

Holter Monitoring and Cardiac Event Recording

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Introduction

The detection and characterization of transient arrhythmias is possible with continuous ambulatory electrocardiography (Holter monitoring) or cardiac event recording.^{18,19} These techniques have significantly increased our appreciation of transient arrhythmias, often undetected with routine electrocardiography, and have provided highly sensitive means to assess need and efficacy of antiarrhythmic therapy. Correlation of heart rate and arrhythmia with the patient's activity or clinical signs is also possible. The role of Holter monitoring in the diagnosis of occult cardiomyopathy, particularly of Doberman pinschers and boxers, has been recently recognized. Studies using long-term electrocardiography in human patients with heart disease have demonstrated the incidence of serious arrhythmias to be much greater than previously determined with routine electrocardiography. Similar results are likely for our patients. The cardiac event recorder has been demonstrated to be a valuable diagnostic tool in the evaluation of humans and animals with a history of syncope. In this article, the clinical use of the Holter monitor and cardiac event recorder will be discussed. Data regarding the utility of Holter monitoring in the diagnosis of occult cardiomyopathy and cardiac event recording in the evaluation of animals presented with syncope will also be provided.

Holter Monitoring

Routine electrocardiography is commonly performed in veterinary medicine to assess patients for the presence of cardiac arrhythmias. This technique is quite reliable when arrhythmias are sustained or very frequent, however transient arrhythmias are often not present at the time of the electrocardiogram and are therefore not detected. This limitation is quite apparent when one considers that a 2 minute rhythm strip comprises only 0.14% of the daily electrocardiographic activity. Other factors confound the use of routine electrocardiography in arrhythmia diagnosis. Most animal (and human) patients subjected to a hospital visit and routine electrocardiography experience elevations in sympathetic tone which may

significantly increase heart rate and alter rhythm.²¹ Routine electrocardiography in a veterinary practice has been demonstrated to increase the heart rate of normal cats 54% (from 118 to 182 bpm) compared to rates determined at home.¹² Patient restraint necessary in performing routine electrocardiography may also preclude development of arrhythmias associated with exertion or arrhythmias occurring with elevated parasympathetic tone. Routine electrocardiography may fail to document arrhythmias occurring in a circadian rhythm. A distinct circadian rhythm of arrhythmia has been demonstrated in boxers with cardiomyopathy¹⁰ (**Figure 1**) and in humans with various cardiovascular disorders.^{17,23} Arrhythmias not detected by routine electrocardiography may be of significant importance. Sudden cardiac death secondary to a lethal arrhythmia often occurs in animals previously “cleared” with routine electrocardiography. Transient ventricular arrhythmias are a hallmark feature of occult cardiomyopathy in dogs, particularly boxers and Doberman pinschers. In dogs and cats with heart disease, routine electrocardiography, in most cases, will underestimate arrhythmia frequency and severity.⁹ This may result in inappropriate antiarrhythmic therapy potentially impacting control of clinical signs and mortality.

In the late 1950's, Dr. Norman Holter devised a system capable of long-term continuous electrocardiographic monitoring to overcome the limitations of routine electrocardiography.¹³ Since that time, “Holter” monitoring has evolved significantly. Recorders are now cassette or mini-cassette and capable of multi-channel, high-fidelity recording over a 24 hour period. Microprocessors and algorithms have been advanced to determine several electrocardiographic parameters.

To perform Holter monitoring, 2-3 channels of modified chest leads are recorded using adhesive patch electrodes attached to a recorder with a cassette or mini-cassette. The patches, lead wires and recorder are then secured using a chest wrap or harness. In most cases, Holter monitoring is performed over a continuous 24 hour period during which the patient engages in routine activity (except swimming). At the conclusion of the recording period, the cassette is processed (analog to digital conversion) using a microprocessor and information converted to waveforms and analyzed by computer algorithms.

Indications for Holter monitoring are listed in **Table 1**.

Technical considerations

Recorders.

Most Holter recorders used today are cassette or mini-cassette capable of simultaneous three channel acquisition (**Figure 2**). Reel-to-reel tape recorders are seldom used. Recorders utilize a motor capable of advancing tape precisely at 1 mm per second throughout the 24 hour recording period. These recorders also have a patient event button, automatic calibrator and carrying case. Power is supplied by a 9-volt disposable battery.

Patient hook-up.

In most cases, 2 or 3 channels (leads) of electrocardiographic activity are recorded. Bipolar leads are used consisting of one exploring electrode and one reference electrode. A ground electrode is also used. A total of 5 electrodes are needed to record 2 channels, 7 to record 3 channels. Electrodes may be placed in an X, Y, and Z configuration or a precordial (V1, V3 and V5) configuration (**Figure 3**). The former is preferred when signal averaged electrocardiography is to be performed, the latter may define P waves better.¹⁹ Patient preparation is critical to obtain diagnostic studies and reduce artifact. At each electrode site, hair is shaved and the skin cleaned and dried. The author prefers to attach leads to the electrodes prior to applying electrodes to the patient. Applying pressure to each electrode for 30-60 seconds will help secure attachment. A chest wrap is then used to cover the electrodes and lead wires and to incorporate the recorder within the carrying case. The recorder is secured over the dorsum, just caudal to the scapulae. Bandaging should not interfere with respiration or use of the patient event button. In small dogs and cats, the recorder may be secured to a cage door during the recording. In cats, a vertical strip of hair may be clipped on either side of the precordium as well as a ventral connecting strip with minimal Elasticon used.²⁵

The recording period.

If possible, the patient should return home during the recording and resume routine activity. The stress or inactivity of hospitalization may significantly alter arrhythmia frequency. Owners should complete a diary during the recording noting any clinical signs and significant changes in activity, such as sleeping or running. This is needed to correlate arrhythmias or changes in heart rate with patient activity. The duration of Holter monitoring is generally 24 hours, although 48 hour recording periods may be achieved with a second tape. A 24 hour recording period is considered minimum to allow assessment of arrhythmias occurring in a diurnal pattern.

Analysis of the recording.

At the conclusion of the recording period, the tape is analyzed using a scanning system consisting of an analog to digital converter, microprocessor, and specialized software (**Figure 2B**). Most systems are capable of fully-automated analysis, although this usually results in a high degree of artifact and incorrect classification of beats when canine or feline tapes are analyzed. To reduce error, extensive operator involvement is needed. Holter reports generated from services using fully automated interpretation are often highly erroneous. Significant problems in the analysis of veterinary Holter recordings include the occurrence of sudden patient movement which may be classified as ventricular ectopy and the presence of sinus arrhythmia which is not accepted as normal (classified as supraventricular ectopy) by software algorithms designed for human medicine. Analysis of 2-3 simultaneous leads is recommended as this facilitates the operator's ability to discern artifact from arrhythmia. Careful analysis of a tape may take as long as 2 hours when frequent arrhythmia is present. Familiarity with the quality control and veterinary experience of the operator as well as review of the full disclosure printout (all complexes printed, usually one hour per page) is crucial for veterinarians making diagnostic or therapeutic decisions using Holter monitoring. With Holter monitoring being increasingly used to screen apparently healthy dogs for occult cardiomyopathy (e.g. pre-breeding examination, basis for DNA evaluation), it is critical that ventricular ectopy not be missed and that artifact not be mistaken as arrhythmia.

Several electrocardiographic parameters are provided in the typical Holter report (**Table 2**). Data detailing number of normal and abnormal beats as well as graphs of heart rate and ectopy over time are provided. A full disclosure should be provided with the report. It is often helpful to have a veterinary cardiologist provide an interpretation of the findings. It is not abnormal for a normal dog's heart rate to drop below 40 bpm or for there to be frequent pauses of up to 3.0 to 3.5 seconds in duration during sleep. Conversely, the heart rate of a healthy athletic dog may exceed 250 bpm during strenuous exertion. Geriatric dogs may have a higher incidence of ventricular premature complexes associated with aging rather than primary heart disease. In humans, up to 240 ventricular premature complexes per day is accepted as normal and this number increases with age. Similar data for the dog and cat is not available, although in one report, ventricular ectopy was found in 26% of a colony of normal beagle dogs undergoing Holter monitoring.²⁴ In the author's and other's experience, ventricular premature complexes or other ventricular ectopy are rare in young to middle-aged dogs without cardiac or systemic disease.¹⁴

Clinical Use of the Holter Monitor

Holter monitoring may be used to screen asymptomatic dogs for arrhythmias suggestive of occult cardiomyopathy (**Figure 4**). The occurrence of ventricular ectopy, in the absence of non-cardiac disease, has been demonstrated to be a reliable marker for occult dilated cardiomyopathy in Doberman pinschers and significantly precedes any clinical signs of heart disease.³⁻⁴ Transient ventricular arrhythmias, often not detected with routine electrocardiography, have also been documented in boxers from several families affected with familial boxer cardiomyopathy.^{8,10} Investigation of familial boxer cardiomyopathy has demonstrated ventricular premature complexes in boxers as young as 6 months old and ventricular ectopy has been demonstrated to precede clinical signs by 3-4 years.^{8,10} In Doberman pinschers with no overt clinical signs of heart disease, Holter monitoring demonstrated the occurrence of over 100 ventricular premature complexes (VPCs) per 24 hour period in 81% of the cases that went on to

develop overt dilated cardiomyopathy or sudden death.³ In a group of normal Doberman pinschers, 65% had no ventricular ectopy and 35% had less than 50 VPCs per 24 hour period.³ Owners and breeders of dogs predisposed to cardiomyopathy are increasingly seeking Holter monitoring as a means of screening their dogs. Guidelines reported for interpretation of Holter recordings from Doberman pinschers are listed in Table 3. In the author's experience, similar results have been noted for boxers screened for boxer cardiomyopathy. Holter monitoring has also been instrumental in characterizing a syndrome of sudden death in young German shepherds.²⁰ The arrhythmia causing sudden death in a Doberman pinscher with cardiomyopathy has been documented with Holter monitoring.²²

Ventricular arrhythmia grading and quantification is also clinically important in dogs with overt dilated cardiomyopathy. The presence of high grade ventricular ectopy (ventricular tachycardia) and myocardial systolic dysfunction is a significant risk factor for sudden death in humans and dogs with cardiomyopathy. Severe ventricular arrhythmias including ventricular tachycardia (**Figure 5**) have been documented in a cat with hypertrophic cardiomyopathy and a normal resting electrocardiogram.¹¹

Holter monitoring has been used to define ventricular arrhythmias in dogs with subaortic stenosis.¹⁵ These dogs are predisposed to sudden death, presumably from lethal ventricular arrhythmias associated with left ventricular hypertrophy. Severity of ventricular ectopy tends to correlate with the degree of left ventricular hypertrophy and outflow obstruction.¹⁵ ST changes suggestive of myocardial ischemia have also been documented using Holter monitoring.¹⁵

Holter monitoring has also been demonstrated to aid in the recognition of serious arrhythmias in dogs with non-cardiac disease. In a case series of 50 dogs with splenic disease (splenic masses, torsion of the splenic pedicle or immune-mediated disease) a high incidence (22 of 50) of rapid ventricular tachycardia was documented with Holter monitoring.¹⁶ Results also demonstrated a relative insensitivity of routine electrocardiographic monitoring (rhythm strip every 6 hours) compared to Holter monitoring. Routine electrocardiography was normal in 29% (4 of 14) of dogs with rapid ventricular tachycardia at > 3,000

ventricular extrasystoles (VE)/hr; 50% (4 of 8) of dogs with rapid ventricular tachycardia at 1,000 to 3,000 VE/hr and 100% (6 of 6) of dogs with 10 to 300 VE/hr without rapid ventricular tachycardia. The authors concluded that periodic rhythm strips were unreliable for detection of ventricular arrhythmias even when frequent ventricular arrhythmia were present.¹⁶

Holter monitoring is also capable of quantifying supraventricular (SV) arrhythmias although this may be a challenge using algorithms designed for human studies which do not accept pronounced sinus arrhythmia as a normal finding. Adjustment of prematurity indices minimum supraventricular tachycardia rate are warranted for each tape analyzed. Atrial fibrillation is detected by most Holter systems today, although aberrantly conducted impulses will be classified as ventricular ectopy. Parameters of supraventricular arrhythmia include total number of SV complexes, couplets and runs of SV tachycardia. Length (number of complexes) and maximum rate of SV tachycardia runs are reported. Serious SV arrhythmia is present in dogs and cats with heart disease causing marked left atrial enlargement such as advanced degenerative valve disease, dilated cardiomyopathy and hypertrophic cardiomyopathy. SV arrhythmia may also exist in animals with non-cardiac disease and digoxin toxicity.

Episodes of sinus arrest and atrioventricular nodal block (second and third degree) may also be documented with Holter monitoring (**Figure 6**). Syncope in some Doberman pinschers has been demonstrated to be secondary to exercise-associated bradycardia or sinus arrest rather than paroxysmal ventricular tachycardia. In two of these cases, use of ventricular antiarrhythmic agents increased frequency of syncope presumably by decreasing sinoatrial nodal function.⁵

Response to antiarrhythmic therapy. Holter monitoring is an ideal means of assessing efficacy of antiarrhythmic therapy. This may involve determining the reduction of supraventricular or ventricular ectopy or the effect of ventricular response rate in cases with atrial fibrillation. In general, a 70% reduction in ectopy is required to distinguish normal variability from drug effect.

Calvert et al recently reported the use of Holter monitoring to assess antiarrhythmic efficacy of tocainide in Doberman pinschers with dilated cardiomyopathy. This study demonstrated reduction of total ventricular ectopy by at least 70% in 80% of the dogs treated. ventricular tachycardia was eliminated in 90% of affected dogs by the time of the first Holter evaluation.⁶

When Holter monitoring is used to assess antiarrhythmic efficacy, sufficient time must be allowed to permit steady state of the antiarrhythmic agent (at least 5 half lives). Holter monitoring has been used to assess pacemaker function in the dog. This is particularly relevant when activity-sensing, rate-regulating pacemakers are used.⁷

Cardiac Event Recording

The cardiac event recorder is an ambulatory microprocessor with a solid-state memory loop capable of recording and storing a single channel electrocardiogram at the time of clinical signs. This unit was designed by Davies and the first report of its use was published in 1987.² The cardiac event recorder is lightweight (100 gm), activated by the owner or other witnessing the event (usually episodic weakness or syncope) and may be worn by small dogs and cats without restricting activity (**Figure 7A**). Unlike the 24 hour Holter monitor, the cardiac event recorder may be worn for one week increasing the diagnostic yield in animals with clinical signs secondary to episodic arrhythmias. Cardiac event recording is ideal in the evaluation of a dog or cat presented with episodic weakness or syncope thought to be secondary to a cardiac arrhythmia. The author uses the King of Hearts Express^{®a} cardiac event recorder which may be programmed to store up to five single channel electrocardiograms. When activated (by pressing the event button), the cardiac event recorder utilizes a memory loop to store the electrocardiogram recorded 30 seconds *before* activation to 30 seconds after activation. These times may be changed by the operator as needed. After one or more events, the cardiac event recorder is detached and the electrocardiogram transmitted transtelephonically to a receiving station for printout and interpretation.

The cardiac event recorder utilizes two adhesive electrodes placed in a base-apex configuration and is relatively easy to apply (**Figure 7B**). A light chest wrap is used to secure the unit over the dorsum. As with Holter monitoring, the animal may be discharged to resume routine activity. A diary is used by the owner to record the clinical signs and the time of their occurrence. The cardiac event recorder will not store an electrocardiogram unless the activation button is pressed, therefore the event (clinical sign) must be witnessed. This has not been a significant limitation in the dog as witnessed syncope or episodic weakness is a feature of all cases. If an event does not occur during the week that the unit is worn, a definitive diagnosis is not possible. Borde evaluated the use of cardiac event recording in 22 dogs presented with a history of recent syncope and a routine electrocardiogram demonstrating no significant abnormalities. When worn for a maximum of one week, the cardiac event recorder yielded diagnostic information in 56% of these cases.¹ The cardiac event recorder is particularly useful in small breed dogs and cats which are encumbered by a Holter monitor and in patients with a history of frequent syncope (> once/week). In addition, results are typically available as soon as the cardiac event recorder is removed and the electrocardiogram transmitted as opposed to a several day delay for Holter monitoring. The cardiac event recorder may be rented from a commercial service (**Table 4**) or the case may be referred to a specialty practice offering this service.

Arrhythmias causing syncope or episodic weakness detected by cardiac event recording are usually bradyarrhythmias (sinus arrest, sinus bradycardia) although tachyarrhythmias have also been demonstrated (**Figures 8-10**).¹

The cardiac event recorder is event-driven and is not suitable for screening asymptomatic dogs or cats for arrhythmias or for determining the efficacy of antiarrhythmic therapy. A comparison of cardiac event recording and Holter monitoring is provided in **Table 5**.

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