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The ECG is a visual representation of the electrical activity of the heart. Electrocardiographic electrodes - called “leads” record the electrical signal at the surface of the skin. The leads can be arranged in a variety of ways to produce visual patterns (the ECG) that we use to “see” the electrical activity of the heart. Cardiologists may use up to twelve leads to completely evaluate the heart but most veterinarians in emergency and general practice only look at a one or two leads. Each arrangement produces a characteristic visual pattern. We are going to focus on the most commonly used arrangement in small animal and exotic species, called Lead-II (‘lead-two’).

The standard color coding arrangement for a 3-lead ECG (the most commonly used arrangement in veterinary medicine) consists of a white, black, and red lead. The white lead should be attached on the right thoracic limb (“right arm” or RA lead) near the elbow or on the foot, the black lead on the left thoracic limb (“left arm” or LA lead) near the elbow or on the foot, and the red lead on the left pelvic limb (“left leg” or LL lead) - but check your system because not all manufacturers follow the standard convention.

There are many catchy phrases to help you remember the correct arrangement. “White on right, smoke (black) before fire (red)” is a popular phrase.

To use the ECG, connect the leads to the patient in the proper locations using electrode coupling gel or paste. This is an electrolyte gel/paste that conducts electricity and will help you to get a “clean” ECG tracing. Ultrasound gel should not be used - it is designed to conduct sound waves, and is not a good electricity conductor. Alcohol should be avoided - it may catch fire if the patient is defibrillated. The stick-on adhesive leads need to be attached to bare skin, and in patients who are asleep can be attached to the paw pads instead of shaving the fur (you may need to use tape to lightly secure them on the paw pads). The alligator clip style attachments should not be left attached to the skin for more than a few minutes - they are painful and if the spring is tight can cause pressure necrosis of the skin where attached. Instead use stick-on pads or clips that are designed to be left in place for longer periods of time. If the patient needs to have the ECG attached for more than about an hour, stick-on pads should be used instead of clips.

The most important thing to remember is that the ECG tells us if the heart has electricity moving through it, and what direction the electricity is traveling through the heart. It does NOT mean the heart is actually beating!!! ALWAYS confirm the heart is beating by listening for a heartbeat or feeling for a pulse.

Important lead-attachment tips:

- Use coupling gel (not ultrasound gel - there is a difference)
- Get good skin contact
- If using alligator clips time should be limited, these are painful (attach them to yourself to see what it feels like), and if the clamps are strong/tight can cause crush injury and ischemic necrosis of the skin
  - Don’t use these clamps on patients with thin or fragile skin
- If using adhesive pads clip fur; can also place on paw pads in animals who are asleep; if securing with tape, don’t make the tape too tight
- Avoid alcohol as a coupling agent - will catch fire if defibrillate the patient

Troubleshooting:

- Poor skin contact - shave fur and/or add coupling gel; clean the electrodes
- Leads plugged into incorrect receptacle
- Leads attached to wrong body parts/location

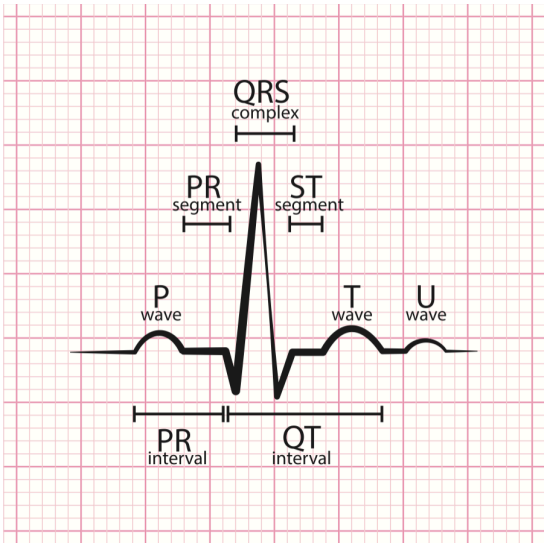
How electricity moves through the heart
The sinoatrial (SA) node it the normal pacemaker of the heart. It sends out a regular, repeating electrical impulse. The electricity spreads across the left and right atrium triggering contraction of the atria. The electrical signal reaches the atrioventricular (AV) node which causes a very slight pause before sending the signal down the Bundle of His. The Bundle of His and the left and right bundle branches are a high-speed electrical conduction system. They carry the electrical signal down into the ventricles, allowing the ventricles to squeeze in a coordinated way delivering blood to the lungs and to the body.

When this electrical system is working correctly, it results in the “normal” P-QRS-T complex on the ECG screen that we are used to seeing. Some diseases can cause disruption of this conducting system - the SA or AV node can stop working, or not work well; or the conducting system can be damaged causing the electricity to spread through the cells instead of using the high-speed conducting system. Any of these problems will cause the ECG shape to change. This shape change can help us to make a diagnosis of where the problem is in the electrical system, and guide our testing and treatments.

Reading the ECG
Reading ECGs is all about pattern recognition. The Lead II ECG should produce a characteristic pattern in a patient with normal electrophysiology that looks like the image to the right.

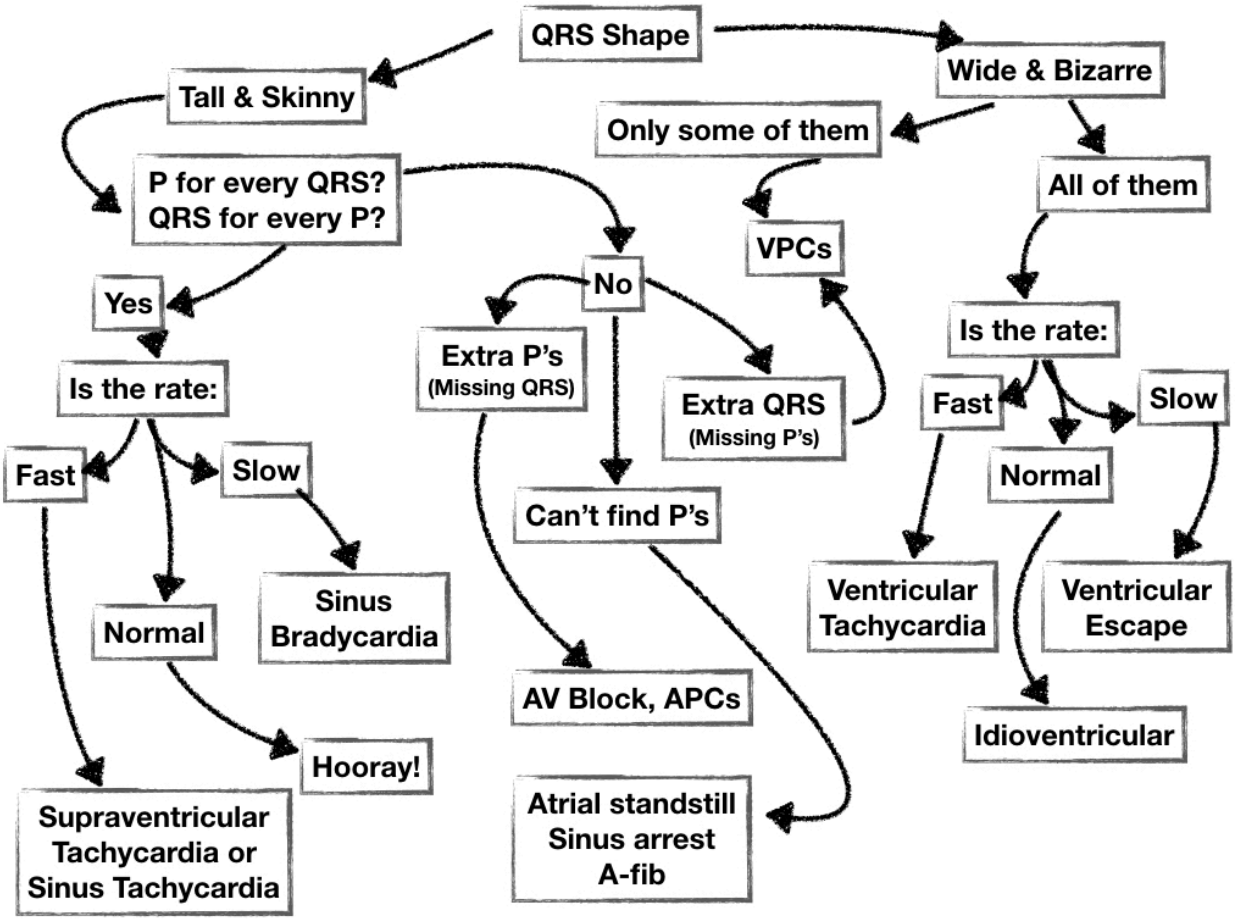
The ECG tells us about the rate and rhythm of the heart’s electrical pattern.

The main parts you will see on the devices we have in the clinic, and what we will talk about today:
P wave = atrial depolarization
QRS complex = ventricular depolarization
T wave = ventricular repolarization



Questions to ask when you look at an ECG:

1. What is the QRS shape? Is it tall and skinny, or wide and bizarre looking?
2. Do all of the QRS complexes look the same? If not, how many different shapes do you see? Two different QRS shapes, or more than two different QRS shapes?
3. If the QRS complexes are all, or mostly tall and skinny: does every QRS complex have a P wave in front of it? Does every P wave have a QRS complex after it? Is the rate fast, normal, slow, or very irregular?
4. If the QRS complexes are wide and bizarre is it all of the QRS complexes, or just some of the QRS complexes that are abnormal? Is the rate fast, slow, normal, or very irregular? Do the wide and bizarre complexes all look the same, or do they have many different shapes?



Heart Rate Guidelines for Normal Animals

Dogs		
Weight	**Heart Rate**	**Critical High**
Under 10kg	110-130	180
10-20kg	100-120	160
20-40kg	80-100	160
>40kg	60-90	160
Cats		
Any weight	160-200	240

Managing arrhythmias

There are two equally important parts to management of arrhythmias: recognizing the arrhythmia (ventricular tachycardia, sinus bradycardia, etc), and identification and management of the underlying disease process that caused the arrhythmia to develop. It is important to recognize that treating some arrhythmias with drugs before looking for and treating an underlying cause could lead to patient deterioration. For example, a dog exsanguinating from a ruptured splenic mass would be expected to develop a profound tachycardia as hemorrhage progresses. This is a normal physiologic response to hypovolemia - the body is trying to maintain cardiac output in the face of a smaller stroke volume. Treatment with an anti-arrhythmic drug to reduce heart rate in this scenario would further decrease the cardiac output and result in circulatory collapse. Instead this patient needs rapid resuscitation with blood transfusions and hemorrhage control. Alternatively, a cat with severe thyrotoxicosis may also develop a profound supraventricular tachycardia for which the appropriate treatment would be a beta-blocking drug such as atenolol. The drug recommendations that follow are made on the assumption that underlying diseases have been investigated and are being managed either concurrently, or prior to starting antiarrhythmic drugs, as appropriate to the situation.

Ventricular tachycardia (sustained ventricular arrhythmia >160/min dogs or 240/min in cats)
Concurrently treat underlying disease/causes

1. Pulse present
    a. Dogs: lidocaine 2mg/kg IV over 1 minute followed by lidocaine constant rate infusion at 50mcg/kg/min (3mg/kg/h). Breakthrough, sustained ventricular tachycardia is treated with 1mg/kg bolus of lidocaine as needed.
    b. Can go up to 80mcg/kg/min (approx. 5mg/kg/h) constant rate infusion if necessary; may cause excessive sedation, nausea at this dose
    c. Cats – lidocaine 1mg/kg IV over 1 minute followed by lidocaine constant rate infusion at 30mcg/kg/min (approx. 2mg/kg/h); max rate is 50mcg/kg/min (3mg/kg/h)
    d. Transition to oral medication for discharge:
        i. Sotalol if base heart rate is elevated once ventricular arrhythmia controlled
        ii. Mexilitene if base heart rate is normal to slow once ventricular arrhythmia controlled
2. Pulseless ventricular tachycardia – (patient will generally be unconscious in addition to the absent pulse) – electrical defibrillation

Idioventricular rhythm (sustained ventricular arrhythmia <160/min in dogs or <240/min in cats; the waveform is uniform in appearance)

1. No drugs, treat underlying causes and monitor for deterioration

Other ventricular arrhythmias

Single VPCs and short runs of ventricular tachycardia (generally lasting <1 minute) are not always treated in the emergency setting. Reasons for treating intermittent VPCs, or short runs of ventricular tachycardia:

1. Multifocal ventricular arrhythmia (the VPCs are arising from multiple areas within the ventricles, and have different shapes on the ECG)
2. R-on-T phenomenon
3. Progressive worsening/becoming more frequent

Atrial fibrillation

In dogs and cats pharmacologic and electrical therapies to terminate atrial fibrillation are usually unsuccessful. Treatment instead focuses on decreasing the number of electrical impulses passing through the AV node to the ventricles. The first-line drug for most veterinarians is diltiazem.

1. Diltiazem – 0.05mg/kg IV over 1-2 minutes. Repeat every 5 minutes up to 0.25mg/kg. Some references go as high as 0.75mg/kg – be cautious.
2. Diltiazem Oral Emergency dosing – when parenteral preparation not available: 0.5mg/kg initial dose, then 0.25mg/kg PO every hour until conversion or total dose of 2mg/kg has been given.

Supraventricular tachycardia
Ensure the patient is not in congestive heart failure and is not hypovolemic

1. Esmolol – ultra-short acting, used as a constant rate infusion. Primarily beta-1 selective
    a. Loading dose 0.25-0.5mg/kg IV over 2-5 minutes
    b. Then continued at 10-200mcg/kg/min, start low and adjust rate up every 10 minutes as needed
2. Propranolol
    a. Note that the IV dose is MUCH lower than the oral dose!!!
    b. Initial dose 0.02mg/kg IV over 2-3 minutes, titrate up every 5 minutes until desired rate decrease achieved or maximum 0.1mg/kg dose reached; can be repeated in 8 hours.
    c. Oral dosing: 0.1-0.2mg/kg PO, repeat q 60 minutes until desired rate decrease or maximum dose of 1.5mg/kg; once dose determined, administer q8h
3. Atenolol
    a. Dogs 0.25-1.5mg/kg PO q12h
    b. Cats ¼ of a 25mg tablet per cat, q12h. Some cats may need higher doses.

The slow rhythms

Slow ventricular rhythms
When a ventricular arrhythmia is identified the heart rate should be carefully assessed. Ventricular rhythms >160 (dogs) or 240 (cats) should be treated as described for ventricular tachycardia above. Rates 80-160 (dogs) or 120-240 (cats) that are classified as idioventricular rhythm (a uniform, persistent ventricular arrhythmia in this rate range) should be monitored. Very slow ventricular arrhythmias need different treatment. Do NOT give lidocaine!

1. P-waves present
    a. 3rd degree AV block – needs a pacemaker
2. P-waves absent
    a. Atrial standstill – evaluate for hyperkalemia and initiate treatment if present; then identify and treat cause of hyperkalemia

Slow sinus rhythms

1. Sinus bradycardia – consider normal for the physically fit patient, physiologic response to hypertension, vagal response, etc
    a. Treat underlying cause (reduce intracranial hypertension, manage systemic hypertension, atropine if vagal response, etc)
2. Sick sinus syndrome – needs a pacemaker

References

1. Ettinger & Feldman Textbook of Veterinary Internal Medicine, 7th ed
2. Dubin. Raid Interpretation of EKGs 6th ed
3. Macintire et al. Manual of Small Animal Emergency and Critical Care, 2nd ed