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Comparison of five electrocardiographic methods for differentiation of wide QRS-complex tachycardias

Marek Jastrzebski[1]*, Piotr Kukla[2], Danuta Czarnecka[3], and Kalina Kawecka-Jaszcz[3]

[1]First Department of Cardiology and Hypertension, University Hospital, Cracow, Poland; [2]Department of Internal Medicine, H. Klimontowicz Specialistic Hospital, Gorlice, Poland; and [3]First Department of Cardiology and Hypertension, Jagiellonian University, College of Medicine, Cracow, Poland

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Aims To compare the sensitivity (SN), specificity (SP), and diagnostic accuracy (ACC) for ventricular tachycardia (VT) diagnosis of five electrocardiographic methods for wide QRS-complex tachycardia (WCT) differentiation, specifically the Brugada, Bayesian, Griffith, and aVR algorithms, and the lead II R-wave-peak-time (RWPT) criterion.

Methods and results We retrospectively analysed 260 WCTs from 204 patients with proven diagnoses. The SN, SP, ACC, and likelihood ratios (LRs) were determined for the five methods. Of the 260 tracings, there were 159 VTs and 101 supraventricular tachycardias. All five methods were found to have a similar ACC although the RWPT had a lower ACC than the Brugada algorithm (68.8 vs. 77.5%, $P = 0.04$). The RWPT had lower (60%) SN than the Brugada (89.0%), Griffith (94.2%), and Bayesian (89%) algorithms ($P < 0.001$). The Griffith algorithm showed lower (39.8%) SP than the RWPT (82.7%), Brugada (59.2%), and Bayesian (52.0%) algorithms ($P < 0.05$). The positive LRs for a VT diagnosis for the RWPT criterion and the Brugada, Bayesian, aVR, and Griffith algorithms were 3.46, 2.18, 1.86, 1.67, and 1.56, respectively.

Conclusion The present study is the first independent 'head-to-head' comparison of several WCT differentiation methods. We found that all five algorithms/criteria had rather moderate ACC, and that the newer methods were not more accurate than the classic Brugada algorithm. However, the algorithms/criteria differed significantly in terms of SN, SP, and LR, suggesting that the value of a diagnosis may differ depending on the method used.

Keywords Ventricular tachycardia • Supraventricular tachycardia • Wide QRS-complex tachycardia • Brugada algorithm • aVR algorithm

Introduction

Wide QRS-complex tachycardia (WCT) may be a ventricular tachycardia (VT) or a supraventricular tachycardia (SVT) with intraventricular conduction disturbance or with a pre-excitation.[1] Despite the existence of several established criteria[2–4] and algorithms[5–7] for differentiation of WCTs, the search continues for an algorithm or criterion/criteria set that can be easily applied without sacrificing specificity (SP) and/or sensitivity (SN) for VT diagnosis.

Two promising approaches were recently developed based on the analysis of only a single electrocardiogram (ECG) lead—either the aVR lead (Vereckei *et al.*)[8] or the limb lead II (Pava *et al.*).[9] However, the SN and SP of those approaches have yet to be tested by others, and past studies have shown that high SNs and SPs reported in original studies cannot always be reproduced in later independent studies.[6,10–14] Moreover, no study has directly compared multiple WCT algorithms.

The present study directly compared the following five types of WCT diagnosis methods: the lead II R-wave-peak-time (RWPT) criterion and the Brugada, Bayesian, Griffith, and aVR algorithms. These five analytical methods were compared in terms of SN, SP, overall diagnostic accuracy, and likelihood ratios (LRs) for a diagnosis of VT.

* Corresponding author. First Department of Cardiology and Hypertension, ul. Kopernika 17, 31-501 Cracow, Poland. Tel: +48 124247301, +48 124247314; fax: +48 124247320, Email: mcjastrz@cyf-kr.edu.pl

Methods

We analysed 260 ECGs showing WCT from 204 patients, where WCT was defined as a rhythm of 100–250 b.p.m. with a QRS ≥ 120 ms. Ventricular tachycardia was defined as a tachycardia that was maintained without the need for structures above the His bundle. The ECGs were obtained in a retrospective fashion from unselected, consecutive patients. All ECGs were standard 12-lead recordings, registered at a paper speed of 25 mm/s and with standard amplification (1 cm/mV). Electrocardiograms were analysed as printed tracings, and use of a magnifying glass was at the physician's discretion. Analysis was performed by a general cardiologist and a cardiac electrophysiologist (P.K. and M.J., respectively), each with extensive experience in such examinations. Those examiners were blinded regarding the clinical data and the previously established WCT diagnosis. A definitive WCT diagnosis was based on the results of an electrophysiology study, or on intracardiac electrograms from an implanted cardiac device, or on data from subsequent ECGs that enabled an unquestionable diagnosis (e.g. re-appearance of P or F waves due to sinus rhythm slowing, or to an increase in AV conduction ratio during atrial flutter with maintenance of the same QRS morphology as during WCT). Each ECG was analysed using each of the following five methods: the lead II RWPT criterion and the Brugada, Bayesian, Griffith, and aVR algorithms. Each method was applied as described in the respective original publication.[5–9] Differences of opinion in ECG analysis between the two examiners were resolved by consensus, facilitated when needed by precise measurements of the duration/amplitude of amplified tracings using a computer-based electrophysiology system (LabSystem PRO, Bard, Lowell, MA, USA).

Each analysis method was assessed in terms of SN, SP, and accuracy (i.e. percentage of correct diagnoses). In addition, in order to provide a more appropriate measure of the clinical diagnostic utility of each method, we calculated the positive and negative LRs for each algorithm and the RWPT.[14] The multistep algorithms (Brugada and lead aVR) were also analysed in terms of the number of misdiagnosed ECGs at each step. The clinical characteristics of the VT and SVT groups were compared using unpaired *t*-tests or the chi-squared test when categorical variables were compared. Confidence intervals for SN, SP, and accuracy were calculated using exact binomial confidence limits. Confidence intervals for LRs were obtained using the Simel method. The equality of more than two sensitivities was tested using Cochran's *Q* test. Any significant Cochran's *Q* statistic was followed by a pairwise McNemar's test. Specificities and accuracies were analysed accordingly. We also calculated the receiver operating characteristic curve for the lead II RWPT and the kappa coefficient (κ) to quantify overall interobserver agreement. For all analyses, a *P* value <0.05 was considered to indicate a significant difference. Statistical analyses were performed using 'R'—a language and environment for statistical computing (http://www.R-project.org).

Results

Patient characteristics

Patient basic demographic and clinical characteristics are summarized in *Table 1*. The patient groups differed in that the SVT group was younger, had a higher proportion of females, less patients on antiarrhythmic drugs, a higher left ventricular ejection fraction, and fewer patients with structural heart disease than the VT group.

Wide QRS-complex tachycardia diagnosis

A definitive WCT diagnosis was based on an electrophysiology study in 216 cases, intracardiac electrogram recordings from an implanted device in 38 cases, and from consecutive ECG data in 6 cases. The 260 tracings comprised 159 VTs and 101 SVTs. The VT types included 12 idiopathic outflow tract, 7 idiopathic fascicular, and 2 other idiopathic types, with the remainder being myocardial scar/fibrosis-related (the distinction was made based on clinical and electrophysiological data). The SVT types included 23 pre-excited tachycardias and 34 pre-existing organic bundle branch block-related, with the remainder resulting from functional interventricular conduction blocks.

Analysis showed that the lowest number of ECG misclassifications was achieved using the Brugada algorithm ($n = 59$; 23%), and those were mainly linked to the second and fourth steps of the algorithm (see Supplementary material available online *Figure S4*). Use of the lead aVR algorithm resulted in 77 misclassifications, and those were mainly linked to the fourth step of that algorithm at which point there were 49 misclassifications alone (see Supplementary material available online *Figure S5*). Moreover, the aVR algorithm was not applicable in two patients due to very low amplitude and multiphasic QRS in lead aVR. In most cases, there was no agreement between the findings of the five algorithms. All five algorithms gave concordant and correct answers in 86 of the 260 cases (33%).

Table 1 Patient clinical characteristics

	SVT ($n = 101$)	VT ($n = 159$)	*P*
Age (years; mean ± SD)	52.3 (±20.8)	61.1 (±15.2)	<0.001
Female/male (*n*)	32/69	25/134	0.002
Left ventricular ejection fraction (%; mean ± SD)	51.9 (±17.3)	34.0 (±15.7)	<0.001
Pre-existing bundle branch block (%)	38.6	37.1	0.81
Use of class I or III antiarrhythmic drugs (%)	8.9	19.5	0.021
History			
Coronary heart disease (%)	23	71	<0.001
Cardiomyopathy (%)	8	14	0.22
No structural heart disease (%)	70	14	<0.001

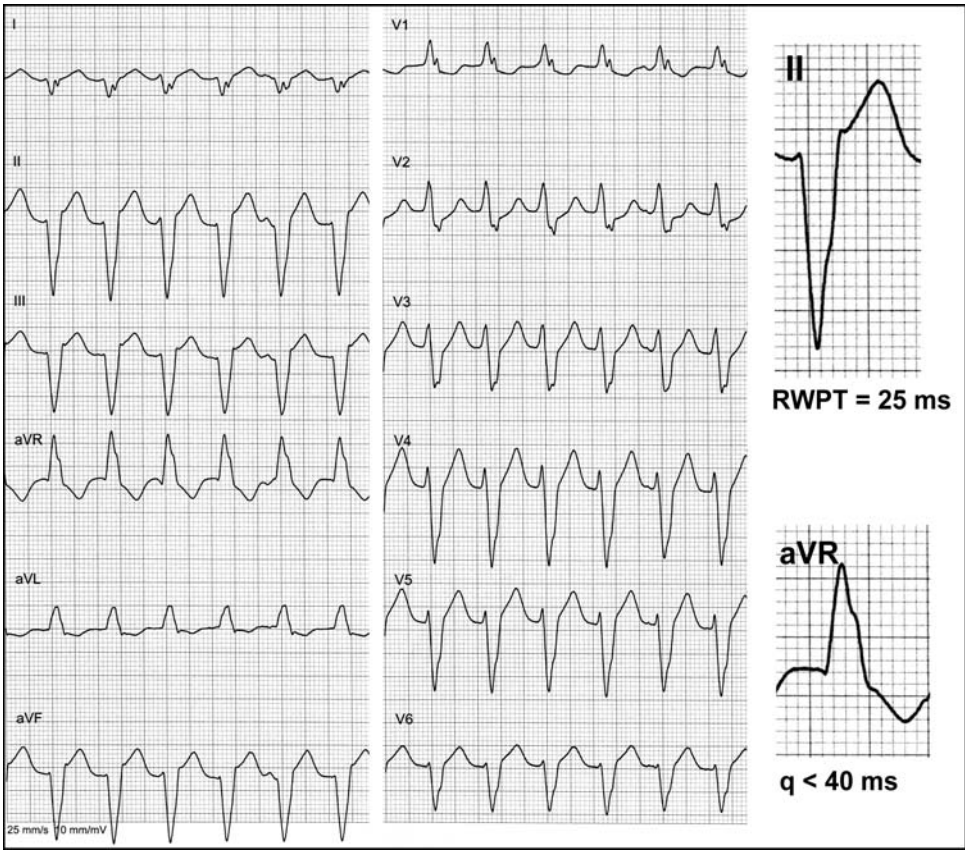

Figure 1 A 12-lead electrocardiogram showing ventricular tachycardia in a 72-year-old male with a history of an old myocardial infarction. This ventricular tachycardia was correctly diagnosed using the Brugada and Griffith algorithms based on either the presence of AV dissociation, and using V1–V6 QRS morphological criteria. However, use of the lead II R-wave-peak-time criterion (R-wave-peak-time = 25 ms) resulted in a misdiagnosis. Use of the aVR algorithm led to a correct diagnosis; however, only based on the final step and by a marginal Vi/Vt ratio value that required meticulous measurement of the Vi and the Vt with a precision that was impossible without digital QRS magnification or magnifying glass.

Examples of discordant diagnoses of VT ECGs are shown in *Figures 1–3*. We quantified interobserver agreement on WCT diagnosis for all tests together and found that the κ value was 0.77.

Sensitivity, specificity, diagnostic accuracy, and likelihood ratios

We assessed the four algorithms and the RWPT criterion for SN, SP, accuracy, and LRs, and the findings are summarized in *Table 2*. Assessment for accuracy showed that each of the five algorithms had only moderate accuracy (~75%). When the algorithms were compared with each other in terms of accuracy, the only significant difference found was that the lead II RWPT method had a lower accuracy than the Brugada algorithm.

In terms of SN and SP, the lead II RWPT and lead aVR methods were found to have less SN than some other algorithms, the RWPT criterion was found to have greater SP than the other algorithms, and the Griffith algorithm had less SP than the Brugada and Bayesian algorithms and the RWPT (*Table 2*).

Analysis of the positive and negative LRs showed that there were important differences between the algorithms (*Table 2*). Diagnosis of SVT by the Griffith algorithm most strongly decreased the chances of a VT, while diagnosis of VT by the lead II RWPT criterion most strongly increased the chances of a VT.

The receiver operating characteristic curve for the lead II RWPT is shown in *Figure S6* (Supplementary material available online). The area under the curve was 77.4% (CI: 71.8–83.0%). The receiver operating characteristic curve identified that an RWPT of 42.5 ms was optimal for differentiating between VT and SVT with an SP of 80.6% and an SN of 64.5% for VT diagnosis. The accuracy for the lead II RWPT criterion was found to be moderate and quite similar (range: 65–71%) over a very broad range of RWPT values (25–65 ms). The highest SP was 98%, and that was observed at an RWPT of 75 ms, at which point the corresponding SN was 35%.

Discussion

The major finding of the present study was that the five methods for WCT differentiation were similar in terms of accuracy. The lead II RWPT criterion, lead aVR, and Bayesian, and Griffith

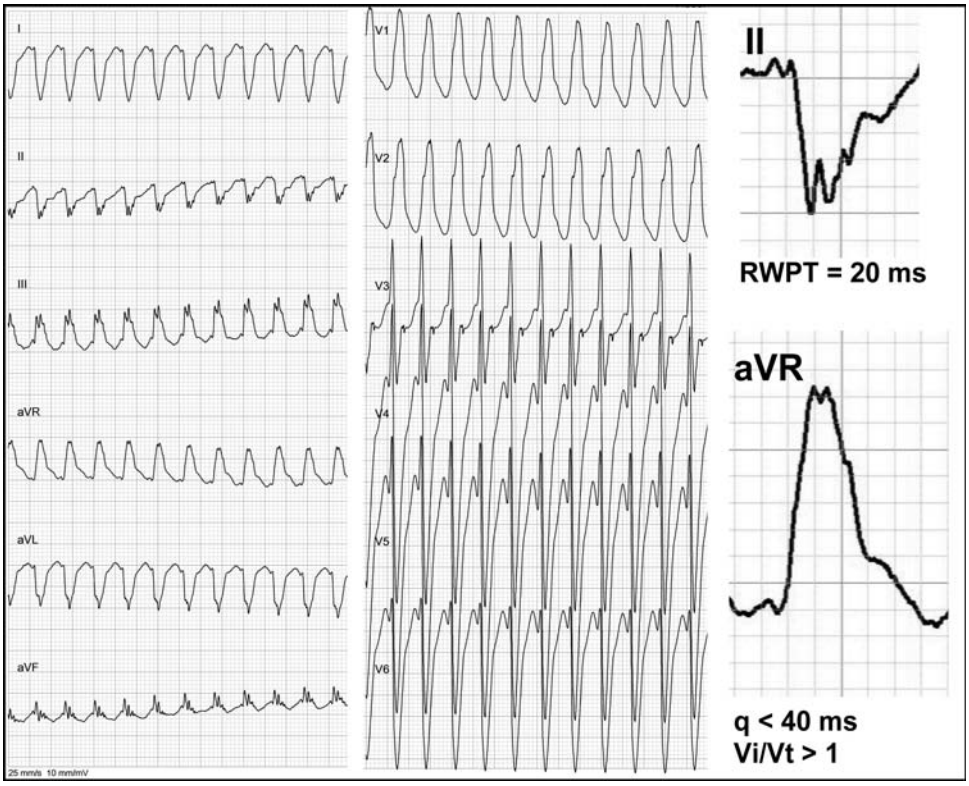

Figure 2 A 12-lead electrocardiogram from a 62-year-old male with a history of two myocardial infarctions. Use of the lead II R-wave-peak-time (R-wave-peak-time = 20 ms) or the aVR (qR with q < 40 ms and Vi/Vt > 1) algorithms resulted in a misdiagnosis. In contrast, a correct diagnosis of ventricular tachycardia was reached using the Brugada or Griffith algorithms.

algorithms, which were all developed in the post-Brugada algorithm era, were found to be either no better or inferior to the classic Brugada algorithm in terms of overall accuracy.

Although we found that the algorithms had similar accuracies, they differed in terms of SN, SP, and LR. Therefore, a diagnosis of VT or SVT by one test does not have the same diagnostic value as the same diagnosis made using another algorithm. For example, a clinician is unlikely to miss a diagnosis of VT when using Griffith's algorithm (high SN), and is unlikely to overdiagnose VT when using the RWPT criterion (high SP).

We also found that the high accuracy and good SN and SP originally reported for the four algorithms and the lead II RWPT criterion in their respective original publications were not reproduced in the current study. This lack of reproducibility was also reported by others.[6,10–14] One possible explanation is that the developers of a particular algorithm are more proficient at using that method than other physicians. Alternatively, it may be that the WCT types in the present study differed from those in the original studies; those studies may have used types more suited to the algorithm being developed. Intentional exclusion or fortuitous underrepresentation of 'difficult' WCT tracings (e.g. organic bundle branch blocks, SVTs in heart failure patients, pre-excited tachycardias, and idiopathic VTs) can improve the performance of an algorithm or differentiation criterion. Wide QRS-complex tachycardia studies obtain ECGs for analysis from electrophysiology study databases; therefore the WCT criteria for SVT are developed mostly on the basis of transient functional bundle branch blocks artificially induced during electrophysiology in otherwise healthy patients. Those criteria are not likely to be as applicable to organic bundle branch block patients, especially with left bundle branch block.[12,14] Recent data support the notion that several of the classic morphological criteria for VT are related not to VT *per se* but to the presence of organic heart disease (e.g. fibrosis, scars, and ventricle dilatation), as they are absent in idiopathic VT[15] yet present during supraventricular rhythm in heart failure patients with left bundle branch block.[14] Idiopathic VTs might be difficult to differentiate from SVTs since the QRS-complex morphology of idiopathic VTs can resemble supraventricular QRS morphology in some aspects, as they also occur in a healthy heart and some rapidly engage the His-Purkinje network. Therefore, it must be noted that in most studies that introduced differentiation criteria or algorithms, patients with pre-existing bundle branch blocks, pre-excitation, idiopathic VTs, and on antiarrhythmic drugs were either excluded or underrepresented, or the studies did not show data regarding inclusions, exclusions, or the proportion of such patients in the study (*Table 3*). Moreover, the proposed factors might be additive (i.e. an examiner with perfect knowledge of his own algorithm plus easier ECGs for testing).

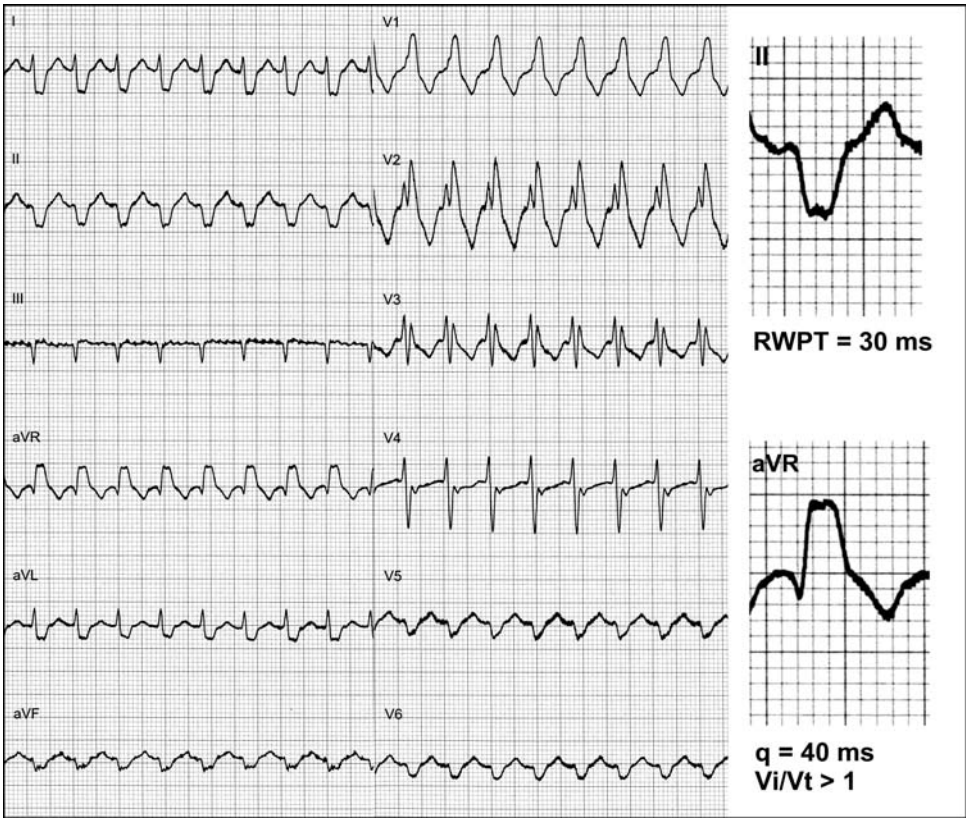

Figure 3 A 12-lead electrocardiogram from a 56-year-old male with moderate heart failure, pre-existing right bundle branch block and frequent episodes of focal left atrial tachycardia. Use of the Brugada or Griffith algorithms resulted in misdiagnosis (criteria for ventricular tachycardia present in V1 and V6). In contrast, use of the lead II R-wave-peak-time criterion (R-wave-peak-time = 30 ms) or the aVR algorithm (qR with q of 40 ms and Vi/Vt > 1) resulted in a correct diagnosis of supraventricular tachycardia.

Table 2 Sensitivity, specificity, positive and negative likelihood ratios for ventricular tachycardia diagnosis, and overall diagnostic accuracy (percentage of correct diagnoses) for five methods of wide QRS-complex tachycardia differentiation

	Brugada	Griffith	Bayesian	Lead aVR	Lead II RWPT	*P*
Accuracy (%)	77.5	73.1	74.7	71.9	68.8	0.04[a]
	(71.8–82.5)	(67.2–78.5)	(68.9–79.9)	(66.0–77.4)	(62.7–7.44)	
Specificity (%)	59.2	39.8	52.0	48.0	82.7	<0.001[b,c]
	(48.8–69.0)	(30.0–50.2)	(41.7–62.2)	(37.8–58.3)	(73.7–89.6)	
Sensitivity (%)	89.0	94.2	89.0	87.1	0.60	<0.001[b,d]
	(83.0–93.5)	(89.3–97.3)	(83.0–93.5)	(80.8–91.9)	(0.52–0.68)	
LR(+)	2.18	1.56	1.86	1.67	3.46	–
	(1.71–2.78)	(1.33–1.85)	(1.50–2.30)	(1.37–2.04)	(2.20–5.43)	
LR(−)	0.18	0.15	0.21	0.27	0.48	–
	(0.11–0.30)	(0.07–0.29)	(0.13–0.34)	(0.17–0.42)	(0.39–0.60)	

Numbers in parentheses are the 95% confidence intervals.
[a]Brugada vs. lead II RWPT.
[b]Lead II RWPT vs. any other algorithm.
[c]$P = 0.01$ for Griffith vs. Brugada or vs. Bayesian.
[d]$P = 0.05$ for Griffith vs. aVR.

Table 3 Wide QRS-complex tachycardia types included in the studies that introduced differentiation criteria or algorithms

	Pre-existing bundle branch block	Pre-excited tachycardias	Idiopathic VTs	Antiarrhythmic drug use
Wellens *et al.*[2]	0	0	[a]	0
Kindwall *et al.*[3]	15 (12.7%); 7 (21.2%) in the SVT group	0	5 (4.2%)	12 (10.1%); 0 in the SVT group
Brugada *et al.*[5]	[a]	[a]	[a]	0[b]
Griffith *et al.*[6]	[a]	[a]	≥5 (≥4.9%)[c]	[a]
Lau *et al.*[7]	[a]	0 (8.2%)[d]	10 (4.1%)[e]	[a]
Lau *et al.*[10]	[a]	0	[a]	[a]
Vereckei *et al.*[8]	144 (29.8%)[f]	20 (4.1%)	38 (7.9%)	158 (32.7%)[g]
Pava *et al.*[9]	[a]	[a] (one case?)	6 (2.7%)[h]	[a]
Current study	98 (37.7%); 39 (38.6%) in the SVT group	23 (8.8%)	21 (8.1%)	40 (15.4%); 9 (8.9%) in the SVT group

[a]No data can be found in the original publication.
[b]No firm data, however, excluded from the first part of the study.
[c]No firm data, albeit 5 RVOT VTs mentioned in the results.
[d]Somewhat extraordinarily pre-excited tachycardias were grouped with VTs (!).
[e]Data available only for some idiopathic VT types (for fascicular VTs).
[f]No data on the percentage of bundle branch blocks in the SVT group, however, in previous publication that was using almost the same electrocardiogram set,[11] there were reported 25% of patients with bundle branch blocks in the SVT group.
[g]No data on the percentage of antiarrhythmic drug use in the SVT group.
[h]Data available only for fascicular VTs and uncertain—mentioned imprecisely in the Discussion.

The lead II R-wave-peak-time criterion

The lead II RWPT method is the most recently published criterion that has yet to be validated by others.[9] Compared to the four algorithms, this method showed the greatest discrepancy between the originally published and the presently observed SN and SP: 93 vs. 60% and 99 vs. 83%, respectively. In addition, we found that the accuracy for RWPT at >50 ms was only 69%, the lowest of the five methods.

In the present study, the lead II RWPT receiver operating characteristic curve showed that a value of 42.5 ms was optimal for differentiating VT from SVT, rather than an RWPT of 50 ms, as originally reported (see Supplementary material available online *Figure S6*).[9] Moreover, the original study reported high SP for a VT diagnosis at an RWPT of 50 ms, whereas we found a high SP only at RWPT values ≥75 ms (SP = 98%), and that had a corresponding low SN of 35% for a VT diagnosis.

The RWPT seems to be an interesting criterion. However, like other single and very specific criteria, it lacks SN, and therefore seems to be inferior to multi-step algorithms that can provide a better balance between SP and SN.

The aVR algorithm

In the original report by Vereckei *et al.*, the aVR algorithm provided superior SN, SP, and accuracy compared with the Brugada algorithm (SN: 96.5 vs. 89.2%; SP: 75 vs. 73.2%; and accuracy: 95.5 vs. 85.5%). In contrast, the present study found that the two algorithms were the same in regard to those three parameters. Our experience during this study had led us to the opinion that the aVR algorithm has practical disadvantages compared with the Brugada algorithm. Firstly, the aVR algorithm was the only one that could not be applied to some cases due to a very low amplitude and multiphasic QRS in the lead aVR. Secondly, assessment of the Vi/Vt ratio in the lead aVR (last step of the algorithm), which was necessary in over 50% of cases, was laborious, and often very difficult or impossible without a magnifying glass. This assessment was particularly frustrating in cases with very similar Vi and Vt values (*Figures 1–3*) leading to a borderline Vi/Vt ratio.

Bayesian algorithm

The SN and SP of the Bayesian algorithm in the present study were similar to those reported in the original publication (89 vs. 97% and 52 vs. 56%, respectively).[7] Like Lau *et al.*,[10] we did not find the Bayesian algorithm to be superior to the Brugada algorithm in terms of accuracy.

Despite the originality and flexibility of the Bayesian algorithm approach, it must be considered that this algorithm is somewhat impractical to use in most clinical settings since it requires a calculator and a list of 19 morphological features with corresponding LRs that have to be multiplied to reach the final verdict.

Griffith algorithm

The Griffith algorithm is an easy to use, two-step algorithm, albeit still based on nine criteria. Of the five methods tested, we found the Griffith algorithm to be the least specific for VT, in that it misclassified 60% of SVTs; this seems to be its major limitation. However, due to its high SN for VT, its overall accuracy was similar to those of the other algorithms. The original report stated SP and SN values of 96 and 64%, respectively,[6] whereas the present values were lower. Similarly, Lau *et al.*[10] reported a lower SP for this algorithm (44%) than originally described.

Brugada algorithm

This classic and probably most widely used WCT algorithm performed marginally better than other WCT algorithms/criteria

that were investigated in the current study, albeit that the differences in accuracy were significant only compared with the lead II RWPT criterion. It seems that this algorithm achieved the best balance in the SN–SP tradeoff, having neither a low SN nor a low SP. However, as was the case with other algorithms, we could not corroborate the high SN, SP, and accuracy that were reported in the original publication.[5] The major discordance was SP: 59.2% in our study vs. 96.5% in the original study. Like us, Lau *et al*., Vereckei *et al*., and Griffith *et al*. found the Brugada algorithm SP to be lower (44, 73.3, and 67%, respectively) than originally reported. This algorithm strongly relies on the new VT criterion introduced by Brugada *et al*.[5]—the presence of an RS interval >100 ms in any of the pre-cordial leads (~32% of WCT diagnoses are made at this step). However, it is known that while this criterion is very good at differentiating a clear-cut functional aberration from a myocardial scar-related VT, it is not so good when faced with organic left bundle branch block QRS morphology, especially in a patient with heart failure or an idiopathic VT.[12,14,16] We found that this criterion was the major factor that lowered the SP of the Brugada algorithm.

Likelihood ratios

Likelihood ratios for whole WCT algorithms have never previously been published, with the exception of the lead II RWPT method and some other single morphological criteria.[7,9] Knowledge of the positive and negative LRs for VT diagnosis for a particular algorithm provides a clinician with a directly comprehensible measure of how much confidence there should be in an initial clinical suspicion of VT following application of the algorithm.[17] The 'yes' or 'no' algorithm approach to VT/SVT diagnosis does not provide information regarding the strength of the reached diagnosis. Using LRs do provide such information, which can be helpful to the clinician. Indeed, if several algorithm results are concordant, it is theoretically possible to multiply the LRs of those algorithms to further strengthen the final diagnosis.

Limitations

Despite great care being taken to ensure correct lead placement during ECG recording, any incorrect placement could affect WCT algorithm findings.

The reproducibility of an algorithm's results is likely dependent upon the experience of the examiner reading the ECG. The present study used only experienced examiners, as have most studies that introduced new algorithms. However, this might not reflect performance and reproducibility of WCT algorithms when used by less experienced physicians.

Conclusions

The present study is the first independent, 'head-to-head' comparison of several electrocardiographic methods for WCT differentiation. We found that all five methods had only moderate accuracy (69–77%), and that the newer algorithms/criteria were not more accurate that the classic Brugada algorithm. As such, no one algorithm/criterion can be recommended as a preferred method for WCT diagnosis. It may be best that physicians choose the algorithm with which they are most familiar. However, clinical need may provide an exception to this general rule: the Griffith algorithm should be considered when a highly sensitive method for VT diagnosis is desired, and the RWPT criterion should be considered when a high degree of SP for VT diagnosis is required.

Supplementary material

Supplementary material is available at *Europace* online.

Conflict of interest: none declared.

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