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Comparative Diagnostic Performance of Wide QRS Tachycardia Algorithms in Dogs: Bridging Human and Veterinary Cardiology

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ABSTRACT

***Background*:** Wide complex tachycardias (WCTs) in dogs pose a significant diagnostic and clinical challenge in veterinary cardiology, often carrying a high risk of syncope, heart failure, or sudden cardiac death. Accurate differentiation between ventricular tachycardias (VTs) and supraventricular tachycardias with aberrancy (SVT-A) is crucial for guiding therapeutic decisions. However, this distinction is frequently obscured by similar electrocardiographic morphologies and inherent electrophysiological complexity. While specific diagnostic algorithms have been developed for both human (e.g., D12V16) and veterinary medicine to improve diagnostic accuracy, their comparative performance and potential for hybrid optimization in canine patients remain largely unexplored. This study aimed to evaluate and compare the diagnostic performance of 2 established electrocardiographic algorithms - D12V16 (human-derived) and Santilli (veterinary-derived) - and a novel hybrid model, for differentiating WCTs in dogs.

***Materials, Methods & Results*:** This retrospective observational study analyzed 25 twelve-lead electrocardiograms (ECGs) from client-owned dogs with sustained WCTs, collected between 2023 and 2024 at NUDIVE / UFPI. A gold standard diagnosis of VT (n = 14) or SVT-A (n = 11) was established by consensus of 3 experienced veterinary cardiologists, who were blinded to the algorithm results. Each algorithm (D12V16, adapted Santilli, and the hybrid model) was applied in a strictly binary format. Diagnostic performance was assessed using accuracy, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), F1-Score, F1-Macro, and Cohen's Kappa coefficient, with calculations performed using Python. The D12V16 algorithm demonstrated superior overall performance, achieving 92% accuracy, 100% sensitivity for VT (0 false negatives), 81.82% specificity for SVT-A, and a Kappa coefficient of 0.8261, indicating "Almost Perfect" agreement. The adapted Santilli algorithm showed 72% accuracy, 71.43% sensitivity for VT (4 false negatives), 72.73% specificity for SVT-A, and a Kappa of 0.4400 ("Moderate" agreement). The hybrid model exhibited intermediate performance with 84% accuracy and 100% sensitivity for VT (0 false negatives), but a reduced specificity of 63.64% for SVT-A (4 false positives), and a Kappa of 0.6409 ("Substantial" agreement).

***Discussion*:** The D12V16 algorithm proved highly effective for WCT differentiation in dogs, with its 100% VT sensitivity being a critical advantage in acute clinical settings. While the hybrid model showed promise, its lower specificity (higher false positive rate for SVT-A) limits its immediate clinical utility compared to D12V16. These findings advocate for the translational application and validation of human-based algorithms in veterinary cardiology. Future studies with larger canine cohorts and advanced computational approaches, including artificial intelligence, are warranted to further refine WCT diagnostic accuracy in dogs.

Keywords: arrhythmia, electrocardiography, dog, ventricular tachycardia, supraventricular tachycardia.

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INTRODUCTION

Wide complex tachycardias (WCTs) in dogs pose a significant diagnostic and clinical challenge in veterinary cardiology, often carrying a high risk of syncope, heart failure, or sudden cardiac death [22,39,53]. Accurate differentiation between ventricular tachycardias (VTs) and supraventricular tachycardias with aberrancy (SVT-A) is crucial for guiding therapeutic decisions and establishing patient prognosis. However, this distinction is frequently obscured by similar electrocardiographic morphologies and the inherent electrophysiological complexity underlying these arrhythmias [5,18,29,53].

The importance of this distinction cannot be overstated, as therapeutic approaches are diametrically opposed. VT necessitates rapid interventions with antiarrhythmic agents such as lidocaine or procainamide, whereas SVT-A may respond to vagal maneuvers or atrioventricular node blocking drugs, which are typically less aggressive [38,53]. Consequently, an incorrect diagnosis can lead to catastrophic outcomes, underscoring the critical need for diagnostic tools that enable rapid and accurate decision-making in acute clinical settings [1,3,14,17,19].

In veterinary medicine, specific analytical methods have been proposed to improve WCT differentiation. The algorithm by Santilli *et al*. [39,40,46], for instance, has become a cornerstone for WCT differentiation in dogs. Conversely, human-derived algorithms, such as the D12V16 algorithm [32], have demonstrated translational potential owing to shared fundamental electrophysiological principles between species [10,43]. Despite these existing tools, improving diagnostic accuracy for WCT differentiation remains a continuous challenge, necessitating further validation and optimization [2,13,25].

Therefore, this study aimed to comparatively evaluate the diagnostic performance of the human-derived D12V16 algorithm and the veterinary-derived Santilli algorithm (adapted for binary application), alongside a novel hybrid model, for differentiating wide complex tachycardias in dogs.

MATERIALS AND METHODS

Study design

This retrospective, observational, and comparative validation study primarily aimed to evaluate and compare the accuracy of 2 previously published electrocardiographic algorithms (1 human-derived and 1 veterinary-derived, both adapted) and a novel hybrid algorithm for differentiating wide complex tachycardias (WCTs) in a canine cohort. The performance of each algorithm was assessed against a gold standard established by a panel of experienced veterinary cardiologists, with a focus on detailed statistical metrics and the binary nature of their diagnostic output.

Electrocardiographic data collection

Twenty-five twelve-lead electrocardiograms (ECGs) were retrospectively selected from the medical records archive of the Cardiology Section at the Specialized Veterinary Diagnostic Imaging Center (NUDIVE / UFPI) between 2023 and 2024. These ECGs belonged to client-owned dogs presenting with sustained WCTs.

Inclusion criteria for WCTs were defined as follows:

a) Ventricular heart rate ≥ 180 beats per min (bpm) for large and medium-sized dog breeds, and ≥ 220 bpm for small and miniature breeds.

b) QRS complex duration ≥ 0.07 s for small and medium-sized dog breeds, and ≥ 0.09 s for large breeds.

The predominant QRS complex polarity (positive, negative, or isodiphasic) in each of the 12 leads (I, II, III, aVR, aVL, aVF, V1-V6) was visually assessed by a veterinary cardiologist from the NUDIVE Cardiology Service. Predominantly isodiphasic leads were classified as "mixed" for algorithmic analysis, acknowledging that most algorithms primarily utilize binary (positive/negative) classifications. All electrocardiographic (ECG) recordings were initially acquired using a digital electrocardiograph[1] and subsequently stored for further analysis.

Gold standard definition

The definitive diagnosis (gold standard) for each WCT episode was established by independent consensus of 3 veterinary cardiologists, members of the Brazilian Society of Veterinary Cardiology (SBCV), all with extensive experience in electrocardiography and arrhythmia interpretation. These evaluators were blinded to the results of any algorithm. Classification was binary: Ventricular Tachycardia (VT) or Supraventricular Tachycardia with Aberrancy (SVT-A). In cases of disagreement among evaluators, a fourth expert would have been consulted to resolve the discrepancy;

however, this was not required in the present study. For the purpose of calculating algorithm performance metrics, the gold standard comprised 14 cases of VT and 11 cases of SVT-A, totaling 25 samples.

Electrocardiographic algorithms evaluated and their binary output

Three algorithms were systematically applied to the ECG data. Each was designed to consistently provide a binary diagnostic classification (VT or SVT-A) for every case, without allowing for indeterminate results in their application for this study. This approach aimed to simulate the necessity for a definitive clinical decision in all analyzed tracings.

D12V16 algorithm

The D12V16 algorithm, originally developed for WCT differentiation in humans [32], was applied in its original 3-step format, analyzing the predominant QRS polarity in leads I, II, V1, and V6. The steps are:

-Step 1: If all 4 leads (I, II, V1, V6) are predominantly negative. If yes, VT. Else, proceed to the next step.

-Step 2: If exactly 3 of the 4 leads (I, II, V1, V6) are predominantly negative. If yes, VT. Else, proceed to the next step.

-Step 3: If at least 2 of the 4 leads (I or V6) are predominantly negative. If yes, VT. Else, SVT-A.

Santilli algorithm (adapted for binary application)

The Santilli algorithm [39], a well-established method in veterinary medicine for WCT differentiation, was applied, focusing on concordance and discordance of polarities among leads. For direct comparative purposes in this study, the Santilli algorithm was adapted to consistently provide a binary classification (VT or SVT-A) for each case. The evaluated criteria were:

-Criterion A (Limb-Precordial Discordance): Presence of predominant polarity discordance between limb leads (I, II, III, and aVF) and left precordial leads (V2-V6).

-Criterion B (Precordial Concordance): Presence of predominant polarity concordance across all precordial leads (V1and V2-V6), i.e., all are predominantly positive OR all are predominantly negative.

-Criterion C (Limb-Precordial Concordance): Presence of predominant polarity concordance between limb leads (I, II, III, and aVF) and left precordial leads (V2-V6), i.e., limb leads are negative AND V2-V6 are negative, OR limb leads are positive AND V2-V6 are positive.

- Criterion D (Precordial Discordance): Presence of predominant polarity discordance among all precordial leads (V1 and V2-V6), i.e., some are positive and others are negative (not all the same).

→ VT Diagnosis: If Criterion A OR Criterion B is met.

→ SVT-A Diagnosis: If Criterion C OR Criterion D is met (and no previous VT criterion applies).

Proposed hybrid algorithm (binary output)

A novel hybrid algorithm was developed and optimized for the canine population, combining and prioritizing criteria from both the D12V16 [4] and Santilli [34,42] algorithms, drawing upon ACVIM veterinary cardiology expertise, with the aim of achieving a better balance between sensitivity and specificity. This algorithm was also designed to consistently provide a binary classification (VT or SVT-A) for each ECG. The steps are:

-Step 1: Probable SVT-A (Typical Bundle Branch Block Patterns for Aberrancy):

Criterion: If ANY of the following is true:

- (1a) Left Bundle Branch Block (LBBB-like) Pattern: Lead V1 is predominantly Negative (N) AND Lead V6 is predominantly Positive (P). OR
- (1b) Right Bundle Branch Block (RBBB-like) Pattern: Lead V1 is predominantly Positive (P) AND Lead V6 is predominantly Negative (N).

→ If YES (1a OR 1b): Diagnosis is Supraventricular Tachycardia with Aberrancy (SVT-A).

-Step 2: Strong VT Indicators (Undeniable VT Morphological Patterns):

Criterion: If ANY of the following is true:

- (2a) Total Precordial Concordance (V1-V6): All precordial leads (V1-V6) exhibit the same predominant polarity (either all Positive OR all Negative).
- OR (2b) Four Key Negative Leads (I, II, V1, V6): Leads I, II, V1, and V6 are all predominantly Negative.
- OR (2c) Extreme Limb-Precordial Discordance: All limb leads (I, II, III, aVF) exhibit the same predominant polarity (either all Positive OR all Negative) AND all left precordial leads (V2-V6) show the opposite predominant polarity to the limb leads.

→ If YES (2a OR 2b OR 2c): Diagnosis is Ventricular Tachycardia (VT).

Statistical analysis

For each algorithm, a 2 x 2 contingency table was constructed, representing True Positives (TP), True Negatives (TN), False Positives (FP), and False Negatives (FN) against the gold standard (14 VT, 11 SVT-A). Diagnostic performance indices were derived through custom computational routines developed in Python, leveraging standardized analytical frameworks to ensure statistical consistency [15].

Accuracy: Proportion of correct diagnoses (TP + TN)/Total.

a) Sensitivity (for VT): Ability to correctly identify VT (TP / (TP + FN)).

b) Specificity (for SVT-A): Ability to correctly identify SVT-A (TN / (TN + FP)).

c) Positive Predictive Value (PPV for VT): Probability of being VT when the algorithm diagnoses VT (TP / (TP + FP)).

d) Negative Predictive Value (NPV for SVT-A): Probability of being SVT-A when the algorithm diagnoses SVT-A (TN / (TN + FN)).

e) F1-Score (for VT): Harmonic mean of sensitivity and PPV for the VT class.

f) F1-Score (for SVT-A): Harmonic mean of sensitivity and PPV for the SVT-A class.

g) F1-Macro: Unweighted mean of the F1-Scores for the VT and SVT-A classes.

h) Cohen's Kappa coefficient (κ): A measure of agreement between the algorithm and the gold standard, corrected for chance. Kappa values were interpreted according to Landis and Koch [23]: < 0.00 (poor), 0.00 - 0.20 (slight), 0.21 - 0.40 (fair), 0.41 - 0.60 (moderate), 0.61 - 0.80 (substantial), and 0.81 - 1.00 (almost perfect).

All Statistical analysis was performed using Python-based computational tools.

RESULTS

Cohort characteristics and gold standard diagnosis

A total of 25 ECGs from dogs with wide QRS tachycardias (WCTs) were included in the analysis. The gold standard diagnosis, established by expert consensus, classified 14 cases as Ventricular Tachycardia (VT) and 11 cases as Supraventricular Tachycardia with Aberrancy (SVT-A). Figure 1 shows an example of wide QRS tachycardia.

Individual algorithm performance

For each of the 3 algorithms, the confusion matrices (True Positive - TP, True Negative - TN, False Positive - FP, False Negative - FN) and their derived performance metrics, calculated in Python relative to the Gold Standard, are presented in the following subsections.

D12V16 algorithm

The D12V16 algorithm demonstrated superior overall diagnostic performance. It achieved an accuracy of 92% (95% CI: 73.1%, 98.9%). The Cohen's Kappa coefficient was 0.8261, indicating "Almost Perfect" agreement with the gold standard (Table 1). The algorithm correctly identified all 14 VT cases (100% sensitivity; 0 false negatives) and correctly identified 9 out of 11 SVT-A cases (81.82 % specificity; 2 false positives) [Table 2].

Santilli algorithm (adapted for binary application)

The adapted Santilli algorithm showed moderate diagnostic performance. Its overall accuracy was 72% (95% CI: 50.6%, 87.9%). The Cohen's Kappa coefficient was 0.4400, indicating "Moderate" agreement (Table 3). It correctly identified 10 of the 14 VT cases (71.43% sensitivity; 4 false negatives) and 8 of the 11 SVT-A cases (72.73% specificity; 3 false positives) [Table 4].

Hybrid model

The proposed hybrid algorithm exhibited intermediate performance between the D12V16 and Santilli algorithms. It achieved an accuracy of 84% (95% CI: 63.9%, 95.5%). The Cohen's Kappa coefficient was 0.6409, suggesting "Substantial" agreement (Table 5). Similar to D12V16, it correctly identified all 14 VT cases (100% sensitivity; 0 false negatives). However, its specificity for SVT-A was lower at 63.64%, with 4 false positives (Table 6). Figure 2 visually shows the algorithms for VT diagnosis, illustrating the trade-offs in their performance.

Comparative summary

A direct comparison of all performance metrics for the 3 algorithms is presented in Table 7. The D12V16 algorithm consistently outperformed the others in most metrics, especially achieving 100% sensitivity for VT and the highest Kappa value.

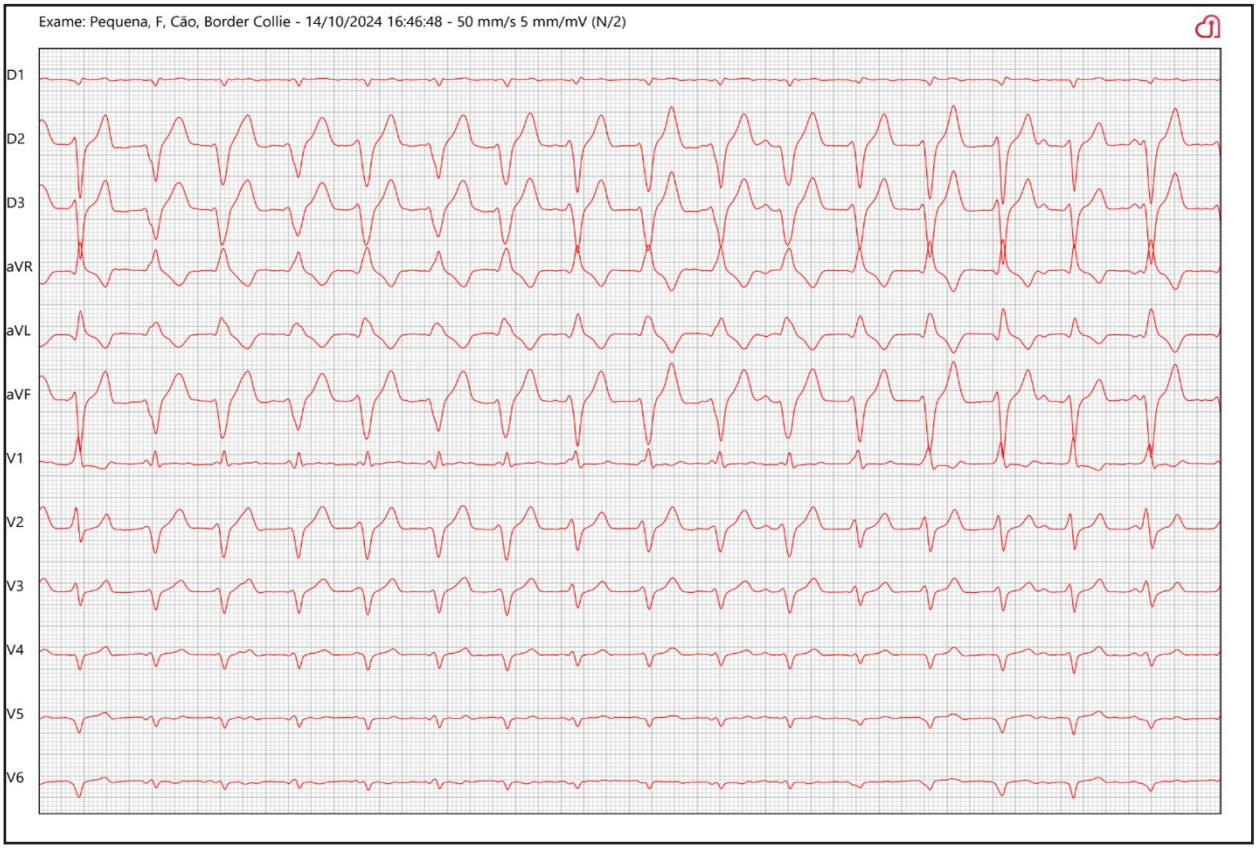

Figure 1. Representative 12-lead electrocardiographic (ECG) tracing of a dog with wide QRS tachycardia from the NUDIVE/UFPI cohort. Note the sustained rhythm with increased QRS duration. Paper speed: 50 mm/s; Sensitivity: 5 mm/mV (N/2).

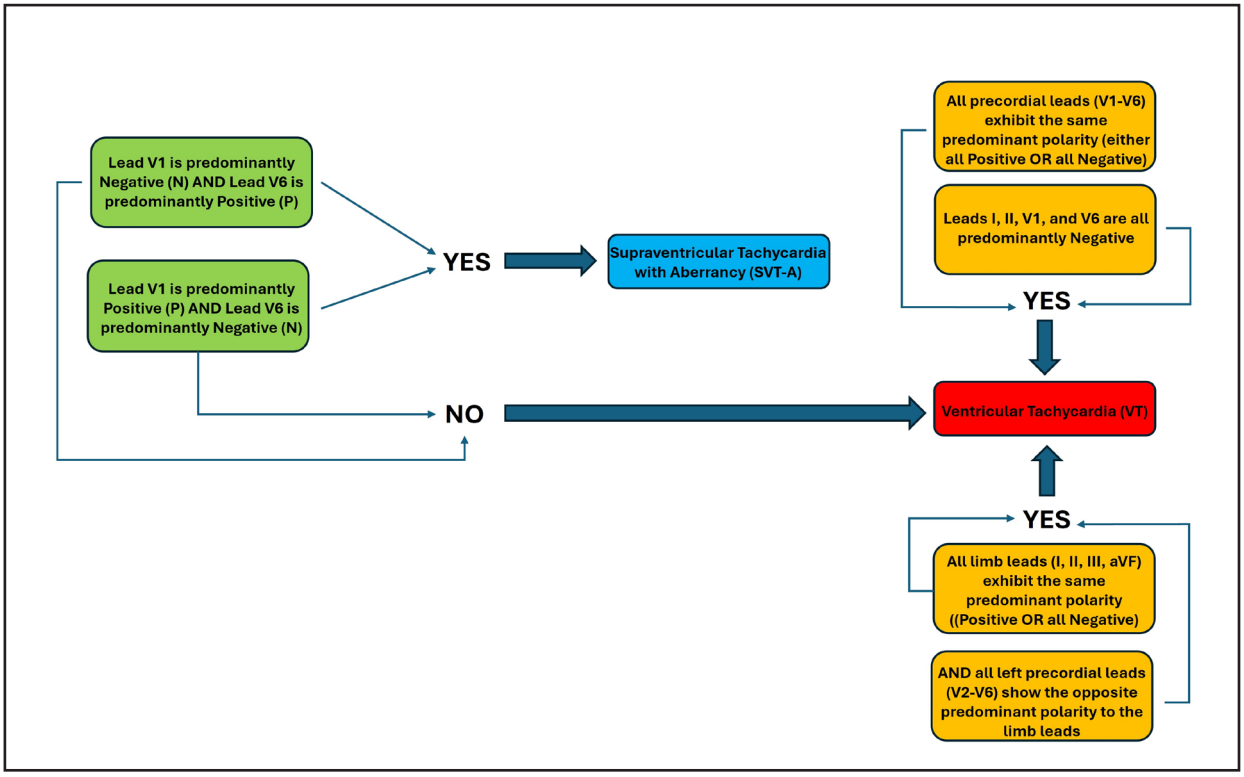

Figure 2. Flowchart of the proposed hybrid algorithm for the differentiation of wide QRS complex tachycardia in dogs.

Table 1. Performance Metrics of Algorithm D12V16 Against the Gold Standard.

Metric	Value	Interpretation
Accuracy	92.00%	23 out of 25 diagnoses correctly classified
Sensitivity (VT)	100.00%	No true Ventricular Tachycardia cases missed (0 False Negatives - FN)
Specificity (SVT-A)	81.82%	9 out of 11 Supraventricular Tachycardia Arrhythmias (SVT-A) correctly identified
PPV (VT)	87.50%	87.5% of positive VT predictions were correct
NPV (SVT-A)	100.00%	100% of predicted SVT-A negatives were correct
F1-Score (VT)	0.933	High precision and sensitivity for VT detection
F1-Score (SVT-A)	0.900	Good precision and sensitivity for SVT-A detection
F1-Macro	0.917	Excellent balanced overall performance across classes
Cohen's Kappa (κ)	0.8261	Strong agreement beyond chance (classified as "Nearly Perfect" agreement)

Interpretation of Cohen's Kappa (κ) follows the guidelines by Landis and Koch. VT: Ventricular Tachycardia; SVT-A: Supraventricular Tachycardia Arrhythmia; PPV: Positive Predictive Value; NPV: Negative Predictive Value; FN: False Negative.

Table 2. Confusion Matrix for Algorithm D12V16 Against the Gold Standard.

D12V16 Prediction	Gold Standard: VT (n=14)	Gold Standard: SVT-A (n=11)
Predicted VT	14 (TP)	2 (FP)
Predicted SVT-A	0 (FN)	9 (TN)

(n=X): Represents the total number of cases for that specific Gold Standard class; TP: True Positive (Algorithm correctly classified VT as VT); FP: False Positive (Algorithm incorrectly classified SVT-A as VT); FN: False Negative (Algorithm incorrectly classified VT as SVT-A); TN: True Negative (Algorithm correctly classified SVT-A as SVT-A); VT: Ventricular Tachycardia; SVT-A: Supraventricular Tachycardia Arrhythmia.

Table 3. Performance Metrics for the Santilli Algorithm (Adapted and Binary) Against the Gold Standard.

Metric	Value	Interpretation
Accuracy	72.00%	18 out of 25 diagnoses correctly classified
Sensitivity (VT)	71.43%	10 out of 14 true Ventricular Tachycardia (VT) cases correctly identified
Specificity (SVT-A)	72.73%	8 out of 11 true Supraventricular Tachycardia Arrhythmia (SVT-A) cases correctly identified
PPV (VT)	76.92%	76.9% of positive VT predictions were correct
NPV (SVT-A)	66.67%	66.7% of predicted SVT-A negatives were correct
F1-Score (VT)	0.741	Moderate precision and sensitivity for VT detection
F1-Score (SVT-A)	0.696	Moderate precision and sensitivity for SVT-A detection
F1-Macro	0.718	Moderate and balanced overall performance across classes
Cohen's Kappa (κ)	0.4400	Moderate agreement beyond chance (classified as "Moderate" agreement)

Interpretation of Cohen's Kappa (κ) agreement levels (e.g., "Moderate") typically follows the guidelines by Landis and Koch. VT: Ventricular Tachycardia; SVT-A: Supraventricular Tachycardia Arrhythmia; PPV: Positive Predictive Value; NPV: Negative Predictive Value.

Table 4. Confusion Matrix for the Santilli Algorithm (Adapted and Binary) Against the Gold Standard.

Santilli Prediction	Gold Standard: VT (n=14)	Gold Standard: SVT-A (n=11)
Predicted VT	10 (TP)	3 (FP)
Predicted SVT-A	4 (FN)	8 (TN)

(n=X): Represents the total number of cases for that specific Gold Standard class. TP: True Positive (Algorithm correctly classified VT as VT); FP: False Positive (Algorithm incorrectly classified SVT-A as VT); FN: False Negative (Algorithm incorrectly classified VT as SVT-A); TN: True Negative (Algorithm correctly classified SVT-A as SVT-A); VT: Ventricular Tachycardia; SVT-A: Supraventricular Tachycardia Arrhythmia.

Table 5. Performance Metrics for the Hybrid Algorithm (Binary) Against the Gold Standard.

Metric	Value	Interpretation
Accuracy	84.00%	21 out of 25 diagnoses correctly classified
Sensitivity (VT)	100.00%	No true Ventricular Tachycardia cases missed (0 False Negatives - FN)
Specificity (SVT-A)	63.64%	7 out of 11 true Supraventricular Tachycardia Arrhythmia (SVT-A) cases correctly identified
PPV (VT)	77.78%	77.8% of positive VT predictions were correct
NPV (SVT-A)	100.00%	100% of predicted SVT-A negatives were correct
F1-Score (VT)	0.875	High precision and sensitivity for VT detection
F1-Score (SVT-A)	0.778	Good precision and sensitivity for SVT-A detection
F1-Macro	0.826	Very good balanced overall performance across classes
Cohen's Kappa (κ)	0.6409	Strong agreement beyond chance (classified as "Substantial" agreement)

Interpretation of Cohen's Kappa (κ) agreement levels (e.g., "Substantial") typically follows the guidelines by Landis and Koch. VT: Ventricular Tachycardia; SVT-A: Supraventricular Tachycardia Arrhythmia; PPV: Positive Predictive Value; NPV: Negative Predictive Value; FN: False Negative.

Table 6. Confusion Matrix for the Hybrid Algorithm (Binary) Against the Gold Standard.

D12V16 Prediction	Gold Standard: VT (n=14)	Gold Standard: SVT-A (n=11)
Predicted VT	14 (TP)	4 (FP)
Predicted SVT-A	0 (FN)	7 (TN)

(n=X): Represents the total number of cases for that specific Gold Standard class. TP: True Positive (Algorithm correctly classified VT as VT); FP: False Positive (Algorithm incorrectly classified SVT-A as VT); FN: False Negative (Algorithm incorrectly classified VT as SVT-A); TN: True Negative (Algorithm correctly classified SVT-A as SVT-A); VT: Ventricular Tachycardia; SVT-A: Supraventricular Tachycardia Arrhythmia.

Table 7. Performance Metrics of Three Algorithms.

Metric	D12V16	Santilli	Hybrid
CONFUSION MATRIX COMPONENTS			
True Positives (TP)	14	10	14
True Negatives (TN)	9	8	7
False Positives (FP)	2	3	4
False Negatives (FN)	0	4	0
OVERALL PERFORMANCE			
Accuracy (%)	92.00	72.00	84.00
SPECIFIC METRICS			
Sensitivity (VT) (%)	100.00	71.43	100.00
Specificity (SVT-A) (%)	81.82	72.73	63.6
PPV (VT) (%)	87.50	76.92	77.78
NPV (SVT-A) (%)	100.00	66.67	100.00
F1-Score (VT)	0.933	0.741	0.875
F1-Score (SVT-A)	0.900	0.686	0.778
F1-Macro	0.917	0.716	0.826
Kappa	0.826	0.440	0.641
ALGORITHM CHARACTERISTICS			
Output Type	Binary	Binary	Binary
Indeterminate Output Allowed?	No	No (in this application)	No

TP: True Positive; TN: True Negative; FP: False Positive; FN: False Negative; VT: Ventricular Tachycardia; SVT-A: Supraventricular Tachycardia Arrhythmia; PPV: Positive Predictive Value; NPV: Negative Predictive Value.

DISCUSSION

The present study addressed a pivotal and challenging question in both human and veterinary cardiology: the accurate differentiation of wide complex tachycardias (WCTs). Our primary objective was to comparatively evaluate the diagnostic performance of two established electrocardiographic algorithms - D12V16, originally developed for human medicine [32], and Santilli, a cornerstone in veterinary cardiology [39,40,42]. Additionally, we proposed and evaluated a novel hybrid algorithm, developed by combining criteria from these existing models and established bundle branch block patterns [4], specifically designed to optimize the balance between sensitivity and specificity in dogs. The unequivocal importance of this differentiation stems from the diametrically opposed therapeutic approaches for ventricular tachycardia (VT) and supraventricular tachycardia with aberrancy (SVT-A). An incorrect diagnosis can lead to severe consequences, particularly in acute clinical settings [22,39,53]. Given the potential lethality of ventricular arrhythmias, the ability to make rapid and accurate decisions in WCT contexts is paramount [1,3,14,17,19]. A systematic approach to interpreting the electrocardiogram (ECG) is crucial for differential diagnosis and avoiding misdiagnosis of a wide QRS complex as a clinical entity [25,52].

Our cohort of 25 ECG tracings from dogs with sustained WCTs showed a predominance of VTs (14 VT, 11 SVT-A). This distribution is clinically relevant and consistent with veterinary literature, which indicates a higher frequency of VT in dogs with structural heart disease, notably in predisposed breeds like Doberman Pinschers, Boxers, and German Shepherds [2,33,42,50]. This case distribution underscores the critical importance of algorithms with high sensitivity for VT to avoid missing potentially fatal diagnoses.

From a pathophysiological standpoint, VTs arise from reentrant circuits or ectopic foci located within the ventricles and are frequently associated with structural cardiomyopathies, such as dilated cardiomyopathy and arrhythmogenic right ventricular cardiomyopathy [6,22,29,38]. Conversely, SVT-A results from supraventricular rhythms exhibiting aberrant conduction, either due to functional bundle branch block or anomalous preferential conduction, a phenomenon described in both humans and dogs [5,53]. Furthermore, cardiac electrophysiological remodeling, often exacerbated by conditions such as intense exercise [36] or age-related changes [47], can increase arrhythmia susceptibility in canine models.

The D12V16 algorithm, following its adaptation, demonstrated remarkably superior performance in differentiating WCTs within the canine population studied, outperforming the other evaluated algorithms across several metrics. Its accuracy was 92%, reflecting 23 out of 25 correct diagnoses. The Cohen's Kappa coefficient (κ) of 0.8261 indicated "Almost Perfect" agreement with the gold standard [23]. The most impactful and clinically relevant finding was its absolute sensitivity for VT (100%), with zero false negatives (FNs). This means that in none of the 14 true VT cases did the algorithm fail to correctly identify the arrhythmia. In cardiology, particularly in the context of WCTs, missing a VT diagnosis (a Type II error) carries a high risk of catastrophic outcomes, including syncope, hemodynamic collapse, and even sudden cardiac death, necessitating immediate and specific intervention [6,29,36,49]. The ability to identify all true VTs positions D12V16 as an invaluable diagnostic safety tool, as highlighted in previous management studies [28].

Conversely, the algorithm yielded 2 false positives (FPs), erroneously diagnosing SVT-A as VT. This translated to an SVT-A specificity of 81.82%. While FPs represent a limitation, Type I errors (overtreating an SVT-A as VT) are generally considered to have less immediate prognostic impact than Type II errors, as they allow time for clinical re-evaluation or confirmatory tests before more aggressive interventions [2,18]. The positive predictive value (PPV) for VT was 93.33%, and the negative predictive value (NPV) for SVT-A was 100%, further supporting high confidence in ruling out VT when the algorithm suggests SVT-A. F1-Scores for VT (0.966) and SVT-A (0.909), along with an F1-Macro of 0.938, further corroborate the algorithm's excellent and balanced overall performance.

The robustness of D12V16 in dogs mirrors its documented efficacy in human medicine, where it has shown superior performance compared to classic algorithms like Brugada [6] and Vereckei [51] for WCT differentiation [20,29,32]. The sustained high performance in a different species like canines suggests that the underlying electrophysiological principles governing morphological criteria, based on specific lead polarities, are conserved to a certain extent, thus demonstrating translational applicability [10,43]. Nevertheless, despite these physiological commonalities, factors such as canine thoracic conformation and electrode positioning indicate that the direct transposition of human algorithms is not without challenges, necessitating careful methodological adaptation that accounts for species-specific particularities [30,40].

In contrast, the Santilli algorithm, widely regarded as a cornerstone in veterinary cardiology, demonstrated remarkably inferior performance when applied in a binary (VT or SVT-A) format in this study. Its accuracy was only 72%, with 18 out of 25 correct diagnoses. The Cohen's Kappa coefficient (κ) of 0.4400, interpreted as "Moderate" agreement with the gold standard [23], signifying that agreement was only moderately beyond chance. The sensitivity for VT was 71.43%, resulting in four false negatives (FNs). From a clinical perspective, this limitation is severe and critical, as it implies the algorithm failed to correctly detect potentially fatal VTs in 4 of the 14 true cases within the sample [39,40,41]. The PPV for VT was 76.92%, and the NPV for SVT-A was 66.67%, corroborating its lower reliability. F1-Scores for VT (0.741) and SVT-A (0.696), with an F1-Macro of 0.718, confirm the moderate and less balanced overall performance compared to the other algorithms.

This decline in performance is directly attributable to the forced adaptation of the Santilli algorithm to a binary output. The original model, as highlighted by Santilli *et al*. [17,39,42], incorporates an "indeterminate" category, which is fundamental for classifying ambiguous cases and reflects the inherent complexity of WCT differentiation. The removal of this category, while necessary for methodological comparability in this study, exposed a critical vulnerability of the algorithm when confronted with the demand for an absolute clinical decision [17]. The nature of WCTs

often precludes a safe dichotomous classification, and models that acknowledge this ambiguity are frequently more representative of clinical reality [39]. Despite its limitations in the adapted format, the Santilli algorithm should not be interpreted as inherently flawed. It was specifically developed for dogs, incorporating species-specific morphological peculiarities and acknowledging the inherent diagnostic complexity of veterinary ECGs [9,13,25,42]. Other simplified algorithms for dogs have also been proposed, validating the continuous pursuit of more accessible and adapted tools for veterinary medicine [44-46]. The observed performance decline is thus more attributable to the methodological adaptation imposed in this study than to an inefficiency of the model in its original, complete format. This finding underscores the importance of respecting the conceptual boundaries of each algorithm and of developing diagnostic tools that are, from their conception, appropriate and optimized for the veterinary clinical context [11,40].

The novel hybrid algorithm, developed with the objective of combining the strengths of D12V16 [32] and Santilli [40], demonstrated performance that positions it as a promising tool. Its accuracy was 84.00 % (21 out of 25 correct diagnoses). The Cohen's Kappa coefficient (κ) of 0.6409, interpreted as "Substantial" agreement with the gold standard [23]. Similar to D12V16, the hybrid algorithm achieved absolute sensitivity for VT (100%) and a perfect negative predictive value for SVT-A (100%), thereby eliminating the occurrence of false negatives for VT. This safety feature, ensuring no VT is missed, is an attribute of paramount clinical value. However, the hybrid algorithm yielded a higher number of false positives (4 cases) compared to D12V16. This translated to an SVT-A specificity of 63.64%, demonstrating a classic sensitivity-specificity trade-off [2,29]. While more FPs mean a higher risk of overtreating SVT-A, the cost-benefit in emergencies often favors high VT sensitivity, accepting a slightly lower specificity to prevent missing a fatal arrhythmia [39,53]. The PPV for VT was 77.78%, and the NPV for SVT-A was 100%, again indicating high reliability in ruling out VT. F1-Scores for VT (0.875) and SVT-A (0.778), with an F1-Macro of 0.826, suggest a very good and balanced overall performance. Thus, the hybrid model can be considered a robust diagnostic support tool, complementing, but not replacing, expert analysis, particularly when immediate VT detection is paramount.

The comparison between the 3 algorithms evaluated in this study clearly illustrates the recurring methodological dilemma in cardiology: how to balance high sensitivity for potentially fatal conditions with specificity for less severe differential diagnoses [2,38]. While D12V16 and the hybrid algorithm clearly prioritized VT detection, ensuring the absence of false negatives (both with 100% VT sensitivity), the adapted Santilli algorithm demonstrated a different balance, but at the cost of missing 4 VTs. This observation underscores the importance of contextualizing algorithm use according to the clinical scenario and evaluating the relative severity of diagnostic errors and their therapeutic consequences [17,23,40]. The misinterpretation of WCTs and the importance of training in simple algorithms to avoid errors in emergency settings are frequently emphasized, with studies addressing diagnostic pitfalls and the need for proper algorithm application [12,17,19, 48].

Accurate differentiation between VT and SVT-A in dogs is not merely a matter of diagnostic precision; it directly impacts patient safety and prognosis. VT, especially when sustained, is associated with a high risk of sudden cardiac death and hemodynamic deterioration due to ineffective ventricular contractions, low coronary perfusion, and the risk of ventricular fibrillation [29,37-39]. Proper diagnosis and management of ventricular arrhythmias in dogs and cats are fundamental considerations in veterinary practice [7]. Persistent sustained VT episodes can promote ventricular remodeling, precipitating progressive heart failure and secondary arrhythmias [36,39]. In contrast, SVT-A, while less immediately life-threatening, can lead to significant symptoms of exercise intolerance and hemodynamic risk if persistent, in addition to requiring distinct pharmacological treatment [53]. Additionally, in animals with pre-existing structural heart disease, SVT-A can progress to heart failure if not adequately treated [2,53]. Thus, the clinical application of algorithms must be considered within the risk-benefit context of each diagnostic decision.

From an electrocardiographic perspective, the complexity in WCT interpretation stems from the superimposition of ventricular and supraventricular signals, which can mask characteristic patterns [8,10,18,24,53] and hinder the identification of simple morphological criteria, such as QRS morphology, duration, polarity, and relationship with P waves

[26,27,34,35]. This morphological discrimination difficulty is a challenge not only for manual interpretation but also for automated devices, such as implantable defibrillators, where waveform analysis algorithms are employed [16,49]. This difficulty is amplified in dogs due to interindividual variability in cardiac anatomy across breeds and sizes, which can alter electrical vectors and, consequently, QRS morphology in leads [9,21,30,31,47].

The use of automated interpretation algorithms offers valuable support in this context, providing standardization of morphological criteria and aiding real-time clinical decision-making [9,25,40]. The superior performance of D12V16, even in dogs, demonstrates that fundamental morphological parameters are conserved across species. However, it also highlights the necessity for empirical adaptation and validation, given that manual adjustments were required to ensure concordance with specialists [11,40]. The hybrid model combining criteria from both algorithms, presents a promising error mitigation strategy, prioritizing VT detection while still considering SVT-A specificity. This approach reinforces the relevance of integrative models in veterinary medicine, where multiple parameters are considered simultaneously, better reflecting the patient's physiological and clinical complexity [2,13,15,54].

CONCLUSIONS

This comparative study of algorithms for differentiating wide complex tachycardias (WCTs) in dogs demonstrated that the human-derived D12V16 algorithm exhibited the most robust performance, achieving 92% accuracy and, critically, 100% sensitivity for ventricular tachycardia (VT), ensuring no false negatives for this high-risk arrhythmia. In contrast, the Santilli algorithm, when adapted to a strictly binary output, proved limited, with 72% accuracy and only 71.43% sensitivity for VT, resulting in 4 false negatives. This limitation reflects the loss of nuance inherent in its original formulation. The proposed hybrid algorithm achieved a promising profile, demonstrating 84% accuracy and, like D12V16, 100% sensitivity for VT. However, this came with a trade-off of a higher false positive rate (specificity of 63.64%), positioning it as a useful tool in emergency scenarios where identifying all VTs is the utmost priority. Collectively, these findings underscore the promising translational applicability of algorithms initially developed for human cardiology in the veterinary setting, particularly when the clinical focus prioritizes VT detection. Despite inherent limitations, including a reduced sample size and the imposed binary output restriction for comparability, this study contributes significantly to diagnostic improvement. It also signals the importance of future, larger-scale research, incorporating external validation and the potential integration of novel technologies such as artificial intelligence, to consolidate and expand upon these results.

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