Equipment Packet: Electrocardiograph

UMDNS #: 11407

Date of Creation: October 14, 2015

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Equipment Packet Contents:

This packet contains information about the operation, maintenance, and repair of electrocardiograms.

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Part II: Included in this Packet:

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1. Operation and Use of Electrocardiographs (ECG)

Featured in this Section:

ECGpedia.org, “Basics.” *Wikipedia*. Retrieved from: http://en.ecgpedia.org/wiki/Basics

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Electrocardiograph, ECG

Brief Introduction to ECG

UMDNS	
16231	Electrocardiographs, Multichannel, Interpretive
18330	Electrocardiographs, Multichannel, Interpretive, Signal-Averaging
18329	Electrocardiographs, Multichannel, Noninterpretive
17687	Electrocardiographs, Multichannel, Noninterpretive, Signal-Averaging
11413	Electrocardiographs, Single-Channel

GMDN	
16231	Interpretive multichannel electrocardiograph
17687	Signal-averaging multichannel electrocardiograph
11413	Single-channel electrocardiograph

Other common names:
Computer-assisted electrocardiographs; interpretive ECG machines; interpretive electrocardiographs; automated electrocardiographs; EKG machines; Electrocardiograph multichannel;

Health problem addressed

Electrocardiographs detect the electrical signals associated with cardiac activity and produce an ECG, a graphic record of the voltage versus time. They are used to diagnose and assist in treating some types of heart disease and arrhythmias, determine a patient's response to drug therapy, and reveal trends or changes in heart function. Multichannel electrocardiographs record signals from two or more leads simultaneously and are frequently used in place of single-channel units. Some electrocardiographs can perform automatic measurement and interpretation of the ECG as a selectable or optional feature.

Product description

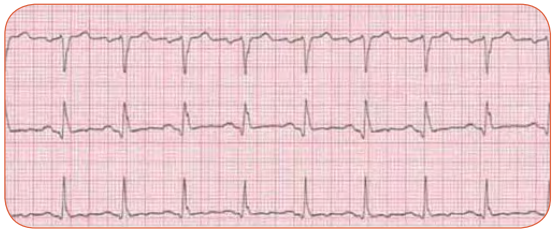
ECG units consist of the ECG unit, electrodes, and cables. The 12-lead system includes three different types of leads: bipolar, augmented or unipolar, and precordial. Each of the 12 standard leads presents a different perspective of the heart's electrical activity; producing ECG waveforms in which the P waves, QRS complex, and T waves vary in amplitude and polarity. Single-channel ECGs record the electric signals from only one lead configuration at a time, although they may receive electric signals from as many as 12 leads. Noninterpretive multichannel electrocardiographs only record the electric signals from the electrodes (leads) and do not use any internal procedure for their interpretation. Interpretive multichannel electrocardiographs acquire and analyze the electrical signals.

Principles of operation

Electrocardiographs record small voltages of about one millivolt (mV) that appear on the skin as a result of cardiac activity. The voltage differences between electrodes are measured; these differences directly correspond to the heart's electrical activity. Each of the 12 standard leads presents a different perspective of the heart's electrical activity; producing ECG waveforms in which the P waves, QRS complex, and T waves vary in amplitude and polarity. Other lead configurations include those of the Frank system and Cabrera leads. The Frank configuration measures voltages from electrodes applied to seven locations—the forehead or neck, the center spine, the midsternum, the left and right midaxillary lines, a position halfway between the midsternum and left midaxillary electrodes, and the left leg.

Operating steps

After the electrodes are attached to the patient, the user selects automatic or manual lead switching, signal sensitivity, frequency-response range, and chart speed. In some units, the operator can choose the lead groupings, their sequence, and the recording duration for each group. In standard 12-lead tracings, signals from each group of leads (i.e., bipolar, augmented, precordial) can be recorded for 2.5 seconds. For a rhythm strip, one lead (usually lead II) is recorded for a full 12 seconds.



Reported problems

Because electrocardiographs have electrical safety standards that are well established and adhered to by all major manufacturers, few problems are associated with their use. Of these, the most common is artifact or noise (e.g., broken electrode wires, poor electrode cleaning or improper application, poor skin preparation, patient movement, baseline drift, and interference). Incorrect placement of ECG leads can cause an abnormality to be overlooked. Chest wall thickness can also affect diagnostic accuracy.

Use and maintenance

User(s): Physicians, nurses, other medical staff

Maintenance: Biomedical or clinical engineer/ technician, medical staff, manufacturer/ servicer

Training: Initial training by manufacturer, operator's manuals, user's guide

Environment of use

Settings of use: Hospital (all areas), family medicine practices and other medical offices

Requirements: Uninterruptible power source, battery backup, appropriate electrodes

Product specifications

Approx. dimensions (mm): 120 x 400 x 350

Approx. weight (kg): 6

Consumables: Batteries, cables, electrodes

Price range (USD): 975 - 6,000

Typical product life time (years): 10

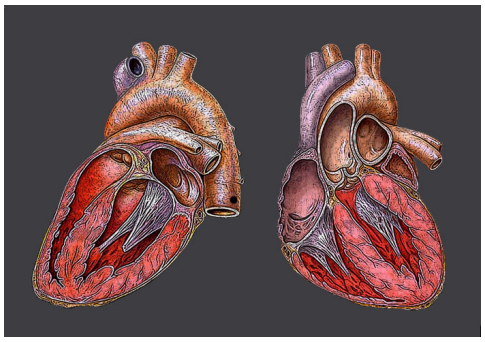
Shelf life (consumables): 1-2 years for disposable electrodes/sensors

Types and variations

Portable, cart, desktop, tabletop

WHO. "Electrocardiograph, ECG." From the publication: Core Medical Equipment. Geneva, Switzerland, 2011.

Heart



Vertebrate heart

The **heart** is a muscular organ found in all animals with a circulatory system (including all vertebrates), that is responsible for pumping blood throughout the blood vessels by repeated, rhythmic contractions. The term *cardiac* (as in cardiology) means "related to the heart" and comes from the Greek καρδιά, *kardia*, for "heart."

The vertebrate heart is composed of cardiac muscle, which is an involuntary striated muscle tissue found only within this organ. The average human heart, beating at 72 beats per minute, will beat approximately 2.5 billion times during an average 66 year lifespan, and weighs approximately 250 to 300 grams (9 to 11 oz) in females and 300 to 350 grams (11 to 12 oz) in males.[1]

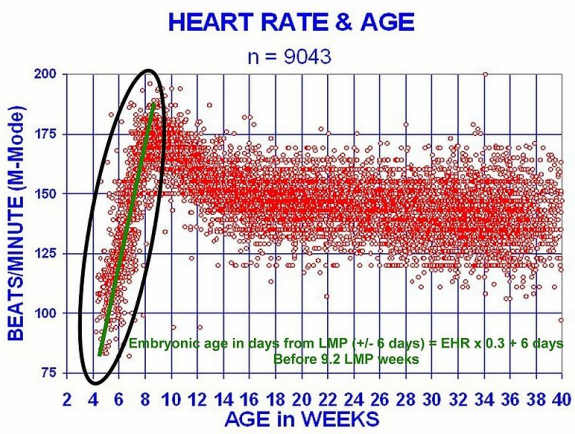
In invertebrates that possess a circulatory system, the heart is typically a tube or small sac and pumps fluid that contains water and nutrients such as proteins, fats, and sugars. In insects, the "heart" is often called the **dorsal tube** and insect "blood" is almost always not oxygenated since they usually respirate (breathe) directly from their body surfaces (internal and external) to air. However, the hearts of some other arthropods (including spiders and crustaceans such as crabs and shrimp) and some other animals pump hemolymph, which contains the copper-based protein hemocyanin as an oxygen transporter similar to the iron-based hemoglobin in red blood cells found in vertebrates.

Early development

The mammalian heart is derived from embryonic mesoderm germ-layer cells that differentiate after gastrulation into mesothelium, endothelium, and myocardium. Mesothelial pericardium forms the outer lining of the heart. The inner lining of the heart, lymphatic and blood vessels, develop from endothelium. Myocardium develops into heart muscle.[2]

From splanchnopleuric mesoderm tissue, the cardiogenic plate develops cranially and laterally to the neural plate. In the cardiogenic plate, two separate angiogenic cell clusters form on either side of the embryo. Each cell cluster coalesces to form an endocardial tube continuous with a dorsal aorta and a vitteloumbilical vein. As embryonic tissue continues to fold, the two endocardial tubes are pushed into the thoracic cavity, begin to fuse together, and complete the fusing process at approximately 21 days.[3]

The human embryonic heart begins beating at around 21 days after conception, or five weeks after the last normal menstrual period (LMP). The first day of the LMP is normally used to date the start of the gestation (pregnancy). It is unknown how blood in the human embryo circulates for the first 21 days in the absence of a functioning heart. The human heart begins beating at a rate near the mother's, about 75-80 beats per minute (BPM).



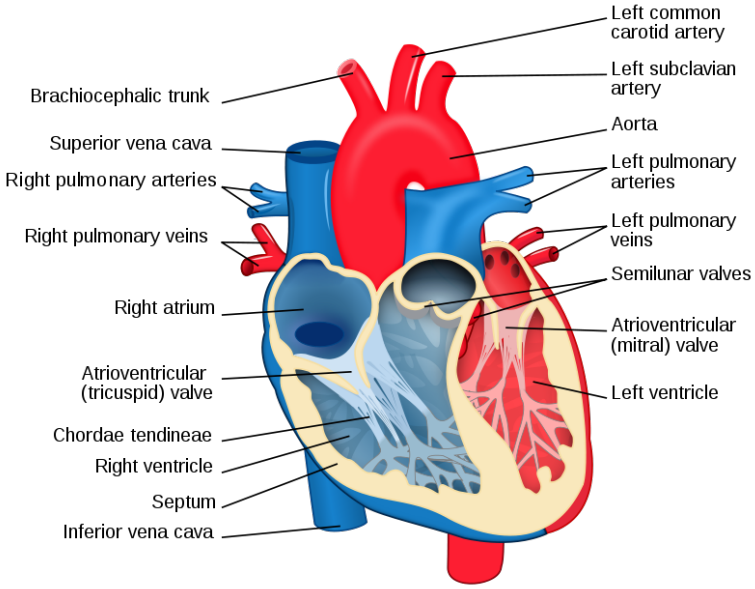
At 21 days after conception, the human heart begins beating at 70 to 80 beats per minute and accelerates linearly for the first month of beating.

The embryonic heart rate (EHR) then accelerates approximately 100 BPM during the first month of beating, peaking at 165-185 BPM during the early 7th week, (early 9th week after the LMP). This acceleration is approximately 3.3 BPM per day, or about 10 BPM every three days, which is an increase of 100 BPM in the first month.[4] After 9.1 weeks after the LMP, it decelerates to about 152 BPM (+/-25 BPM) during the 15th week post LMP. After the 15th week, the deceleration slows to an average rate of about 145 (+/-25 BPM) BPM, at term. The regression formula, which describes this acceleration before the embryo reaches 25 mm in crown-rump length, or 9.2 LMP weeks, is: Age in days = EHR(0.3)+6. There is no difference in female and male heart rates before birth.[5]

Structure

The structure of the heart varies among the different branches of the animal kingdom. (See Circulatory system.) Cephalopods have two "gill hearts" and one "systemic heart". In vertebrates, the heart lies in the anterior part of the body cavity, dorsal to the gut. It is always surrounded by a pericardium, which is usually a distinct structure, but may be continuous with the peritoneum in jawless and cartilaginous fish. Hagfishes, uniquely among vertebrates, also possess a second heart-like structure in the tail.[6]

In humans



Structure diagram of the human heart. Blue components indicate de-oxygenated blood pathways and red components indicate oxygenated pathways.

The heart is enclosed in a double-walled sac called the pericardium. The superficial part of this sac is called the fibrous pericardium. This sac protects the heart, anchors its surrounding structures, and prevents overfilling of the heart with blood. It is located anterior to the vertebral column and posterior to the sternum. The size of the heart is about the size of a fist and has a mass of between 250 grams and 350 grams. The heart is composed of three layers, all of which are rich with blood vessels. The superficial layer, called the visceral layer, the middle layer, called the myocardium, and the third layer which is called the endocardium. The heart has four chambers, two superior atria and two inferior ventricles. The atria are the receiving chambers and the ventricles are the discharging chambers. The pathway of blood through the heart consists of a pulmonary circuit and a systemic circuit. Blood flows through the heart in one direction, from the atrias to the ventricles, and out of the great arteries, or the aorta for example. This is done by four valves which are the tricuspid atrioventricular valve, the mitral atrioventicular valve, the aortic semilunar valve, and the pulmonary semilunar valve.[7]

In fish

Primitive fish have a four-chambered heart; however, the chambers are arranged sequentially so that this primitive heart is quite unlike the four-chambered hearts of mammals and birds. The first chamber is the sinus venosus, which collects de-oxygenated blood, from the body, through the hepatic and cardinal veins. From here, blood flows into the atrium and then to the powerful muscular ventricle where the main pumping action takes place. The fourth and final chamber is the conus arteriosus which contains several valves and sends blood to the *ventral aorta*. The ventral aorta delivers blood to the gills where it is oxygenated and flows, through the dorsal aorta, into the rest of the body. (In tetrapods, the ventral aorta has divided in two; one half forms the ascending aorta, while the other forms the pulmonary artery).[6]

In the adult fish, the four chambers are not arranged in a straight row but, instead, form an S-shape with the latter two chambers lying above the former two. This relatively simpler pattern is found in cartilaginous fish and in the more primitive ray-finned fish. In teleosts, the conus arteriosus is very small and can more accurately be described as part of the aorta rather than of the heart proper. The conus arteriosus is not present in any amniotes which presumably having been absorbed into the ventricles over the course of evolution. Similarly, while the sinus venosus is present as a vestigial structure in some reptiles and birds, it is otherwise absorbed into the right atrium and is no longer distinguishable.[6]

In double circulatory systems

In amphibians and most reptiles, a double circulatory system is used but the heart is not completely separated into two pumps. The development of the double system is necessitated by the presence of lungs which deliver oxygenated blood directly to the heart.

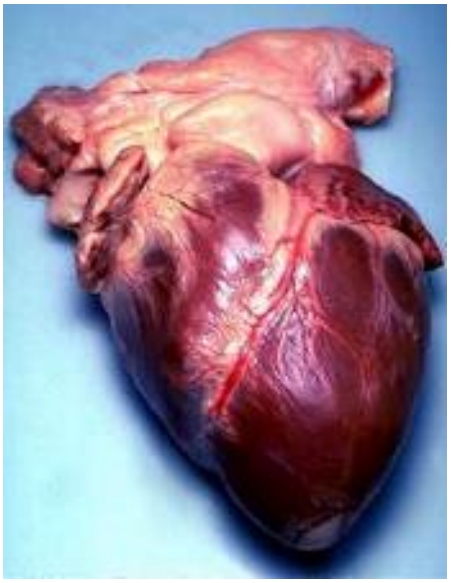
In living amphibians, the atrium is divided into two separate chambers by the presence of a muscular septum even though there is only a single ventricle. The sinus venosus, which remains large in amphibians but connects only to the right atrium, receives blood from the vena cavae, with the pulmonary vein by-passing it entirely to enter the left atrium.

In the heart of lungfish, the septum extends part-way into the ventricle. This allows for some degree of separation between the de-oxygenated bloodstream destined for the lungs and the oxygenated stream that is delivered to the rest of the body. The absence of such a division in living amphibian species may be at least partly due to the amount of respiration that occurs through the skin in such species; thus, the blood returned to the heart through the vena cavae is, in fact, already partially oxygenated. As a result, there may be less need for a finer division between the two bloodstreams than in lungfish or other tetrapods. Nonetheless, in at least some species of amphibian, the spongy nature of the ventricle seems to maintain more of a separation between the bloodstreams than appears the case at first glance. Furthermore, the conus arteriosus has lost its original valves and contains a spiral valve, instead, that divides it into two parallel parts, thus helping to keep the two bloodstreams separate.[6]

The heart of most reptiles (except for crocodilians; *see below*) has a similar structure to that of lungfish but, here, the septum is generally much larger. This divides the ventricle into two halves but, because the septum does not reach the whole length of the heart, there is a considerable gap near the openings to the pulmonary artery and the aorta. In practice, however, in the majority of reptilian species, there appears to be little, if any, mixing between the bloodstreams, so the aorta receives, essentially, only oxygenated blood.[6]

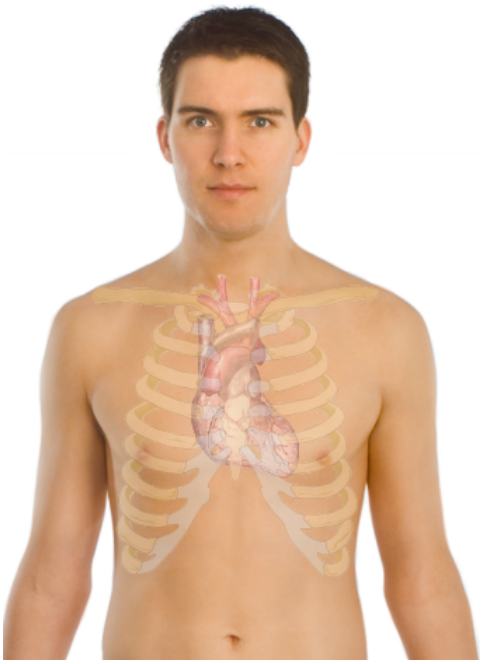
The fully-divided heart

Archosaurs, (crocodilians, birds), and mammals show complete separation of the heart into two pumps for a total of four heart chambers; it is thought that the four-chambered heart of archosaurs evolved independently from that of mammals. In crocodilians, there is a small opening, the foramen of Panizza, at the base of the arterial trunks and there is some degree of mixing between the blood in each side of the heart; thus, only in birds and mammals are the two streams of blood - those to the pulmonary and systemic circulations - kept entirely separate by a physical barrier.[6]



Human heart removed from a 64-year-old male.

In the human body, the heart is usually situated in the middle of the thorax with the largest part of the heart slightly offset to the left, although sometimes it is on the right (see dextrocardia), underneath the sternum. The heart is usually felt to be on the left side because the left heart (left ventricle) is stronger (it pumps to all body parts). The left lung is smaller than the right lung because the heart occupies more of the left hemithorax. The heart is fed by the coronary circulation and is enclosed by a sac known as the pericardium; it is also surrounded by the lungs. The pericardium comprises two parts: the fibrous pericardium, made of dense



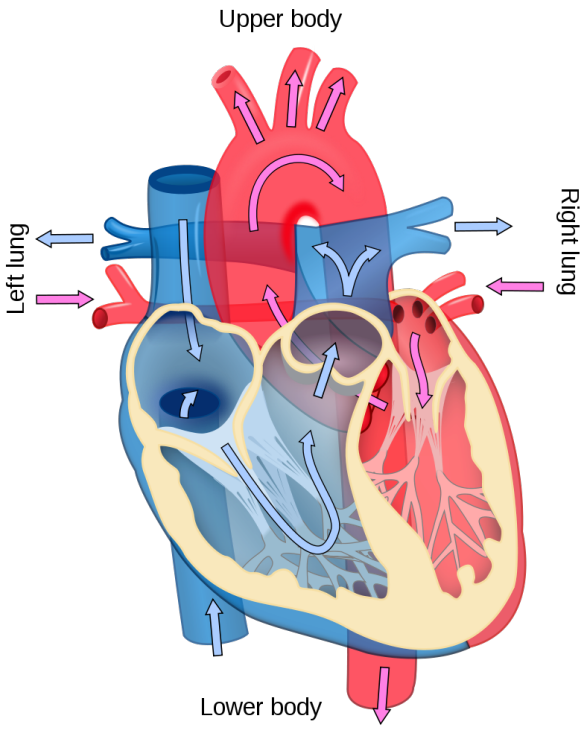
Surface anatomy of the human heart. The heart is demarcated by:
-A point 9 cm to the left of the midsternal line (apex of the heart)
-The seventh right sternocostal articulation
-The upper border of the third right costal cartilage 1 cm from the right sternal line
-The lower border of the second left costal cartilage 2.5 cm from the left lateral sternal line.[8]

fibrous connective tissue, and a double membrane structure (parietal and visceral pericardium) containing a serous fluid to reduce friction during heart contractions. The heart is located in the mediastinum, which is the central sub-division of the thoracic cavity. The mediastinum also contains other structures, such as the esophagus and trachea, and is flanked on either side by the right and left pulmonary cavities; these cavities house the lungs.[9]

The *apex* is the blunt point situated in an inferior (pointing down and left) direction. A stethoscope can be placed directly over the apex so that the beats can be counted. It is located posterior to the 5th intercostal space just medial of the left mid-clavicular line. In normal adults, the mass of the heart is 250-350 g (9-12 oz), or about twice the size of a clenched fist (it is about the size of a clenched fist in children), but an extremely diseased heart can be up to 1000 g (2 lb) in mass due to hypertrophy. It consists of four chambers, the two upper atria and the two lower ventricles.

Functioning

In mammals, the function of the right side of the heart (see right heart) is to collect de-oxygenated blood, in the right atrium, from the body (via superior and inferior vena cavae) and pump it, via the right ventricle, into the lungs (pulmonary circulation) so that carbon dioxide can be dropped off and oxygen picked up (gas exchange). This happens through the passive process of diffusion. The left side (see left heart) collects oxygenated blood from the lungs into the left atrium. From the left atrium the blood moves to the left ventricle which pumps it out to the body (via the aorta). On both sides, the lower ventricles are thicker and stronger than the upper atria. The muscle wall surrounding the left ventricle is thicker than the wall surrounding the right ventricle due to the higher force needed to pump the blood through the systemic circulation.



Blood flow diagram of the human heart. Blue components indicate de-oxygenated blood pathways and red components indicate oxygenated pathways.

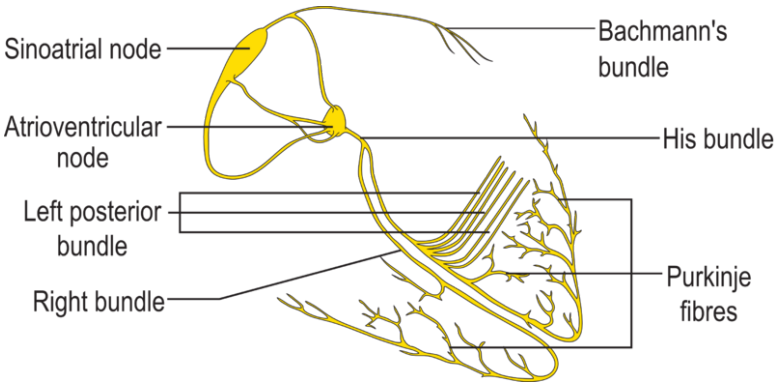


Image showing the conduction system of the heart

Starting in the right atrium, the blood flows through the tricuspid valve to the right ventricle. Here, it is pumped out the pulmonary semilunar valve and travels through the pulmonary artery to the lungs. From there, oxygenated blood flows back through the pulmonary vein to the left atrium. It then travels through the mitral valve to the left ventricle, from where it is pumped through the aortic semilunar valve to the aorta. The aorta forks and the blood is divided between major arteries which supply the upper and lower body. The blood travels in the arteries to the smaller arterioles and then, finally, to the tiny capillaries which feed each cell. The (relatively) deoxygenated blood then travels to the venules, which coalesce into veins, then to the inferior and superior venae cavae and finally back to the right atrium where the process began.

The heart is effectively a syncytium, a meshwork of cardiac muscle cells interconnected by contiguous cytoplasmic bridges. This relates to electrical stimulation of one cell spreading to neighboring cells.

Some cardiac cells are self-excitable, contracting without any signal from the nervous system, even if removed from the heart and placed in culture. Each of these cells have their own intrinsic contraction rhythm. A region of the human heart called the **sinoatrial node**, or pacemaker, sets the rate and timing at which all cardiac muscle cells

contract. The SA node generates electrical impulses, much like those produced by nerve cells. Because cardiac muscle cells are electrically coupled by inter-calated disks between adjacent cells, impulses from the SA node spread rapidly through the walls of the artria, causing both artria to contract in unison. The impulses also pass to another region of specialized cardiac muscle tissue, a relay point called the **atrioventricular node**, located in the wall between the right artrium and the right ventricle. Here, the impulses are delayed for about 0.1s before spreading to the walls of the ventricle. The delay ensures that the artria empty completely before the ventricles contract. Specialized muscle fibers called Purkinje fibers then conduct the signals to the apex of the heart along and throughout the ventricular walls. The Purkinje fibres form conducting pathways called bundle branches. This entire cycle, a single heart beat, lasts about 0.8 seconds. The impulses generated during the heart cycle produce electrical currents, which are conducted through body fluids to the skin, where they can be detected by electrodes and recorded as an electrocardiogram (ECG or EKG).[10] The events related to the flow or blood pressure that occurs from the beginning of one heartbeat to the beginning of the next can be referred to a cardiac cycle.[11]

The SA node is found in all amniotes but not in more primitive vertebrates. In these animals, the muscles of the heart are relatively continuous and the sinus venosus coordinates the beat which passes in a wave through the remaining chambers. Indeed, since the sinus venosus is incorporated into the right atrium in amniotes, it is likely homologous with the SA node. In teleosts, with their vestigial sinus venosus, the main centre of coordination is, instead, in the atrium. The rate of heartbeat varies enormously between different species, ranging from around 20 beats per minute in codfish to around 600 in hummingbirds.[6]

Cardiac arrest is the sudden cessation of normal heart rhythm which can include a number of pathologies such as tachycardia, an extremely rapid heart beat which prevents the heart from effectively pumping blood, fibrillation, which is an irregular and ineffective heart rhythm, and asystole, which is the cessation of heart rhythm entirely.

Cardiac tamponade is a condition in which the fibrous sac surrounding the heart fills with excess fluid or blood, suppressing the heart's ability to beat properly. Tamponade is treated by pericardiocentesis, the gentle insertion of the needle of a syringe into the pericardial sac (avoiding the heart itself) on an angle, usually from just below the sternum, and gently withdrawing the tamponading fluids.

History of discoveries

A preserved human heart with a visible gunshot wound

The valves of the heart were discovered by a physician of the Hippocratean school around the 4th century BC. However, their function was not properly understood then. Because blood pools in the veins after death, arteries look empty. Ancient anatomists assumed they were filled with air and that they were for transport of air.

Philosophers distinguished veins from arteries but thought that the pulse was a property of arteries themselves. Erasistratos observed the arteries that were cut during life bleed. He described the fact to the phenomenon that air escaping from an artery is replaced with blood which entered by very small vessels between veins and arteries. Thus he apparently postulated capillaries but with reversed flow of blood.

The 2nd century AD, Greek physician Galenos (Galen) knew that blood vessels carried blood and identified venous (dark red) and arterial (brighter and thinner) blood, each with distinct and separate functions. Growth and energy were derived from venous blood created in the liver from chyle, while arterial blood gave vitality by containing pneuma (air) and originated in the heart. Blood flowed from both creating organs to all parts of the body where it was consumed and there was no return of blood to the heart or liver. The heart did not pump blood around, the heart's motion sucked blood in during diastole and the blood moved by the pulsation of the arteries themselves.

Galen believed that the arterial blood was created by venous blood passing from the left ventricle to the right through 'pores' in the inter ventricular septum while air passed from the lungs via the pulmonary artery to the left side of the heart. As the arterial blood was created, 'sooty' vapors were created and passed to the lungs, also via the pulmonary artery, to be exhaled.

The first major scientific understanding of the heart was put forth by the medieval Arab polymath Ibn Al-Nafis, regarded as the father of circulatory physiology.[12] He was the first physician to correctly describe pulmonary circulation,[13] the capillary[14] and coronary circulations.[15] Prior to this, Galen's theory was widely accepted, and improved upon by Avicenna. Al-Nafis rejected the Galen-Avicenna theory and corrected many wrong ideas that were put forth by it, and also adding his new found observations of pulse and circulation to the new theory. His major observations include (as surmised by Dr. Paul Ghalioungui):[14]

1. "Denying the existence of any pores through the interventricular septum."
2. "The flow of blood from the right ventricle to the lungs where its lighter parts filter into the pulmonary vein to mix with air."
3. "The notion that blood, or spirit from the mixture of blood and air, passes from the lung to the left ventricle, and not in the opposite direction."
4. "The assertion that there are only two ventricles, not three as stated by Avicenna."
5. "The statement that the ventricle takes its nourishment from blood flowing in the vessels that run in its substance (i.e. the coronary vessels) and not, as Avicenna maintained, from blood deposited in the right ventricle."
6. "A premonition of the capillary circulation in his assertion that the pulmonary vein receives what comes out of the pulmonary artery, this being the reason for the existence of perceptible passages between the two."

Ibn Al-Nafis also corrected Galen-Avicenna assertion that heart has a bone structure through his own observations and wrote the following criticism on it:[16]

> "This is not true. There are absolutely no bones beneath the heart as it is positioned right in the middle of the chest cavity where there are no bones at all. Bones are only found at the chest periphery not where the heart is positioned."

For more recent technological developments, see Cardiac surgery.

Healthy heart

Obesity, high blood pressure, and high cholesterol can increase the risk of developing heart disease. However, fully half the amount of heart attacks occur in people with normal cholesterol levels. Heart disease is a major cause of death (and the number one cause of death in the Western World).

Of course one must also consider other factors such as lifestyle, for instance the amount of exercise one undertakes and their diet, as well as their overall health (mental and social as well as physical).[17] [18] [19] [20]

See also

- Cardiac cycle
- Heart disease
- Human heart
- Electrocardiogram
- Electrical conduction system of the heart
- Physiology
- Trauma triad of death
- Langendorff Heart

External links

- Atlas of Human Cardiac Anatomy [21] - Endoscopic views of beating hearts - Cardiac anatomy
- Heart contraction and blood flow (animation) [22]
- Heart Disease [23]
- eMedicine: Surgical anatomy of the heart [24]
- Interactive 3D heart [25] This realistic heart can be rotated, and all its components can be studied from any angle.
- Heart Information [26]
- Oath of Awareness [27] Heart disease awareness site
- SmartyMaps: Interactive Overview of the Human Heart [28]

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[3] Main Frame Heart Development> (http://www.meddean.luc.edu/lumen/MedEd/GrossAnatomy/thorax0/heartdev/main_fra.html)

[4] OBGYN.net "Embryonic Heart Rates Compared in Assisted and Non-Assisted Pregnancies" (http://www.obgyn.net/us/us.asp?page=/us/cotm/0001/ehr2000)

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Basics

Introduction to Electrocardiography

«Introduction Step 1: Rhythm»

Contents

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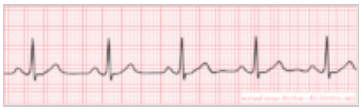
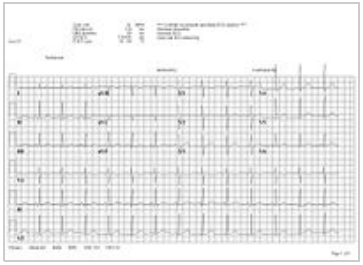
some notes about authorship

How do I begin to read an ECG?

Click on the ECG to see an enlargement. Where do you start when interpreting an ECG?



A short ECG registration of normal heart rhythm (sinus rhythm)



An example of a normal ECG. *Click on the Image for an enlargement*

- On the top left are the patient's information, name, sex and date of birth
- At the right of that are below each other the Frequency, the conduction times (PQ,QRS,QT/QTc), and the heart axis (P-top axis, QRS axis and T-top axis)
- Farther to the right is the interpretation of the ECG written (this may be missing in a 'fresh' ECG, but later the interpretation of the cardiologist or computer will be added)
- Down left is the 'paper speed' (25 mm/s on the horizontal axis), the sensitivity (10mm/mV) and the filter's frequency (40Hz, filters noise from eg. lights).
- There is a calibration. At the beginning of every lead is a vertical block that shows with what amplitude a 1 mV signal is drawn. So the height and depth of these signals are a measurement for the voltage. If this is not set at 10 mm, there is something wrong with the machine setting.
- Finally we have the ECG leads themselves.These will be discussed below.

Note that the layout is different for each machine, but most machines will show the information above somewhere.

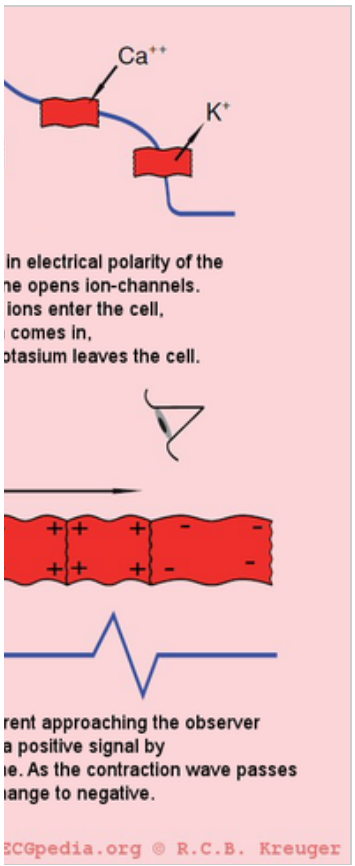
What does the ECG register?

The electrocardiogram

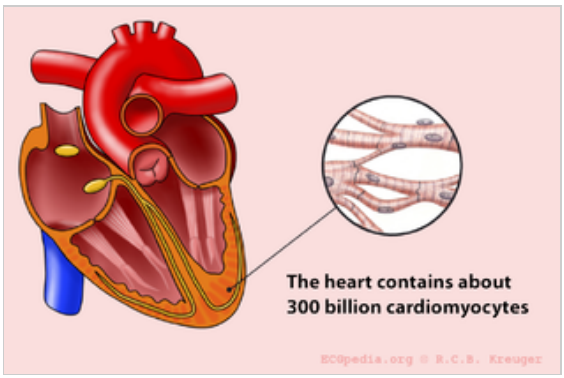
An electrocardiogram (ECG or EKG) is a register of the heart's electrical activity.

Just like skeletal muscles, heart muscles are electrically stimulated to contract. This stimulation is also called *activation* or *excitation*. Cardiac muscles are electrically charged at rest. The inside of the cell is negatively charged relative to the outside (resting potential). If the cardiac muscle cells are electrically stimulated, they depolarize (the resting potential changes from negative to positive) and contract. The electrical activity of a single cell can be registered as the action potential. As the electrical impulse spreads through the heart, the electrical field changes continually in size and direction. The ECG is a graph of these electrical cardiac signals.

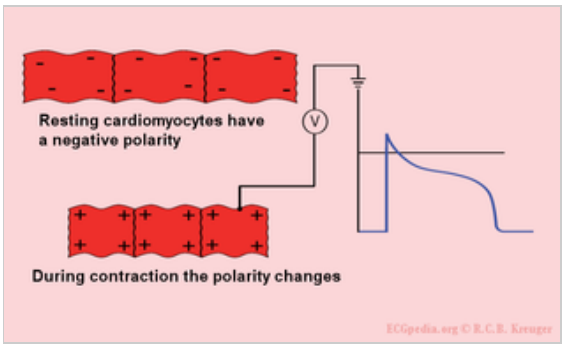
The ECG represents the sum of the action potentials of millions of cardiomyocytes



ardiomyocytes



The heart consists of approximately 300 billion cells

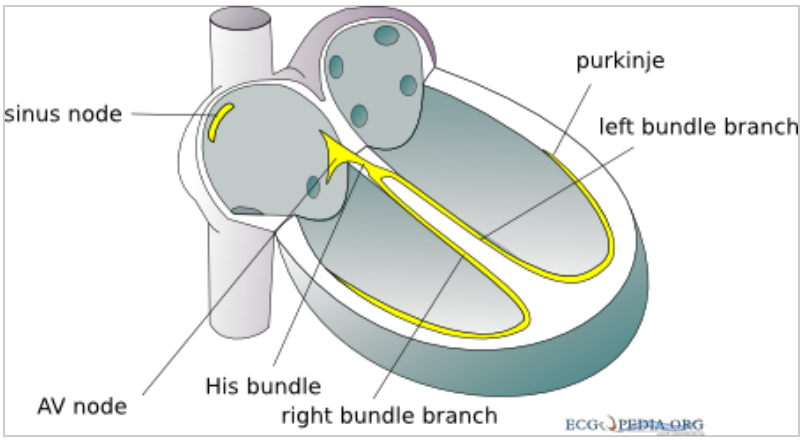


In rest the heart cells are negatively charged. Through the depolarization by surrounding cells they become positively charged and they contract.

The individual action potentials of the individual cardiomyocytes are averaged. The final result, which is shown on the ECG, is actually the average of billions of microscopic electrical signals.

During the depolarization, sodium ions stream into the cell. Subsequently, the calcium ions stream into the cell. These calcium ions cause the actual muscular contraction.

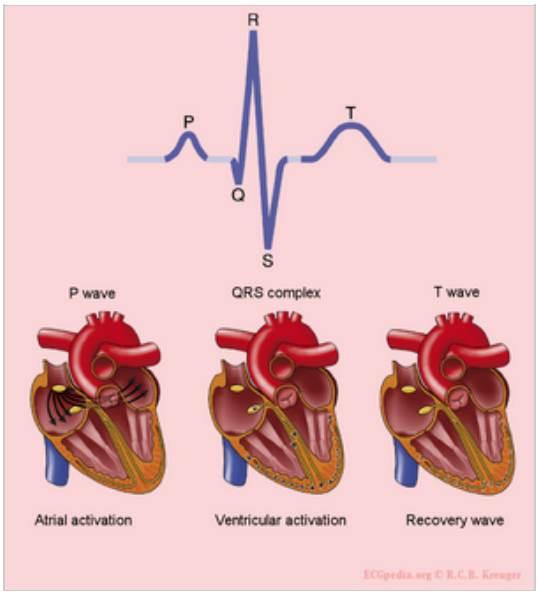
Finally the potassium ions stream out of the cell. During repolarization the ion concentration returns to its precontraction state. On the ECG, an action potential wave coming toward the electrode is shown as a positive (upwards) signal. Here the ECG electrode is represented as an eye.



The conduction system of the heart

The sinoatrial node (SA node) contains the fastest physiological pacemaker cells of the heart; therefore, they determine the heart rate. First the atria depolarize and contract. After that the ventricles depolarize and contract. The electrical signal between the atria and the ventricles goes from the sinus node via the atria to the AV-node (atrioventricular transition) to the His bundle and subsequently to the right and left bundle branches, which end in a dense network of Purkinje fibers. The depolarization of the heart results in an electrical force which has a direction and magnitude; an electrical vector. This vector changes every millisecond of the depolarization. In the animation vectors for atrial depolarization, ventricular depolarization and ventricular repolarization are shown.

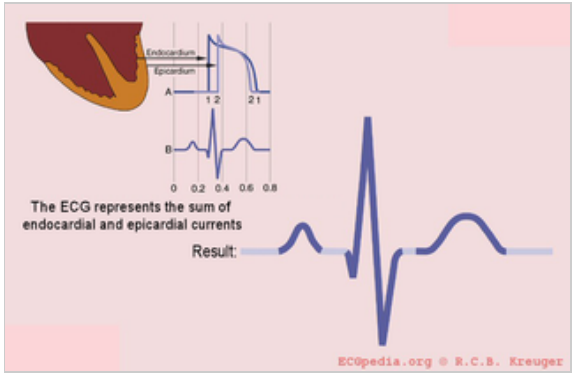
The different ECG waves



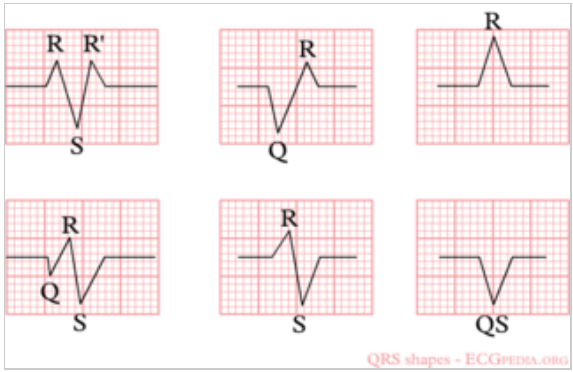
The origin of the different waves on the ECG

The **P wave** is the result of the atrial depolarization. This depolarization starts in the SA (sinoatrial) node. The signal produced by pacemaker cells in the SA node is conducted to the right and left atria. Normal atrial repolarization is not visible on the ECG (but can be visible during atrial infarction and pericarditis).

The **QRS complex** is the average of the depolarization waves of the inner (endocardial) and outer (epicardial) cardiomyocytes. As the endocardial cardiomyocytes depolarize slightly earlier than the outer layers, a typical QRS pattern occurs (figure).



The QRS complex is formed by the sum of the electric avtivity of the inner (endocardial) and the outer (epicardial) cardiomyocytes



Example of the different QRS configurations

The **T wave** represents the repolarization of the ventricles. There is no cardiac muscle activity during the T wave.

One heart beat consists of an atrial depolarization --> atrial contraction --> p-wave, ventricular depolarization --> ventricular contraction --> ORS-complex and the resting phase (including the repolarization during the T-wave) between two heart beats.

Have a look at this [animation of the heart cycle (http://www-medlib.med.utah.edu/kw/pharm/hyper_heart1.html)]

The origin of the **U wave** is unknown. This wave possibly results from "afterdepolarizations" of the ventricles.

The letters "Q", "R" and "S" are used to describe the QRS complex

- Q: the first negative deflection after the p-wave. If the first deflection is not negative, the Q is absent.
- R: the positive deflection
- S: the negative deflection after the R-wave
- Small print letters (q, r, s) are used to describe deflections of small amplitude. For example: qRS = small q, tall R, deep S.
- R`: is used to describe a second R-wave (as in a right bundle branch block)

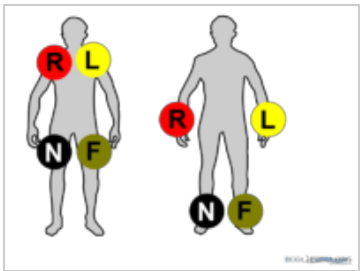
See figure for some examples of this.

The history of the ECG

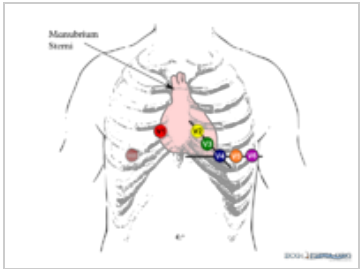
A concise history of the ECG is presented in a different chapter.

The ECG electrodes

Electrical activity going through the heart can be measured by external (skin)electrodes. The electrocardiogram (ECG) registers these activities from electrodes which have been attached onto different places on the body. In total, twelve leads are calculated using ten electrodes.



The limb leads


The chest leads

The ten electrodes are:

- **The four extremity electrodes:**
  - LA - left arm
  - RA - right arm
  - N - neutral, on the right leg (= electrical earth, or point zero, to which the electrical current is measured)
  - F - foot, on the left leg

It makes no difference whether the electrodes are attached proximal or distal on the extremities. *However*, it is best to be uniform in this. (eg. do not attach an electrode on the left shoulder and one on the right wrist).

- **The six chest electrodes:**
  - V1 - placed in the 4th intercostal space, right of the sternum
  - V2 - placed in the 4th intercostal space, left of the sternum
  - V3 - placed between V2 and V4
  - V4 - placed 5th intercostal space in the nipple line. Official recommendations are to place V4 under the breast in women.[1]
  - V5 - placed between V4 and V6
  - V6 - placed in the midaxillary line on the same height as V4 (horizontal line from V4, so not necessarily in the 5th intercostal space)

With the use of these 10 electrodes, 12 leads can be derived. There are 6 extremity leads and 6 precordial leads.

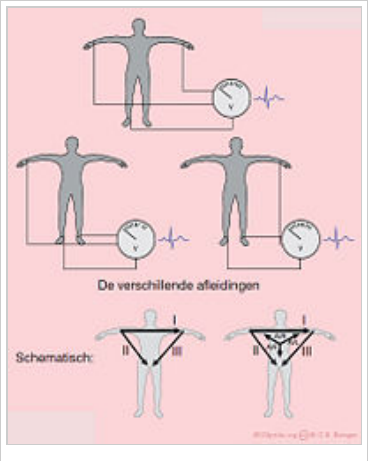
The Extremity Leads

The extremity leads are:

- **I** from the right to the left arm
- **II** from the right arm to the left leg
- **III** from the left arm to the left leg

An easy rule to remember: lead **I** + lead **III** = lead **II** This is done with the use of the height or depth, independent of the wave (QRS, P of T). Example: if in lead I, the QrS complex is 3 mm in height and in lead III 9mm, the height of the QRS-complex in lead II is 12mm.

Other extremity leads are:



- **AVL** points to the left arm
- **AVR** points to the right arm
- **AVF** points to the feet

The capital A stands for "augmented" and V for "voltage".

(aVR + aVL + aVF = 0)

The Chest Leads

The precordial, or chest leads, **(V1,V2,V3,V4,V5 and V6)** 'observe' the depolarization wave in the frontal plane.

Example: V1 is close to the right ventricle and the right atrium. Signals in these areas of the heart have the largest signal in this lead. V6 is the closest to the lateral wall of the left ventricle.

ECG variants

Besides the standard 12 lead ECG a couple of variants are in use:

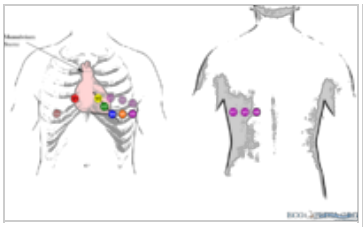
- The **3 channel ECG** uses 3 or 4 ECG electrodes. Red is on the right, yellow on the left arm, green on the left leg ('sun shines on the grass') and black on the right leg. These basic leads yield enough information for rhythm-monitoring. For determination of ST elevation, these basic leads are inadequate as there is no lead that gives (ST) information about the anterior wall. ST changes registered during 3-4 channel ECG monitoring should prompt acquisition of a 12 lead ECG.
- The **5 channel ECG** uses 4 extremitiy leads and 1 precordial lead. This improves ST segment accuracy, but is still inferior to a 12 lead ECG. [2][3]
- In **vector electrocardiography** the movement of electrical acitivity of the P, QRS and T wave is described. Additional X,Y and Z leads are recorded. Vector electrocardiography is rarely used nowadays, but is sometimes useful in a research setting.
- In **body surface mapping** several arrays are used to accurately map the cardiac electrical wavefront as it moves over de body surface. With this information the electrical acitivity of the heart can be calculated. This is sometimes used in a research setting.

Color coding of the ECG leads

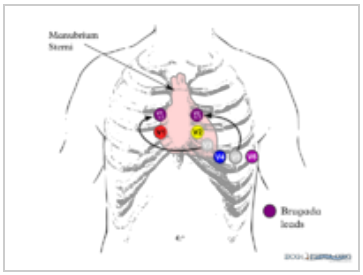
Two systems for ECG lead color coding are used: the AHA (*American Heart Association*) system and the IEC (*International Electrotechnical Commission*) system:

	AHA (*American Heart Association*)		IEC (*International Electrotechnical Commission*)	
Location	**Inscription**	**Colour**	**Inscription**	**Colour**
Right Arm	**RA**	White	**R**	Red
Left Arm	**LA**	Black	**L**	Yellow
Right Leg	**RL**	Green	**N**	Black
Left Leg	**LL**	Red	**F**	Green
Chest	**V1**	Brown/Red	**C1**	White/Red
Chest	**V2**	Brown/Yellow	**C2**	White/Yellow
Chest	**V3**	Brown/Green	**C3**	White/Green
Chest	**V4**	Brown/Blue	**C4**	White/Brown
Chest	**V5**	Brown/Orange	**C5**	White/Black
Chest	**V6**	Brown/Purple	**C6**	White/Violet

Special Leads



Leads V7,V8 and V9 can be helpful in the diagnosis of posterior myocardial infarction



Changed lead positions of leads V3 and V5 to increase the sensitiviy to 'catch' a Brugada pattern on the ECG.

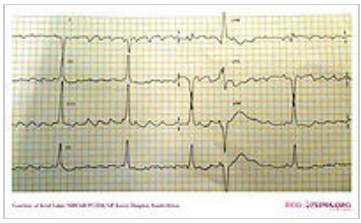
Throughout history extra lead positions have been tried. Most are rarely used in practice, but they can deliver very valuable diagnostic clues in specific cases.

- Leads to improve diagnosis in **right ventricular en posterior infarction**:

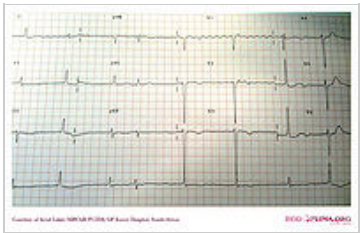
  In case of an inferior wall infarct, extra leads may be used:

  1. On a right-sided ECG, V1 and V2 remain on the same place. V3 to V6 are placed on the same place but mirrored on the chest. So V4 is in the middle of the right clavicle. The ECG should be marked as a *Right-sided ECG*. V4R (V4 but right sided) is a sensitive lead for diagnosing right ventricular infarctions.

  2. Leads V7-V8-V9 can be used to diagnose a posterior infarct. After V6, leads are placed towards the back. See the chapter Ischemia for other ways of diagnosing posterior infarction.



A patient with atrial fibrillation with a 'Lewis Lead' positioning of the leads. Compared with the normal lead configuration, the atrial signal is enlarged. Although some parts have a 'sawtooth' appearance consistent with atrial flutter, the rhythm is atrial fibrillation as there is a changing pattern in the atrial activity.



The same patient with a normal lead configuration. The rhythm is atrial fibrillation. The atrial activity in lead V1 is organized probably due to a organisation of electrical activity after it enters the right atrial appendage, close to lead V1.

- Leads to improve detection of **atrial rhyhtm**:

  In wide complex tachycardia, good detection of atrial rhythm and atrio-ventricular dissociation can be very helpful in the diagnosis process. An esophagal ECG electrode placed close to the atria can be helpful. Another, less invasive, method is the **Lewis Lead**. This is recorded by changing the limb electrodes, placing the right arm electrode in the second intercostal space and the left arm electrode in the fourth intercostal space, both to the right of the sternum. Furthermore gain is increased to 20mm/mV and paper speed to 50mm/sec.[4]ß

- Lead positioning to enhance detection of Brugada syndrome

A ladder diagram is a diagram to explain arrhythmias. The figure shows a simple ladder diagram for normal sinus rhythm, followed by av-nodal extrasystole. The origin of impulse formation (sinus node for the first two beats and AV junction for the third beat) and the conduction in the heart are shown.

Technical Problems

Also read the chapter about Technical Problems. That will help you recognize electrical disturbances and lead reversals.

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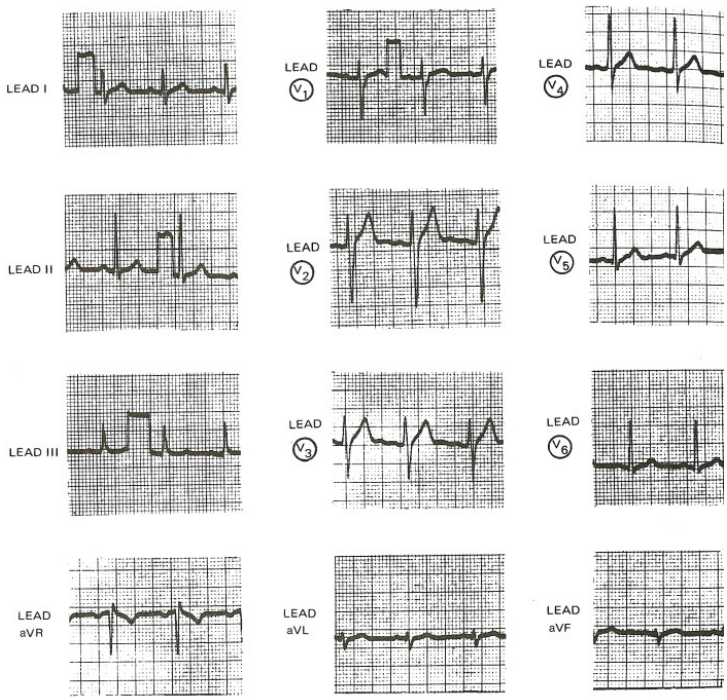
Category: ECG Course

2.5 Electrocardiographs

2.5.1 Clinical Use and Principles of Operation

An ECG amplifier, (EKG is a German term that is widely used), is an amplifier with from three to ten inputs combined to show from one to twelve traces (leads) of cardiac electrical activity. Each input amplifies the signal from two or more electrodes placed on the skin.

If the ECG is being used to monitor a patient's condition, then usually three to five wires are connected to the patient and a low resolution ECG waveform and the heart rate are continuously displayed and observed by the physician. Monitoring devices will include alarms for significant changes in rhythm or waveform. If the ECG is being used as a diagnostic tool, then typically six to ten wires are connected to the patient and one or two cardiac cycles are displayed, or printed, in high resolution.



This image shows typical ECG images from all the most common leads. The square pulse is 1 mV in height. Most developing world systems only display leads I, II and III, with some adding aVR, aVL and aVF.

Most ECG machines in the developing world are of the monitoring type. For these, three or four patient cable leads are directly connected to the patient's extremities: right leg (RL – not always used), right arm (RA), left leg (LL), and left arm (LA). If the machine is reasonably modern, it will have a color code marked on the leads. However, the color code is different in Europe, and developing world hospitals often have a mixture of European and American donations. So, the color code is of little value. A fifth connection marked "C" is often present, but rarely used and may be left unconnected in most cases. A switch on the front will change the display to monitor the difference between different electrode pairs: I, II, III, aVr, aVl, aVf, and V. The table below shows the active electrodes for each switch setting. The RL lead, if present, is always active, as it is used as a ground, either driven or passive, to reduce noise. If the RL lead is not present, then one of the unused leads is being used as the reference.

SWITCH SETTING	ELECTRODES USED
Lead I	LA, RA
Lead II	LL, RA
Lead III	LL, LA
Lead aVr	RA, LA, LL
Lead aV1	RA, LA, LL
Lead aVf	RA, LA, LL
Lead V	C, RA, LA, LL (rarely used)

The terminology can get confusing between inputs, which have wires which are called leads by the engineer, and inputs, corresponding to clinically significant features, which are also called leads by the clinical staff. Using the term clinically, there are limb leads and modified limb leads. Limb leads have the electrodes placed on the limbs, typically wrists and just above the ankles. Modified limb leads have the electrodes placed on the shoulders and just above the patient's waist. Limb leads are used only for monitoring. For diagnostic purposes, there are 12-lead ECG machines, with electrodes connected at specific spots across the chest, in addition to the modified limb leads. In addition to the six leads already mentioned (Leads I, II, III, aVR, aVL and aVF) the 12-lead machine will display V1, V2, V3, V4, V5 and V6, a total of 12 leads.

To operate, the machine should first be switched on. Then, the device should be connected to the patient via the appropriate series of electrodes. After a few seconds, the device should begin to record the ECG. In some cases, a start button must be pushed. Some of the 12-lead ECG's require a series of user inputs to record the patient's name, gender and other factors.

All inputs are isolated from the power supply of the amplifier by an isolation transformer. This prevents any power supply fault from putting voltage on the electrodes and potentially giving an electrical shock to the patient. Also each input has a diode, resistor or spark gap circuit that will short any high voltage/high current pulses to ground so the amplifier is not damaged by, for example, defibrillation. The input impedance of an ECG amplifier is typically 100 megaohms.

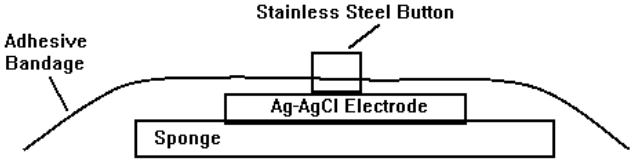
Amplifiers, both those used for monitoring and diagnostics, have a switching mechanism that selects the waveform (lead) to be displayed. The switch may be rotary, pushbutton or flat panel. On some recorders there is an automatic button which switches the output through all leads depending upon the mode. On some units there is a calibrate position on the switch which, when selected, displays a 1 mV signal. The 1 mV calibration signal is used to confirm the gain of the amplifier and is a good way to do a quick check to see if the amplifier is properly functioning. If the output shows the 1 mV signal the amplifier is working.

The standard gain of an ECG amplifier is about 1,000 cm/V, meaning that a 1 mV signal on the body surface creates a 1 cm deflection of the display device. However, some amplifiers have an automatic gain control and some may have switches with settings like 0.25 (gain of 250), 0.5 (gain of 500), 1.0 (gain of 1,000 Standard) 3.0 (gain of 3,000) and 5.0 (gain of 5,000). As with any amplifier, saturation can become a problem, even at the lowest gain setting. This is common when the patient is small, a neonate or a thin, athletic adult. A distorted waveform, usually with some peaks or valleys or, in the worst case, a flat line at the top or bottom of the display will result. There also can be a voltage offset caused by the electrodes placed on the patient. This offset voltage can move the base line up or down and can cause temporary saturation of the amplifier.

ECG amplifiers have two frequency responses that are selectable, monitor and diagnostic. The monitor frequency response for long-term observation of the patient's ECG, as in intensive care, is 0.5 to 35 Hz. Many of the monitors in the developing world do not observe modern standardization of the frequency ranges. Therefore, the monitoring frequency range may range

as high as 50 Hz. The diagnostic frequency response is from 0.1 to 100 Hz, or up to 150 Hz, with or without a notch filter to remove 50 or 60 Hz power line noise.

There are many different types of electrodes used to connect the patient to the monitor. These electrodes range from short to long-term use. Monitoring electrodes are single use items with a central column of conductive material surrounded by a plastic foam or paper tape disc or square to hold the conductive column in place. At the top of the conductive column is a snap that the lead wire is attached to, that goes to the patient cable that goes to the amplifier (figure 2.6.2). These electrodes cost between $0.05 and $0.11 each. They cannot be cleaned or otherwise reused. As these electrodes age, the conductive column will dry out, rendering the electrode useless.



Disposable ECG electrodes look something like large buttons. However, they are often reused in the developing world, making them a constant source of problems.

There are non-disposable alternatives for monitoring. The most common is the plate electrode that is held on to the patient with a rubber belt. Between the electrode and the patient's skin a conductive gel is placed to assure good electrical contact. However, this gel is not critical. A saline soaked gauze, or even a few drops of water, may improve the recording quality. If plate electrodes are in use they should be checked and cleaned on every inspection.

For diagnostic ECG recordings, the most common electrodes are multiuse. The "Welch cup" is the most common of these. This is a cup-shaped, silver-coated electrode with a suction bulb on the top. Corrosion is a common problem as is the lack of suction as the suction bulb ages. It is not unusual to find the suction bulb full of conductive gel and fungus has been known to grow in the bulbs.

There are two general methods of displaying the ECG waveforms, electronically or on paper. The most common form of electronic display is on a screen or CRT. The size of the display and the type of phosphor used in the manufacture of the CRT can enter into the quality of the waveform. The presentation of the ECG trace can be in the same format as a paper/chart presentation with the newest data closest to the left edge of the display, often called a moving or solid trace display. Some manufactures use an ERASE BAR presentation, sometimes called a stationary trace. In this presentation the waveform is stationary and a blank space, or bar, moves across the CRT with the newest data being to the left of the space/bar.

The other common method of waveform presentation is on paper. The size and shape of the paper varies between manufacturers. There are four general types of paper used for waveform presentation, ink, clay, wax and chemical/thermal. Each has specific benefits and problems.

Ink paper has a shiny surface, with grid lines pre-printed. They can be single sheet or continuous strip, roll or z-fold, or a continuous strip that can do a single sheet. In most cases there are many channels of waveform presented with one or more ECG lead configurations per channel. The marking of the leads is done with alpha characters or dots and dashes. If the stylus is not properly maintained there can be blotching or smudging on the waveforms. Wax paper is for hot stylus recordings. It is rare. Thermal paper is the most common paper. It comes in rolls and z-folds. Its distinguishing feature, in most cases, is the lack of grid lines. Thermal paper looks like, and essential is, thermal fax paper. The chart speeds on most

recorders and electronic displays are 25 and 50 mm/sec. Some may have additional speeds. When the chart speed is 25 mm/sec each mm on the horizontal axis is 0.04 seconds.

2.5.2 Common Problems

By far the most common call to engineering is simple user error. ECG's are common donations in the developing world, but the manuals are not. Even when the manuals are delivered with the machines, they are often in a language that the staff does not speak. Even when the staff can read the manual, they often don't. Modern ECG recorders can present a myriad of buttons and controls and can be quite confusing. For all of these reasons, if the machine turns on, the first thing to suspect is user error in the operation of the machine.

A common problem in older machines is getting the correct rate. The heart-rate meter may not have an automatic gain control. In these cases, the user may not realize that they have to adjust the gain for the rate to read correctly.

User error can extend beyond the operation of the machine. Though the positioning of the electrodes is the doctor or nurse's job, when done poorly, it can result in a call to engineering. The most typical symptom is a saturated ECG or an ECG distorted by power line noise. A few points to remember for electrode placement are: 1) electrodes should not be placed on scar tissue, 2) electrodes should not be placed over a lot of body hair, 3) electrodes placed closer than 2 inches from each other may not record a clear signal, and 4) if more than one device requires that electrodes be placed on the patient they may interfere with each other. Switching to different leads, repositioning electrodes and shaving the skin may resolve these problems.

After the electrode the weakest link in an ECG system is the lead wires. The patient cable should last for many years. However, abusive use can lead to wire breakage. Before rejecting a lead wire, try a different wire from another machine to confirm that this is the cause. Lead wires often look to be in poor condition because of tape residue on the cable. This residue can be removed using alcohol or other solvents.

If the lead wire is at fault, replacement is the preferred option. However, lead wires can be repaired in some cases. To find the faulty wire, for each position on the patient selector switch, wiggle the patient cord at its end, in the middle where the five leads fan out, and at the machine plug end. A break will be evidenced by a violent deflection on the display. If the break is in the last, typically quite thin, part of the lead, this can be cut and soldered in the standard fashion, as the last dozen inches are typically unshielded wire. If there is a shield, be sure to reconnect it as well.

The most common problem is in the connection to the main cord, or the connection to the machine. This wire contains potentially two or three layers before the conductor. If the violent deflections occur when the patient cable is wiggled at its plug end, and this occurs with several lead sets, then the socket is broken. As replacement sockets are nearly impossible to find in the developing world, you must consider rebuilding the socket (a time consuming, and often unrewarding venture), or consider permanently soldering the lead set to the machine, if the hospital desperately needs that ECG.

2. Diagrams and Schematics of Electrocardiographs (ECG)

Featured in this Section:

Cromwell, L. et. al. “Fig. 5.1. Block Diagram of an ECG Machine.” From the publication Biomedical Instrumentation and Measurements. Prentice Hall (1973), pg. 155.

Carlson, S. “Citizen Science—DIY ECGs.” *Make:*. Posted march 25, 2013. Retrieved from: http://makezine.com/2013/03/25/citizen-science-diy-ecgs/

ECGpedia.org, “ECG Reference Card.” *Wikipedia*. Retrieved from: http://www.ecgpedia.org/A4/ECGpedia_on_1_A4En.pdf

Openstax College. “The Cardiac Cycle, Fig. 40.14.” From the publication: *Biology*. Rice University: 2013, pgs. 1205.

Figure 1: ECG Quick Reference Card

ECG PEDIA.ORG — part of cardionetworks.org

Before you start

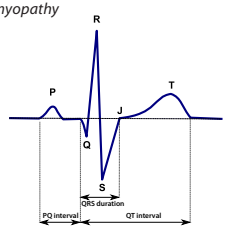
Check name, date, time, paperspeed (25 mm/sec), scale (10 mm/mV). Continue with the 7+2 step-plan.

Step 1: Rhythm

Sinus rhythm(SR) (60-100/min): every P wave is followed by a QRS
Narrow QRS tachycardias (QRS<120ms; >100/min) are always supraventricular tachycardias (SVT):

Sinustachycardia: sinusrhythm > 100/min. *Eg. Fever / Psych. stress / Cardiomyopathy*
Atrial fibrillation (AFIB): irregular
- Permanent = chronic.
- Persisting = recurring after chemical / electrical cardioversion
- Paroxysmal = comes and goes spontaneously: SR ⟶ AFIB ⟶ SR

Atrial flutter: flutter waves on baseline. Often regular 300 / min with a 2:1, 3:1 or 4:1 block.
AVNRT: AV nodal re-entry tachycardia. Regular, 180-250 / min. P in QRS complex (resulting in RsR' in V1), often young patients and paroxysmal. *Valsalva / carotid massage / adenosine can terminate episode.*



Wide complex tachycardias (QRS>120ms): possible risk of sudden death, always consult with cardiologist.

Ventricular tachycardia. Arguments for VT (Brugada criteria): fusion (sudden narrow beat), absence of RS precordialy, RS > 100ms, AV dissociation, atypical LBBB. *Typically in older patient with previous MI. Unconscious? ⟶ proceed to immediate defibrillation.*
SVT with aberrancy. Typical in younger patient. How was the QRS duration / shape on a previous non-tachycardic ECG?
Ventricular fibrillation = no QRS-complexes, but chaotic ECG-pattern, like 'noise' ⟶ mechanical cardiac arrest ⟶ *resuscitate. If patient is conscious it probably is noise.*

Bradycardia (<60/min). Consider stop / reduce beta-blocker / digoxin / Ca-antagonist. *Asymptomatic sinusbradycardia with a normal blood pressure in general doesn't require treatment.*
- **1st degree AV-block**: prolonged PQ-interval (> 200ms)
- **2nd degree AV-block type I (Wenkebach)**: PQ interval increases until 1 QRS complex is blocked. *Good prognosis.*
- **2nd degree AV-block type II (Mobitz)**: PQ interval is normal, but not every P wave is followed by QRS. *Requires pacemaker.*
- **3rd degree AV-block** = complete block. AV dissociation: no relationship between P waves and QRS. *Requires pacemaker.*
- **Ventriculair escape rhythm:** wide complex rhythm < 40/min; dangerous. *Consult cardiologist. Ischemia? Severe electrolyte shift?*

Step 2: Heart rate

Count the number of large grids between two QRS complexes: 1 box in between = 300/min, 2=150/min - 100 - 75 - 60 - 50 - 40. Or use methods at the bottom of this page.

Step 3: Conduction intervals (PQ, QRS, QT)

Normal: PQ <200ms (5 small squares), QRS < 120ms (3 squares), QTc ♂< 450 ms, ♀< 460 ms, preferably measured in lead II or lead V5.

$$QTc = \frac{QT}{\sqrt{RR(\text{in sec})}}$$

PQ > 200ms = AV block (above)
PQ < 120ms + delta-wave = Wolff-Parkinson-White syndrome (WPW), risk of a circus movement tachycardias (= AVRT: AV re-entry tachycardia)
QRS > 120ms = wide QRS complex, check V1:
- **Left Bundle Branch Block (LBBB)** Latest activity towards the left, away from V1, so QRS ends **negatively in V1**. *New LBBB? Consider ischemia.*
- **Right Bundle Branch Block (RBBB)** RsR' (rabbit ear) latest activity rightwards, (on average) **positive in V1**
- **Intraventricular conduction delay=** if it's not LBBB nor RBBB

Maximal QTc per given heart rate: what QT value at what heart rate results in a QTc of 450ms?	
50/min:	QT 493ms
60/min:	QT 450ms
70/min:	QT 417ms
80/min:	QT 390ms
90/min:	QT 367ms
100/min:	QT 349ms

QTc > 450ms: *consider: hypokalemia, post myocardial infarction, long QT syndrome, medication (full list on torsades.org). Risk of torsade de pointes deteriorating into ventricular fibrillation (risk increases especially >500ms).*

Step 4: Heart axis

Heart axis: vector of the average electrical activity. Normal between –30° and +90°. Expecially axis deviation compared to previous ECG is relevant.
Normal hart axis: QRS positive in II and AVF
Left axis: AVF and II negative. *Eg. left anterior fascicular block (LAFB), LVH.*
Right axis. I negative, AVF positive. *Eg. pulmonary embolism, COPD.*

Step 5: P wave morphology

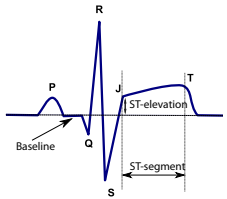
Normal P wave: positive in I and II, bifasic in V1, similar shape in every beat.*Otherwise consider ectopic atrial rhythm.*
Left atrial enlargement: terminal negative part in V1 > 1mm². *e.g. mitral-regurgitation.*
Right atrial enlargement P>2.5mm high in II, III, AVF and / or P>1.5mm in V1. *e.g. COPD*

Step 6: QRS morphology

Pathologic Q waves? Old myocardial infarction (*see ischemia*)
Left ventricular hypertrophy (LVH): R in V5/V6 + S in V1 > 35 mm. *Seen in e.g. hypertension, aortic valve stenosis.*
R wave progression: R increases V1-V5. R>S beyond V3
Microvoltages (<5mm in extremity leads): *E.g. cardiomyopathy, tamponade, obesity, pericarditis*
Wide QRS complex (QRS > 120ms): see Step 3

Step 7: ST morphology

ST elevation: *consider ischemia, pericarditis, LVH, benign ST elevation, 'early repolarisation'*
ST depression: *can be reciprocal in ischemie, strain pattern in LVH, digoxin intoxication*
Negative T wave: (not in the same direction as the QRS complex) *consider (subendocardial) ischemia, LVH*
Flat T wave (<0.5 mm): *aspecific*



How to measure ST elevation?

Step +1: Compare with previous ECG

New LBBB? Change in axis?. New pathologic Q waves? Reduced R wave height?

Step +2: Conclusion (1 sentence)

Example: Sinustachycardia with ST elevation in the chest leads with a trifascicular block consistent with an acute anterior myocardial infarction

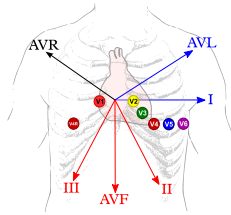
Ischemia

Acute myocardial infarction (AMI): symptoms (chest pain, vagal response), ECG consistent with transmural ischemia (ST elevations (+reciprocal depressions), new LBBB, sometimes already pathologic Q waves), sometimes already elevated cardiac markers for AMI (Troponin / CKMB). 'Time is muscle'. If you suspect AMI ⟶ consult cardiologist immediately (< 5 min.)
ST-elevation points at the infarcted area:
- **Anterior:** V1-V4. Coronary territory: LAD. *sometimes tachycardia*
- **Inferior:** II, III, AVF. Coronary: 80% RCA (bradycardia, elevation III>II; depression in I and / or AVL), otherwise RCX (in 20%).
- **Right ventricular MI:** ST↑ in V1 and V4R. *IV fluids if hypotensive*
- **Posterior:** high R wave and ST depressie in V1-V3
- **Lateral:** elevation in I, AVL, V6. Coronary: LAD (Diagonal branch)
- **Left main:** diffuse ST depression with ST elevation in AVR. Very high risk of cardiogenic shock

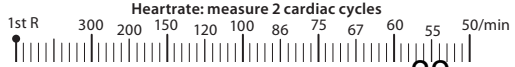
Reciprocal depression: depression in reciprocal territory (e.g. ST depression in II, III, AVF during anterior MI).
IPL-infarction: inferior-posterior-lateral. They frequently come together
Pathologic Q-wave (any Q in V1-V3 or Q width > 30ms in I, II, AVL, V4-V6; minimal in 2 contiguous leads, minimal depth 1 mm): previous MI. Leads III and AVR may have a Q wave, which is non-pathological.

Miscellaneous

VPB (ventricular premature beat, VES: ventricular extrasystole, PVC, Premature ventr. contr.). QRS > 120ms. Seen in 50% of healthy men. Increased risk of arrhythmias if: complex form, very frequent occurence (> 30 / hour) or R on T. Consider: Ischemia? Previous MI? Cardiomyopathy?
PAC (premature atrial contraction, AES): abnormal P wave, mostly narrow (normal) QRS complex
Pericarditis: ST elevation in all leads. PTA depression in II (between the end of the P wave and the beginning of Q wave)
Hyperkalemia: tall T waves. QRS wide, flat P
Hypokalemia: QT prolongs, U wave, torsade
Hypocalcemia: ST prolongs, 'normal' T
Hypercalcemia: QT short, high T
Digoxin-intoxication: sagging ST depressions
Pulmonary embolism: sinustachycardia, deep S in I, Q wave and negative T in III, negative T V1-V3, right axis, sometimes RBBB
Chest lead positioning: V1= 4th intercostal space right (IC4R), V2=IC4L, V3=between V2 en V4, V4=IC5 in midclavicular line, V5=between V4 and V6, V6= same height as V4 in axillary line. To register V4R, use V3 in the right mid-clavicular line.

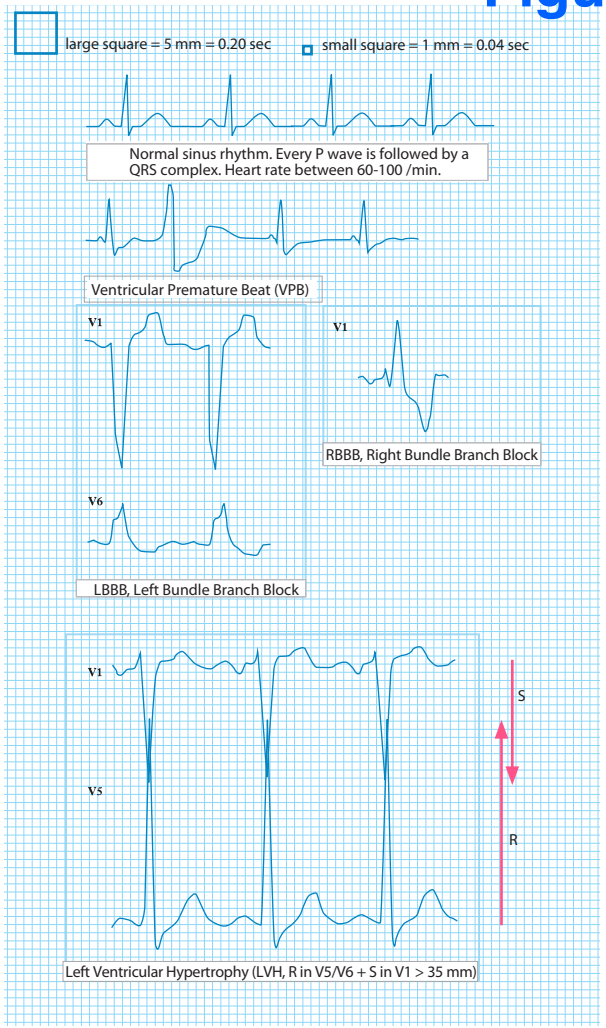


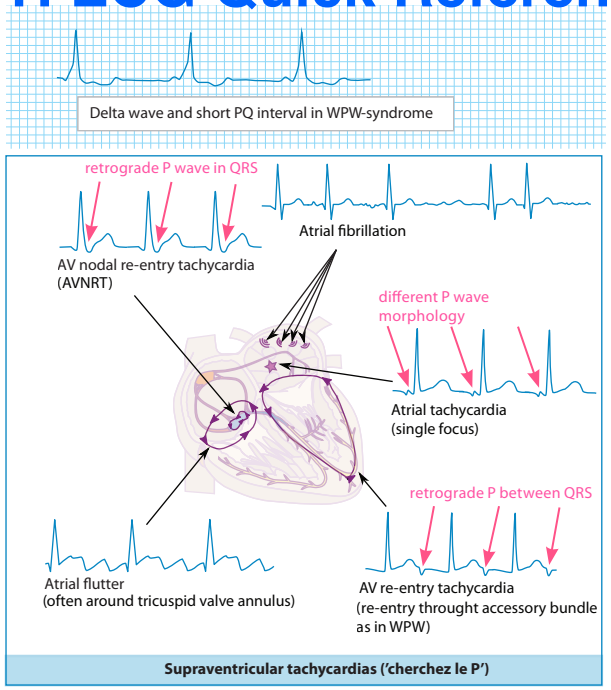
Heartrate: measure 2 cardiac cycles



Heart rate = 10 times number of QRS complexes within these 15 cm (= 6 seconds x 25 mm/sec)

Figure 1: ECG Quick Reference Card





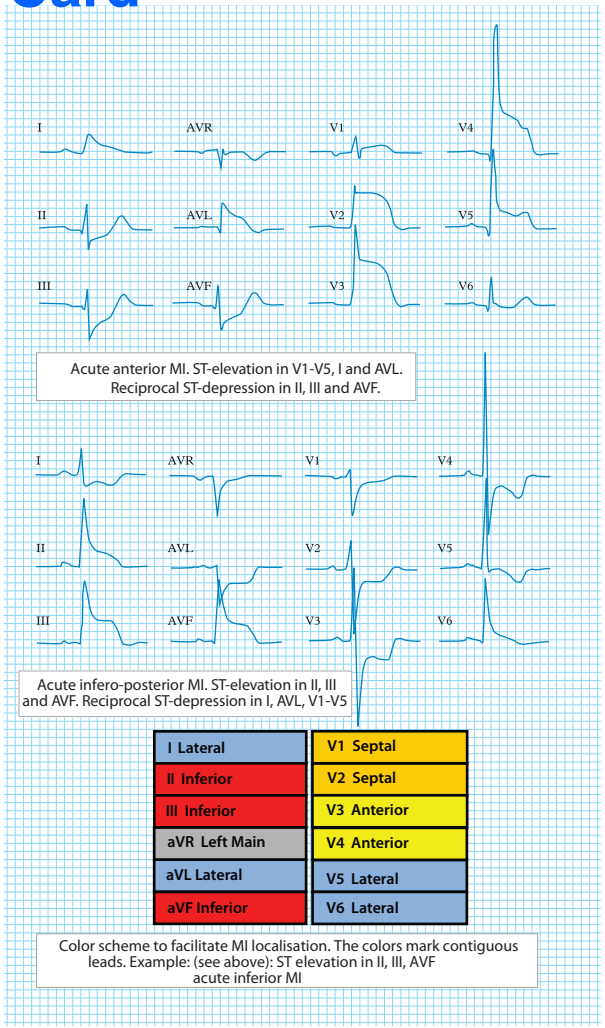


Figure 2: The Heart and Electrocardiogram Readings

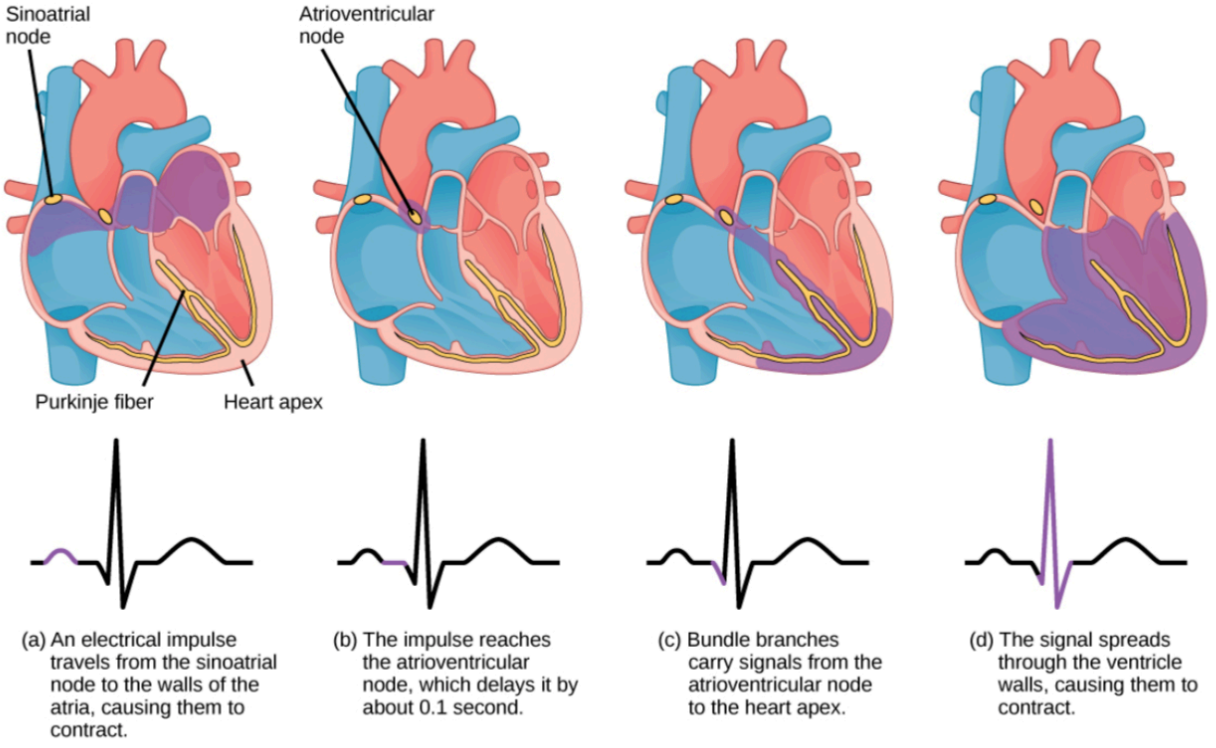
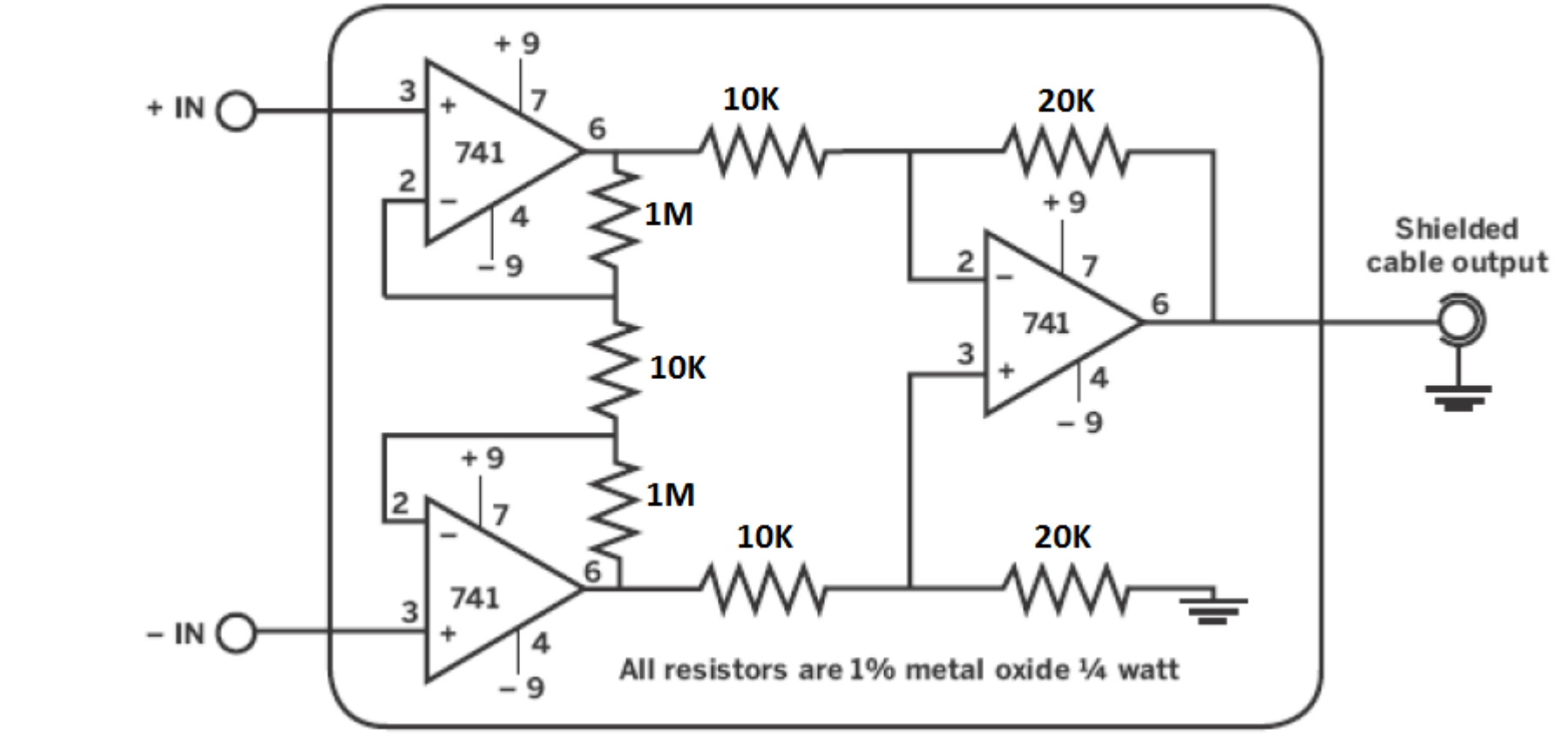


Figure 40.14 The beating of the heart is regulated by an electrical impulse that causes the characteristic reading of an ECG. The signal is initiated at the sinoatrial valve. The signal then (a) spreads to the atria, causing them to contract. The signal is (b) delayed at the atrioventricular node before it is passed on to the (c) heart apex. The delay allows the atria to relax before the (d) ventricles contract. The final part of the ECG cycle prepares the heart for the next beat.

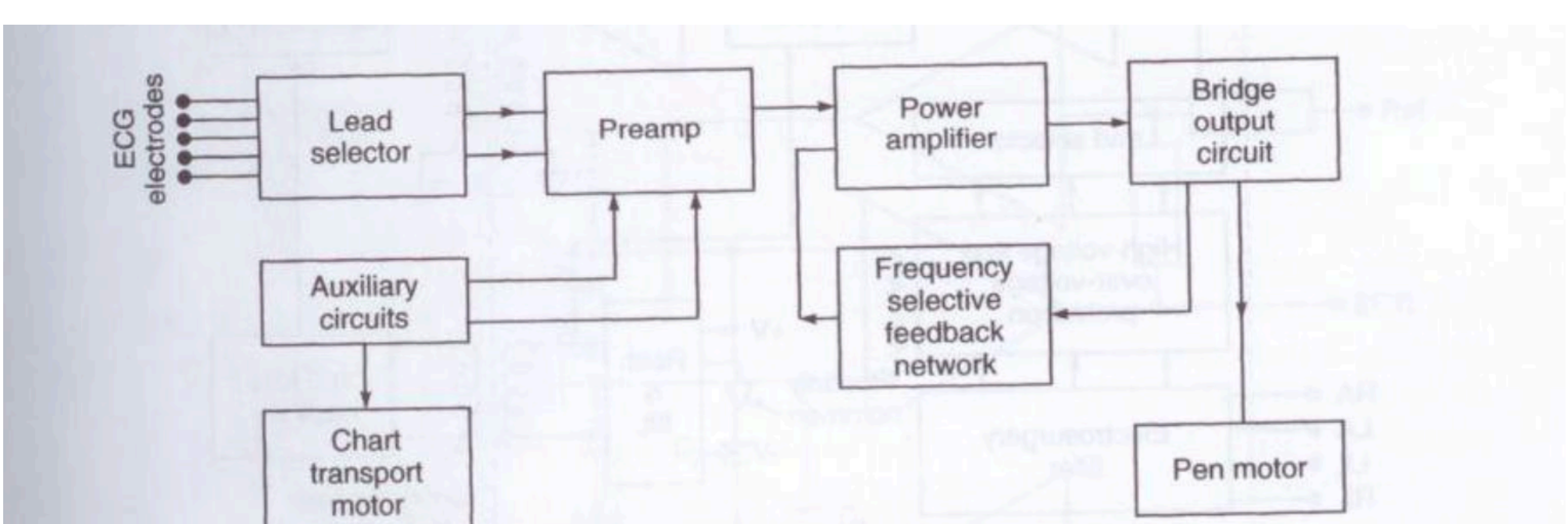
Openstax College. "The Cardiac Cycle, Fig. 40.14." From the publication: Biology. Rice University: 2013, pgs. 1205.

Figure 3: Instrumentation Amplifier



Carlson, S. "Citizen Science—DIY ECGs." Make:. Posted march 25, 2013. Retrieved from: http://makezine.com/2013/03/25/citizen-science-diy-ecgs/

Figure 4: Block Diagram of a Electrocardiograph Machine



➤ **Fig. 5.1** *Block diagram of an ECG machine*

Cromwell, L. et. al. "Fig. 5.1. Block Diagram of an ECG Machine." From the publication Biomedical Instrumentation and Measurements. Prentice Hall (1973), pg. 1

3. Preventative Maintenance and Safety of Electrocardiographs (ECG)

Featured in this Section:

Developing World Healthcare Technologies Laboratory, "ECG Monitor: How To Use." *DHT Lab*, Duke University, 2006.

Cooper, Justin and Alex Dahinten for EWH. "Electrocardiogram (ECG) Preventative Maintenance." From the publication: *Medical Equipment Troubleshooting Flowchart Handbook*. Durham, NC: Engineering World Health, 2013.

EQUIPMENT

Electrocardiogram (ECG) Preventative Maintenance

Preventative Maintenance

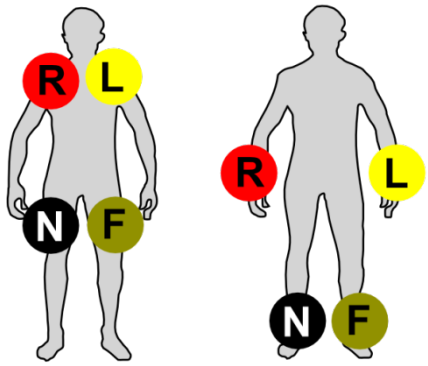
- Clean casing
- Clean electrodes and inspect for corrosion or adhered debris after each use
- Inspect insulation for defects and debris
- Inspect cables for defects, replace if necessary
- If battery-powered, regularly check batteries to prevent corrosion
- Re-stock and refill ink and paper as needed

Electrode Guide

Proper Placement of 12 Lead ECG

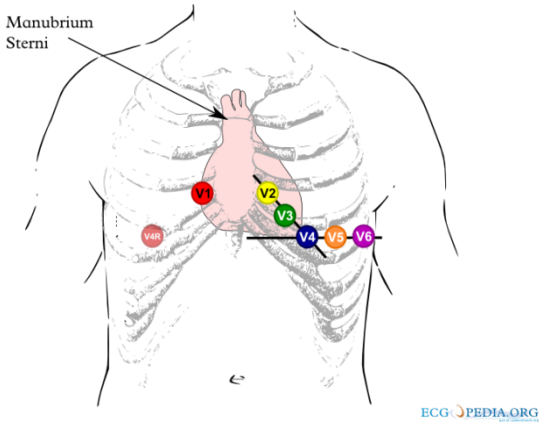
For the 4 extremity electrodes placement:

- L or LA is placed on the left arm
- R or RA is placed on the right arm
- N - neutral, on the right leg (= electrical earth, or point zero, to which the electrical current is measured)
- F - foot, on the left leg
- It does not matter whether the electrodes are placed on the bottoms or tops of extremities, but be consistent. Place electrodes in similar spots on extremities. (eg. do not attach an electrode on the left shoulder and one on the right wrist). Also, avoid bony parts such as elbows or knees.



For the 6 chest electrodes placement:

- V1 is placed to the right of the sternum in the 4th intercostal space.
- V2 is placed to the left of the sternum in the 4th intercostal space



- V3 is placed between V2 and V4
- V4 is placed in the 5th intercostal space on the nipple line. Place V4 beneath the breast in women.
- V5 is placed between V4 and V6
- V6 is placed in the midaxillary line on the same height as V4 on the horizontal line from V4 (not necessarily in the 5th intercostal space)

Common lead misplacements:

- Right and left arm electrode reversal
- Right leg and right arm electrode reversal
- Left arm and left leg electrode reversal
- Right arm and left leg electrode reversal
- Left arm and right leg electrode reversal

To make replacement ECG pads:

Materials

1. Bottle caps
2. Nickel-plated brass sewing snap buttons, size 3
3. Flathead screwdriver
4. Utility knife (boxcutter, X-Acto or another sharp-bladed, small knife)
5. Pot, water and a stove
6. Optional: tweezers/forceps

Steps

1. Boil the bottle caps in water for 30 minutes.
2. Peel off the lining. Start the peel by prying an edge off with the screwdriver, then carefully pull the rest out with your fingers or with tweezers or forceps. Take care not to rip the lining during this process. If the lining is too hard to remove, heat the cap in the water again.
3. Make an "X" in the center of the lining, about 1cm big.
4. Insert a size-3 nickel-plated brass sewing snap into it.
5. Trim the tiny corners of plastic from the edge of the button nub.

To make ECG conductive gel:

Materials

1. Water, one cup
2. Salt, two tablespoons
3. Flour, one cup
4. Bleach

Steps

1. Mix the water and salt.
2. Slowly pour in the flour. The mixture will become gelatinous. Mix it until it the consistency is the same.
3. Add a drop of bleach (to make the gel sterile).

Proper skin preparation:

1. Shave body hair before application, if in excess.
2. Avoid placing electrodes on any burn or scar tissue.
3. Make sure electrodes have some sort of conductive gel between skin and metal contact.
4. Make sure electrode is firmly attached to skin. Apply tape, if necessary.
5. If steps 1-4 struggle, use a light skin abrasive such as sand paper.
6. Reapply conducting gel every couple of hours to avoid skin irritation and loss of signal.

Electrocardiograph Calibration

Knowledge Domain: Mechanical
Unit: Calibration
Skill: ECG Monitor

Tools and Parts Required:

1) **ECG that requires calibration**
2) **A test patient**
3) **Alcohol swab**
4) **Watch that counts seconds**

Introduction

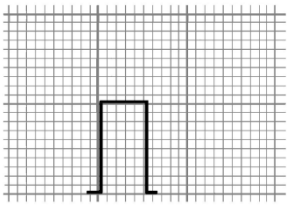
Electrocardiographs (ECGs) monitor the electrical activity of the heart. ECGs are used to detect heart attacks or diagnose abnormal heart rhythms. ECGs are found in ambulances, intensive care units, and other healthcare facilities. Sometimes ECGs also have an apnea monitor. Apnea monitors detect changes in breathing.

Identification and Diagnosis

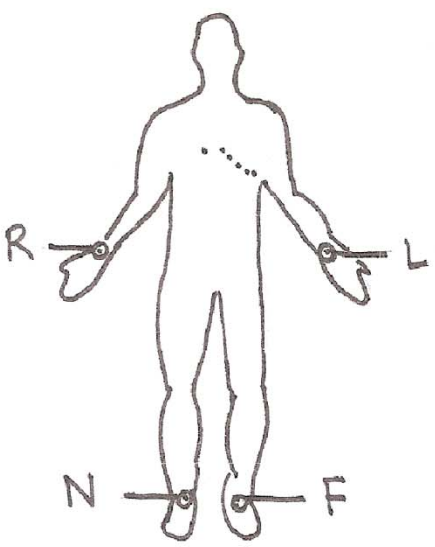
ECG monitors should be calibrated about every six months, as part of preventative maintenance.

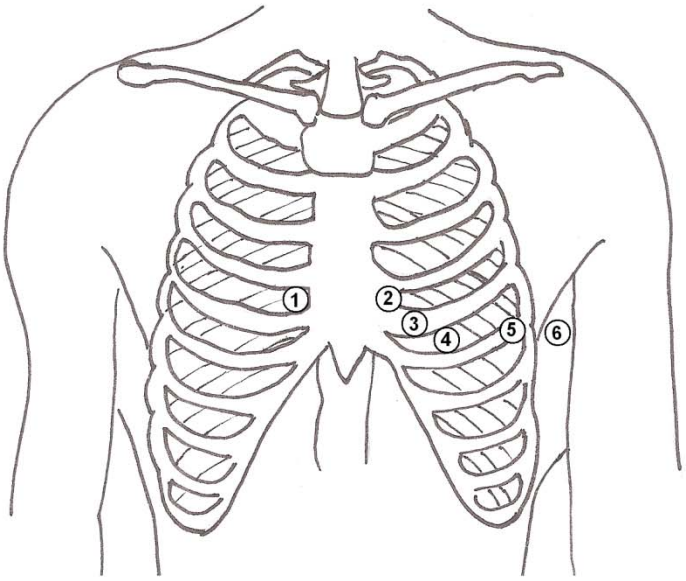
Procedure

1. Turn the machine on. Depress the “1 millivolt” or “calibration” button.
    a. For analog machines: Check that the stylus has deflected 10 small squares, similar to the picture at right.
    b. For electric machines: Insure that a square wave form appears when the button is pressed. The wave should resemble the picture at right.

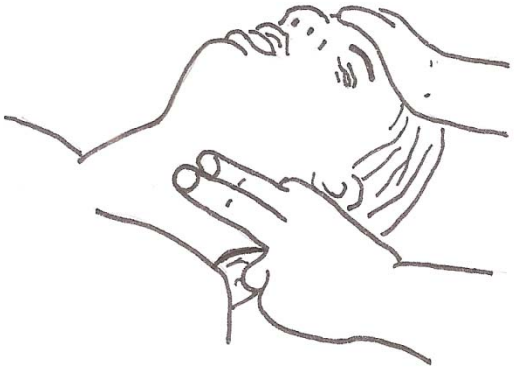


2. Find someone who will be your test patient.
3. Clean the test patient’s chest with an alcohol swab. Attach the electrodes and leads to the patient. Follow the ECG manual for electrode placement. Use the pictures below as a guide. The number of electrodes you will attach depends if the ECG is made for 3-lead (monitoring) or 12-lead (diagnostic) use. 3-lead ECG’s generally have four connections to the patient. 12-lead ECG’s have ten connections to the patient.





4. Check the ECG heart rate measurement
   - Find the patient's pulse. You can find the pulse in two places. The radial pulse is on the inside of the wrist. The carotid pulse is between the windpipe and large muscle in the neck. Place two fingers on one of these areas. Press lightly until you feel a pulse. Do not use your thumb to take pulse.



   - Using a watch to time 30 seconds, count the heartbeats. Multiply the number of heartbeats by 2. This is the patient's heart rate.
   - Compare the calculated heart rate to the ECG's reading. The ECG reading should match within 2 beats per minute.
5. Check the alarms*
   - Set the maximum heart rate by navigating through the machine's menus** to an option resembling "alarm limits." Set the maximum heart rate on the ECG machine below your patient's heart rate. The high heart rate (tachycardia) alarm should sound.

- Set the minimum rate alarm on the ECG machine above your patient's heart rate. The low heart rate (bradycardia) alarm should sound.
- Remove the wires from the patient. The electrode-off (or lead-off) alarm on the ECG machine should sound.

If the ECG has an apnea monitor, follow this procedure:

6. Attach the electrodes to the patient following the picture guide and the ECG manual.
7. Check the breathing rate
   - Count how many breaths are taken over 1 minute.
   - Compare the calculated breathing rate to the ECG machine's reading. The ECG machine's reading should be within 1 breath per minute.
8. Check the alarms
   - Set the maximum breathing rate on the ECG apnea monitor below your patient's breathing rate. The high breathing (hyperventilation) alarm should sound.
   - Set the minimum breathing rate on the ECG apnea monitor above your patient's breathing rate. The low breathing (hypoventilation) alarm should sound.
   - Instruct the patient to hold his breath. The apnea alarm should sound.

*Note: Not all ECG monitors have all alarms.

** Menus for different device models may differ.

Exercise

Calibrate your ECG with a partner. Your instructor must verify your work before you continue.

Preventative Maintenance and Calibration

Always calibrate every medical device before returning it to use.

4. Troubleshooting and Repair of Electrocardiographs (ECG)

Featured in this Section:

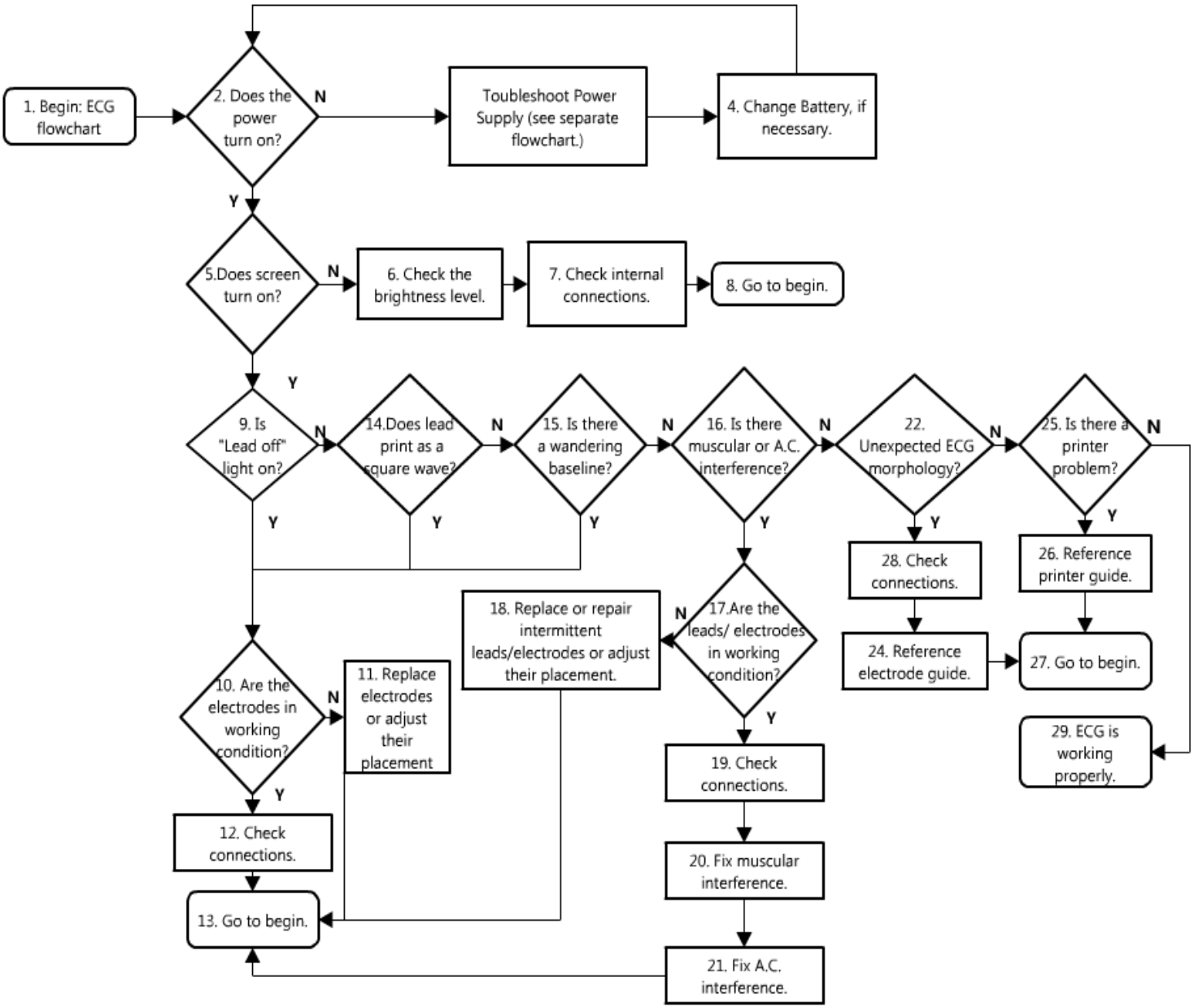
Cooper, Justin and Alex Dahinten for EWH. “Electrocardiogram (ECG) Troubleshooting Flowchart.” From the publication: *Medical Equipment Troubleshooting Flowchart Handbook*. Durham, NC: Engineering World Health, 2013.

Strengthening Specialised Clinical Services in the Pacific. *User Care of Medical Equipment: A first line maintenance guide for end users*. (2015).

ECG Troubleshooting Flowchart

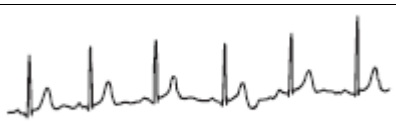
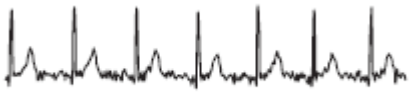
Electrocardiogram (ECG) Repair and Troubleshooting

Flowchart



Description

#	Text Box	Comments
1	Begin: ECG flowchart	Start diagnostic process for a work order on an ECG
2	Does ECG power on?	Lights, displays, and sounds are indications that device is powered on. Also, check the power cords for continuity. See BTA skills on Connections.
3	Troubleshoot power supply (separate flowchart)	ECG's have an AC to DC power supply. See Flowchart on Power Supply, and BTA skills on Power Supply.
4	Change battery if necessary.	If there is a battery, test its ability to receive and hold a charge. See BTA skills on Batteries.
5	Does screen turn on?	No obvious brightness or color change on display screen?
6	Check brightness level.	If possible, raise brightness level of screen.
7	Check internal connections.	Check for obvious wiring issues such as damaged or disconnected wires. See BTA skills for Connections and Electrical Simple.
8	Go to begin.	Return to box 1, Begin: ECG
9	Is "Lead off" light on?	"Lead off" light will likely be near display window. It indicates that there is a bad connection somewhere between the patient electrodes and the machine. (1) See BTA skills for Electrical Simple.
10	Are the electrodes in working condition?	Check for damage or corrosion to the electrode or electrode insulation.
11	Replace electrodes or adjust their placement.	See electrode guide below for replacement of electrodes as well as electrode placement and a conducting gel recipe. If possible, attach a patient simulator to the patient cables. If proper signal with simulator, electrodes are non-functional.
12	Check connections.	If possible, attach patient simulator to patient cables, if no signal replace cables. Ensure proper connections between ECG and electrodes and ensure patient is not moving. Make sure electrode has proper contact with patient's skin. (1) See BTA skills for Electrical Simple.
13	Go to Begin.	Return to box 1, Begin: ECG
14	Does lead print as square wave?	Does one or more lead display as a square wave?  (1)
15	Is there a wandering baseline?	Does display show an unsteady baseline signal?

		 (1) Note: In an analog ECG machine, a wandering baseline may be caused by the INSTO adjust or if the stylus pegs violently
16	Is there muscular interference or AC interference?	Does display show muscular or AC interference (picture): Even peaked, regular voltage superimposed on waveforms?  (1)
17	Are leads/electrodes in working condition?	Check for damage or corrosion to the electrode or electrode insulation. If possible, attach a patient simulator to the patient cables. If proper signal with simulator, electrodes are non-functional.
18	Replace or repair intermittent leads/electrodes or adjust their placement.	See electrode guide below for replacement of electrodes as well as electrode placement and a conducting gel recipe.
19	Check connections.	If possible, attach patient simulator to patient cables, if no signal replace cables. Ensure proper connections between ECG and electrodes and ensure patient is not moving. Make sure electrode has proper contact with patient's skin. (1) See BTA skills for Electrical Simple.
20	Fix muscular interference.	Make sure patient is comfortable and not tense, if possible turn on muscular filter. See user's manual for instructions on muscular filter. (1)
21	Fix AC interference.	Verify that patient is not touching any metal. Verify power cable is not touching patient cable. If possible, turn on AC filter according to instructions in user's manual. Also, try running on battery power, if possible. (1) See BTA skills on Power Supply and Electrical Simple.
22	Unexpected ECG morphology?	Does display show an unexpected ECG morphology?
23	Reference electrode guide.	Check electrode guide below, particularly on lead placement to ensure proper location.
24	Check connections.	If possible, attach patient simulator to patient cables, if no signal replace cables. Ensure proper connections between ECG and electrodes and ensure patient is not moving. Make sure electrode has proper contact with patient's skin. (1) See BTA skills for Electrical Simple.

25	Is there a printer problem?	Does printer not print or print output that does not match display
26	Refer to printer guide	Use Printer flowchart to determine possible problems with printer output. ? If it is an analog ECG machine, the stylus heat and pressure can cause poor trace display. Refer to the service manual or online documentation.
27	Go to Begin	Return to box 1, Begin: ECG
28	Check connections	If possible, attach patient simulator to patient cables, if no signal replace cables. Ensure proper connections between ECG and electrodes and ensure patient is not moving. Make sure electrode has proper contact with patient's skin. (1) See BTA skills for Electrical Simple.
29	ECG is working properly.	Return the machine to service via the appropriate clinical personnel.

ECG Troubleshooting Table

User Care of Medical Equipment – First line maintenance for end users

Troubleshooting – ECG Machines

	Fault	Possible Cause	Solution
1.	ECG traces have artefacts or base line drift	Improper earthing	Check for good connection of reference electrode Try with battery power only. If the recording improves then problem is with earthing. Check the earthing Power the machine from another outlet with proper electrical earth
2.	ECG traces have artefacts in one or more traces, but not in all traces	Improper electrode connection with patient or problem with the ECG cable	Check the patient cable continuity with continuity tester. Replace cable if found faulty Check the electrodes expiration date Check patient skin preparation Reposition electrodes Check limb electrodes and chest electrodes for damage, replace if necessary
3.	Paper feed not advancing	Incorrect paper loading	Use instructions to reload paper
4.	Printing not clear or not uniform	Printing head problem	Adjust the printing head temperature or position Clean the printing head with head cleaner. If no improvement, replace the printing head. Check the paper roller and replace if not smooth
5.	The machine shuts down after a few minutes while on battery power.	Problem with battery or charging circuit	Recharge the unit overnight If there is no improvement then replace the battery (if accessible) If still no improvement, refer to technician

User Care Checklist – ECG Machines

Daily	
Cleaning	✓ Clean off dust with dry cloth ✓ Wipe gel off reusable electrodes after every use
Visual checks	✓ Check that battery charge indicator, power indicator and patient cable connector indicators are working
Function checks	✓ Check operation of machine before use using 1mV pulse ✓ Check the baseline of the ECG recording is steady ✓ Check the printing is clear and replace dust cover

Weekly	
Cleaning	✓ Clean the printing head, electrodes and connectors
Visual checks	✓ Check all cables are not bent, knotted or damaged ✓ Replace any damaged electrical plugs, sockets or cables ✓ Check all knobs, switches and indicators are tightly fitted
Function checks	✓ Check the operation of recordings with 1mV pulse button ✓ Check battery power can operate the equipment

Every six months
Biomedical Technician check required

5. Resources for More Information Electrocardiographs (ECG)

Featured in this Section:

ECGpedia.org, "Welcome to ECGpedia." *Wikipedia*. Retrieved from: http://en.ecgpedia.org/

WHO. "Electrocardiograph Machine and Stethoscopes." From the publication: *Maintenance and Repair of Laboratory, Diagnostic Imaging and Hospital Equipment*, WHO, 1996.

Resources for More Information:

Internal Resources at library.ewh.org: For more information about ECG's, please see the following resources in the BMET Library!

1. WHO. "Electrocardiograph Machine and Stethoscopes." From the publication: *Maintenance and Repair of Laboratory, Diagnostic Imaging and Hospital Equipment*, WHO, 1996.

External Resources for More Information:

2. **ECGpedia:** This website is a comprehensive, open-source resource about the use, operation, and theory behind electrocardiograms. This website includes videos, a textbook, case studies, and an ECG course. ECGpedia.org, "Welcome to ECGpedia." *Wikipedia*. Retrieved from: http://en.ecgpedia.org/
    - **ECGpedia Homepage:** http://en.ecgpedia.org/
    - **ECG Textbook:** http://en.ecgpedia.org/wiki/Textbook
    - **ECG Videos:** http://en.ecgpedia.org/
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