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Original article

Vereckei criteria as a diagnostic tool amongst emergency medicine residents to distinguish between ventricular tachycardia and supra-ventricular tachycardia with aberrancy

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Summary
Background: Accurate electrocardiographic (ECG) differentiation of ventricular tachycardia (VT) from supraventricular tachycardia with aberrancy (SVT-A) on ECG is key to therapeutic decision-making in the emergency department (ED) setting.
Objective: The goal of this study was to test the accuracy and agreement of emergency medicine residents to differentiate VT from SVT-A using the Vereckei criteria.
Methods: Six emergency medicine residents volunteered to participate in the review of 114 ECGs from 86 patients with a diagnosis of either VT or SVT-A based on an electrophysiology study. The resident reviewers initially read 12-lead ECGs blinded to clinical information, and then one week later reviewed a subset of the same 12-lead ECGs unblinded to clinical information.

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Results: One reviewer was excluded for failing to follow study protocol and one reviewer was excluded for reviewing less than 50 blinded ECGs. The remaining four reviewers each read 114 common ECGs blinded to clinical data and their diagnostic accuracy for VT was 74% (sensitivity 70%, specificity 80%), 75% (sensitivity 76%, specificity 73%), 61% (sensitivity 81%, specificity 25%), and 68% (sensitivity 84%, specificity 40%). The intraclass correlation coefficient (ICC) was 0.31 (95% CI 0.22—0.42). Eliminating two of the four reviewers who left a disproportionately high number of ECGs unclassified resulted in an increase in overall mean diagnostic accuracy (70—74%) and agreement (0.31—0.50) in the two remaining reviewers. Three reviewers read 45 common ECGs unblinded to clinical information and had accuracies for VT 93%, 93% and 78%.
Conclusion: The new single lead Vereckei criteria, when applied by emergency medicine residents achieved only fair-to-good individual accuracy and moderate agreement. The addition of clinical information resulted in substantial improvement in test characteristics. Further improvements (accuracy and simplification) of algorithms for differentiating VT from SVT-A would be helpful prior to clinical implementation.

Introduction

Background

The treatment of supraventricular tachycardia with aberrancy (SVT-A) differs from ventricular tachycardia (VT) in hemodynamically stable patients. Atrioventricular (AV) nodal blocking agents are often the preferred method of choice in SVT-A, but can result in adverse clinical consequences in VT [1,2]. Differentiating between these two wide complex tachycardias is key to therapeutic decision-making, but can be challenging. In the emergency department (ED) setting, the differential diagnosis is most often based on history, physical examination, and electrocardiographic (ECG) interpretation. Accurate ECG interpretation with recognition of the different rhythms contributes to appropriate management of these patients.

In an effort to help distinguish between VT and SVT-A, Brugada proposed a set of sequential criteria against which to compare an ECG [3]. However, emergency physicians frequently disagreed with each other and with cardiologists in their interpretation of the ECG using these criteria; studies suggest moderate agreement at best with reported kappa statistics ranging from 0.42 to 0.58 [4,5]. Vereckei proposed a new set of criteria that aimed to simplify the Brugada algorithm by eliminating the need for interpreting complex morphological criteria. Instead, Vereckei's approach in Step 4 uses an estimation of initial (v_i) and terminal (v_t) ventricular activation velocity ratio (v_i/v_t). This results in the algorithm having overall greater diagnostic accuracy than the Brugada criteria (90.7% vs 85.5%) [1]. With a further modification that restricts the analysis to only the aVR lead, the algorithm was shown to distinguish between different rhythms on wide QRS complex tachycardia with an overall test accuracy of 91.5% [6] (Fig. 1). Whether emergency physicians can accurately apply these criteria has not yet been determined. Further, how consistent they are in their accuracy from one ECG to the next is important. If accuracies are similar, but agreement is disparate, it suggests the reproducibility of the criteria may be low.

Goals of this investigation

This study was designed to test the accuracy of emergency medicine residents' determination of the cause of wide QRS complex tachycardia using Vereckei's proposed criteria. In addition, we explored agreement between physicians, and whether the addition of clinical information about the patient had an impact on the diagnostic accuracy.

Methods

Study design

This was an observational diagnostic study, which was approved by the local Institutional Review Board.

Subjects and setting

Patient data and ECGs were provided without identifiers by one of the authors (AV). These ECGs were those used for earlier evaluations of the diagnostic accuracy of the Vereckei criteria [3], and included ECGs from 86 unique patients with a diagnosis of either VT or SVT-A based on an electrophysiology study. The ECGs were obtained near the time of the electrophysiology study. Six emergency medicine residents participated in the ECG review. The residents were from an academic center with an emergency medicine residency that is a 4-year program with 48 total residents.

Selection of participants

All of the residents in the residency program were offered the opportunity to participate in the study. Time commitment was outlined so residents knew whether they would be able to volunteer. The six residents received an overview of the Vereckei criteria and how they were applied during a formal lecture, as well as receiving copies of both Vereckei articles which they could refer to when they were reviewing the 12-lead ECGs.

Study design

The resident reviewers were given copies of the manuscripts describing the original and the simplified Vereckei criteria [1,6] and a figure of the criteria for reference during 12-lead ECG review (Fig. 1). They were then instructed to independently review the 119 ECGs blinded to clinical information. At least one week after completion of the blinded review,

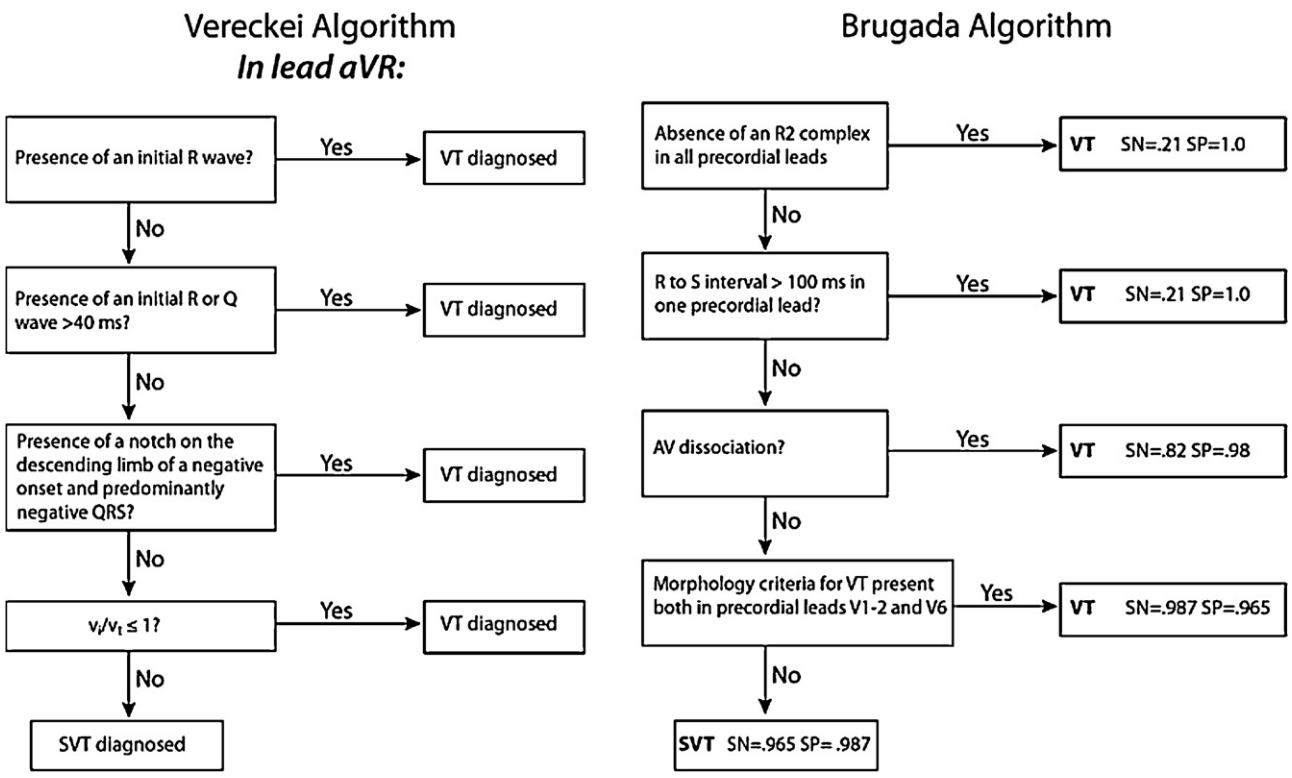

Figure 1 The Vereckei and Brugada algorithms. SVT, supraventricular tachycardia with aberrancy; VT, ventricular tachycardia; v_i/v_t, initial (v_i) and terminal (v_t) ventricular activation velocity ratio; SN = sensitivity; SP = specificity.

the reviewers were asked to review 50 of the same ECGs in combination with clinical information which included age, sex, past medical history, and outpatient medications. All reviewers were blinded to the criterion standard diagnosis regardless of whether clinical information was available. Reviewers completed a standardized data collection form for each ECG reading that included diagnosis (SVT-A, VT, or indeterminate) as well as which step of the algorithm determined the diagnosis.

Index test and criterion standard

The index test was the interpretation of the ECG using the sequential Vereckei criteria shown in Fig. 1. For this study, the criterion standard diagnosis was the result of an electrophysiology study conducted at the time of the patient's hospitalization.

Data analysis

Data are summarized using medians and ranges and counts and percentages unless otherwise indicated. Accuracy of ECG interpretation was calculated as the proportion of correctly identified arrhythmias (VT vs SVT-A). Test characteristics calculated for each resident included sensitivity, specificity, and likelihood ratios (LR). The intraclass correlation coefficient (ICC) was used as a summary measure of agreement, and diagnostic test statistics were also computed. Cases which were unclassified by the residents were treated as incorrect answers. All analyses were conducted using SPSS 18.0 for Windows (SPSS Inc., Chicago, IL, USA).

Results

The ECG readings provided by one reviewer were excluded for failure to follow study protocol. This reviewer had not completed the case report form correctly. One reviewer reviewed less than 50 blinded ECGs and was excluded from the blinded analysis. Blinded analysis was completed using 114 common ECGs from 86 patients, read by four reviewers. Of these, 74/114 (65%) had VT diagnosed by the criterion standard. Three of the five remaining reviewers read 45 common ECGs unblinded to clinical data. Those ECGs with a criterion standard of VT were more likely than those without a criterion standard of VT to have a history of myocardial infarction [40/79 (51%) vs 1/40 (3%)], previous ventricular arrhythmias [19/79 (24%) vs 0/40 (0%)], a history of cardiomyopathy [11/79 (14%) vs 1/40 (3%)], and use of anti-arrhythmic medications [37/79 (47%) vs 2/40 (5%)].

Blinded to clinical data, the diagnostic accuracy of the four reviewers for VT was 74% (95% CI 65—81%), 75% (95% CI 65—82%), 61% (95% CI 52—70%), and 68% (95% CI 59—77%) (Table 1). The overall mean accuracy amongst the four reviewers was 70%. The ICC was 0.31 (95% CI 0.22—0.42; $p < 0.001$). Complete agreement amongst the four reviewers on the correct diagnosis occurred on 38/114 (33%) of the ECGs, and in 11/114 cases (10%) the four reviewers agreed completely on an incorrect diagnosis. Complete agreement by all reviewers on the correct diagnosis at each individual step shows this occurred: at Step 1 5/114 (4%) of the time, at Step 2 0/114 (0%), Step 3 0/114 (0%), and Step 4 2/114 (2%).

Table 1 Test characteristics for ventricular tachycardia for 114 electrocardiograms read by 4 resident reviewers blinded to clinical data.

#	Accuracy			Sensitivity			Specificity			Likelihood ratio +			Likelihood ratio −		
	%	(95% CI)		%	(95% CI)		%	(95% CI)		%	(95% CI)		%	(95% CI)	
1	73.7	64.5	81.3	70.3	58.4	80.1	80.0	63.9	90.4	3.51	2.49	4.95	0.37	0.25	0.52
2	74.6	65.4	82.0	75.7	64.1	84.6	72.5	55.9	84.9	2.75	1.97	3.85	0.34	0.22	0.49
3	61.4	51.8	70.2	81.1	70.0	88.9	25.0	13.2	41.5	1.08	0.78	1.50	0.76	0.37	1.64
4	68.4	59.0	76.6	83.8	73.0	91.0	40.0	25.3	56.6	1.40	1.01	1.93	0.41	0.21	0.73

#, reviewer number.

Two of the four reviewers left a disproportionately high number [41 (36%) and 23 (20%)] of ECG's unclassified when they arrived at the final algorithm step. Eliminating these two reviewers from the analysis resulted in an increase in overall mean accuracy for VT in the two remaining reviewers from 70% to 74%. Further, agreement also improved from an ICC of 0.31 (95% CI 0.22—0.42) to 0.50 (95% CI 0.35—0.63, $p < 0.001$).

Individual reviewer accuracy across algorithm steps was varied. When overall accuracy was considered, Step 1 was 73%, Step 2 was 86%, Step 3 was 89%, and Step 4 was 67%. Three of the four reviewers achieved a higher number of correct individual diagnoses of VT at Step 1 than any other step (Fig. 2). The reviewers made fewer decisions at Steps 2 and 3, until Step 4 where a greater proportion of incorrect and indeterminate decisions were selected.

There were 45 ECGs that were reviewed unblinded to clinical information. Medical comorbidities were common, including a history of myocardial infarction in 41 (34.5%), previous ventricular arrhythmias in 19 (16.0%), a history of cardiomyopathy in 312 (10.0%), and use of antiarrhythmic medications in 39 (32.8%). For the 45 ECGs that were reviewed both blinded and unblinded to clinical data, the three reviewers' accuracies for VT were 84% (95% CI 70—93%), 78% (95% CI 63—88%), and 84% (95% CI 70—92%) when blinded, and 93% (95% CI 81—98%), 93% (95% CI 81—98%), and 78% (95% CI 63—88%), when unblinded, respectively (Tables 2 and 3, respectively). The ICC in this subset of ECGs was 0.39 (95% CI 0.21—0.57; $p < 0.001$) when blinded to clinical data, and 0.38 (95% CI 0.20—0.57; $p < 0.001$) when unblinded. Complete agreement on correct diagnosis by all reviewers occurred in 27/45 (60%) cases when blinded, and 32/45 (71%) cases when unblinded.

Discussion

Our results suggest that when using Vereckei's proposed single lead criteria for differentiating SVT-A from VT, the mean diagnostic accuracy of emergency medicine residents for VT diagnosis was only fair-to-good (61—75%) when blinded to clinical data. A large number of ECGs were left as ''indeterminate'' by the reviewers suggesting they had difficulty consistently applying the criteria. However, in the subset of ECGs for which reviews were repeated unblinded to clinical data their accuracy was good-to-excellent (78—93%). The test characteristics suggest LRs that were not clinically meaningful (greater than 0.1 and less than 10) when the algorithm was used in isolation, without clinical information. However, when reviewers were unblinded to clinical information, diagnostic accuracy improved and the LR suggests that answering ''no'' to all 4 steps of the Vereckei criteria (Table 3) could confidently identify a patient with SVT-A. Further, resident comfort level with algorithm interpretation appeared to have an impact on the accuracy of the resident's utilization of the algorithm. The two residents who left very few ECGs in the ''unclassified'' category had increased diagnostic accuracy (74% vs 70%) when compared to those who left a large proportion of ECGs ''unclassified''.

Agreement was low-to-moderate (0.31—0.60) amongst the residents. Indeed, all four reviewers agreed on the correct diagnosis in only one-third of the ECGs reviewed blinded to clinical data. Agreement also varied with each Step in the algorithm. Similar to its impact on diagnostic accuracy, resident comfort level with algorithm interpretation also appeared to have an impact on agreement, as the reviewers who left few ECGs as unclassified had higher levels of agreement with each other. The addition of clinical information

Table 2 Test characteristics for ventricular tachycardia for 45 electrocardiograms read by 3 resident reviewers blinded to clinical data.

#	Accuracy			Sensitivity			Specificity			Likelihood ratio +			Likelihood ratio −		
	%	(95% CI)		%	(95% CI)		%	(95% CI)		%	(95% CI)		%	(95% CI)	
1	84.4	69.9	93.0	82.9	67.4	92.3	100	39.6	97.6	—	—	—	—	—	—
2	77.8	62.5	88.3	80.5	64.6	90.6	50.0	9.2	90.8	1.61	0.60	4.34	0.39	0.12	1.90
3	84.0	70.3	92.4	87.0	73.0	94.6	50.0	9.2	90.8	1.74	0.65	4.66	0.26	0.08	1.32

#, reviewer number.

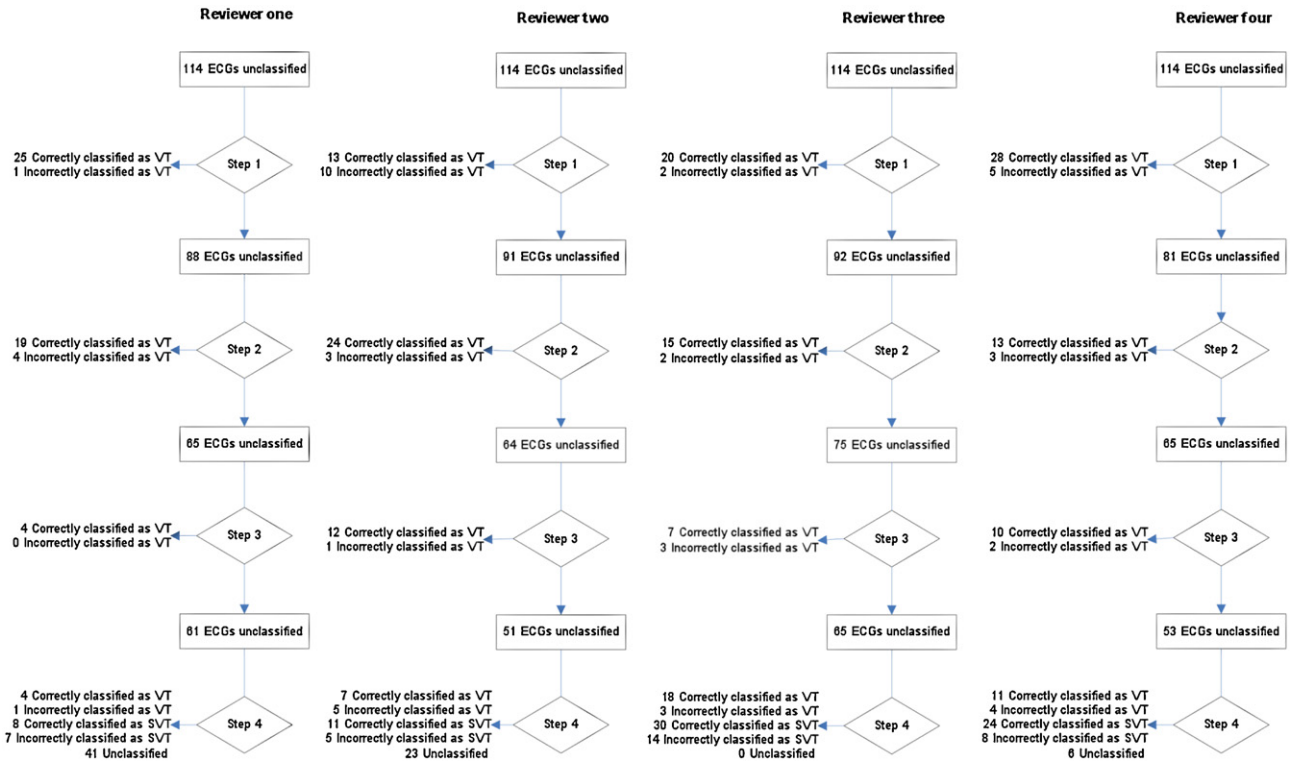

Figure 2 Correct diagnosis by Step per reviewer. ECG, electrocardiogram; VT, ventricular tachycardia.

was helpful in improving diagnostic accuracy and agreement amongst the resident reviewers.

Interestingly, the reviewers appeared to use Step 1 to correctly categorize a large proportion of patients with VT. Steps 2 and 3 were used less frequently, and Step 4 resulted in a large proportion of patients with either incorrect or indeterminate ECGs. This was likely a reflection of ECGs that were difficult to interpret through all four steps, or the comfort level of the residents applying Steps 2 and 3 of the algorithm. Further, the utilization of Step 4 by skilled cardiologists may have been helpful in prior studies, but this step was particularly problematic in our study of residents. Determining the magnitude of the initial (v_i) and terminal (v_t) 40 ms of the QRS complex on the ECG can be difficult in an ECG where the QRS voltage is low or there is a fast ventricular rate. While evaluation of the activation velocity ratio appears to accurately differentiate VT from SVT, its interpretation may need to be simplified further to improve its generalizability for ED residents. Unblinding of clinical information appeared to improve the proportion of patients with the correct diagnoses for two of the three reviewers, from 84% to 93%, and 78% to 93%. Many of the subjects whose ECGs were reviewed unblinded to clinical information had cardiovascular comorbidities, likely influencing the reviewers' decision-making process. Previous studies suggest coronary artery disease, structural heart disease, history of myocardial infarction or congestive heart failure, age > 35 years, and male sex have been associated with increased likelihood of VT [2].

Limitations

Our data suggest, despite fair-to-good accuracy, agreement between emergency medicine residents' ECG interpretation for distinguishing between VT and SVT-A is only moderate.

Table 3 Test characteristics for ventricular tachycardia for 45 electrocardiograms read by 3 resident reviewers unblinded to clinical data.

#	Accuracy			Sensitivity			Specificity			Likelihood ratio +			Likelihood ratio −		
	%	(95% CI)		%	(95% CI)		%	(95% CI)		%	(95% CI)		%	(95% CI)	
1	93.3	80.7	98.3	92.7	79.0	98.1	100	39.6	97.6	—	—	—	0.07	0.02	0.19
2	93.3	80.7	98.3	97.6	85.6	99.9	50.0	9.2	90.8	1.95	0.73	5.21	0.05	0.01	0.26
3	77.8	62.5	88.3	80.5	64.6	90.6	50.0	9.2	90.8	1.61	0.60	4.34	0.39	0.12	1.90

#, reviewer number.

These results should be tempered by several limitations. The number of ECGs with an independent criterion standard available was limited, not all residents reviewed all ECGs as planned, and the number of residents was small. The ECGs that were not read may have been those most difficult to interpret, so excluding these ECGs or reviewers could falsely increase the diagnostic accuracy. Also, the blinded and unblinded sets were derived from the same pool of ECGs, allowing for the possibility of recall bias. To minimize this possibility, the residents reviewed the blinded and unblinded sets at least one week apart and were not aware of the correct diagnosis until after completion of the study. However, it is possible that with only one week in between the two reviews and the smaller number of ECGs there was recall bias. Further, the residents reviewed ECGs knowing they were either SVT-A or VT, which is not typical of practice, and may have had an impact on their performance. Finally, in practice, treatment decisions also depend on patient stability, thus possibly having an impact on how residents may classify the ECGs.

The ECGs used for this study were obtained in patients referred for electrophysiology testing to determine their underlying arrhythmia diagnosis. This could introduce referral bias into our study, leading to a higher prevalence of VT in our cohort compared to an unselected cohort of ED patients with wide complex tachycardia. Further, to generalize from our results requires the assumption that the ECG obtained at the time of the electrophysiology work-up would be equivalent with an ECG performed in the ED. However, our approach ensured an independent criterion standard obtained at the same time as the ECG.

Since the recruited residents were from the first through fourth year of training, we suspected the experience level of the resident could impact accuracy. However, we were only able to directly compare two residents from different levels of training. While a second-year resident performed better than a fourth-year resident reviewing 114 ECGs blinded to clinical information, we are unable to make any significant conclusions. Future research should consider how training, both in general and specific to application of criteria such as those proposed by Vereckei, as well as the time the resident spent familiarizing themselves with the articles and reviewing the ECGs, might have an impact on accuracy of differentiating the causes of wide QRS complex tachycardia.

We chose to have the criterion standard be the results of the electrophysiology study. We could have chosen to use a cardiologist's interpretation of the Vereckei criteria as the criterion standard. However, choosing a cardiology over read would only let us know how a resident agreed with a cardiologist and not whether the criteria could be used to make a diagnosis and direct a clinical action.

Conclusion

The new single lead Vereckei criteria, when applied by emergency medicine residents achieved only fair-to-good individual accuracy and moderate agreement. The addition of clinical information resulted in substantial improvement in test characteristics. Test characteristics suggested very few false negatives, such that answering ''no'' to all 4 steps of the Vereckei criteria could identify a patient with SVT-A. Residents who were able to apply the algorithm in the majority of the ECGs had better accuracy and agreement when compared to a group of residents who left a large proportion of ECGs as uninterpretable. Further improvements (accuracy and simplification) of algorithms for differentiating VT from SVT-A would be helpful prior to clinical implementation.

Acknowledgments

SPC conceived the study, which was designed with input from CJL. SC, WC, BG, MH, GC, TT, CW, GS participated in collection and interpretation of the data. RPB was responsible for data management. KWH and CJL were responsible for statistical analysis. RPB drafted the manuscript and all authors contributed significantly to its revision and approved the final version. SPC takes responsibility for the manuscript as a whole.

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