Ambulatory electrocardiographic evaluation of the occurrence of arrhythmias in healthy Salukis

Robert A. Sanders MS, DVM

Tsumugi Anne Kurosawa DVM

Mary Dee Sist DVM

From the Department of Small Animal Clinical Sciences, College of Veterinary Medicine, Michigan State University, East Lansing, MI 48824 (Sanders); the Clinical Science and Services, Royal Veterinary College, Hatfield, Hertfordshire, AL9 7TA, England (Kurosawa); and the Michigan State University Veterinary Diagnostic Laboratory, 4125 Beaumont Rd, Lansing, MI 48910 (Sist).

Address correspondence to Dr. Sanders (ras@cvm.msu.edu).

OBJECTIVE
To determine the frequency and complexity of ventricular arrhythmias in a group of healthy Salukis evaluated by means of continuous Holter monitoring for 7 days.

DESIGN
Prospective case series.

ANIMALS
25 healthy Salukis > 18 months old.

PROCEDURES
In all dogs, a history was obtained and a physical examination and transthoracic echocardiography were performed to verify the absence of structural cardiac disease. Dogs then underwent Holter monitoring for 7 days. Data recorded included heart rate parameters and the occurrence of conduction disturbances, ventricular premature complexes, ventricular couplets, ventricular triplets, ventricular bigeminy, ventricular trigeminy, and ventricular tachycardia.

RESULTS
25 dogs (13 sexually intact females, 2 spayed females, and 10 sexually intact males) were enrolled in the study. All 25 dogs had at least one 24-hour period during which ventricular premature complexes were detected. Median number of ventricular premature complexes during any 24-hour period in all dogs was 2 (interquartile [25th to 75th percentile] range, 0 to 4). There were no significant differences between males and females in regard to median number of ventricular premature complexes per 24-hour period or recorded heart rate parameters.

CONCLUSIONS AND CLINICAL RELEVANCE
For Salukis in the study population, 7-day Holter monitoring revealed infrequent ventricular arrhythmias. These findings suggested that detection of a ventricular arrhythmia in a healthy Saluki may be an indication for further diagnostic evaluation. (*J Am Vet Med Assoc* 2018;252:966–969)

The presence of cardiac disease in Salukis was first documented by Ogburn et al[1] in 1979 in a report describing several congenital cardiac diseases in a group of 6 related Salukis. Anomalies noted included patent ductus arteriosus, pulmonic stenosis, and congenital malformation of the tricuspid and mitral valves. Since then, there has been limited scientific evaluation of the prevalence of cardiac disease in Salukis. In a 2011 summary of a survey of Saluki health conducted by the Kennel Club (the official kennel club of the United Kingdom) and British Small Animal Veterinary Association Scientific Committee, cardiac disease (16/93 [17.2%]) was the most commonly reported disease condition and was the second leading cause of death (19/132 [14.4%]).[2] Although most dogs died of unknown causes, underlying cardiomyopathy resulting in sudden cardiac death was considered possible. In 1997, researchers[3] evaluated 50 Salukis and suggested that ventricular arrhythmias were present in 10 (20%) of the dogs on the basis of a brief in-hospital ECG.

ABBREVIATIONS

IQR Interquartile (25th to 75th percentile) range

Ventricular arrhythmias are an important cause of morbidity and death in veterinary patients. In German Shepherd Dogs, Doberman Pinschers, and Boxers, ventricular arrhythmias have been reported to be the result of heritable cardiac disease, and the risk of sudden cardiac death in dogs with ventricular arrhythmias is considered to be high.[4–6] Studies[7,8] investigating the use of brief ECGs as a screening tool in Doberman Pinschers and Boxers have shown this method to have low sensitivity but high specificity to predict the development of clinically important heart disease, and evaluation by means of long-term (ie, > 24 hours) ambulatory electrocardiography or Holter monitoring in patients with even a single abnormal beat on a brief ECG is recommended.[7,8]

Currently, we are not aware of published studies evaluating the frequency and complexity of ventricular arrhythmias in overtly healthy Salukis. Therefore, the objective of the study reported here was to determine the frequency and complexity of ventricular arrhythmias in a group of healthy Salukis evaluated by means of continuous Holter monitoring for 7 days.

Materials and Methods

Case selection criteria

Overtly healthy client-owned Salukis > 18 months of age were prospectively recruited at the Michigan State University College of Veterinary Medicine for inclusion in the study over a 1-year period. Eligible dogs were screened for preexisting cardiac disease by obtaining a complete medical history (including medication history) and performing a physical examination and transthoracic echocardiography. Pedigrees were obtained in an effort to not include closely related dogs. Female dogs that were in estrus, pregnant, or lactating were excluded from the study. Standard M-mode, 2-D, and spectral Doppler echocardiography was performed by a single operator (RAS) with an ultrasonographic unit equipped with a 3.5- to 7.5-MHz phased-array transducer.[a] Measurements from each eligible dog were compared with reference values for Salukis.[b] The left atrium-to-aorta ratio was obtained by means of a 2-D method on a right parasternal short-axis view obtained at end systole. Left atrial enlargement was defined as a left atrium-to-aorta ratio > 1.6. The study protocol was approved by the Animal Care and Use Committee of Michigan State University. Written informed consent authorizing study participation was obtained from each dog owner.

7-day Holter monitoring

Study dogs underwent outpatient continuous ambulatory Holter monitoring with a 3-lead 2-channel system[c] for 7 days; owners were asked to keep a diary of their dogs' activities and events during this period. During the recording period, owners were encouraged to allow their dogs to continue normal activities while wearing the Holter monitor. Dogs did not receive treatment with any medications known to produce ventricular arrhythmias and did not receive omega-3 fatty acids supplements for at least 8 weeks prior to or during the 7-day Holter monitoring period. The Holter recordings were analyzed by use of an automated system,[d] with analyses verified by a trained cardiology research assistant (TAK) working under the guidance of a board-certified veterinary cardiologist (RAS). This verification process involved detection of ventricular premature complexes that were identified as normal complexes by the automated system and vice versa. For each dog, each 24-hour period of data was individually analyzed and only included in the study analysis if there were > 21 hours of usable data without clinically important artifacts available for the 24-hour period. Data collected included heart rate parameters (minimum, mean, and maximum heart rate and number of pauses lasting > 2 seconds) and the occurrence of conduction disturbances. The frequency of isolated ventricular premature complexes, ventricular couplets, and ventricular triplets, and episodes of ventricular tachycardia were recorded. Additionally, episodes of ventricular bigeminy and ventricular trigeminy were noted **(Appendix)**. The severity of ventricular arrhythmias during each 24-hour period was graded on a scale from 0 to 4, where grade 0 = no ventricular premature complexes; grade 1 = a single ventricular premature complex; grade 2 = bigeminy, trigeminy, or multiform ventricular premature complexes; grade 3 = ventricular couplets or triplets; and grade 4 = R-on-T phenomenon (superimposition of an ectopic beat on the T wave of a preceding beat) or ventricular tachycardia (≥ 4 consecutive ventricular premature complexes).[9]

Statistical analysis

Data were assessed for normality with the Shapiro-Wilk test. Data found to be normally distributed are reported as mean ± SD. Nonnormally distributed data are reported as median and IQR. Median number of ventricular premature complexes per 24-hour period and median minimum, median mean, and median maximum heart rate during each 24-hour period for males and females were compared with the Mann-Whitney *U* test. Values of $P < 0.05$ were considered significant. Statistical analyses were performed with a commercial software program.[e]

Results

Thirty-one client-owned Salukis were evaluated for inclusion in the study. Of these, 6 were excluded because a heart murmur was auscultated during physical examination. Twenty-five Salukis (13 sexually intact females, 2 spayed females, and 10 sexually intact males) met the study selection criteria and were enrolled. Age at the time of study inclusion ranged from 18 months to 9 years (IQR, 42 to 84 months). Body weight ranged from 15 to 30 kg (33.1 to 66.1 lb; IQR, 19.6 to 24.6 kg [43.1 to 54.1 lb]). In 4 of the 25 dogs, patient compliance issues resulted in only 5 days with > 21 hours of usable data. For each of the remaining 21 Salukis, 7 days of usable data were obtained. Thus, a total of 167 days of data were analyzed.

Median minimum heart rate of all dogs was 34 beats/min (IQR, 32 to 38 beats/min), median maximum heart rate was 160 beats/min (IQR, 149 to 173 beats/min), and median mean heart rate was 56 beats/min (IQR, 54 to 64 beats/min). Median number of pauses lasting > 2 seconds during each 24-hour period was 2,201 (IQR, 758 to 4,523), and median duration of the longest pause was 3.7 seconds (IQR, 2.9 to 4.5 seconds). There were no significant differences found between males and females with regard to median minimum heart rate ($P = 0.196$), median mean heart rate ($P = 0.196$), median maximum heart rate ($P = 0.723$), or median number of pauses lasting > 2 seconds ($P = 0.428$) during any 24-hour period. Second-degree atrioventricular block was noted during at least one 24-hour period in 8 of the 25 (32%) dogs. Ventricular escape beats (beats with a ventricular morphology that terminated a pause of > 1,500 milliseconds) were detected during at least one 24-hour period in 19 of the 25 (76%) dogs. For all dogs combined, median number of ventricular escape beats during any 24-hour period was 0 (IQR, 0 to 1.5). Three dogs had higher numbers of ventricular escape beats, with median numbers of ventricular escape beats per 24-hour period of 612, 79, and 130. Ventricular escape beats in these 3 dogs occurred as couplets, triplets, and runs of 4 consecutive ventricular escape beats with long coupling intervals. Second-degree atrioventricular block was not noted in these 3 dogs, and these dogs did not have high numbers of ventricular premature complexes.

All 25 (100%) dogs had at least one 24-hour period during which ventricular premature complexes were detected. However, ventricular arrhythmias were not consistently present during every 24-hour period, with no ventricular premature complexes detected during 61 of the 167 (37%) recording days. The frequency of ventricular premature complexes during each 24-hour period was summarized for individual dogs (**Supplementary Table S1** available at avmajournals.avma.org/doi/suppl/10.2460/javma.252.8.966). For all dogs, median number of ventricular premature complexes during any 24-hour period was 2 (IQR, 0 to 4). Three dogs (2 males and 1 female) had substantially higher numbers of ventricular premature complexes, compared with the remaining dogs. There was no significant ($P = 0.69$) difference between males and females in regard to median number of ventricular premature complexes per 24-hour period. Complex ventricular arrhythmias (eg, ventricular couplets, ventricular triplets, and ventricular tachycardia) were rare. Infrequent ventricular couplets and triplets were noted in 8 of the 25 (32%) and 2 of the 25 (8%) Salukis, respectively. Two dogs each had an isolated episode of nonsustained ventricular tachycardia. Each episode of ventricular tachycardia was brief, with one dog's episode consisting of 8 monomorphic beats (ventricular rate, 160 beats/min) and the other dog's episode consisting of 4 monomorphic beats (ventricular rate, 187 beats/min). Ventricular bigeminy was detected in 3 of the 25 (12%) dogs, and 1 episode of ventricular trigeminy was detected in 1 (4%) other dog. Median severity grade of the ventricular arrhythmias for all dogs was 1 (IQR, 0 to 2).

Discussion

For Salukis in the study population, 7-day continuous Holter monitoring revealed infrequent ventricular arrhythmias. These findings suggested that detection of a ventricular arrhythmia in a healthy Saluki may be an indication for further diagnostic evaluation.

Minimum, mean, and maximum heart rates and rhythm patterns for dogs in the present study were generally similar to those reported for other breeds of dogs.[5,9–13] However, some potentially important differences were detected. For example, second-degree atrioventricular block was detected in 8 of the 25 (32%) Salukis in the present study, compared with 20 of 138 (14.5%) research Beagles in one study[11] and 28 of 50 (56%) small-breed dogs in another.[12] Pauses lasting > 2 seconds were identified more frequently in the Salukis in the present study (23/25 [92%]) than in Beagles (63/90 [70%]),[11] and number of pauses lasting > 2 seconds during any 24-hour period (median, 2,201; IQR, 758 to 4,523) was greater for Salukis in the present study than for Cairn Terriers (mean ± SD, 712 ± 1,113 pauses), Wirehaired Dachshunds (551 ± 388 pauses), and Cavalier King Charles Spaniels (26 ± 63 pauses).[12] We suggest that the frequent occurrence of second-degree atrioventricular block and the high number of pauses lasting > 2 seconds in the dogs of the present study may represent a normal breed variant or be related to the athletic characteristics of this breed and of the individual study dogs. A 6-year study[14] of Olympic athletes with no evidence of heart disease found that atrioventricular block occurred more frequently during periods of heavy training. Additionally, in a study[15] comparing cardiac rhythm in human endurance athletes versus nonathletic controls, athletes had significantly lower minimum, mean, and maximum heart rates and higher incidences of pauses lasting > 2 seconds and first- and second-degree atrioventricular block.

Results of the present study indicated that ventricular arrhythmias occurred infrequently in Salukis. Most (22/25 [88%]) dogs in the study population had < 20 ventricular premature complexes detected during any 24-hour period, although the remaining 3 had high numbers of ventricular premature complexes. This was similar to results of other studies[9–13] involving healthy dogs of other breeds that underwent 24-hour Holter monitoring. A study[11] of 228 Beagles reported that 49 (21%) had infrequent ventricular premature complexes (≤ 9 ventricular premature complexes during any 24-hour period).[11] However, these dogs were housed in a research facility, and it may be difficult to compare those dogs with dogs living in a household with variable daily activities. The authors of a study[9] of 50 large-breed dogs representing 13 breeds reported that 34 of 50 (68%) dogs had no ventricular premature complexes and 16 of 50 (32%) dogs had < 24 ventricular premature complexes during any 24-hour period, with a mean of 2 ventricular premature complexes per 24-hour period. In a third study[10] that included 14 dogs of various breeds, 11 (79%) had < 10 ventricular premature complexes per 24-hour period, with a mean of 8 ventricular premature complexes per 24-hour period. The remaining 3 dogs in that study had a high frequency of ventricular arrhythmias; however, 2 of these 3 dogs were Boxers, a breed known to be predisposed to development of ventricular arrhythmias.[10] Because an antemortem diagnosis of occult cardiomyopathy is challenging, it is possible that those 2 dogs were not actually healthy.

Complex ventricular arrhythmias are thought to be uncommon in healthy dogs. Previous studies[9–12] of healthy dogs reported no ventricular couplets or triplets or episodes of ventricular tachycardia during a 24-hour Holter monitoring period. Additionally, detailed information regarding the frequency of ventricular couplets and triplets and ventricular tachycardia in healthy Boxers has not been reported. However, in a study[6] of Boxers with normal ECGs, the median severity grade of ventricular arrhythmias was 0 (range, 0 to 3), suggesting that complex ventricular arrhythmias were uncommon. In the present study, complex ventricular arrhythmias were more common, with 10 of 25 (40%) Salukis having at least 1 occurrence of a ventricular couplet or triplet or episode of ventricular tachycardia during the Holter monitoring period. However, it is difficult to compare results of the present study with past investigations, for which data were acquired during a single 24-hour monitoring period. In human patients, use of 7-day versus 24-hour Holter monitoring periods has been found to increase sensitivity for detecting ventricular arrhythmias.[16] We are only aware of 1 previous published study[17] of veterinary patients that included a 7-day Holter monitoring period; however, the authors did not report de-

tailed information regarding the frequency of couplets and triplets or episodes of ventricular tachycardia.

A limitation of the present study was its small sample size, which raises concerns that dogs evaluated may not accurately represent the overall population of Salukis. Although Salukis were included in the present study only if they had no history or clinical signs suggestive of heart disease and no abnormalities detected during physical and echocardiographic examinations, some dogs could possibly have had occult cardiomyopathy or noncardiac disease (eg, neoplasia, or endocrine or metabolic disorders) that potentially produced ventricular arrhythmias. Evaluation of biomarkers, myocardial biopsy samples, and genetic testing may have been useful to identify occult cardiomyopathy, but this testing was not feasible in the present study. Two years after the initial evaluation for each dog in the present study, follow-up information was collected through telephone or email contact with the owners. There were no reports of any notable cardiovascular problems in any of the dogs. The 3 dogs with markedly higher numbers of ventricular arrhythmias were reported to be free from clinical signs of cardiac disease and to have no changes noted on physical examination or echocardiographic examination 2 years following completion of the study.

Acknowledgments

Supported by the American Kennel Club Canine Health Foundation.

Footnotes

a. Vivid 7, General Electric Medical System, Waukesha, Wis.
b. Lehtinen SM, Wiberg ME, Häggstrom J. Breed-specific reference ranges for echocardiography in Salukis (abstr). *J Vet Intern Med* 2014;29:471.
c. Lifecard CF Holter monitor, Spacelabs Health Care Inc, Snoqualmie, Wash.
d. Pathfinder Digital, Spacelabs Health Care Inc, Snoqualmie, Wash.
e. SPSS, version 20, IBM, Chicago, Ill.

References

1. Ogburn PN, Peterson M, Jeraj K. Multiple cardiac anomalies in a family of Saluki dogs. *J Am Vet Med Assoc* 1981;179:57–63.
2. The Kennel Club UK and British Small Animal Veterinary Association Scientific Committee. Summary results of the Purebred Dog Health Survey for the Saluki Breed. Jan 7, 2011. Available at: www.thekennelclub.org.uk/media/16694/saluki.pdf. Accessed Jan 13, 2015.
3. Saluki Health Research Inc. Salukis with broken hearts. Available at: www.salukihealthresearch.com/SHR_heart.html. Accessed Jan 13, 2015.
4. Moise NS, Meyers-Wallen V, Flahive WJ, et al. Inherited ventricular arrhythmias and sudden death in German Shepherd Dogs. *J Am Coll Cardiol* 1994;24:233–243.
5. Calvert CA, Jacobs GJ, Smith DD, et al. Association between results of ambulatory electrocardiography and development of cardiomyopathy during long-term follow-up of Doberman Pinschers. *J Am Vet Med Assoc* 2000;216:34–39.
6. Stern JA, Meurs KM, Spier AW, et al. Ambulatory electrocardiographic evaluation of clinically normal adult Boxers. *J Am Vet Med Assoc* 2010;236:430–433.
7. Meurs KM, Spier AW, Wright NA, et al. Comparison of in-hospital versus 24-hour ambulatory electrocardiography for detection of ventricular premature complexes in mature Boxers. *J Am Vet Med Assoc* 2001;218:222–224.
8. Wess G, Schulze A, Geraghty N, et al. Ability of a 5-minute electrocardiography (ECG) for predicting arrhythmias in Doberman Pinschers with cardiomyopathy in comparison with a 24-hour ambulatory ECG. *J Vet Intern Med* 2010;24:367–371.
9. Meurs KM, Spier AW, Wright NA, et al. Use of ambulatory electrocardiography for detection of ventricular premature complexes in healthy dogs. *J Am Vet Med Assoc* 2001;218:1291–1292.
10. Hall LW, Dunn JK, Delaney M, et al. Ambulatory electrocardiography in dogs. *Vet Rec* 1991;129:213–216.
11. Ulloa HM, Houston BJ, Altrogge DM. Arrhythmia prevalence during ambulatory electrocardiographic monitoring of Beagles. *Am J Vet Res* 1995;56:275–281.
12. Rasmussen CE, Vesterholm S, Ludvigsen TP, et al. Holter monitoring in clinically healthy Cavalier King Charles Spaniels, Wire-haired Dachshunds, and Cairn Terriers. *J Vet Intern Med* 2011;25:460–468.
13. Lamb AP, Meurs KM, Hamlin RL. Correlation of heart rate to body weight in apparently normal dogs. *J Vet Cardiol* 2010;12:107–110.
14. Meytes I, Kaplinsky E, Yahini JH, et al. Wenckebach A-V block: a frequent feature following heavy physical training. *Am Heart J* 1975;90:426–430.
15. Viitasalo MT, Kala R, Eisalo A. Ambulatory electrocardiographic recording in endurance athletes. *Br Heart J* 1982;47:213–220.
16. Pastor-Pérez FJ, Manzano-Fernandez S, Goya-Esteban R, et al. Comparison of detection of arrhythmias in patients with chronic heart failure secondary to non-ischemic versus ischemic cardiomyopathy by 1 versus 7-day Holter monitoring. *Am J Cardiol* 2010;106:677–681.
17. Spier AW, Meurs KM. Evaluation of spontaneous variability in the frequency of ventricular arrhythmias in Boxers with arrhythmogenic right ventricular cardiomyopathy. *J Am Vet Med Assoc* 2004;224:538–541.

Appendix

Definitions of heart rate parameters and conduction disturbances recorded during analysis of 7-day Holter monitor recordings from 25 healthy, client-owned Salukis.

Variable	Definition
Minimum heart rate	1-min average of the lowest sinus heart rate over a 24-h period
Mean heart rate	1-min average of the sinus heart rate over a 24-h period
Maximum heart rate	1-min average of the highest sinus heart rate over a 24-h period
Sinus pause	Interval of > 2 s between consecutive sinus complexes
Ventricular premature beat	Premature QRS complex originating at or distal to the bundle of His and not associated with a P wave
Ventricular couplet	2 consecutive ventricular premature complexes
Ventricular triplet	3 consecutive ventricular premature complexes
Ventricular tachycardia	≥ 4 consecutive ventricular premature complexes
Ventricular escape beat	A QRS complex originating at or distal to the bundle of His and preceded by a sinus pause
Ventricular bigeminy	A pattern with a ventricular premature beat as every other complex
Ventricular trigeminy	A pattern with a ventricular premature beat as every third complex