Use of signal-averaged electrocardiography in the evaluation of arrhythmogenic right ventricular cardiomyopathy in Boxers

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Objective—To assess signal-averaged electrocardiography (SAECG) for evaluation of Boxers with arrhythmogenic right ventricular cardiomyopathy (ARVC) and identify dogs at risk for sudden death (SD) or death related to congestive heart failure (CHF).

Design—Prospective study.

Animals—94 Boxers with ARVC and 49 clinically normal non-Boxers (controls).

Procedure—Boxers were screened for ARVC, and severity was estimated by use of echocardiography, 24-hour ambulatory ECG, and SAECG. Statistical evaluation was performed to identify significant differences in SAECG variables relative to clinical outcome, frequency of ventricular arrhythmias, and systolic function. Sensitivity, specificity, and positive and negative predictive values were evaluated for each SAECG variable for occurrence of SD or death related to CHF. Late potentials were also evaluated as a predictor of cardiac-related death.

Results—Differences were detected in SAECG variables on the basis of clinical outcome, systolic function, and frequency of ventricular arrhythmias. More severely affected dogs had significantly more abnormal SAECG findings. The presence of late potentials, defined as 2 abnormal root mean square values (of 4), was associated with high sensitivity, specificity, and negative predictive value for cardiac-related SD or death secondary to CHF.

Conclusions and Clinical Relevance—Results suggest that SAECG is a useful noninvasive diagnostic test to evaluate dogs affected with ARVC and identify individuals at risk for cardiac-related death. (*J Am Vet Med Assoc* 2004;225:1050–1055)

Arrhythmogenic right ventricular cardiomyopathy (ARVC) of Boxers, which has also been referred to as Boxer cardiomyopathy and familial ventricular arrhythmias of Boxers, is an inherited disease of Boxers that predisposes to the development of ventricular arrhythmias, resulting in syncope or **sudden death (SD)**.[1,2,a] A subset of dogs with this disease may also develop myocardial failure with progression to **congestive heart failure (CHF)**, a condition that more closely resembles dilated cardiomyopathy in other large breeds of dogs.[1] Dogs that have ventricular arrhythmias may never develop clinical signs, remain without clinical signs for a variable length of time before developing clinical signs, or die suddenly without clinical signs. Diagnosis of the disease is typically achieved by the use of routine in-hospital **electrocardiography (ECG)**, ambulatory ECG (Holter monitoring), and 2-dimensional echocardiography. Standard diagnostic evaluation of these dogs permits, in most but not all instances, identification of affected individuals. However, identification of affected dogs that are at risk of developing clinical signs (ie, syncope and SD) is more problematic. The need for risk stratification to identify at-risk animals is central to management of the disease.

Most clinically important ventricular arrhythmias associated with SD are caused by reentrant mechanisms resulting from abnormalities in either ventricular conduction or repolarization.[3,4] **Signal-averaged ECG (SAECG)** is a noninvasive electrocardiographic technique that enables detection of abnormal conduction by identifying late potentials in the QRS complex, which are otherwise hidden in baseline noise during standard ECG.[5] These late potentials can be identified as high-frequency, low-voltage potentials that occur in the terminal portions of the QRS complex. Late potentials are believed to represent areas of abnormal conduction that may contribute to reentry.[6-8] Consequently, late potentials may serve as a pathophysiologic marker of a reentrant substrate and identify individuals at risk for fatal arrhythmias. We hypothesized that Boxers with severe ARVC would have SAECG recordings consistent with late potentials and SAECG would be a valuable noninvasive diagnostic test for identification of at-risk dogs with severe disease. The purpose of this study was to perform SAECG in Boxers to determine whether abnormalities in SAECG recordings consistent with late potentials correlate with disease severity.

Materials and Methods

Inclusion criteria—Dogs were prospectively recruited to participate in a multiphase study of Boxer ARVC through The Ohio State University. Evaluation included a 24-hour ambulatory ECG, 2-dimensional echocardiography to assess myocardial function and exclude congenital abnormalities, and a SAECG. Exclusion criteria included dogs with additional concurrent heart disease or that were receiving antiarrhythmic medication. A group of clinically normal, non-Boxers were also evaluated by use of SAECG as a control population. These dogs were screened by use of auscultation and Holter monitoring and were excluded if any evidence of cardiovascular disease (murmurs or abnormal Holter findings) was identified. Dogs of mixed breeds that were believed to include Boxer, Doberman Pinscher, or another breed at high risk for any cardiomyopathy were excluded. Clinically

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Presented in part at the 18th American College of Veterinary Internal Medicine Forum, Denver, May 2001.

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normal dogs were recruited on a voluntary basis, chiefly from the staff and students associated with the veterinary school at The Ohio State University. Informed consent was obtained for all dogs evaluated.

Ambulatory ECG—Twenty-four-hour ambulatory ECGs[b] were obtained with a 7-lead, 3-channel electrode system and acquired with an analog tape recorder. Leads were arranged to approximate the frontal leads I, II, and III. Recordings were analyzed with a prospective software analysis algorithm with continuous user interaction[c] by a trained cardiology research assistant under the guidance of a veterinary cardiologist. The presence and complexity of ventricular arrhythmias were identified. The number of **ventricular premature complexes (VPCs)** was tabulated, and the complexity of the ventricular arrhythmia was graded as grade 0 = no VPCs were detected; grade 1 = only single, monomorphic VPCs were detected; grade 2 = single VPCs were detected and were present either in a bigeminal or trigeminal pattern, or multiform complexes were detected; grade 3 = couplets or triplets were detected; or grade 4 = runs of ventricular tachycardia (≥ 4 beats) or the RonT phenomenon were detected.

Cardiac ultrasound—Cardiac ultrasound[d] was performed in unsedated dogs positioned in right lateral recumbency. Aortic velocity was obtained with a subcostal transducer position to exclude congenital valvular or subvalvular aortic stenosis.[9] Two-dimensional and M-mode imaging in the parasternal right and long axis views were performed to assess cardiac dimensions and function. Dogs were excluded from the study if they had aortic velocities > 2.25 m/s (pressure gradient > 20 mm Hg), suggestive of aortic stenosis, or evidence of other additional congenital lesions or substantial acquired valvular disease. These conditions, however, were not encountered; therefore, no dogs were excluded.

SAECG—Signal-averaged ECG was similarly performed in unsedated dogs in right lateral recumbency. Electrodes were placed on the body surface after hair was clipped and skin debrided to facilitate good skin-electrode contact. Leads were placed to approximate leads I, aVF, and V10, creating an orthogonal lead system comprising the X, Y, and Z axes, respectively. A commercial SAECG system was used[e] to achieve a low-noise baseline to facilitate identification of late potentials. Data points were sampled at 2,000 samples/s and filtered with a high-pass frequency cutoff of 25 and 40 Hz. At the beginning of the recording, a template QRS beat was identified to define the typical morphologic features against which other QRS complexes would be compared to exclude artifact and ectopic or abnormal QRS features. This template beat was also used to identify the limits for the region of interest for baseline noise calculation; the isoelectric portion of the S-T segment was used for this purpose. The QRS complexes that had 95% homology with the predetermined template beat were accepted and included in the analysis. Successive QRS complexes were included in the averaging process until the averaged value of the baseline noise was ≤ 0.75 μV. The QRS complexes of each lead were signal-averaged and filtered with a 25- and 40-Hz high-pass filter. These averaged and filtered QRS complexes were summated to yield a composite filtered QRS complex. A satisfactory SAECG allowed evaluation of a sufficient number of normal ventricular complexes so as to achieve a final noise of 0.75 μV. Dogs with bundle branch block that caused QRS complex widths > 80 milliseconds were excluded from evaluation because identification of late potentials is complicated by preexisting conduction defects and wide QRS complexes.[10,11]

Several parameters were generated during SAECG analysis that were used to detect late potentials. The QRSd is defined as the width of the filtered QRS complex by computer-determined QRS onset and offset points. Late potentials will increase the filtered QRS width, thereby increasing QRSd values. The **low amplitude signal (LAS)** is the duration of time that the voltage of the terminal QRS complex remains < 40 μV before its termination. As with the QRSd, the duration of LAS increases with late potentials. **Root mean square (RMS)** values represent the mean voltage of the terminal QRS, typically defined as the last 40 milliseconds (RMS40) or 30 milliseconds (RMS30) of the QRS complex. Unlike QRSd and LAS, RMS values are inversely proportional to the degree of late potentials. The QRS complexes that do not have late potential activity will abruptly terminate, yielding a relatively large RMS value. Conversely, late potentials allow for a more gradual QRS offset and results in a smaller RMS value. All parameters were calculated at high-pass frequency cutoff values of both 40 and 25 Hz. The QRSd values are independent of the high-pass frequency filter used. Therefore, 7 parameters were used, including QRSd, LAS-40, RMS40-40, RMS30-40, LAS-25, RMS40-25, and RMS30-25.

Subject categorization—Dogs were grouped on the basis of disease severity as measured by VPC frequency, systolic function, and clinical outcome. For categorization by VPC frequency, dogs were grouped into 4 categories as group 1 = < 10 VPCs/24 h; group 2 = 10 to 100 VPCs/24 h; group 3 = 101 to 1,000 VPCs/24 h; and group 4 = > 1,000 VPCs/24 h. Systolic function was assessed by use of percentage fractional shortening. Dogs with fractional shortening of < 20% were considered to have systolic dysfunction. On the basis of clinical outcome, dogs were classified as **clinically affected (Clin)**, **not clinically affected (Nonclin)**, having SD, or having CHF. Dogs were considered to have clinical signs if a history consistent with syncope was identified or if a syncopal episode was witnessed in the clinic.

Statistical analyses—Data were analyzed on the basis of VPC frequency, systolic function, and clinical assessment. The number of VPCs was grouped as described (groups 1 to 4), and 1-way ANOVA was used to identify differences in each SAECG parameter on the basis of VPC frequency group.

Table 1—Descriptive data for 7 signal-averaged electrocardiography (SAECG) variables in 94 Boxers. The 95th percentile is recorded for variables that increase with the severity of late potentials (QRSd and LAS), and the fifth percentile is recorded for variables that decrease with the severity of late potentials (RMS).

Parameter	Minimum	Maximum	Mean	Median	95%/5%
QRSd (ms)	49.5	81.5	66.5	67	75.5
LAS40 (ms)	1	27	15.1	15	23.5
RMS40-40 (μV)	41.2	435.5	234.9	236.9	76.6
RMS30-40 (μV)	22.1	404.8	167.2	155.9	43.5
LAS25 (ms)	0	22	9.8	10	19
RMS40-25 (μV)	64	710.9	369.2	354.8	129.3
RMS30-25 (μV)	30.9	601.5	253.4	242.4	57.7

QRSd = Duration of filtered QRS complex. LAS = Low amplitude signal (duration of time < 40 μV). RMS = Root mean square value of the terminal 40 (RMS40) or 30 (RMS30) milliseconds (ms). The LAS and RMS were filtered at 40 and 25 Hz.

Table 2—Descriptive data for 49 non-Boxers for 7 SAECG variables. *See* Table 1 for key.

Variable	Minimum	Maximum	Mean	Median	95%/5%
QRSd (ms)	53	83	63.9	63	78.5
LAS40 (ms)	4.5	25	14	14	24.5
RMS40-40 (μV)	169.1	625	342.6	337.5	175.1
RMS30-40 (μV)	35.5	459.4	229.8	220.1	62.1
LAS25 (ms)	29	22	7.2	7	15
RMS40-25 (μV)	271.2	919.1	534.4	530.4	280.2
RMS30-25 (μV)	68.3	737	359.2	357.8	107.5

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One-way ANOVA was also used to identify differences in each SAECG parameter on the basis of the clinical outcome of each dog as categorized (Nonclin, Clin, SD, or CHF). The Student *t* test was used to identify differences in SAECG parameters between dogs with systolic dysfunction and those with normal function and to identify differences in SAECG parameters between males and females to evaluate the effect of sex on SAECG. For each test, differences were considered significant at $P = 0.05$. For 1-way ANOVA, Tukey post hoc tests were performed when a significant difference was identified.

Results

Ninety-three Boxers satisfied the inclusion criteria, and 1 additional dog was also included. The additional dog died before a 24-hour ambulatory ECG could be recorded, but an SAECG and echocardiogram were obtained prior to death. The dog was included because the information obtained from echocardiography and in-hospital ECG was sufficient to accurately diagnose and classify the disease. Therefore, 93 dogs were used in the evaluation of VPC frequency. Forty-nine clinically normal non-Boxers were also evaluated as a control group.

Of the 94 Boxers, 37 (39%) were male and 57 (61%) were female. Ages ranged from 1 to 12 years, with a median of 5 years. The number of VPCs ranged from 0 to 23,699 VPCs/24 h, with a median of 7 VPCs/24 h. On the basis of VPC frequency, 49 (52%) dogs were in group 1, 17 (18%) dogs were in group 2, 10 (11%) dogs were in group 3, and 17 (18%) dogs were in group 4. When grouped by clinical outcome, 66 (70%) dogs were in the Nonclin group, 13 (14%)

Table 3—Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) for cardiac-related death (sudden death or congestive heart failure) in Boxers. Values were obtained from the 95th and 5th percentiles of clinically normal non-Boxers. *See* Table 1 for key.

Variable	Value for 95th/5th percentile	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
QRSd (ms)	> 78.5	7	100	100	85
LAS40 (ms)	> 24.5	20	100	100	87
RMS40-40 (µV)	< 175.1	93	82	50	98
RMS30-40 (µV)	< 62.1	40	98	75	90
LAS25 (ms)	> 15	27	91	36	87
RMS40-25 (µV)	< 280.2	93	84	52	98
RMS30-25 (µV)	< 107.5	47	94	58	90

Table 4—Values for each SAECG variable that maximized sensitivity (sens) and NPV by correctly identifying all 15 Boxers that had cardiac-related death (CD; sudden death or congestive heart failure). *See* Table 1 for key.

Variable	Value to capture all CD dogs (sens & NPV=100)	No. of false positives	Specificity (%)	PPV (%)
QRSd (ms)	≥ 49	All 79	0	16
LAS40 (ms)	≥ 0	All 79	0	16
RMS40-40 (µV)	≤ 213	26	67	37
RMS30-40 (µV)	≤ 156	32	60	31
LAS25 (ms)	≥ 0	All 79	0	16
RMS40-25 (µV)	≤ 362	34	57	31
RMS30-25 (µV)	≤ 247	34	57	31

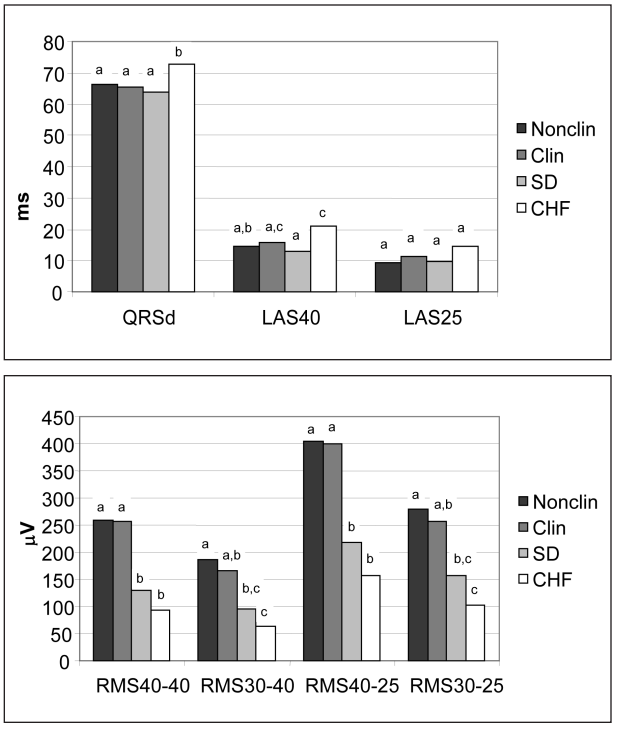

Figure 1—Seven signal-averaged electrocardiography (SAECG) variables in 94 Boxers characterized by clinical outcome (NONCLIN = Boxers without clinical signs. CLIN = Boxers with clinical signs. SD = Boxers with sudden death. CHF = Boxers with congestive heart failure). Top panel represents variables that increase in magnitude as severity of late potentials increase (QRSd and LAS). Lower panel represents variables that decrease in magnitude with increasing late potential severity (RMS). QRSd = Duration of filtered QRS complex. LAS = Low amplitude signal (duration of time < 40 µV). RMS = Root mean square value of the terminal 40 (RMS40) or 30 (RMS30) milliseconds. The LAS and RMS were filtered at 40 and 25 Hz. [a-c]Different superscripts indicate significant ($P < 0.05$) differences among clinical outcome groups.

Table 5—Values for each SAECG variable that optimized specificity and minimized false positives in 15 Boxers that had a cardiac-related death. *See* Table 1 for key.

Variable	Value to minimize false positives (maximize specificity)	No. of CD dogs captured (n = 15)	No. of false positives	Sensitivity (%)	Sensitivity (%)	PPV (%)	NPV (%)
QRSd (ms)	≥ 77	4	0	26.7	100	100	88
LAS40 (ms)	≥ 23	6	3	40	96	67	89
RMS40-40 (µV)	≤ 86	7	1	47	99	88	91
RMS30-40 (µV)	≤ 45	6	0	40	100	100	90
LAS25 (ms)	> 20	2	1	13	99	67	86
RMS40-25 (µV)	≤ 147	7	1	47	99	88	97
RMS30-25 (µV)	≤ 76	6	2	40	98	75	90

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dogs were in the Clin group, 8 (9%) dogs were in the SD group, and 7 (7%) dogs were in the CHF group.

Descriptive data for Boxers and clinically normal non-Boxers for each SAECG variable were tabulated (**Tables 1 and 2**, respectively). The 95th percentile was listed for variables that increase with degree of severity of late potentials (QRSd and LAS). The fifth percentile was listed for variables that vary inversely with the degree of late potentials (RMS40 and RMS30).

The 95th and 5th percentiles for each SAECG variable from the control dogs were used to calculate sensitivity, specificity, and positive and negative predictive

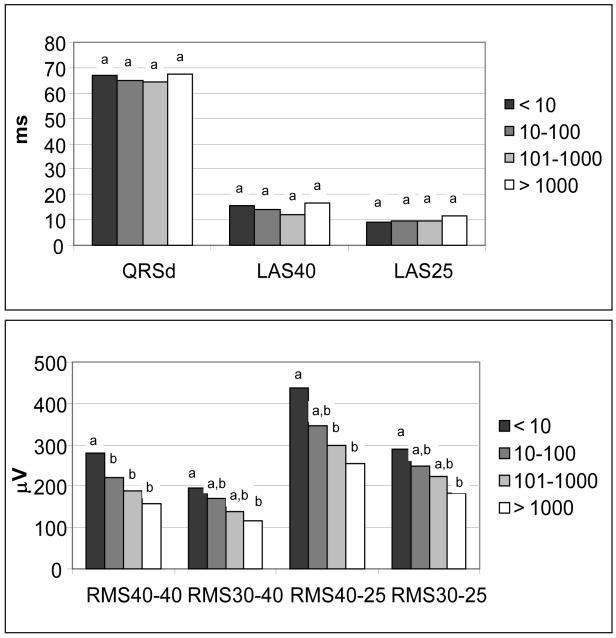

Figure 2—Seven SAECG variables in 94 Boxers characterized by frequency of ventricular arrhythmias. *See* Figure 1 for key.

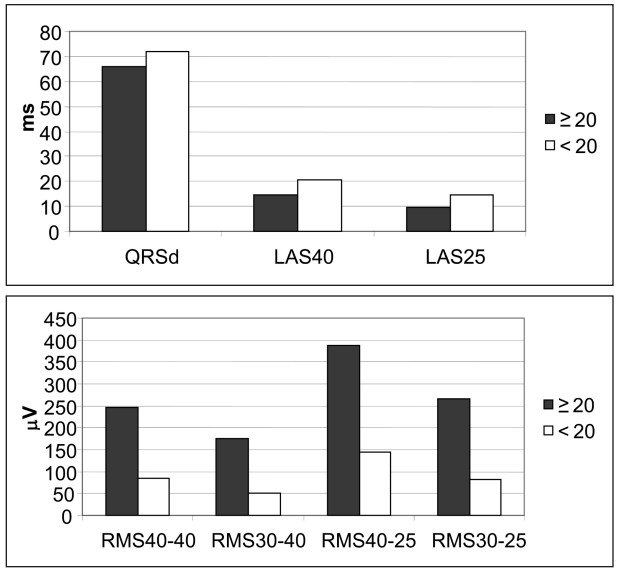

Figure 3—Seven SAECG variables in 94 Boxers characterized by systolic function, with dysfunction defined as a fractional shortening < 20%. Significant differences were identified in all variables in the top panel at $P < 0.05$ and in the bottom panel at $P < 0.001$. *See* Figure 1 for key.

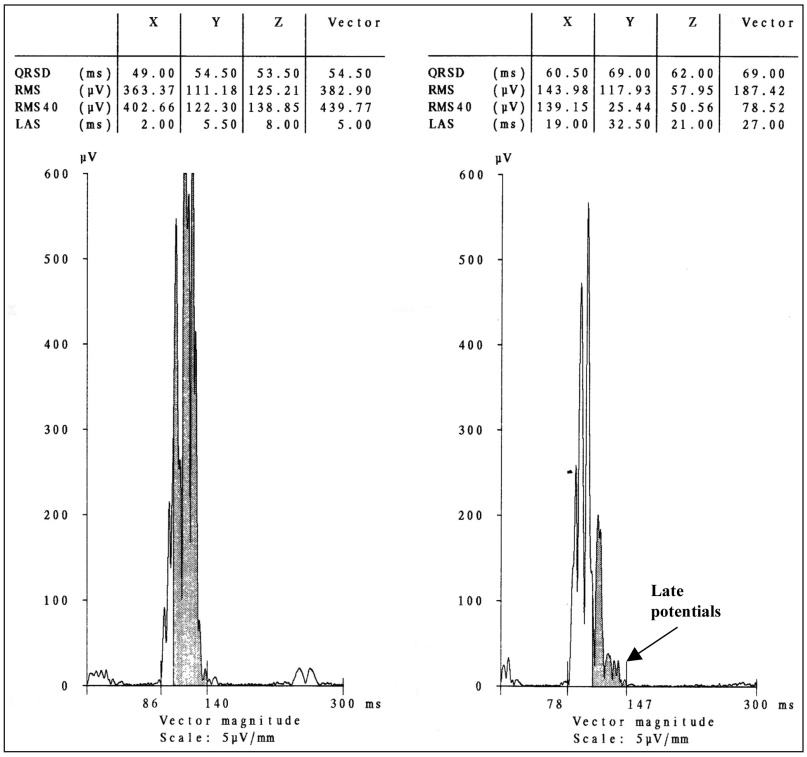

Figure 4—Examples of SAECGs from a clinically normal dog (left panel) and a Boxer with arrhythmogenic right ventricular cardiomyopathy (right panel). In the affected dog, notice the low-amplitude potential in the terminal portion of the QRS complex, consistent with late potentials. The QRSd and LAS are increased, and the RMS values are decreased, compared with the clinically normal dog. *See* Figure 1 for key.

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values for individual SAECG variables in the Boxers (**Table 3**). Values that optimize for sensitivity and specificity were also tabulated (**Tables 4 and 5**, respectively).

Results of the 1-way ANOVA for SAECG variables based on clinical outcome and VPC frequency groups were depicted graphically (**Figures 1 and 2**, respectively). Comparisons of SAECG variables between dogs with and without systolic dysfunction were determined (**Figure 3**). Examples of SAECGs from a clinically normal dog and from a dog that subsequently died were recorded (**Figure 4**).

Identification of late potentials was defined by those variables that were most significant in ANOVA and *t* test evaluation. The most discriminating values were the RMS values (RMS40 and RMS30) taken both at 25 and 40 Hz. Dogs that had 2 of 4 RMS values lower than the fifth percentile were considered to have late potentials. On the basis of these criteria, late potentials correctly identified 14 of 15 dogs that had a cardiac-related death (either SD or CHF), yielding sensitivity of 93%; 13 of 79 clinically normal dogs were incorrectly identified as having late potentials, yielding a specificity of 84%. On the basis of these results, the positive predictive value was 52%, with a negative predictive value of 98.5%.

Discussion

To our knowledge, this is the first study to evaluate the use of SAECG in the assessment of ARVC in Boxers. The results of this study indicate that SAECG is a useful tool in the evaluation of ARVC in Boxers. Differences between groups of dogs categorized by disease severity measured by quantification of VPC frequency, presence of systolic dysfunction, and clinical outcome were identified. Signal-averaged ECG proved useful in identifying those dogs that are most likely to have a cardiac-related death (either SD or CHF). For each variable, values could be identified that were associated with either high sensitivity (with high negative predictive value) or high specificity (with high positive predictive value) for a cardiac-related death; however, numerous false positives and false negatives occurred. The presence of late potentials (defined as 2 abnormal RMS values) was associated with high sensitivity, specificity, and negative predictive value. The lower positive predictive value was a result of the low prevalence of dogs with a cardiac-related death. However, SAECG had high sensitivity in the affected dogs.

Signal-averaged ECG has been used infrequently in veterinary medicine in the evaluation of canine heart disease. In the assessment of dilated cardiomyopathy in Doberman Pinschers[12] and in 4 dogs with sustained ventricular arrhythmias,[13] late potentials had the ability to potentially identify dogs that were more likely to have a cardiac-related death. In those reports, the manifestation of cardiac disease was similar to the subset of Boxers that either have severe arrhythmias or develop systolic dysfunction and CHF.

In human medicine, the evaluation and assessment of patients with ventricular arrhythmias uses a variety of diagnostic approaches. A major goal in the evaluation of such patients is to identify those individuals who are at the highest risk of adverse events, particularly SD. Diagnostic testing used for these purposes includes Holter evaluation, exercise testing, radionucleotide ventrigulography, and programmed stimulation.[10] With the exception of Holter monitoring, the usefulness of these other modalities is limited in veterinary medicine because of a combination of expense, invasiveness, and patient compliance. Consequently, this has resulted in the search for less invasive testing that may be more readily performed in veterinary patients.

Diseases for which SAECG has been used in the evaluation of ventricular arrhythmias include dilated cardiomyopathy, hypertrophic cardiomyopathy, arrhythmogenic right ventricular dysplasia-cardiomyopathy, ischemic heart disease, and nonspecific causes of syncope.[6,8,10,14]

In human medicine, SAECG is not used as a single diagnostic test but is frequently used as a screening tool to identify at-risk patients in whom additional testing is indicated, particularly electrophysiologic study.[7,8,11] In human studies,[7,8,10] late potentials as identified by SAECG have predicted the development of inducible ventricular arrhythmias on electrophysiologic testing and SAECG may be used as an independent diagnostic tool.

The identification of late potentials on SAECG is dependent on the technique used because normal values are highly dependent on recording and filtering technique.[7] Identification of late potentials can be performed several ways, including via temporal (time), spectral (frequency), and spatial averaging techniques.[7,8] Spatial averaging allows identification of late potentials of a single QRS complex by placing multiple electrodes over the body surface. Signal noise is reduced by comparing closely spaced electrodes, with the assumption that cardiac electrical activity between these electrodes is more consistent than random noise.

Spectral, or frequency domain, analysis is achieved by analyzing the frequency content of the terminal QRS signal. This technique lacks reproducibility, is very sensitive to recording variables, and is not more informative, compared with temporal averaging.[8,11,15] For these reasons, frequency analysis was not performed in our study.

In our study, temporal, or time domain, analysis was used for identification of late potentials. Unlike spectral analysis, this technique identifies late potentials by reducing baseline noise through averaging of successive QRS complexes and application of digital filters. The averaging process allows repeatable, consistent signals to persist, while eliminating random signals.

An important factor influencing the time domain analysis is the manner of end-point determination. The end point of the procedure can be defined by either a predetermined number of averaged beats or by a predetermined noise level.[6-8,11,13,16,17] Both methods have been used, but end-point determination based on noise level may yield better reproducibility.[8,17] The ideal level of end-point noise has not been absolutely defined but is likely to be between 1 and 0.3 μV.[6-8,11,13,16,17] There exists a trade-off between accuracy associated with lower levels of noise and reproducibility associated with higher levels of noise.[7,8,16] For these reasons, and to increase the chance that a particular noise level could consistently be achieved in unsedated dogs, we chose to determine an end point using a noise level of 0.75 μV, regardless of the number of beats necessary to achieve that level.

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The Boxer form of ARVC has substantial similarities to ARVC in humans. Arrhythmogenic right ventricular cardiomyopathy in humans is an inherited disease in which affected individuals are at risk for development of ventricular arrhythmias and increased risk of SD. Myocardial infiltration of fibrous and adipose tissue is the predominant pathologic finding in these patients, and the degree of infiltration correlates with the severity of disease.[6,11,18] Late potentials identified in patients with ARVC are believed to arise from conduction abnormalities secondary to myocardial fibrofatty infiltration, and the presence of late potentials is dependent on the severity of disease.[6] This finding supports the conclusion that SAECG is most useful in identifying abnormal conduction and increased risk of adverse arrhythmic events in patients with the more severe forms of the disease, suggestive of more substantial myocardial infiltration.[6,11] This pattern was also identified in our study of Boxers and lends credence to the similarities between the 2 diseases. In our study, the dogs with more severe disease, as measured by either VPC frequency or clinical status, were more likely to have late potentials on their SAECG. Those dogs with less severe disease were often indistinguishable from unaffected, clinically normal dogs.

Several limitations existed in this study. As is the case with many clinical studies in veterinary medicine, one limitation was the low number of dogs. This was particularly true for those dogs that had a cardiac-related death, including SD (n = 8) and CHF (7). With regard to VPC frequency, only 17 (18%) dogs had > 1,000 VPCs/24 h, whereas > 50% had < 10 VPCs/24 h. Only 7 (7%) dogs had fractional shortening < 20%, consistent with systolic dysfunction.

The identification of a particular Boxer as affected or unaffected can be difficult because no clear diagnostic criteria presently exist for this disease in Boxers. Consequently, reference values were generated from clinically normal non-Boxers. It may be more desirable to compare clinically normal Boxers with abnormal Boxers, but the uncertainty of identifying a Boxer as clinically normal or abnormal precludes this distinction at this time. Thus, reference SAECG variable values were derived from a clinically normal non-Boxer control group that was screened for heart disease.

The presence of late potentials was not absolute, even in the most severely affected groups. Some dogs that died suddenly or from CHF had fewer late potentials than dogs that were otherwise clinically normal. Explanations for late potentials in an otherwise healthy individual may include technical artifacts or noise level. It is possible that the noise level chosen was too low or that spurious signals that persist in the averaging process do not necessarily represent true late potentials.[7,11] Alternatively, late potentials indicate the existence of an anatomic substrate for arrhythmia formation. However, a reentrant circuit requires additional modifiers or triggering mechanisms to induce reentry and ventricular arrhythmias.[11] As many as 4% to 6% of healthy humans have late potentials.[6,8] The absence of late potentials in otherwise affected individuals may simply reflect a decreased amplitude in potential or abnormal potentials that are buried in a baseline with too high a noise level.[6] It is also possible that the mechanism for arrhythmia formation differs between subsets of patients and that in some patients, the arrhythmias are automatic in nature and not reentrant.[6]

Despite these limitations, the conclusions of this study support the findings observed in humans with ARVC that late potentials do occur in patients with arrhythmic disease and abnormal electrical activity parallels disease severity. We also conclude that SAECG has clinical usefulness in Boxers with ARVC, and it may be necessary to determine whether different subsets of these dogs can be differentiated on the basis of late potentials.

[a]Basso C, Fox PR, Meurs KM, et al. Arrhythmogenic right ventricular cardiomyopathy causing sudden death in Boxer dogs: new animal model of human disease (abstr). *Circulation* 2002;106(suppl 2):199.
[b]Cardiocorder cassette recorder, Del Mar, Irvine, Calif.
[c]Accuplus Holter analysis system, Del Mar, Irvine, Calif.
[d]System 5, VingMed, General Electric, Fairview, Conn.
[e]Pagewriter Xli with SAECG module M1700, Hewlett Packard, Palo Alto, Calif.

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