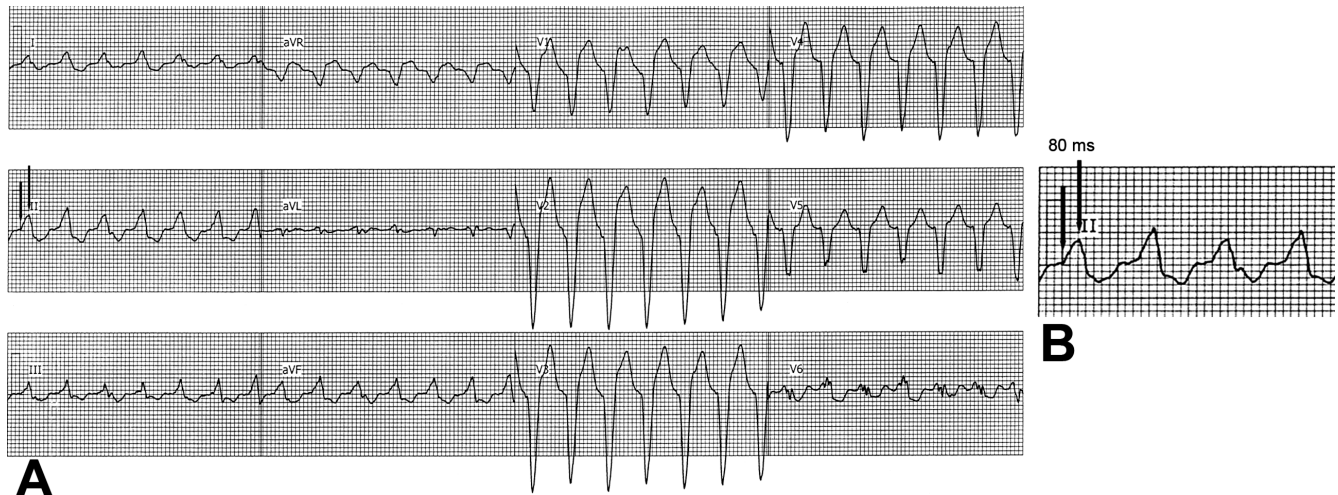
Table 1
Clinical Characteristics

Characteristic	SVT	VT	Preexcitation SVT
WCT ECG tracings, *n*	62	142	8
Patients, *n*	58	79	8
Age (yr), mean (SD)	44 (19)	54 (18)	39 (21)
Female/male	25/33	14/65	1/7
Antiarrhythmic drugs,%*	5	44	0
Preexisting bundle branch block[†]	29	25	0
Past history*			
Post MI,%	2	44	0
Cardiomyopathy,%	3	15	0
No structural heart disease,%	91	39	100

*% of patient *n.*
[†]% of WCT ECG tracings *n.*
ECG = electrocardiogram; MI = myocardial infarction; SVT = supraventricular tachycardia; VT = ventricular tachycardia; WCT = wide QRS complex tachycardia.

Table 2
The Percentage of Correct Diagnoses (Overall Test Accuracy) Made Using the Two ECG Reading Methods

ECG Method	Correct Diagnosis	95% CI
aVR Vereckei algorithm		
Seven readers	1,251/1,484 (84.3%)*	82.0–86.0
Four experienced readers	738/848 (86.6%)*	84.4–88.7
Three inexperienced readers	517/636 (81.3%)	78.9–83.7
RWPT criterion		
Seven readers	1,182/1,484 (79.6%)	77.2–82.1
Four experienced readers	671/848 (79.1%)	76.6–81.6
Three inexperienced readers	511/636 (80.3%)	77.9–82.8

The numbers represent number of correct diagnoses/total number of tracings investigated with the ECG method (percentage = test accuracy). The overall (for both VT and SVT diagnosis test accuracy of the two ECG methods were compared statistically.
*p < 0.001 vs. the RWPT criterion evaluated by the same number of observers.
RWPT = lead II R-wave peak time criterion; SVT = supraventricular tachycardia; VT = ventricular tachycardia.

(302 of 1,484; 20.4%) were mostly due to VTs misdiagnosed as SVTs (219 of 302; 72.5%) by the seven observers together using the lead II RWPT criterion, which is the more dangerous type of misclassification. The diagnosis was established in the first step in approximately 25% of the cases and in the fourth step in 50% to 60% of WCTs using the aVR Vereckei algorithm, although there was some variation among the observers.

Sensitivity, Specificity, and Predictive Values
Table 3 demonstrates the sensitivity, specificity, and predictive values of the two ECG methods. Because only two final diagnoses (VT or SVT) were possible with the ECG methods used, the specificity and positive predictive value (PPV) for VT diagnosis were the same as the sensitivity and negative predictive value (NPV) for SVT diagnosis (respectively), and inversely, the sensitivity

and NPV for VT diagnosis were the same as the specificity and PPV 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 seven observers together, as well as the experienced and inexperienced observers subgroups, achieved significantly superior sensitivity and inferior specificity for VT diagnosis using the aVR Vereckei algorithm compared with the lead II RWPT criterion.

The mean PPV for VT diagnosis reached by the seven observers together was significantly greater for the lead II RWPT criterion than that for the aVR Vereckei algorithm. However, there was no difference in the PPVs for the lead II RWPT criterion compared with that for the aVR Vereckei algorithm in the experienced or in the

Table 3
Sensitivity, Specificity, and Predictive Values of the Two ECG Methods for VT Diagnosis

ECG Method	Sensitivity	Specificity	PPV	NPV
aVR Vereckei algorithm				
Seven readers	92.4[†] (90.8–94)	64.7[†] (60.3–69.2)	86.4[‡] (84.4–88.4)	77.8[‡] (73.6–82.1)
Four experienced	93.0* (91.0–95.0)	71.0* (65.3–76.6)	88.6 (86.1–91.1)	80.7[‡] (75.5–86)
Three inexperienced	91.6* (89.0–94.1)	56.5* (49.3–63.6)	83.6 (80.3–86.8)	73.4 (66.2–80.7)
RWPT criterion				
Seven readers	79.1 (76.7–81.6)	80.9 (77.2–84.6)	90.9 (89.1–92.8)	61.6 (57.6–65.6)
Four experienced	76.3 (72.9–79.7)	85.9 (81.6–90.2)	92.9 (90.6–95.2)	60.0 (54.9–65.1)
Three inexperienced	82.9 (79.4–86.4)	74.2 (67.9–80.5)	88.6 (85.6–91.6)	64.2 (57.8–70.6)

Numbers represent percentage values; numbers in parentheses are 95% CI. A significant between ECG methods difference refer-ring to the same number of observers in predictive values (‡) is indicated by disjoint (nonoverlapping) 95% CIs.
*p < 0.001 vs. that of the RWPT criterion evaluated by the same number of observers.
†p < 0.0001 vs. that of the RWPT criterion evaluated by the same number of observers.
RWPT = lead II R-wave peak time criterion; NPV = negative predictive value; PPV = positive predictive value; VT = ventricular tachycardia.

inexperienced observers subgroups. The aVR Vereckei algorithm had a greater mean NPV for VT diagnosis in the hands of the seven observers together and of the experienced observers subgroup compared with that for the lead II RWPT criterion (Table 3).

The sensitivity, specificity, and predictive values for VT diagnosis of the seven observers together using either ECG method were lower than those reported in the original publications (sensitivity 92.4% vs. 96.5%, specificity 64.7% vs. 75%, PPV 86.4% vs. 92.7%, NPV 77.8% vs. 86.6% for the aVR Vereckei algorithm; sensitivity 79.1% vs. 93.2%, specificity 80.9% vs. 99.3%, PPV 90.9% vs. 98.2%, NPV 61.6% vs. 93.3% for the lead II RWPT criterion).

The mean kappa value of the seven observers together suggested a moderate interobserver agreement for both ECG methods ($\kappa = 0.49$, 95% CI = 0.46 to 0.52 for the aVR Vereckei algorithm; $\kappa = 0.60$, 95% CI = 0.57 to 0.63 for the lead II RWPT criterion). However, the in-terobserver agreement of the experienced observers was good, far superior to the fair to moderate agree-ment of the inexperienced observers for both ECG methods ($\kappa = 0.73$, 95% CI = 0.67 to 0.78 vs. $\kappa = 0.27$, 95% CI = 0.19 to 0.35 for the aVR Vereckei algorithm; $\kappa = 0.73$, 95% CI = 0.67 to 0.78 vs. $\kappa = 0.46$, 95% CI = 0.38 to 0.54 for the lead II RWPT criterion).

DISCUSSION

Main Findings

The mean overall test accuracy of the aVR Vereckei algorithm achieved by all seven observers was superior to that of the lead II RWPT criterion, which was mainly due to the better overall test accuracy achieved by the experienced four observers. The aVR Vereckei algo-rithm was superior in sensitivity and NPV and inferior in specificity and PPV to the lead II RWPT criterion when mean values of all seven observers were com-pared. The incorrect diagnoses of the aVR Vereckei algorithm were mainly due to misdiagnosis of SVT as VT (in 65.7% of cases), and those of the lead II RWPT criterion were mostly due to the potentially more dan-gerous misdiagnosis of VT as SVT (in 72.5% of cases).

This study revealed the real-life diagnostic value of the two ECG methods as we found lower overall test accu-racy, sensitivity, specificity, and predictive values in the current study than in the original publications for the two ECG methods. It seems likely that in the hands of experienced physicians, the four-step, but still simple, aVR Vereckei algorithm has a greater diagnostic value than the single-step, very simple lead II RWPT criterion. However, both ECG methods have comparable diagnos-tic value when used by inexperienced physicians. The effect of experience on the results achieved is also reflected in the far better interobserver agreement among the experienced than among the inexperienced observers. The results of this analysis should be inter-preted with caution given its post hoc nature and the small sample size.

The Potential Utility of the aVR Vereckei Algorithm and Lead II RWPT Criterion in Real Life

These two ECG methods can be well applied in real life in the stressful and urgent setting of a WCT, because both are simple, use only one lead for analysis, and eliminate the difficult-to-recall morphologic criteria. In the hands of experienced observers, the aVR Vereckei algorithm proved to be superior to the lead II RWPT criterion. When the two ECG methods were applied by inexperienced physicians, the two ECG methods had comparable diagnostic value.

Because the differential diagnosis of WCTs is a quite complicated task requiring experience in cardiology, it may be recommended for an inexperienced physician to consult with a supervisor, if possible, and apply together the simple and more accurate aVR Vereckei algorithm. If there is no supervisor available for consul-tation, the inexperienced physician alone can apply the simpler lead II RWPT criterion at the expense of a somewhat greater likelihood of misdiagnosis.

Head-to-head Comparison of Different ECG Methods for WCT Differential Diagnosis by Independent Authors

The only other study[25] that compared the diagnostic value of the aVR Vereckei algorithm and lead II RWPT

criterion compared five ECG methods for differentiation of WCT (the lead II RWPT criterion, Brugada, Griffith,[30] Bayesian,[31] and aVR Vereckei algorithms) and did not find any significant differences between the diagnostic accuracy of the five ECG methods, although the diagnostic accuracy of lead II RWPT criterion tended to be slightly lower than that of the aVR Vereckei algorithm (68.8% vs. 71.9%, respectively). Similar to our results, they verified a superior specificity and inferior sensitivity for VT diagnosis of the lead II RWPT criterion compared with those of the aVR Vereckei algorithm (82.7% vs. 48% for specificity and 60% vs. 87.1% for sensitivity, respectively) and failed to reproduce the high diagnostic accuracy, sensitivity, and specificity reported for the four algorithms and the lead II RWPT criterion in their respective original publications. However, in a study by Jastrzebski et al.,[25] in contrast to our approach and the recommendation of Brugada and coworkers[32] and of Fernando Pava (personal communication), when the mechanism of WCT was preexcitation SVT and the final diagnosis by the applied aVR Vereckei, Brugada algorithms, or lead II RWPT criterion was VT, they considered it as an incorrect diagnosis and the SVT diagnosis as a correct one. This important discrepancy renders difficult the comparison of the results of the two studies. However, the potential misclassification of their 23 preexcitation SVTs out of the total 260 WCTs might not have significantly changed the conclusions of Jastrzebski et al.[25] In a recent report, four emergency resident reviewers analyzed WCT ECG tracings using the aVR Vereckei algorithm.[26] When two of the four reviewers who left disproportionately high numbers of ECGs unclassified at the final step of the algorithm were eliminated from the analysis, the two remaining reviewers achieved a somewhat lower but similar overall test accuracy (70 and 74%) to the mean overall test accuracy of our three inexperienced observers (81.3%). In a pediatric population, lower diagnostic accuracy for both the Brugada and the aVR Vereckei algorithms (69% vs. 66%, respectively) has been reported with no difference in the diagnostic accuracy between the two algorithms.[25]

Practical Application of ECG Methods for WCT Differentiation

Although we failed in real life to reproduce the high overall test accuracy, sensitivity, specificity, and predictive values reported by the original authors, the two investigated ECG methods showed good-to-very good overall test accuracies, sensitivities, and PPVs and fair-to-good specificities and NPV values. Currently there is no single and very simple ECG method available (and very likely such a method will not be available in the future) that is able to diagnose the mechanism of WCT with a close to 100% diagnostic accuracy regardless of the level of experience of the physician applying the method. Thus, there is no simple ECG criterion that can obviate the experience of the evaluating physician.

When confronted with a hemodynamically stable WCT, a useful practical approach is to look for clinical signs of AV dissociation (e.g., "cannon" A waves) and assess the patient's clinical characteristics. A history of prior myocardial infarction, congestive heart failure, and angina strongly suggests VT, while age < 35 years, recurrent tachycardia over a period of more than 3 years, and absence of structural heart disease favor SVT.[2] One should evaluate the 12-lead WCT ECG for the most specific criteria in a sequence of decreasing specificity such as AV dissociation, <1:1 AV ratio, >1:1 VA ratio, northwest axis (between ± 180 and -90 degrees), initial R or Rs wave in lead aVR, absence of RS complex in the precordial leads, and concordant pattern in the precordial leads. The presence of any of the above criteria strongly suggests VT. If our results are confirmed by other investigators, a lead II RWPT ≥ 50 milliseconds might be also used in the future to strongly suggest VT. SVT diagnosis is highly likely if the morphology of the WCT corresponds to any combination of a typical bundle branch block or fascicular block and the v_i/v_t ratio > 1. If the morphology of WCT definitely does not correspond to any combination of typical bundle branch block or fascicular block VT or preexcitation SVT diagnosis is very likely, a $v_i/v_t \leq 1$ strongly suggests VT or preexcitation SVT as well.[1] When a sinus rhythm ECG is available and the QRS morphology in the sinus rhythm ECG is identical to that of the WCT ECG, SVT diagnosis (or rarely antidromic AV reentrant tachycardia) is highly likely.[1,33] However, bundle branch reentry VT, fascicular VT, and high midseptal VT may be associated with identical QRS morphology during WCT to that during sinus rhythm as well, and this way may masquerade as SVT in patients with fixed intraventricular conduction disturbances.[34] Using the Valsalva maneuver, carotid sinus massage, or adenosine administration may help elucidate the WCT mechanism. The termination of tachycardia strongly suggests SVT; however, idiopathic outflow tract VT may be terminated as well by these maneuvers. Even if the tachycardia itself remains unaffected, these maneuvers may clarify the WCT mechanism by inducing AV or VA block or slowing down the sinus or atrial rate.[2,3] When all these measures fail to establish a certain diagnosis of SVT, then the WCT should be treated as a VT. One should keep in mind that the differential diagnosis of regular monomorphic WCT is not absolutely necessary for acute management, because it can be successfully treated with electrical cardioversion regardless of the mechanism.

LIMITATIONS

Certain circumstances in this study might have influenced the results. The observers were blinded not only to the electrophysiologic diagnosis, but also to the clinical characteristics of the patients. The knowledge of patients' histories might have improved the results, and would have better mimicked real life. On the other hand, the short training the observers received before starting the evaluation might have improved the results.

In contrast to some other studies[13,16,30,31] from which patients with antiarrhythmic drug treatment, idiopathic VT, and either preexistent bundle branch block were excluded or their presence was not specified, we chose to include WCT tracings obtained from patients with the above features in our study, which might have decreased the diagnostic accuracy of the ECG methods used.

A limitation of the ECG methods was their inability to differentiate pre-excitation SVT from VT. From a therapeutic standpoint it is not so vital whether the diagnosis of preexcitation SVT as VT or SVT is considered correct, because until one refrains from the administration of agents that are contraindicated in WCTs of unknown origin (such as verapamil) it is no matter what is its exact mechanism. IV adenosine administration is considered safe in regular, monomorphic WCTs of unknown origin and might terminate a preexcitation SVT. IV procainamide is a recommended treatment for both VT and preexcitation SVT, and it may be also effective (or at least not harmful) in SVT-A; direct current cardioversion can terminate almost all kinds of WCTs as well.

The v_i/v_t criterion in the fourth step of the aVR Vereckei algorithm is a bit more complicated than the first three steps of the algorithm. The use of the fourth step was necessary to establish the diagnosis in approximately 50% to 60% of cases, which is a limitation of this ECG method compared with the very simple, one-step lead II RWPT criterion. As the sample size was not calculated prior to performing the study, our ability to make any conclusions regarding failure to reject the null hypothesis is substantially limited by not knowing what the potential effect size we would have been able to elucidate.

CONCLUSIONS

The aVR lead Vereckei algorithm had a superior overall test accuracy, sensitivity, and negative predictive value for ventricular tachycardia diagnosis and inferior specificity and positive predictive value for ventricular tachycardia diagnosis compared to those of the lead II R-wave peak time criterion. The incorrect diagnoses made by the aVR Vereckei algorithm were mainly due to misdiagnosis of supraventricular tachycardia as ventricular tachycardia, while the majority of incorrect diagnoses made by the lead II R-wave peak time criterion were mostly due to misdiagnosis of ventricular tachycardia as supraventricular tachycardia, which is the more dangerous error. We failed to reproduce the excellent overall test accuracy, sensitivity, specificity, and predictive values reported originally for both electrocardiographic methods. A post hoc analysis suggests that the two electrocardiographic methods have similar diagnostic value when applied by inexperienced physicians, and the diagnostic value of the aVR Vereckei algorithm is superior in the hands of experienced physicians.

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