Chapter 1 Normal ECG

This chapter serves as a brief overview of how to perform an ECG, what it measures, and what a normal ECG looks like. We hope to provide a baseline of understanding that will put the rest of the book into context and set the stage for optimal ECG recording and diagnosis. Practitioners familiar with the basics of ECG recording and interpreting may wish to skip this chapter.

Before recording

Before beginning the ECG a physical examination (either a complete physical if the animal is stable or a triage physical) is performed. A triage physical exam is focused on life-threatening body systems (heart, lungs, mentation) while putting the additional non-life threatening aspects of the physical exam off until the animal is stable (e.g., rectal exam, fundic exam, and so on). Listening to the heart and lungs, feeling the pulses, evaluating perfusion (mentation, pulse strength, mucous membrane color, body temperature, etc.) are all essential components of evaluating a cardiac arrhythmia.

The stethoscope has a bell (the smaller side on a two-sided stethoscope), which picks up low frequency sounds. On a stethoscope with only one side the bell picks up low-frequency sounds with gentle pressure against the thorax. Low-frequency sounds are best for detecting a gallop rhythm (heart sounds 3 and 4). The diaphragm (larger side on a two-sided stethoscope) picks up higher frequency sounds, including murmurs and clicks. In a stethoscope with only one side the diaphragm picks up high-frequency sounds with more firm pressure against the thorax. The ear pieces are inserted into the ears facing forward and stethoscopes with smaller diaphragms (pediatric and neonate) are essential for practitioners who examine small-sized (puppy, kitten) and exotic patients.

Life-Threatening Cardiac Emergencies for the Small Animal Practitioner, First Edition. Maureen McMichael and Ryan Fries.

ECG set up

The pet is placed in right lateral recumbency on a pad or towel if they are stable. Padding the table minimizes electrical interference from the metal table. A cold table without padding may also increase artifact by causing the animal to shiver or keep changing positions in an attempt to get more comfortable. If the animal is not stable they should be allowed to remain in whatever position is most comfortable while recording the ECG.

One person should hold the animal with limbs extended (forelimbs extended toward the head and rear limbs extended toward the tail) and 70% isopropyl alcohol should be placed between the ECG clips and the animal to increase contact. When a signal is either unclear or absent additional alcohol can be added and it may need to be re-applied frequently. The traumatic alligator clips hurt (try them) and atraumatic clips (which are flat and do not pinch) should be used whenever possible. These may decrease resistance (and artifact) on the part of the animal as they are significantly more comfortable. Adhesive electrodes are best for long-term use.

Minimizing sounds and movement are essential for proper interpretation of the ECG. Respiratory sounds (holding the mouth closed in a panting, but stable animal), shivering (towel or pad under the animal), or purring (turning on tap water) should all be eliminated or minimized to the extent possible while always keeping the animal's health status uppermost in mind.

The clips are placed with the white lead (RA; right arm) on the right forelimb near the back of the triceps, the black lead (LA; left arm) on the left forelimb near the back of the triceps, the red lead (LL; left leg) on the left rear limb just proximal to the stifle on the front of the thigh, and the green lead (RL; right leg, grounding lead), if used, on the right rear limb just proximal to the stifle on the front of the thigh.

Recording the ECG

Leads allow an assessment of the electrical activity of the heart from several different angles. Each angle is called a lead. The standard ECG includes all six of the limb leads; lead I, II, III, aVR, aVL, aVF. Generally a rhythm strip is produced at the bottom of the page and is most often a longer run of lead II.

Paper speed is very important and ideally two different speeds should be used for assessment. A recording for 30–60 s, at 25 mm/s is done first. This slower speed allows more complexes on the strip and helps to assess for abnormalities in the rhythm (e.g., ventricular premature contractions, atrial premature contractions, and so on). This is followed by recording of a rhythm strip (usually lead II) at 50 mm/s for 2–3 min or longer depending on the disorder.

The standardization signal should, ideally, be set at 1 cm = 1 mV, which means that each tiny square equals 0.1 mV in height. If this standardization is changed the complexes may look very small or very tall and a misdiagnosis can occur.

What is measured

Electrical impulses move through the heart via the specialized conduction system starting at the sinoatrial node, moving to the atrioventricular node and then down the bundle of His to the Purkinje fibers. In a normal heart the muscle contracts in response to this electrical stimulus. It is important to note that the ECG only records the electrical activity of the heart and does not assess contractility. The echocardiogram is the gold standard for cardiac function and chamber enlargement. We recommend a new book in this series, *Echocardiography for the SA practitioner*, by June Boon. It is a concise manual of performing and interpreting echocardiograms in small animals.

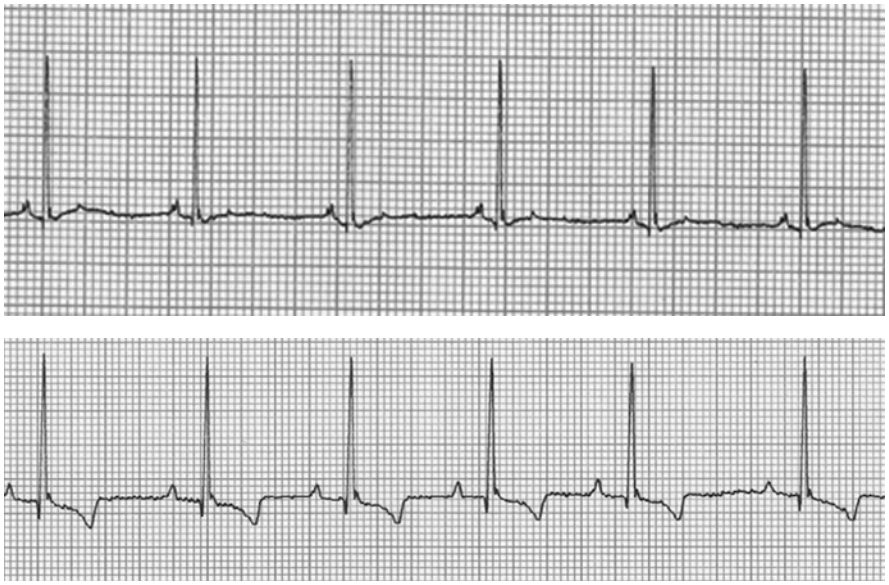
Normal ECG

The P wave represents atrial depolarization and P waves can be positive (upright), negative (downward), or biphasic. The QRS complex represents ventricular depolarization.

The Q wave is the first negative deflection following the P wave and it is followed by the R wave. The R wave is the first positive deflection after the P wave (the Q wave may not be present or visible). R waves should always be positive in lead I. The leads should be checked for position on the patient if this is not the case. The S wave is the negative deflection that follows the R wave. The T wave represents ventricular repolarization (relaxation) and T waves can be positive (upright), negative (downward), or biphasic. Not all of these waves must be present in an ECG but every R wave must be followed by a T wave. This is helpful when trying to decide which wave is present between two R waves—if there is truly only one it must be a T wave.

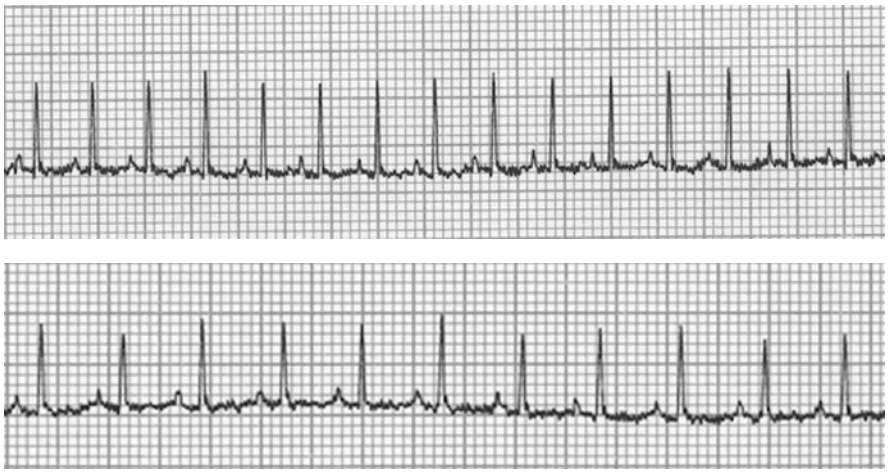
Calculating the heart rate

There are several ways to calculate the heart rate. We will only describe two here. More can be found in resources in the "Further reading" section. The number of R-R intervals between two sets of marks can be counted. These are the tick marks at the top of the ECG paper. This equates to 3 seconds if the paper speed is 50 mm/s. This number (the number of R-R intervals between the tick marks) is then multiplied by 20 to get the heart rate. Alternatively an average-sized pen



Figures 1 and 2 Normal ECG Canine.

can be placed on the strip and the R-R intervals counted between one end of the pen and the other. This number can be multiplied by 20 (if the paper speed is 50 mm/s). If the paper speed is 25 mm/s the number of R-R intervals between tick marks (or using the pen) can be multiplied by 10 "pen times ten." Always verify the heart rate on the ECG machine or that calculated by the above methods, with auscultation of the animal.



Figures 3 and 4 Normal ECG feline.

Calculating the mean electrical axis

The mean electrical axis (MEA) reflects the area of the heart that takes the longest for electrical depolarization to travel through. In normal hearts it is the left ventricle (the thickest part of the heart muscle). If there is hypertrophy of the right ventricle the MEA may shift to the right. It may also be shifted if there is a conduction disturbance (i.e., bundle branch block), which slows down the ventricular depolarization in the area of the block. The normal MEA for dogs is +40 to +100 degrees and for cats it is −5 to +160 degrees. There are several ways to calculate the MEA (see "Further reading" for excellent cardiology texts) and for the sake of brevity we will describe only one here. An isoelectric lead is one where the complexes have an equal amount of positive and negative deflection so that the total electrical energy is net neutral. It is usually the smallest complex seen on the ECG. If an isoelectric lead can be identified then the MEA is perpendicular to that lead. For example, if the isoelectric lead is aVL then the MEA is aVR, which is either +30 degrees or −150 degrees. If the QRS is positive in aVR then the MEA is +30, whereas if the QRS is negative in aVR then the MEA is −150.

Measuring the complexes

The height of the P wave is measured from baseline to the top of the P wave. The width of the P wave is measured from the inside of the start of the P wave to the end of the P wave. An increase in either height or width, or both, may point to atrial enlargement. An increase in height may point to right atrial enlargement and is called P-pulmonale. An increase in P wave width may indicate left atrial enlargement and is called P-mitrale. Notching of the P wave may also be an indicator of left atrial enlargement. An absent P wave may be either artifact (check all leads) or may be seen with atrial fibrillation, junctional rhythms, and some other arrhythmias. Normal values for dogs and cats can be found in references in the "Further reading" section.

The P-R interval is measured next and is measured from the beginning of the P wave to the beginning of the Q wave. It reflects AV junction activation and prolongation suggests that the impulse is slowed down traveling through the AV node (first-degree heart block).

The width of the QRS complex is measured from the beginning of the Q wave to the end of the S wave (where it comes back to baseline). There are nuances that may make measurement here difficult (e.g., no Q wave etc.) and the "Further reading" section has a wealth of information for those interested in delving more deeply into ECGs. The height of the R wave is measured from the baseline (where it starts) to the top of the R wave and the depth of the Q or S wave is measured from baseline to the deepest part of the respective wave. Increased duration of the QRS suggests abnormal ventricular depolarization (e.g., left bundle branch block)

and increased height of the R wave suggests left ventricular enlargement. A small amplitude R wave may indicate pericardial effusion, severe pleural effusion, and hypothyroidism. The S wave, when increased in height (i.e., deeply negative) suggests right ventricular enlargement while increases in width suggest abnormal depolarization of the right ventricle (e.g., right bundle branch block).

The ST segment is measured from the baseline at the end of the S wave (i.e., where it returns to baseline) to the beginning of the T wave and represents early ventricular repolarization. Elevation may indicate myocardial hypoxia, infarct, or pericarditis. Depression may indicate myocardial hypoxia, infarct, trauma, digoxin toxicity, or alterations in serum potassium (see Chapter 4, ST segment abnormalities).

The T wave is the first deflection after the QRS complex and should be less than $^1/_4$ the size of the R wave in height. The T wave may be upright or negative or even biphasic. Tall and tented (sharp) T waves may indicate hyperkalemia, which may be a life-threatening emergency (see Chapter 4, T wave abnormalities). Depression or elevation from baseline may indicate myocardial hypoxia, cardiac hypertrophy, or electrolyte alterations (including hyperkalemia). In emergency situations electrolyte measurement should be done to rule out hyperkalemia first, followed by assessment of oxygenation to rule out hypoxia. If the findings are normal then a cardiac consultation is recommended. Low amplitude or inverted T waves may indicate hypokalemia, hypocalcemia, or ischemia. Alternans of the T wave (variation in height with alternating beats) has been reported with hypocalcemia.

The Q-T interval is measured from the beginning of the Q wave to the end of the T wave and represents ventricular depolarization through ventricular repolarization. Ideally it should be less than half of the previous R-R interval in width. A prolonged Q-T interval is not common in dogs and cats but is important as it can degenerate into a potentially fatal arrhythmia called torsade de pointes (see Chapter 3, Torsade de pointes). This is a ventricular rhythm that is a bit more regular than ventricular fibrillation but with a polarity that rotates around the baseline. It seems as if the complexes alternate between taller and shorter complexes and it has been described as resembling ribbon candy. It may occur in brief periods (~5 s) or it may degenerate into ventricular fibrillation. Prolongation of the QT interval can be hereditary in Dalmatian and English Springer Spaniel dogs or can be caused by numerous drugs, hypokalemia, hypocalcemia, or toxicity in other breeds.

A systematic approach to reading ECGs is recommended. This includes calculation of the heart rate (and verifying this with auscultation of the heart and lungs), checking for and minimizing artifacts, evaluating the rhythm (is there a P wave for every QRS, is the rhythm regular, irregular, or irregularly irregular, etc.) and, when the animal is stable, measuring the complexes. The information gained from evaluation of the ECG must be put into context with the species (e.g., sinus arrhythmia is never normal in a cat), the breed (e.g., prolonged QT

syndrome in Dalmatian and English Springer Spaniels), the physical examination (e.g., does the heart rate on the ECG and on auscultation match, are there heart beats without concurrent pulses, etc.), and additional diagnostics (e.g., CBC, biochemistry panel, radiographs, echocardiogram, and so on).

The following sections highlight life-threatening arrhythmias and cardiac conditions most likely to be encountered in small animal practice.