As their role expands, veterinary technicians are required to perform more diagnostic tests. In addition to assisting veterinarians, technicians often have primary responsibility for performing tests and reporting the results to a veterinarian. Technicians need to ensure that these tests are performed proficiently and provide data of a quality that veterinarians can rely on to make proper diagnoses.

This article can help improve technicians’ skills in obtaining and interpreting electrocardiograms (ECGs). Technicians should be able to identify artifacts and correct them, obtain ECGs of diagnostic quality, and locate and identify common arrhythmias on ECGs.

The Basics
An ECG is a recording of the electric activity of the heart. The P-QRS-T complex represents the depolarization and repolarization of both atria and ventricles. The P wave represents atrial depolarization, the QRS complex represents ventricular depolarization, and the T wave signifies ventricular repolarization. An ECG allows clinicians to identify arrhythmias, calculate heart rate, and to some extent, estimate heart chamber size. Continuous ECGs are used for postsurgical or long-term monitoring of the heart rate and rhythm or for monitoring patients at risk of developing arrhythmias. In addition, the effectiveness of antiarrhythmic drug therapy can be monitored with 24-hour (Holter) or continuous ECGs.

ECGs are requested for many reasons (BOX 1). When a patient has an audible arrhythmia or what seems to be an inappropriate heart rate on auscultation, a baseline ECG is useful. However, ECGs are also obtained for preanesthesia work-ups, monitoring during anesthesia and after surgery, trauma and shock management, and evaluation of certain metabolic diseases, drug toxicosis, syncope (fainting spells), and seizures. ECGs are also helpful in determining the effectiveness of antiarrhythmic therapy.

A standard six-lead ECG tracing records leads I, II, and III; aVR; aVL; and aVF. Leads I, II, and III are bipolar standard limb leads. aVR, aVL, and aVF are unipolar limb leads that are part of the four limb leads (TABLE 1). The cables (leads) are usually color coded and labeled using human medical terminology indicating where to attach them to the patient (TABLE 1).

Before using an ECG machine, familiarize yourself with it. In the owner’s manual, read about all the functions that the machine offers. Know where the power switch is, how to replace the paper supply, how to make adjustments if artifacts are present, and how to change the sizes of the complexes to facilitate interpretation. Technicians should be able to change the paper speed and the gain, adjust the filter, and record all the leads or only specific ones. Most
new machines simultaneously record all six leads, but many older machines require the operator to switch from lead to lead.

Paper speed is usually set at 25 or 50 mm/sec. The faster the paper speed, the easier it is to measure and evaluate each complex. The lead II rhythm strip may be recorded at 50 or 25 mm/sec. A slower speed increases the number of complexes on the paper, allowing better comparison between heartbeats. Adjusting the filter helps minimize high-frequency artifacts created by patient trembling or purring, but such adjustments decrease the amount of high-frequency information available in the QRS complex and may affect overall QRS voltage in some circumstances. Feline ECGs are often harder to evaluate because the complexes are smaller and P waves may be almost nonexistent. Increasing the ECG gain setting, which determines how large the complexes appear for each mV of voltage input, can make these small complexes larger, allowing easier ECG interpretation. The standard gain setting is 1 cm = 1 mV; adjustment can be made in both directions (e.g., the gain can be increased to 2 cm = 1 mV for patients with low-amplitude complexes or decreased to ½ cm = 1 mV for patients with high-amplitude complexes that are too large for the ECG paper at the standard calibration).

Preparation

To obtain an ECG, position the patient in right lateral recumbency (FIGURE 1). To help minimize artifacts and increase comfort, the table on which the patient lies should be covered with a thick towel or rubber mat. Laying the patient directly on a stainless-steel tabletop increases the possibility of electric artifacts. With the patient in lateral recumbency, extend the front and rear legs away from the patient’s body and parallel to each other. If the electrodes are attached too close to the chest or the legs remain flexed (folded against the body), increased respiratory motion artifact may result. The cables (leads) are attached as indicated in TABLE 1. The LA and RA leads are ideally placed below the left and right elbows, respectively, where the skin is thin and loose (the legs are essentially volume conductors for the torso, so the exact location of the leads on the limbs is unimportant; the leads should simply be placed to minimize all motion artifacts). The rear leads (RL and LL) are ideally placed below the stifles. A small amount of electrode gel (ideally) or alcohol must be applied to each electrode unless disposable gel electrodes are used. To minimize respiratory motion artifacts, ensure that the leads are not lying against the patient’s chest wall. The person restraining the patient should avoid touching the electrodes because motion artifacts can be easily caused.

If a patient is stressed, dyspneic, or too large to place on the table, an ECG can be recorded with the patient in sternal recumbency or a standing position. Irregularities such as abnormal heart rhythm or rate can be identified on an ECG with the patient in any position, but measurement of waveforms (complexes) is more accurate with patients in right lateral recumbency. If the patient becomes less stressed and can be placed in lateral recumbency, another ECG can be obtained for a better tracing.

Identifying Artifacts

Technicians should be able to identify three common artifacts (i.e., respiratory, other movement, and electric artifacts), which are usually easy to resolve.

Respiratory artifacts, which appear as a wandering or uneven baseline correlating with the patient’s breathing, are caused by patient panting, respirations (deep), dyspnea, or purring (FIGURE 2). Calming the patient and applying gentle chest pressure may help resolve these artifacts. If panting is the problem, hold the patient’s mouth closed for a few seconds or blow on the patient’s nose. With dyspneic patients, technicians may have to accept a wandering baseline or wait until the patient is more stable.

Patient movement (e.g., shaking, trembling, twitching) artifacts are best resolved by having an extra person help calm or distract the patient so that it stops moving.

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**TABLE 1  Lead Placement**

<table>
<thead>
<tr>
<th>Limb Placement</th>
<th>Color</th>
<th>Human Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right front leg</td>
<td>White</td>
<td>RA (right arm)</td>
</tr>
<tr>
<td>Left front leg</td>
<td>Black</td>
<td>LA (left arm)</td>
</tr>
<tr>
<td>Right rear leg</td>
<td>Green</td>
<td>RL (right leg)</td>
</tr>
<tr>
<td>Left rear leg</td>
<td>Red</td>
<td>LL (left leg)</td>
</tr>
</tbody>
</table>
Movement artifacts change the baseline only when the patient moves. For example, the baseline may be clean and flat as it should be until the patient trembles, which can make the baseline uneven. Movement may be difficult to control while a patient is standing; it is hard to keep a standing patient from moving its feet. If trembling is causing the movement, roll up a small towel and place it between the patient’s legs; this often allows the cable leads to avoid direct contact with moving (trembling) legs and muscles and helps create a better tracing.

Electric (60 Hz) artifacts appear as a "saw-toothed" jagged baseline (FIGURE 3). This can be minimized by placing a rubber mat under the patient, rewetting the leads to ensure proper contact, and ensuring that no one is touching the leads. Electric equipment (e.g., clippers, fans) plugged into the same circuit as the ECG machine should be turned off. If this does not help, try moving the ECG machine to another room or having another person help restrain the patient. Sometimes, a person unknowingly discharges static electricity, interfering with the machine.

Understanding Electric Impulses and Complexes

Before evaluating an ECG, it is important to know how the heart is activated electrically and what the ECG complexes signify. Normally, the first electric activity in the heart is generated in the sinoatrial (SA) node, which is located in the right atrium near the entrance of the cranial vena cava. The impulse originating from the SA node depolarizes the right and left atria in sequence, causing the P wave. The impulse continues to the atrioventricular (AV) node, where the conduction velocity slows. The electric impulse then travels out of the AV node, down the rapidly conducting bundle of His, and into the Purkinje fibers, which divide into the right and left bundle branches, rapidly distributing the electric activation impulse to the ventricles, which then depolarize from the endocardial surface to the epicardial surface. The sequence of atrial and ventricular activation is similar in dogs and cats, resulting in the typical P-QRS-T waveforms.

Knowing what each segment of the waveform represents is helpful in evaluating the ECG. Each waveform (complex) should have a P wave, QRS complex, and T wave (FIGURE 3). The P wave represents atrial depolarization. The P-R interval is the amount of time it takes from the beginning of the P wave until the first deflection of the QRS complex; it represents the time of atrial activation and conduction through the AV node. On the ECG, the P-R interval appears...
as a straight line between the beginning of the P wave and the beginning of the QRS complex. The QRS complex follows the P-R interval and signifies depolarization of the right and left ventricles. The S-T segment is the period of time from the completion of ventricular depolarization to the beginning of ventricular repolarization. The Q-T interval, measured from the first deflection of the QRS complex until the end of the T wave, represents the total amount of time it takes for depolarization and repolarization of the ventricles.

ECG paper has a standard format. For standard gain calibration, 1 cm in height equals 1 mV as recorded by the ECG. Time is measured in seconds or milliseconds on the horizontal axis. When the width of a wave, such as a P wave, is measured, the time the wave takes from beginning to end is measured in seconds. Most ECG paper has heavy and fine gridlines. At a paper speed of 50 mm/sec, each box created by heavy gridlines represents 0.1 second along the horizontal axis, and each box created by fine gridlines represents 0.02 second along the horizontal axis (FIGURE 3). This is important to remember when calculating heart rate. The fine gridlines create 25 boxes within the heavy gridlines. At standard gain calibration (1 cm = 1 mV), each fine-gridline box represents 0.1 mV on the vertical axis. Each heavy-gridline box represents 0.5 mV (1 mV = 1 cm) on the vertical axis.²

**Evaluation**

To evaluate an ECG, answer the following questions: Is the heart rate normal for the environmental circumstance and species? Is the heart rhythm regular? Are P waves present? If so, are they uniform? Is there a P wave in front of every QRS complex at a reasonable P-R interval? Is there a QRS complex for every P wave? Are the P-R intervals uniform? Are the QRS complexes uniform and of a normal duration? If all of these criteria are met, the rhythm is probably sinus. A normal sinus rhythm usually shows little variation between waveforms, but there are a few exceptions. A sinus arrhythmia shows cyclic variation with respiration (FIGURE 4). As the patient inhales, its heart rate increases; as the patient exhales, its heart rate decreases. A patient with a wandering pacemaker may show variation in the P-R interval and the P-wave morphology. The P waves may become notched or flat or have a negative or biphasic deflection. Wandering pacemakers and sinus arrhythmia are found in many healthy patients and generally require no medical treatment.

**Heart Rate**

Heart rate can be manually calculated by various methods. The easiest method to understand and perform, once the paper speed is known, to determine how many P–QRS–T wave complexes occur in either 6 seconds (then multiply that number by 10 to get the heart rate per minute) or in 3 seconds (then multiply that number by 20). The following two methods are also reliable and frequently used:

- **The 1500 or 3000 method** is very useful and accurate for calculating regular rhythms. At a paper speed of 50 mm/sec, there are 3000 fine-gridline boxes/min. For two complexes, count the fine-gridline boxes between two R waves, and divide 3000 by the result. At a paper speed of 25 mm/sec, there are 1500 fine-gridline boxes/min. For two complexes, count the fine-gridline boxes between two R waves, and divide 1500 by the result.

- **The 10 or 20 method** uses hash marks visible at the edge of the paper. At a paper speed of 50 mm/sec, one hash mark to the next represents 1.5 seconds. To calculate the heart rate at this speed, count all the complexes for 3 seconds (within three hash marks) and multiply the result by 20. At a paper speed of 25 mm/sec, one hash mark to the next represents 3 seconds.
To calculate the heart rate at this speed, count all the complexes for 6 seconds (within three hash marks) and multiply the result by 10. The 10 or 20 method helps to determine heart rates when P waves are not consistently present with QRS waves.¹

Cats and dogs that are stressed by being in a clinic can have high heart rates that decrease in a familiar environment.¹

**Arrhythmia**

If the heart rhythm looks abnormal (e.g., too fast, slow, or irregular), determine what is wrong. Normal sinus rhythm rates are 60 to 160 per minute in most dogs and 140 to 220 per minute in cats. Heart rates above these limits are classified as tachycardia; heart rates below these limits are classified as bradycardia. Are there P waves without subsequent QRS complexes? Are there QRS complexes that appear out of line or too early? Is there a long pause without a QRS complex? Does the whole tracing look strange? Are you sure this is not due to an artifact?

**Ventricular Premature Complexes**

Ventricular premature complexes (VPCs) are common arrhythmias (FIGURE 5). VPCs indicate that an electric impulse originated in the ventricle, before the next “normal” complex was expected. On the ECG, a VPC appears as a QRS complex that is wider and appears different than normal QRS complexes. In most instances, VPCs do not have associated P waves. VPCs can be present for multiple reasons. VPCs can be caused by stress, splenic disease, cardiac disease, infections that irritate the heart muscle, trauma, and unknown causes. VPCs can originate in the right or left ventricle and can appear as a single deflection or in pairs called *couplets*. VPCs occurring in a pattern of three or more in a row are called *ventricular tachycardia* (*v-tach*; FIGURE 6). *V-tach* can be a medical emergency if it is sustained (>30 seconds without a normal sinus complex). In this situation, cardiac efficiency and output usually decrease dramatically and an antiarrhythmic medication such as lidocaine must be injected to try to convert this abnormal rhythm back to sinus rhythm.²

**Heart Block**

Heart block is described as an impediment to conduction between the atria and ventricles. There are three basic forms of heart block. Evaluation of the P wave and QRS complex helps determine whether heart block is present.
First-degree heart block (first-degree AV block) is indicated by a longer-than-normal P-R interval (FIGURE 7). When the P-R interval is >0.13 seconds (in dogs), first-degree heart block is present. This finding generally needs no medical treatment but may be a sign of a drug effect (e.g., due to digoxin or β-adrenergic blockade).

Second-degree heart block (second-degree AV block) is often subdivided into Mobitz type I and Mobitz type II (FIGURE 8). In Mobitz type I, the P-R interval is variable, often is progressively prolonging before the blocked QRS complex. In Mobitz type II, the P-R interval is fixed, leading to the blocked QRS complex. In both cases, the key finding is P waves without an ensuing QRS complex. There is a concern that Mobitz type II can develop into third-degree heart block. Low-grade (i.e., infrequent) Mobitz type I is rarely a serious clinical problem and is a normal finding in some animals with marked sinus arrhythmia.

Third-degree heart block (third-degree AV block) is usually a medical emergency, often requiring implantation of a pacemaker. On an ECG, third-degree heart block appears as many P waves with no regularly associated QRS complexes. The P waves occur at their own rate, meaning that they are independent of the ventricular rate, which is much slower than the atrial rate. The atrial and ventricular rates need to be measured. It is not uncommon for an affected patient to have bradycardia with a heart rate of ≤40 bpm. Third-degree heart block is usually due to disease of the AV node, which prevents proper conduction to the electric impulse from the atria to the ventricles.²

Atrial Fibrillation
Atrial fibrillation is a rapid, irregular heart rhythm in which
the atria are constantly and chaotically being depolarized by abnormal electric impulses that do not originate in the sinus node (FIGURE 9). Certain giant-breed dogs, such as Great Danes and Irish wolfhounds, are prone to atrial fibrillation, which can cause tachycardia (ventricular response rates usually ≥160 bpm) and affect cardiac performance. ECG characteristics of atrial fibrillation are a lack of P waves (fine, undulating waves called F waves may be visible in the ECG baseline) and a rapid heart rate with QRS complexes that are irregularly irregular (i.e., irregular variation between R waves). Atrial fibrillation can be treated with medications that reduce conduction velocity in the AV node to slow the ventricular response to the fibrillating atria and improve cardiac output. If untreated, atrial fibrillation can lead to heart failure.2

**Conclusion**

The ECG is an essential part of veterinary medicine that can be used in various areas of a hospital. Technicians can strengthen the veterinary team by knowing how to obtain and interpret ECGs and alerting the veterinarian to medical emergencies.

**References**

Article #1 FREE CE Test
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1. Which type of heart block results in independent atrial and ventricular heart rates?
   a. third-degree heart block
   b. first-degree heart block
   c. second-degree heart block, Mobitz type II
   d. atrial fibrillation

2. Which artifact can be caused by panting?
   a. electric interference
   b. a wandering baseline
   c. tachycardia
   d. a wandering pacemaker

3. At a paper speed of 50 mm/sec, a technician counts 20 small boxes between the R-R intervals. If the 1500 or 3000 method is used, the patient’s heart rate is ____ bpm.
   a. 300  
   b. 200  
   c. 150  
   d. 120

4. Proper patient positioning for a standard six-lead ECG tracing is
   a. right lateral recumbency with the limbs outstretched.
   b. left lateral recumbency with the limbs outstretched.
   c. right lateral recumbency with only the front limbs outstretched.
   d. right lateral recumbency with the limbs in a relaxed position.

5. Which of the following is least in need of continuous ECG monitoring?
   a. splenectomy
   b. arrhythmia
   c. monitoring the efficacy of lidocaine treatment in a patient with v-tach
   d. murmur evaluation

6. An ECG that does not show a QRS complex for every P wave indicates that
   a. atrial fibrillation is present.
   b. the electrodes were poorly grounded.
   c. an AV block is present.
   d. bradycardia is present.

7. An ECG with a paper speed of 25 mm/sec was obtained for a puppy, revealing a heart rate of 150 bpm. Using the 10 or 20 method, how many complexes were counted in 6 seconds?
   a. 10
   b. 15
   c. 20
   d. 30

8. Which part of the waveform represents a delay in electric activity at the AV node to allow proper atrial contraction and ventricular filling?
   a. the P wave
   b. the S-T segment
   c. the Q-T interval
   d. the P-R interval

9. The length of a straight line between the beginning of the P wave and the beginning of the QRS complex is
   a. the P-R interval.
   b. atrial depolarization.
   c. the atrial relaxation period.
   d. the transelectric period.

10. Located at the junction of the right atrium and the interventricular septum, the ________ allow(s) (1) electric conduction to slow and (2) proper filling of both ventricles before ventricular depolarization.
    a. AV node
    b. SA node
    c. Purkinje fibers
    d. right and left bundle branches

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