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Performing an Electrocardiogram Using the ECG Application on Apple Watch

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Annotation: The research project discusses the electrocardiogram and its usefulness in diagnosing various diseases that affect the heart and helps in finding the appropriate solution to these diseases using the application of the electrocardiogram on the Apple Watch, as well as the design and manufacture of a portable device to measure the electrocardiogram.

Introduction

The first attempts to record the electrical activity of the muscle were made by a number of Scientists started in 1666 by (Franciscoridi), and in 1792 it was published report of the Italian scientist (Luigi Galvani) who applied a preliminary recording process for the contractile muscle, after that, research continued in the field of electrocardiography, as follows:

- In 1872, Alexander Muirhead is reported to have attached wires to the wrist of a patient with fever to obtain an electronic record of their heartbeat.
- In 1882, John Burdon-Sanderson working with frogs, was the first to appreciate that the interval between variations in potential was not electrically quiescent and coined the term "isoelectric interval" for this period.

- In 1887, Augustus Waller invented an ECG machine consisting of a Lippmann capillary electrometer fixed to a projector. The trace from the heartbeat was projected onto a photographic plate ؛ This allowed a heartbeat to be recorded in real time.
- In 1895, Willem Einthoven assigned the letters P, Q, R, S, and T to the deflections in the theoretical waveform he created using equations which corrected the actual waveform obtained by the capillary electrometer to compensate for the imprecision of that instrument. He continued to use the letters P, Q, R, S, and T, and these letters are still in use today.
- In 1897, the string galvanometer was invented by the French engineer Clément Ader.
- In 1901, Einthoven, working in Leiden, the Netherlands, used the string galvanometer: the first practical ECG. This device was much more sensitive than the capillary electrometer Waller used.

2-1 Electrocardiograms

Electrocardiograms are recorded by machines that consist of a set of electrodes connected to a central unit. Early ECG machines were constructed with analog electronics, where the signal drove a motor to print out the signal onto paper. Today, electrocardiographs use analog-to-digital converters to convert the electrical activity of the heart to a digital signal. Many ECG machines are now portable and commonly include a screen, keyboard, and printer on a small wheeled cart. Recent advancements in electrocardiography include developing even smaller devices for inclusion in fitness trackers and smart watches. These smaller devices often rely on only two electrodes to deliver a single lead I. Portable six-lead devices are also available.

Recording an ECG is a safe and painless procedure. The machines are powered by mains power but they are designed with several safety features including an earthed (ground) lead. Other features include:

- Defibrillation protection: any ECG used in healthcare may be attached to a person who requires defibrillation and the ECG needs to protect itself from this source of energy.
- Electrostatic discharge is similar to defibrillation discharge and requires voltage protection up to 18,000 volts.
- Additionally, circuitry called the right leg driver can be used to reduce common-mode interference (typically the 50 or 60 Hz mains power).
- ECG voltages measured across the body are very small. This low voltage necessitates a low noise circuit, instrumentation amplifiers, and electromagnetic shielding.
- Simultaneous lead recordings: earlier designs recorded each lead sequentially, but current models record multiple leads simultaneously.

Most modern ECG machines include automated interpretation algorithms. This analysis calculates features such as the PR interval, QT interval, corrected QT (QTc) interval, PR axis, QRS axis, rhythm and more. The results from these automated algorithms are considered "preliminary" until verified and/or modified by expert interpretation.

2-2 Cardiac monitors

Besides the standard electrocardiograph machine, there are other devices capable of recording ECG signals. Portable devices have existed since the Holter monitor was produced in 1962. Traditionally, these monitors have used electrodes with patches on the skin to record the ECG, but new devices can stick to the chest as a single patch without need for wires. Implantable devices such as the artificial cardiac pacemaker and implantable cardioverter-defibrillator are capable of measuring a "far field" signal between the leads in the heart and the implanted battery/generator that resembles an ECG signal (technically, the signal recorded in the heart is called an electrogram, which is interpreted differently). Advancement of the Holter monitor became the implantable loop recorder that performs the same function but in an implantable device with batteries that last on the order of years. Additionally, smartwatch devices are capable of recording an ECG signal as well, such as with the 4th generation Apple Watch.

2-3 Electrodes and leads

Electrodes are the actual conductive pads attached to the body surface. Any pair of electrodes can measure the electrical potential difference between the two corresponding locations of attachment. Such a pair forms a lead. However, "leads" can also be formed between a physical electrode and a virtual electrode, known as Wilson's central terminal (WCT), whose potential is defined as the average potential measured by three limb electrodes that are attached to the right arm, the left arm, and the left foot, respectively.

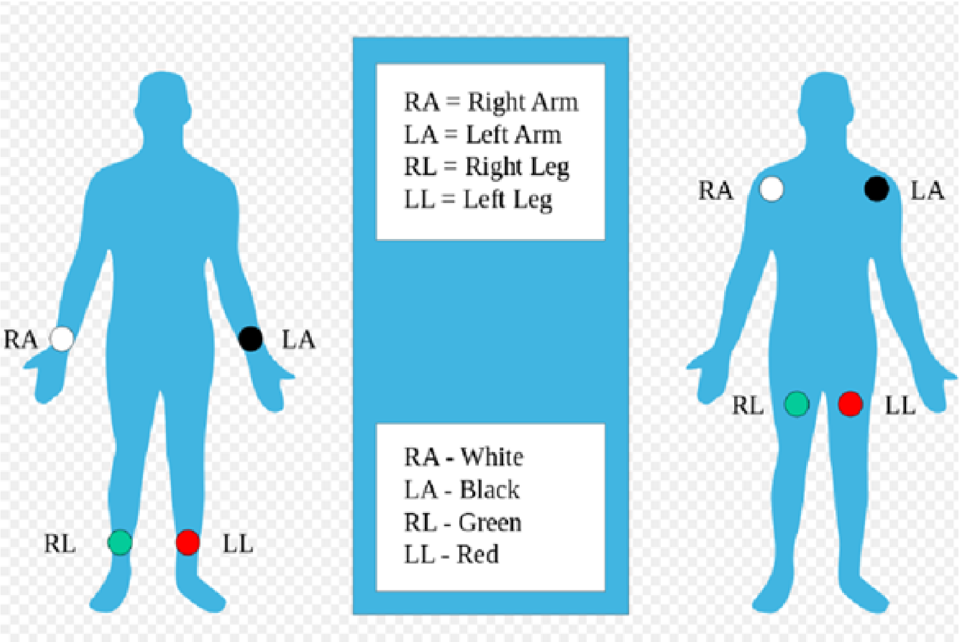

Fig. (2-1) represent Proper Placement of the Limb Eelectrodes

Commonly, 10 electrodes attached to the body are used to form 12 ECG leads, with each lead measuring a specific electrical potential difference (as listed in the table below).

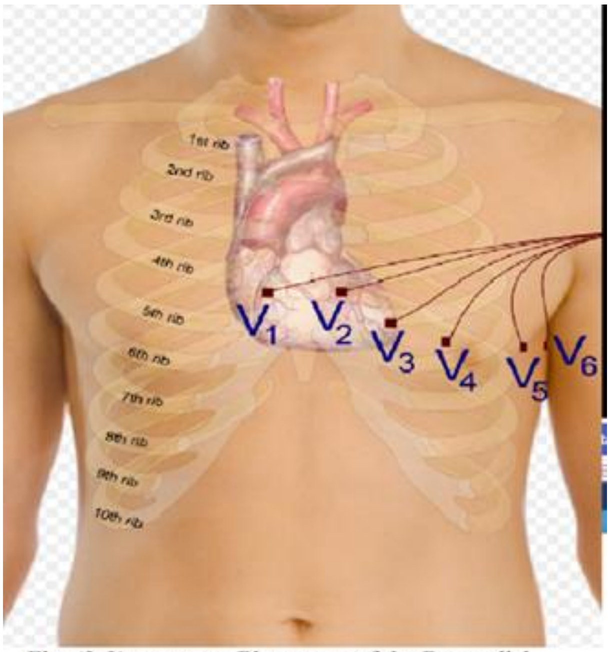

Fig. (2-2) represent Placement of the Precordial Electrodes

Leads are broken down into three types: limb; augmented limb; and precordial or chest. The 12-lead ECG has a total of three limb leads and three augmented limb leads arranged like spokes of a wheel in the coronal plane (vertical), and six precordial leads or chest leads that lie on the perpendicular transverse plane (horizontal).

The 10 electrodes in a 12-lead ECG are listed below.

Electrode name	Electrode placement
RA	On the right arm, avoiding thick muscle.
LA	In the same location where RA was placed, but on the left arm.
RL	On the right leg, lower end of inner aspect of calf muscle. (Avoid bony prominences)
LL	In the same location where RL was placed, but on the left leg.
V_1	In the fourth intercostal space (between ribs 4 and 5) just to the right of the sternum (breastbone)
V_2	In the fourth intercostal space (between ribs 4 and 5) just to the left of the sternum.
V_3	Between leads V_2 and V_4.
V_4	In the fifth intercostal space (between ribs 5 and 6) in the mid-clavicular line.
V_5	Horizontally even with V_4, in the left anterior axillary line.
V_6	Horizontally even with V_4 and V_5 in the mid-axillary line.

Two types of electrodes in common use are a flat paper-thin sticker and a self-adhesive circular pad. The former are typically used in a single ECG recording while the latter are for continuous recordings as they stick longer. Each electrode consists of an electrically conductive electrolyte gel and a silver/silver chloride conductor. The gel typically contains potassium chloride – sometimes silver chloride as well – to permit electron conduction from the skin to the wire and to the electrocardiogram.

The common virtual electrode, known as Wilson's central terminal (V_W), is produced by averaging the measurements from the electrodes RA, LA, and LL to give an average potential of the body:

$$V_W = \frac{1}{3}(\text{ RA} + \text{LA} + \text{LL})$$

In a 12-lead ECG, all leads except the limb leads are assumed to be unipolar (aVR, aVL, aVF, V1, V2, V3, V4, V5, and V6). The measurement of a voltage requires two contacts and so, electrically, the unipolar leads are measured from the common lead (negative) and the unipolar lead (positive). This averaging for the common lead and the abstract unipolar lead concept makes for a more challenging understanding and is complicated by sloppy usage of "lead" and "electrode". In fact, instead of being a constant reference, VW has a value that fluctuates throughout the heart cycle. It also does not truly represent the center-of-heart potential due to the body parts the signals travel through.

2-3-1 Limb leads

Leads I, II and III are called the limb leads. The electrodes that form these signals are located on the limbs – one on each arm and one on the left leg. The limb leads form the points of what is known as Einthoven's triangle.

- Lead I is the voltage between the (positive) left arm (LA) electrode and right arm (RA) electrode:

I = LA - RA

- Lead II is the voltage between the (positive) left leg (LL) electrode and the right arm (RA) electrode:

II = LL - RA

- Lead III is the voltage between the (positive) left leg (LL) electrode and the left arm (LA) electrode:

III = LL - LA

2-3-2 Augmented limb leads

Leads aVR, aVL, and aVF are the augmented limb leads. They are derived from the same three electrodes as leads I, II, and III, but they use Goldberger's central terminal as their negative pole. Goldberger's central terminal is a combination of inputs from two limb electrodes, with a different combination for each augmented lead. It is referred to immediately below as "the negative pole".

- Lead augmented vector right (aVR) has the positive electrode on the right arm. The negative pole is a combination of the left arm electrode and the left leg electrode:

$$aVR = RA - \frac{1}{2}(LA + LL) = \frac{3}{2}(RA - V_W)$$

- Lead augmented vector left (aVL) has the positive electrode on the left arm. The negative pole is a combination of the right arm electrode and the left leg electrode:

$$aVL = LA - \frac{1}{2}(LA + LL) = \frac{3}{2}(LA - V_W)$$

- Lead augmented vector foot (aVF) has the positive electrode on the left leg. The negative pole is a combination of the right arm electrode and the left arm electrode:

$$aVF = LL - \frac{1}{2}(LA + LL) = \frac{3}{2}(LL - V_W)$$

Together with leads I, II, and III, augmented limb leads aVR, aVL, and aVF form the basis of the hexaxial reference system, which is used to calculate the heart's electrical axis in the frontal plane.

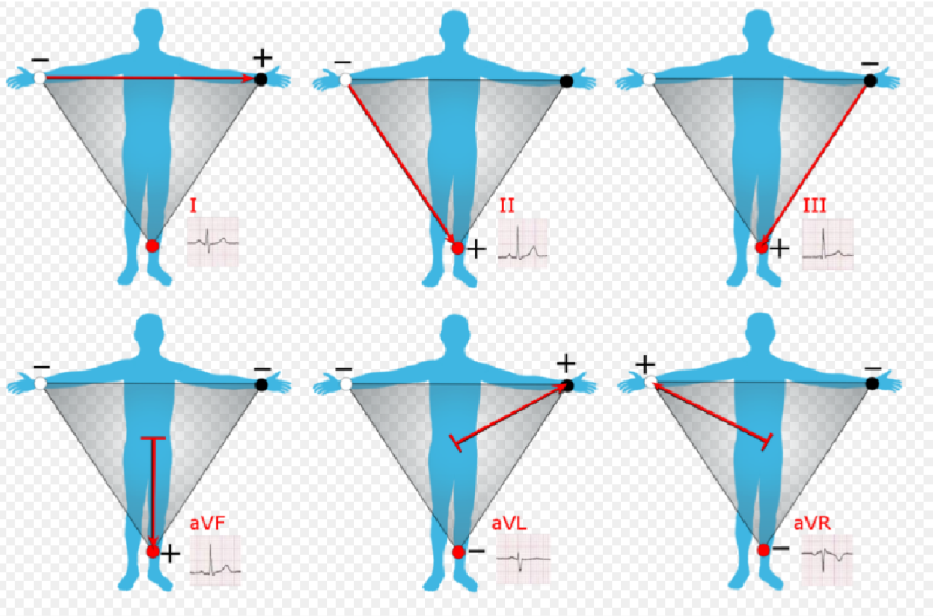

Fig. (2-3) represents the Limb leads and Augmented Limb leads.

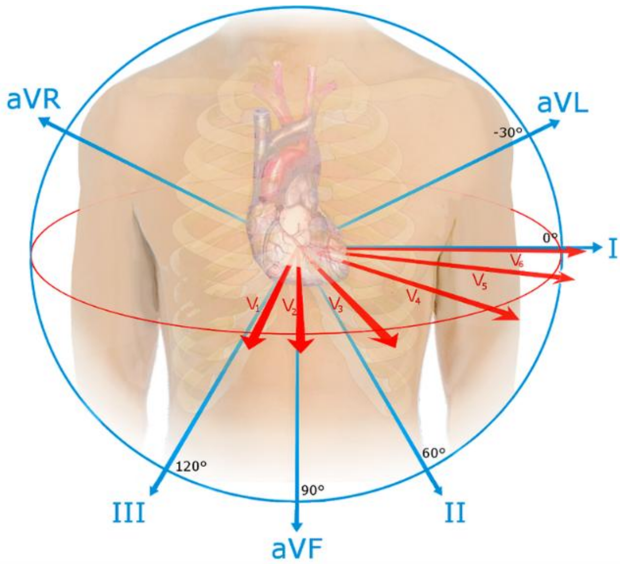

Fig. (2-4) represents Oriention of Leads

2-4 Types of ECG measuring devices:

2-4-1 ECG machine:

Fig. (2-5) ECG Machine

Electrocardiographs all share the same principle, but differ slightly in terms of components. The device generally consists of the following parts:

1- Calibration:

This part works effectively to adjust the device and calibrate it properly before starting the electrocardiogram, so it makes a square wave.1mv)) It turns out that the device is in good condition.

2- Sensitivity point:

This part is very important in maintaining the sensitivity of the device, since in its normal state it emits (1mv) and by using the sensitivity point, the wave can be enlarged or reduced according to the patient's condition.

3- The location:

Its entirety of work to set the thermal indicator.

4- Sign:

This wave is used at an abnormal wave in the planning so that the doctor can know the disease. It can also be used to differentiate between one conductor and another.

5- Thermal indicator:

The thermal indicator in the ECG device draws the wave on the paper, and it is precisely a thermal resistance in which a limited current passes, which raises the temperature of the tracer, to perform the required drawing process.

6- Speed setting:

The ECG device contains two speeds (25-50 mm/s), each speed is used according to the existing situation and determined by the doctor back to the heart. If the patient is old, his pulse is somewhat weak, so we use the low speed (25 mm/s). And if a young person has a fast pulse, the high speed is used until we get to keep pace with the planning of the patient's condition.

7- Screen:

This is when the doctor dispenses with paper or does not need it, to obtain a continuous reading of the heart.

8- The Separator:

One of the protection circuits in the device, as it uses a protection circuit from high currents and voltages, and it is truly a successful method in all devices.

9. Filter:

Its currency is limited to filtering the wave from external influences that can affect the electrocardiogram, because side effects such as neon and other devices in the same examination room have a major role in obtaining a wrong electrocardiogram.

10. Cable connection point:

Through it, we connect the body and the device.

11. Ground :

It is used as usual for leakage of excess charges, and protection against electric shocks.

12. Electrodes:

The device consists of five electrodes that are placed in specific places in the body.

2-4-1-1 The main stages of the planning process:

1. Signal amplification stage.
2. The motor speed regulation stage.
3. The time management stage.
4. Stage processing capacity.
5. Phase voltage regulation.
6. The stage of body temperature regulation.

1. Signal amplification stage:

Fig. (2-6) represents Chest connections

- **Connecting the electrocardiogram**

Chest connections:

If the chest connections V1 to V6 are recorded, the three resistors will be present and the point V will be connected to one input of the amplifier.

The electrical pathway of the chest, which is in the form of an absorbent cup, sticks to the chest and is fixed in the following places

(V1) = right fourth space to the sternal edge

(V2) = left fourth space on the sternal edge

(V3) = Halfway between V2 and V4

(V4) = 5th space left at mid clavicle line.

2-4-1-2 Device jamming:

The point at which problems that affect the proper functioning of the device begin is the problem of interference from various sources such as electromagnetic and radioactive waves in transmission stations, all electric motors, electronic devices that generate high vibration, high pressure towers, and natural sources such as lightning and thunder.

Sources of interference affect electrocardiograms in several ways, including:

- **By direct delivery:**

It is the presence of sources of electromagnetic energy, and its effect depends on the distance. If the distance is short, the effect is induction, and if it is long, the effect is with radiation waves, and to reduce and limit them, we follow the following:

1- Increasing the distance between the energy sources and the sensitive medical device. For example, we do not place the power cables feeding the motor close to an electrocardiogram or those who meet a patient.

2- Using shielded wires containing a tungsten clip for sensitive electronic devices.

3- Avoid using the oscillation as much as possible.

- **Noise from light sources:**

And this interference is through fluorescent tubes that are used at the beginning of operation, which generates an electromagnetic wave in every operation attempt, so it is not recommended to use them near medical devices and it is preferable to use tungsten lamps.

2-4-2 Holter Monitor device

It is a portable device that continuously monitors the electrical activity of the various cardiovascular systems for at least 24 hours (often for two weeks at a time). The device was invented by the American physicist Norman Holter, who also invented the device for measuring remote heart monitoring in 1949.

2-4-2-1 What is a Holter monitor?

The Holter monitor is a type of portable electrocardiogram (ECG). It records the electrical activity of the heart continuously over 24 hours or longer while you are away from the doctor's office. A standard or "resting" ECG is one of the simplest and fastest tests used to evaluate the heart. Electrodes (small, plastic patches that stick to the skin) are placed at certain points on the chest and abdomen. The electrodes are connected to an ECG machine by wires. Then, the electrical activity of the heart can be measured, recorded, and printed. No electricity is sent into the body.

Natural electrical impulses coordinate contractions of the different parts of the heart. This keeps blood flowing the way it should. An ECG records these impulses to show how fast the heart is beating, the rhythm of the heart beats (steady or irregular), and the strength and timing of the electrical impulses. Changes in an ECG can be a sign of many heart-related conditions.

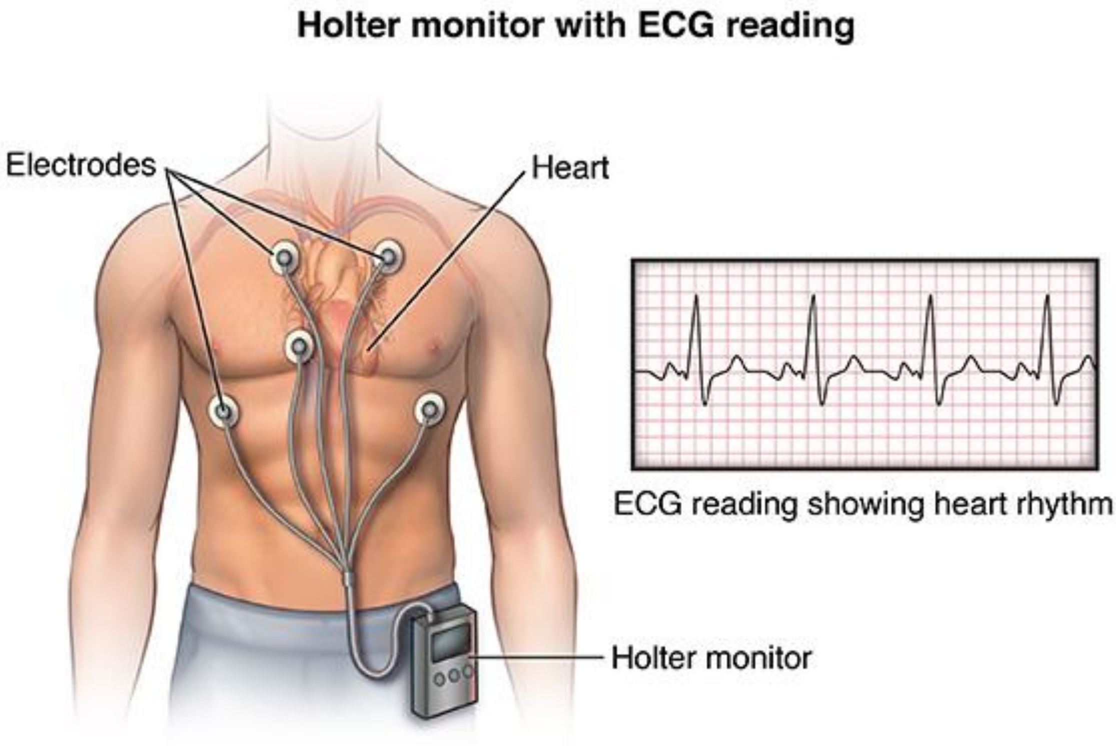

Fig. (2-7) represents Holter monitor

The healthcare provider may request a Holter monitor ECG if a person has symptoms, such as dizziness, fainting, low blood pressure, ongoing fatigue (tiredness), and palpitations and a resting ECG doesn’t show a clear cause. Patient wears the same kind of ECG electrode patches on his chest, and the electrodes are connected by wires to a small, portable recording device.

Certain arrhythmias (abnormal heart rhythms) may occur only now and then. Or, they may occur only under certain conditions, such as stress or activity. Arrhythmias of this type are hard to record on an ECG done in the office. Because of this, the healthcare provider might request a Holter monitor to get a better chance of capturing any abnormal heartbeats or rhythms that may be causing the symptoms. Some Holter monitors also have an event monitor feature that you activate when you notice symptoms.

Patient will get instructions on how long he will need to wear the monitor (usually 24 to 48 hours), how to keep a diary of his activities and symptoms during the test, and personal care and activity instructions, which include keeping the device dry while he is wearing it.

2-4-2-2 Why might we need a Holter monitor?

Some reasons for healthcare provider to request a Holter monitor recording or event monitor recording include:

- To evaluate chest pain that can't be reproduced with exercise testing
- To evaluate other signs and symptoms that may be heart-related, such as tiredness, shortness of breath, dizziness, or fainting
- To identify irregular heartbeats or palpitations

- ➢ To assess risk for future heart-related events in certain conditions, such as hypertrophic cardiomyopathy (thickened heart walls), after a heart attack that caused weakness of the left side of the heart, or Wolff-Parkinson-White syndrome (where an abnormal electrical conduction pathway exists within the heart)
- ➢ To see how well a pacemaker is working
- ➢ To determine how well treatment for complex arrhythmias is working

There may be other reasons for healthcare provider to recommend the use of a Holter monitor.

2-4-2-3 What are the risks of a Holter monitor?

The Holter monitor is an easy way to assess the heart's function. Risks associated with the Holter monitor are rare. It can be hard to keep the electrodes stuck to skin, and extra tape may be needed. It may be uncomfortable when the sticky electrodes and tape are taken off. If the electrodes are on for a long time, they may cause tissue breakdown or skin irritation at the application site.

There may be other risks depending on your specific medical condition. Be sure to discuss any concerns with your healthcare provider before wearing the monitor. Certain factors or conditions may interfere with or affect the results of the Holter monitor reading. These include, but are not limited to:

- ✓ Close proximity to magnets, metal detectors, high-voltage electrical wires, and electrical appliances such as shavers, toothbrushes, and microwave ovens. Cell phones and MP3 players can also interfere with the signals and should be kept at least 6 inches away from the monitor box.
- ✓ Smoking or using other forms of tobacco.
- ✓ Certain medicines.
- ✓ Excessive sweating, which may cause the leads to loosen or come off.

2-4-2-4 How do we get ready for a Holter monitor?

- ✓ Healthcare provider will explain the procedure to patient and he can ask questions.
- ✓ Patient does not need to fast (not eat or drink).
- ✓ Based on patient medical condition, healthcare provider may request other specific preparation.

2-4-2-5 What happens during a Holter monitor?

A Holter monitor recording is generally done on an outpatient basis. Procedures may vary depending on your condition and your healthcare providers practice.

Generally, a Holter monitor recording follows this process:

1. Patient will be asked to remove any jewelry or other objects that may interfere with the reading.
2. Patient will be asked to remove your clothing from the waist up so that electrodes can be attached to your chest. The technician will ensure your privacy by covering you with a sheet or gown and exposing only the necessary skin.
3. The areas where the electrodes patches are placed are cleaned, and in some cases, hair may be shaved or clipped so that the electrodes will stick closely to the skin.
4. Electrodes will be attached to patient chest and abdomen. The Holter monitor will be connected to the electrodes with wires. The small monitor box may be worn over your shoulder like a shoulder bag, around his waist, or it may clip to a belt or pocket.

5. Find out if patient will have to change the batteries in the monitor. Be sure he know how to do it and have extra batteries on hand.
6. Once patient has been hooked up to the monitor and given instructions, he can return to his usual activities, such as work, household chores, and exercise, unless your healthcare provider tells he otherwise. This will allow his healthcare provider to identify problems that may only occur with certain activities.
7. Patient will be instructed to keep a diary of his activities while wearing the monitor. He must write down the date and time of his activities, particularly if any symptoms, such as dizziness, palpitations, chest pain, or other previously experienced symptoms, occur.

2-4-2-6 What happens after a Holter monitor?

Patient should be able to go back his normal diet and activities, unless his healthcare provider instructs his differently.

Generally, there is no special care after a Holter monitor recording.

Patient must tell his healthcare provider if he develops any signs or symptoms he had before the recording (for example, chest pain, shortness of breath, dizziness, or fainting). Healthcare provider may give him other instructions after the procedure, depending on his particular situation.

2-4-3 Performing an electrocardiogram using the ECG application on Apple Watch.

2-4-3-1 How to use the ECG app

Fig. (2-8) represents ECG Apple Watch

The ECG app can record your heartbeat and rhythm using the electrical heart sensor on Apple Watch Series 4, Series 5, Series 6, or Series 7* and then check the recording for atrial fibrillation (AFib), a form of irregular rhythm.

The ECG app records an electrocardiogram which represents the electrical pulses that make your heart beat. The ECG app checks these pulses to get your heart rate and see if the upper and lower chambers of your heart are in rhythm. If they're out of rhythm, that could be AFib.

The ECG app is currently available only in certain countries and regions. Learn where the ECG app is available.

*The ECG app is not supported on Apple Watch SE.

2-4-3-2 Here's what you need

- Make sure that the ECG app is available in your country or region. Learn where the ECG app is available.
- Update your iPhone to the latest version of iOS and Apple Watch to the latest version of watchOS.
- The ECG app is not intended for use by people under 22 years old.

2-4-3-3 Install and set up the ECG app

The ECG app is installed during the ECG app setup in the Health app. Follow these steps to set up the ECG app:

1. Open the Health app on your iPhone.
2. Follow the onscreen steps. If you don't see a prompt to set up, tap the Browse tab, then tap Heart > Electrocardiograms (ECG) > Set Up ECG App.
3. After you complete set up, open the ECG app to take an ECG.

If you still don't see the app on your Apple Watch, open the Watch App on your iPhone and tap Heart. In the ECG section, tap Install to install the ECG app.

The ECG app isn't available in every country or region. Learn where the ECG app is available.

2-4-3-4 Take an ECG

You can take an ECG at any time, when you're feeling symptoms such as a rapid or skipped heartbeat, when you have other general concerns about your heart health, or when you receive an irregular rhythm notification.

1. Make sure that your Apple Watch is snug and on the wrist that you selected in the Apple Watch app. To check, open the Apple Watch app, tap the My Watch tab, then go to General > Watch Orientation.
2. Open the ECG app on your Apple Watch.
3. Rest your arms on a table or in your lap.
4. With the hand opposite your watch, hold your finger on the Digital Crown. You don't need to press the Digital Crown during the session.
5. Wait. The recording takes 30 seconds. At the end of the recording, you will receive a classification, then you can tap Add Symptoms and choose your symptoms.
6. Tap Save to note any symptoms, then tap Done.

2-4-3-5 How to read results

After a successful reading, you will receive one of the following type of results on your ECG app. Regardless of the result, if you aren't feeling well or are experiencing any symptoms, you should talk to your doctor.

Sinus rhythm

A sinus rhythm result means the heart is beating in a uniform pattern between 50 and 100 BPM. This happens when the upper and lower chambers of the heart are beating in sync. A sinus rhythm result only applies to that particular recording and doesn't mean your heart beats with a consistent pattern all the time. It also does not mean that you're healthy. If you're not feeling well or are feeling any symptoms, you should talk to your doctor.

Atrial fibrillation

An AFib result means the heart is beating in an irregular pattern. The ECG app ver. 1 can check for AFib between 50 and 120 BPM. The ECG app ver. 2 can check for AFib between 50 and 150 BPM.* AFib is the most common form of serious arrhythmia, or irregular heart rhythm. If you receive an AFib classification and you have not been diagnosed with AFib, you should talk to your doctor.

Low or high heart rate

A heart rate under 50 BPM or over 120 BPM in ECG version 1 affects the ECG app's ability to check for AFib. In ECG version 2, a heart rate under 50 BPM or over 150 BPM can affect the ECG app's ability to check for AFib.

- A heart rate can be low because of certain medications or if electrical signals are not properly conducted through the heart. Training to be an elite athlete can also lead to a low heart rate. Learn more about low heart rates from the American Heart Association.
- A high heart rate could be due to exercise, stress, nervousness, alcohol, dehydration, infection, AFib, or other arrhythmia. Learn more about high heart rates from the American Heart Association.

Inconclusive

An inconclusive result means the recording can't be classified. It could be due to one of the following situations:

- In ECG version 1, your heart rate is between 100 and 120 BPM and you are not in AFib. The ECG app version 2 was also tested in a clinical trial with approximately 546 subjects, and demonstrated 99.3% specificity with respect to sinus rhythm classification, and 98.5% sensitivity for AFib classification for the classifiable results.
- You have a pacemaker or implantable cardioverter defibrillator (ICD).
- The recording may show signs of other arrhythmias or heart conditions that the app is not designed to recognize.
- Certain physiological conditions may prevent a small percentage of users from creating enough signal to produce a good recording.

For ECG version 1, you might also get an inconclusive result if you are not resting your arms on a table during a recording, or wearing your Apple Watch too loose. Learn how to get the best results.

2-4-3-6 Poor Recording

This classification is unique to ECG version 2. Poor Recording means the result can't be classified. If you get a Poor Recording result, there are a few things you can try in order to get a better recording.

- Rest your arms on a table or in your lap while you take a recording. Try to relax and not move too much.

- Make sure that your Apple Watch isn't loose on your wrist. The band should be snug and the back of your Apple Watch needs to be touching your wrist.
- Make sure that your wrist and your Apple Watch are clean and dry. Water and sweat can cause a poor recording.
- Make sure that your Apple Watch is on the wrist you selected in Settings.
- Move away from any electronics that are plugged into an outlet to avoid electrical interference.

If you need help, contact Apple Support.

2-4-3-7 View and share your Health information

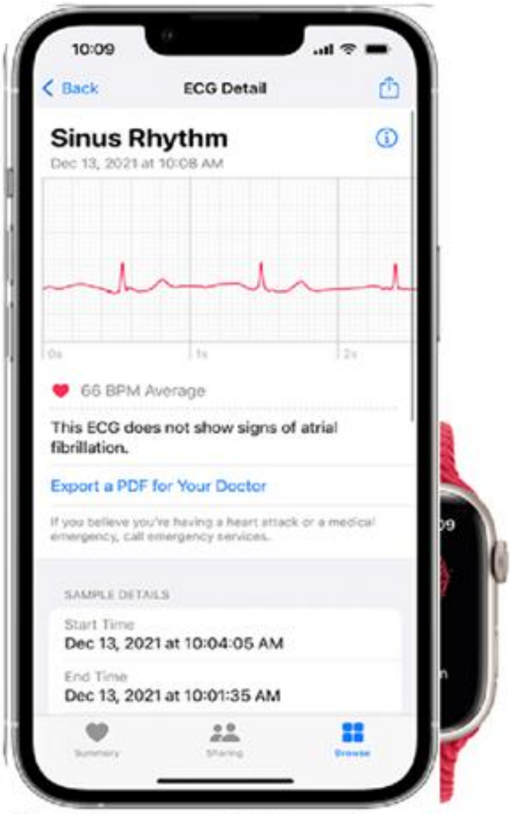

Fig. (2-9) represents ECG waveform

The ECG waveform, its associated classifications, and any noted symptoms will be saved in the Health app on your iPhone. You can also share a PDF with your doctor.

1. Open the Health app.
2. Tap the Browse tab, then tap Heart > Electrocardiograms (ECG).
3. Tap the chart for your ECG result.
4. Tap Export a PDF for Your Doctor.
5. Tap the Share button to print or share the PDF.

2-4-3-8 How to get the best results

1. Rest your arms on a table or in your lap while you take a recording. Try to relax and not move too much.
2. Make sure that your Apple Watch isn’t loose on your wrist. The band should be snug, and the back of your Apple Watch needs to be touching your wrist.
3. Make sure that your wrist and your Apple Watch are clean and dry.

4. Make sure that your Apple Watch is on the wrist that you selected in the Apple Watch app. To check, open the Apple Watch app, tap the My Watch tab, then go to General > Watch Orientation.
5. Move away from any electronics that are plugged into an outlet to avoid electrical interference.

A small percentage of people may have certain physiological conditions preventing the creation of enough signal to produce a good recording — for example, the positioning of the heart in the chest can change the electrical signal levels, which could impact the ECG app's ability to obtain a measurement.

Liquid-free contact is required for the ECG app to work properly. Use of the ECG app may be impacted if the Apple Watch and/or skin aren't entirely dry. Make sure that your wrist and hands are thoroughly dry before attempting a reading. To ensure the best reading after swimming, showering, heavy perspiration, or washing your hands, clean and dry your Apple Watch. It may take up to one hour for your Apple Watch to completely dry.

2-4-3-9 Things you should know

- The ECG app cannot detect a heart attack. If you ever experience chest pain, pressure, tightness, or what you think is a heart attack, call emergency services immediately.
- The ECG app cannot detect blood clots or a stroke.
- The ECG app cannot detect other heart-related conditions. These include high blood pressure, congestive heart failure, high cholesterol, or other forms of arrhythmia.
- If you're not feeling well or are feeling any symptoms, talk to your doctor or seek immediate medical attention.

2-4-3-10 How the ECG app works

The ECG app on Apple Watch Series 4, Series 5, Series 6, or Series 7 generates an ECG that is similar to a single-lead (or Lead I) ECG. In a doctor's office, a standard 12-lead ECG is usually taken. This 12-lead ECG records electrical signals from different angles in the heart to produce twelve different waveforms. The ECG app on Apple Watch measures a waveform similar to one of those twelve waveforms. A single-lead ECG is able to provide information about heart rate and heart rhythm and enables classification of AFib. However, a single-lead ECG cannot be used to identify some other conditions, like heart attacks. Single-lead ECGs are often prescribed by doctors for people to wear at home or within the hospital so that the doctor can get a better look at the underlying rate and rhythm of the heart. However, the ECG app on Apple Watch Series 4, Series 5, Series 6, or Series 7 allows you to generate an ECG similar to a single-lead ECG without a prescription from your doctor.

In studies comparing the ECG app on Apple Watch to a standard 12-lead ECG taken at the same time, there was agreement between the ECG app classification of the rhythm as sinus or AFib compared to the standard 12-lead ECG.

The ability of the ECG app to accurately classify an ECG recording into AFib and sinus rhythm was tested in a clinical trial of approximately 600 subjects, and demonstrated 99.6% specificity with respect to sinus rhythm classification and 98.3% sensitivity for AFib classification for the classifiable results.

The clinical validation results reflect use in a controlled environment. Real world use of the ECG app may result in a greater number of strips being deemed inconclusive and not classifiable.

3-1 Introduction to ECG

An electrocardiogram is a picture of the electrical conduction of the heart. By examining changes from normal on the ECG, clinicians can identify a multitude of cardiac disease processes.

There are two ways to learn ECG interpretation — pattern recognition (the most common) and understanding the exact electrical vectors recorded by an ECG as they relate to cardiac electrophysiology. As basing ECG interpretation on pattern recognition alone is often not sufficient.

Interpretation of the ECG is fundamentally about understanding the electrical conduction system of the heart. Normal conduction starts and propagates in a predictable pattern, and deviation from this pattern can be a normal variation or be pathological.

Like all medical tests, what constitutes "normal" is based on population studies. The heartrate range of between 60 and 100 beats per minute (bpm) is considered normal since data shows this to be the usual resting heart rate

3-2 Parts of an ECG

The standard ECG has 12 leads. Six of the leads are considered “limb leads” because they are placed on the arms and/or legs of the individual. The other six leads are considered “precordial leads” because they are placed on the torso (precordium).

The six limb leads are called lead I, II, III, aVL, aVR and aVF. The letter “a” stands for “augmented,” as these leads are calculated as a combination of leads I, II and III.The six precordial leads are called leads V1, V2, V3, V4, V5 and V6.

Figure (3-1) is a normal 12-lead ECG tracing.

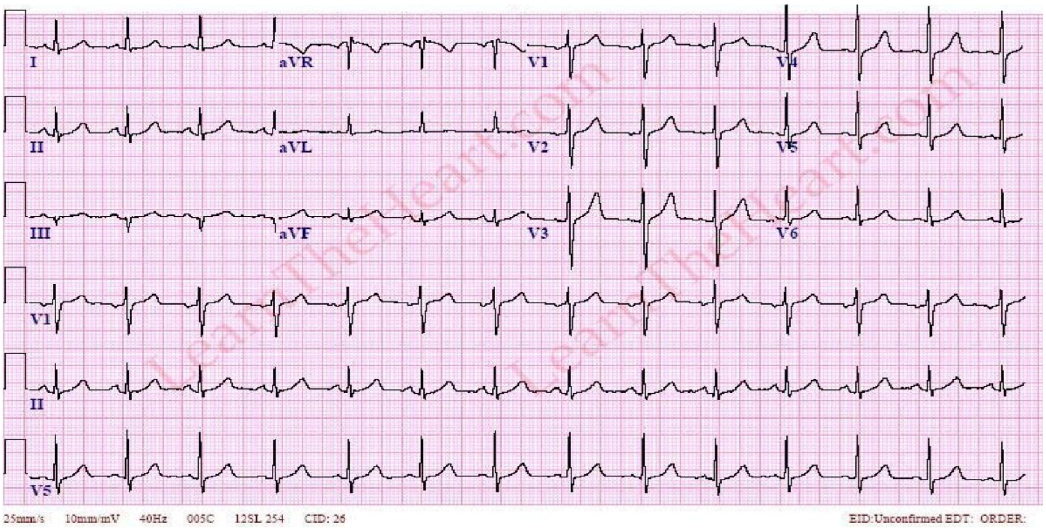

Fig.(3-1) represents a normal 12-lead of ECG tracing

Interpretation of the ECG is ultimately that of pattern recognition. In order to understand the patterns found, it is helpful to understand the theory of what ECGs represent. The theory is rooted in electromagnetics and boils down to the four following points:

- ✓ depolarization of the heart toward the positive electrode produces a positive deflection.
- ✓ depolarization of the heart away from the positive electrode produces a negative deflection.
- ✓ repolarization of the heart toward the positive electrode produces a negative deflection.
- ✓ repolarization of the heart away from the positive electrode produces a positive deflection.

Thus, the overall direction of depolarization and repolarization produces positive or negative deflection on each lead's trace. For example, depolarizing from right to left would produce a positive deflection in lead I because the two vectors point in the same direction. In contrast, that same depolarization would produce minimal deflection in V1 and V2 because the vectors are perpendicular, and this phenomenon is called isoelectric.

Normal rhythm produces four entities – a P wave, a QRS complex, a T wave, and a U wave –

that each have a fairly unique pattern. Fig. (3-2):

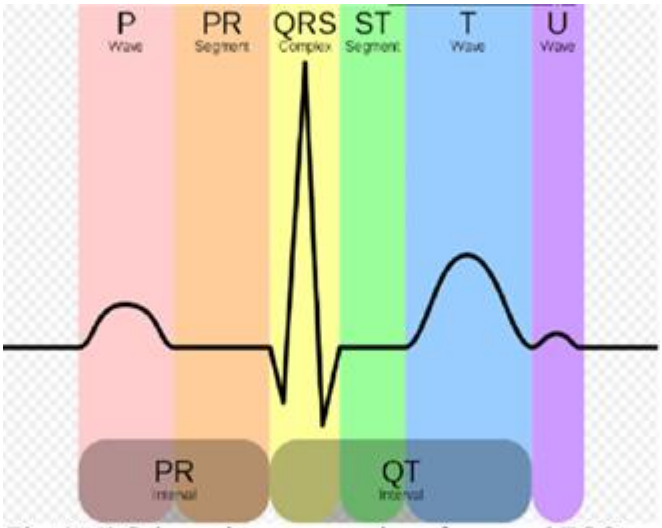

Fig. (3-2) Schematic representation of a normal ECG

- ✓ The P wave represents atrial depolarization.
- ✓ The QRS complex represents ventricular depolarization.
- ✓ The T wave represents ventricular repolarization.
- ✓ The U wave represents papillary muscle repolarization.

Changes in the structure of the heart and its surroundings (including blood composition) change the patterns of these four entities.

3-3 Background grid

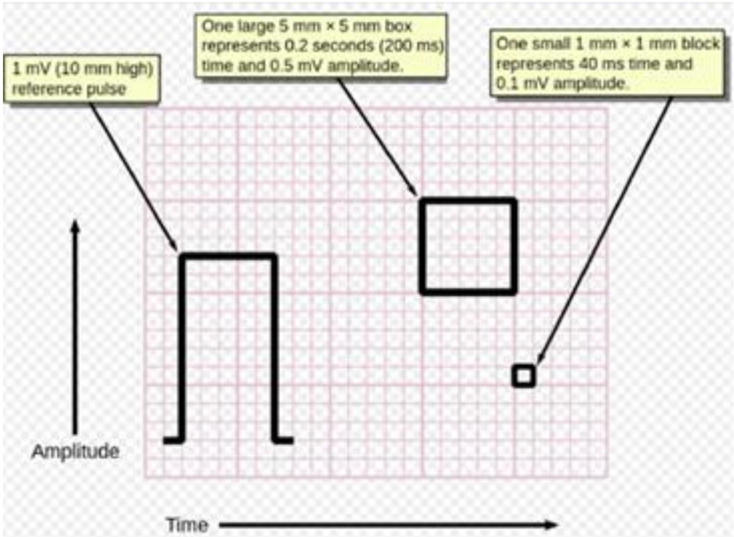

Fig. (3-3) Measuring time and coltage with ECG graph paper

ECGs are normally printed on a grid. The horizontal axis represents time and the vertical axis represents voltage. The standard values on this grid are shown in the adjacent image at 25mm/sec:

A small box is 1 mm × 1 mm and represents 0.1 mV × 0.04 seconds.

A large box is 5 mm × 5 mm and represents 0.5 mV × 0.20 seconds.

The "large" box is represented by a heavier line weight than the boxes. See Fig. (3-3).

3-4 Rate and rhythm

In a normal heart, the heart rate is the rate at which the sinoatrial node depolarizes since it is the source of depolarization of the heart. Heart rate, like other vital signs such as blood pressure and respiratory rate, change with age. In adults, a normal heart rate is between 60 and 100 bpm (normocardic), whereas it is higher in children. A heart rate below normal is called "bradycardia" (<60 in adults) and above normal is called "tachycardia" (>100 in adults). A complication of this is when the atria and ventricles are not in synchrony and the "heart rate" must be specified as atrial or ventricular (e.g., the ventricular rate in ventricular fibrillation is 300–600 bpm, whereas the atrial rate can be normal [60–100] or faster [100–150]).

In normal resting hearts, the physiologic rhythm of the heart is normal sinus rhythm (NSR). Normal sinus rhythm produces the prototypical pattern of P wave, QRS complex, and T wave. Generally, deviation from normal sinus rhythm is considered a cardiac arrhythmia. Thus, the first question in interpreting an ECG is whether or not there is a sinus rhythm. A criterion for sinus rhythm is that P waves and QRS complexes appear 1-to-1, thus implying that the P wave causes the QRS complex.

Once sinus rhythm is established, or not, the second question is the rate. For a sinus rhythm, this is either the rate of P waves or QRS complexes since they are 1-to-1. If the rate is too fast, then it is sinus tachycardia, and if it is too slow, then it is sinus bradycardia.

If it is not a sinus rhythm, then determining the rhythm is necessary before proceeding with further interpretation. Some arrhythmias with characteristic findings:

- Absent P waves with "irregularly irregular" QRS complexes is the hallmark of atrial fibrillation.
- A "saw tooth" pattern with QRS complexes is the hallmark of atrial flutter.
- A sine wave pattern is the hallmark of ventricular flutter.
- Absent P waves with wide QRS complexes and a fast heart rate is ventricular tachycardia.

Determination of rate and rhythm is necessary in order to make sense of further interpretation.

3-5 Determining Axis

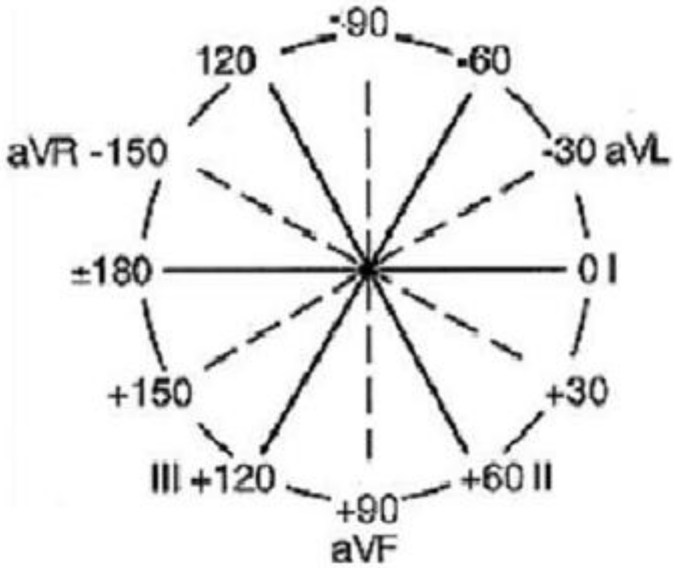

Fig. (3-4) represents Axis of ECG

The axis of the ECG is the major direction of the overall electrical activity of the heart. It can be normal, leftward (left axis deviation, or LAD), rightward (right axis deviation, or RAD) or indeterminate (northwest axis). The QRS axis is the most important to determine. However, the

P wave or T wave axis can also be measured. To determine the QRS axis, the limb leads (not the precordial leads) need to be examined. The depiction of the standard leads and their relationship to the cardiac axis is below.

Note that lead I is at zero degrees, lead II is at +60 degrees, and lead III is at +120 degrees. Lead aVL (L for left arm) is at -30 degrees and lead aVF (F for foot) is at +90 degrees. The negative of lead aVR (R for right arm) is at +30 degrees; the positive of lead aVR is actually at -150 degrees. Although memorizing the above picture is crucial to accurately determining axis, some shortcuts to quickly determine the axis are outlined below.

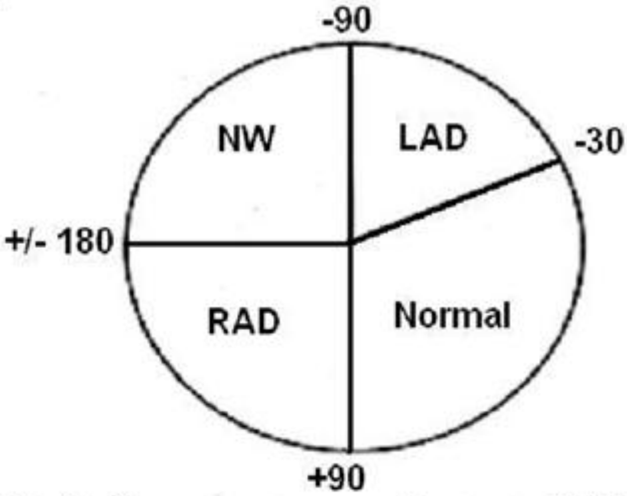

Fig. (3-5) represents some shortcut of Axis

The normal QRS axis should be between -30 and +90 degrees. Left axis deviation is defined as the major QRS vector, falling between -30 and -90 degrees. Right axis deviation occurs with the QRS axis and is between +90 and +180 degrees. Indeterminate axis is between +/- 180 and -90 degrees. This is summarized in the figure below.

Where: LAD = Left Axis Deviation, RAD = Right Axis Deviation, NW = Northwest axis, or indeterminate axis.

The fastest non-specific method to determine the QRS axis is to find the major direction of the QRS complex — positive or negative — in leads I and aVF.

3-5-1 Normal QRS Axis

If the QRS complex is upright (positive) in both lead I and lead aVF, then the axis is normal. The image below demonstrates this example, with the electrical vector heading towards the positive of lead I and the positive of lead aVF, as indicated by the arrows. The QRS axis is thus between these two arrows, which falls within the normal range.

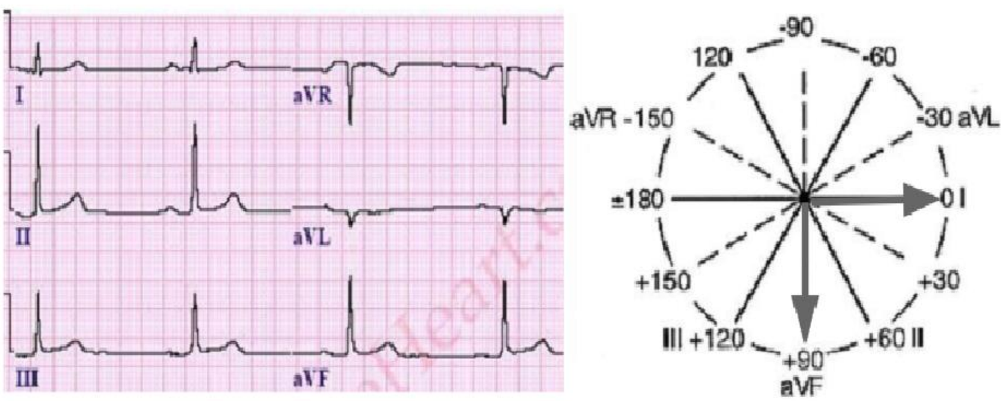

Fig. (3-6) represents Normal QRS Axis: Positive in Lead I and aVF

3-5-2 Left Axis Deviation (LAD)

If the QRS is upright in lead I (positive) and downward in lead aVF (negative), then the axis is between 0 and -90 degrees. However, recalling that left axis deviation is defined as between -30 and -90, this scenario is not always technically left axis deviation. In this scenario, the QRS axis could fall between 0 and -30, which is within normal limits. To further distinguish normal from left axis deviation in this setting, look at lead II. If lead II is downward (negative), then the axis is more towards -120, and left axis deviation is present. If the QRS complex in lead II is upright (positive), then the axis is more towards +60 degrees, and the QRS axis is normal.

The causes of LAD are listed below. Note that the first three account for almost 90% of ECG tracings with LAD:

1- Normal variant

2- Left anterior fascicular block

3- Left ventricular hypertrophy (rarely with LVH; usually axis is normal)

4- Left bundle branch block (rarely with LBBB)

5- Mechanical shift of heart in the chest (lung disease, prior chest surgery, etc.)

6- Inferior myocardial infarction

7- Wolff-Parkinson-White syndrome with “pseudo infarct” pattern

8- Ventricular rhythms (accelerated idio-ventricular or ventricular tachycardia)

9- Ostium primum atrial septal defect

Below is an example of LAD to help visualize the above explanation:

Fig. (3-7) represent Left Axis Deviation of the QRS Axis: Positive in Lead I, negative in lead aVF and lead II

3-5-3 Right Axis Deviation (RAD)

If the QRS is predominantly negative in lead I and positive in lead aVF, then the axis is rightward (right axis deviation). The causes of RAD are listed below.

1- Normal variant

2- Right bundle branch block

3- Right ventricular hypertrophy

4- Left posterior fascicular block

5- Dextrocardia

6- Ventricular rhythms (accelerated idioventricular or ventricular tachycardia)

7- Lateral wall myocardial infarction

8- Wolff-Parkinson-White syndrome

9- Acute right heart strain/pressure overload — also known as McGinn-White Sign or S1Q3T3 that occurs in pulmonary embolus

Below is a pictorial example of RAD.

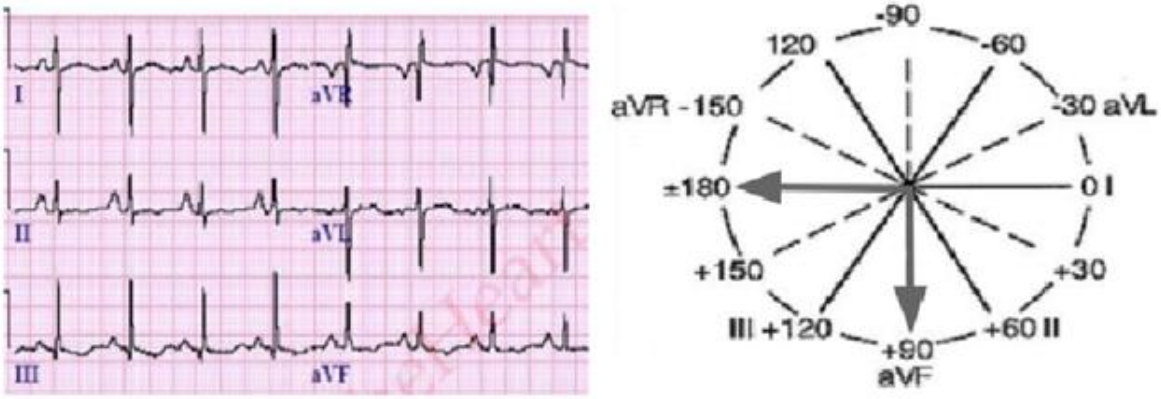

Fig. (3-8) represents Right Axis Deviation of the QRS Axis: Negative in Lead I and positive in lead aVF

3-6 Amplitudes and intervals

All of the waves on an ECG tracing and the intervals between them have a predictable time duration, a range of acceptable amplitudes (voltages), and a typical morphology. Any deviation from the normal tracing is potentially pathological and therefore of clinical significance.

For ease of measuring the amplitudes and intervals, an ECG is printed on graph paper at a standard scale: each 1 mm (one small box on the standard 25mm/s ECG paper) represents 40 milliseconds of time on the x-axis, and 0.1 millivolts on the y-axis. Table below represents the amplitudes and intervals.

Feature	Description	Duration
P wave	depolarization spreads from the SA node towards the AV node, and from the right atrium to the left atrium.	<40ms
PR interval	The PR interval is measured from the beginning of the P wave to the beginning of the QRS complex.	120 to 200 ms
QRS	QRS complex usually has a much larger amplitude than the P wave..	80 to 100 ms
ST segment	The ST segment connects the QRS complex and the T wave;.	
T wave	The T wave represents the repolarization of the ventricles.	160ms

3-7 When should an ECG be done?

3-7-1 Cases that require ECG:

ECG is used in the following cases:

- ✓ Examination of the heart rhythm to diagnose any abnormality in it, such as slow or fast.
- ✓ Knowing whether the amount of blood flowing to the heart is small or sufficient.
- ✓ Examination of any abnormalities in the heart, such as: defect or weakness in the heart muscle or an enlarged heart.
- ✓ Diagnosis of any abnormality in the electrical heart.
- ✓ Examination of any blockages in the arteries and valves of the heart.

- ✓ Checking for an imbalance of chemicals in the blood that control heart activity.
- ✓ Examine for any change or any abnormality in the location of the heart.
- ✓ Diagnosis of congenital defects in the chambers of the heart.
- ✓ Check for heart inflammation.
- ✓ Knowing the causes of some symptoms that indicate a possible heart problem, such as: Shortness of breath, chest pain or constant discomfort above the waist, dizziness and lightheadedness, palpitations.
- ✓ Examination of the effectiveness of medications taken by a heart patient.
- ✓ Checking the patient's condition in the following cases:

Experiencing a fainting spell or severe weakness. New symptoms of stroke appear in less than 24 hours. Difficulty breathing for no apparent reason. Cardiac arrest. Recent use of cocaine or illegal drugs.

3-7-2 Categories that need ECG:

To continue answering the question when should an ECG be done? Routine ECG testing is preferred by the following groups:

a - People who have a medical history that includes at least one heart problem.

b - People who have risk factors that may increase their chances of developing heart disease, such as: genes and obesity.

c- Persons who are being prepared for surgery.

d - Patients who have a pacemaker.

e - Patients who take medications for heart diseases.

3-8 Diseases diagnosed by ECG

Numerous diagnoses and findings can be made based upon electrocardiography, and many are discussed above. Overall, the diagnoses are made based on the patterns. For example, an "irregularly irregular" QRS complex without P waves is the hallmark of atrial fibrillation; however, other findings can be present as well, such as a bundle branch block that alters the shape of the QRS complexes. ECGs can be interpreted in isolation but should be applied – like all diagnostic tests – in the context of the patient. For example, an observation of peaked T waves is not sufficient to diagnose hyperkalemia; such a diagnosis should be verified by measuring the blood potassium level. Conversely, a discovery of hyperkalemia should be followed by an ECG for manifestations such as peaked T waves, widened QRS complexes, and loss of P waves.

ECG is used with other tests as well to diagnose the severity of various heart problems and their causes, especially the following cases:

3-8-1 Coronary heart disease:

Coronary heart disease is a disease that affects a person when fat accumulates inside the coronary arteries feeding the heart, and over time these arteries become hardened, and this occurs as a result of things and factors, such as: smoking, high cholesterol, high blood pressure, diabetes.

Symptoms of this disease include persistent chest pain or even heart failure and heart attack.

3-8-2 Heart muscle disease:

Heart muscle disease, just as the name implies, is a disease of the heart muscle, causing weakness in the walls of the heart's chambers, making them thick, dilated, or stiff and tight, affecting the heart's ability to pump blood. This disease increases the chances of developing heart failure in particular.

3-8-3 Heart palpitations:

Heart palpitations and arrhythmias affect many age groups, but are generally more common among older adults, and heart palpitations come in many different types.

There are many causes that may lead to heart palpitations, such as: drinking alcohol and obesity, or having diseases such as: heart attack or heart failure. Heart palpitations are one of the common causes of a heart attack, and having it increases the chances of having a stroke in general.

3-8-4 Heart attack:

A heart attack is a medical emergency that must be dealt with immediately, as one of the arteries of the heart becomes completely blocked, usually due to the presence of a blood clot in it. Among the main symptoms of a heart attack are the following:

Chest pain, feeling of heaviness extending from the chest to the jaws and neck, shortness of breath, dizziness and general weakness, feeling anxious. The following is an organized list of possible ECG-based diagnoses:.

- ✓ Rhythm disturbances or arrhythmias.
- ✓ Atrial fibrillation and atrial flutter without rapid ventricular response
- ✓ Premature atrial contraction (PACs) and premature ventricular contraction (PVCs).
- ✓ Sinus arrhythmia.
- ✓ Sinus bradycardia and sinus tachycardia.
- ✓ Sinus pause and sinoatrial arrest.
- ✓ Sinus node dysfunction and bradycardia-tachycardia syndrome
- ✓ Supraventricular tachycardia
- ✓ Atrial fibrillation with rapid ventricular response
- ✓ Atrial flutter with rapid ventricular response
- ✓ AV nodal reentrant tachycardia
- ✓ Atrioventricular reentrant tachycardia
- ✓ Junctional ectopic tachycardia
- ✓ Atrial tachycardia
- ✓ Ectopic atrial tachycardia (unicentric)
- ✓ Multifocal atrial tachycardia
- ✓ Paroxysmal atrial tachycardia
- ✓ Sinoatrial nodal reentrant tachycardia
- ✓ Torsades de pointes (polymorphic ventricular tachycardia)
- ✓ Wide complex tachycardia
- ✓ Ventricular flutter
- ✓ Ventricular fibrillation
- ✓ Ventricular tachycardia (monomorphic ventricular tachycardia)
- ✓ Pre-excitation syndrome

- ✓ Lown–Ganong–Levine syndrome
- ✓ Wolff–Parkinson–White syndrome
- ✓ J wave (Osborn wave)
- ✓ Heart block and conduction problems:
- ✓ Aberration
- ✓ Sinoatrial block: first, second, and third-degree
- ✓ AV node
- ✓ First-degree AV block
- ✓ Second-degree AV block (Mobitz [Wenckebach] I and II)
- ✓ Third-degree AV block or complete AV block
- ✓ Right bundle
- ✓ Incomplete right bundle branch block
- ✓ Complete right bundle branch block (RBBB)
- ✓ Left bundle
- ✓ Complete left bundle branch block (LBBB)
- ✓ Incomplete left bundle branch block
- ✓ Left anterior fascicular block (LAFB)
- ✓ Left posterior fascicular block (LPFB)
- ✓ Bifascicular block (LAFB plus LPFB)
- ✓ Trifascicular block (LAFP plus FPFB plus RBBB)
- ✓ QT syndromes
- ✓ Brugada syndrome
- ✓ Short QT syndrome
- ✓ Long QT syndromes, genetic and drug-induced
- ✓ Right and left atrial abnormality

Electrolytes disturbances and intoxication:

- ✓ Digitalis intoxication
- ✓ Calcium: hypocalcemia and hypercalcemia
- ✓ Potassium: hypokalemia and hyperkalemia
- ✓ Serotonin Toxicity

Ischemia and infarction:

- ✓ Wellens' syndrome (LAD occlusion)
- ✓ de Winter T waves (LAD occlusion) [65]
- ✓ ST elevation and ST depression
- ✓ High Frequency QRS changes
- ✓ Myocardial infarction (heart attack)
- ✓ Non-Q wave myocardial infarction

3-9 ECG benefits

ECGs are usually found in ambulances, emergency rooms and other rooms in hospitals.

The electrocardiogram is used for its many benefits. Among the benefits of electrocardiography are the following:

1- Make sure the heart is healthy before performing surgeries.

2- Diagnosing arrhythmias, where one of the benefits of electrocardiography is to diagnose arrhythmia, and to confirm the diagnosis of tachycardia and slow heartbeat.

3- Diagnosis of narrowing or blockage of the arteries of the heart, such as coronary artery disease.

4- Monitoring the efficiency of some heart disease treatments, such as: various medications, or a pacemaker

5- Diagnosis of a heart attack, if symptoms are suspected.

6- Diagnosis of cardiomyopathy, as one of the benefits of ECG is to diagnose the thickening or enlargement of the walls of the heart.

3-10 When is an electrocardiogram used?

ECG is used in several cases, including:

1- Presence of a heart attack

2 - Having a family history of heart disease.

3 - The presence of some diseases that increase the risk of a heart attack, such as: high blood pressure, high blood cholesterol, diabetes and inflammatory diseases.

4- The following symptoms appear: a- Chest pain. b - Dizziness and confusion; c- Heart palpitations. d- The speed of the pulse. e- Shortness of breath f- Fatigue, general weakness and difficulty doing exercise.

3- 11 ECG restrictions

Despite the many benefits of ECG, there are some limitations that limit the benefits of its use. Among these restrictions are:

1- The ECG records the heartbeat and heart rhythm only during the few seconds that the ECG is used; It is possible that the ECG device will not detect any intermittent disturbances in the heartbeat, and in this case a mobile heart rate monitor (Ambulatory Monitoring) is used to detect the heartbeat and rhythm over a wider period.

2- ECG results usually appear normal even with some diseases, such as coronary artery disease.

3- The ECG device may detect some defects, although there are no problems or diseases.

Necessary procedures for using the electrocardiogram detector

3-12 How to prepare:

You do not need to prepare much, it is enough for you to only eat certain foods to make the results more clear on the device.

3-12-1 Before completing the procedure:

The technical assistant may try to help during the placement of the device, such as helping the patient to wear the examination garment or removing any hair that may affect the device’s stickers.

3-12-2 During the procedure:

You need to breathe normally but you may lie down, you should feel warm and be stable during the procedure, because any movement will affect the result.

4-1 What is the device and how does it work?

It is a device that was manufactured manually and used for ECG and works on direct current (battery).

Manufacturing goal:

An electrocardiogram is considered as a reference to the doctor and a real-time reading of the condition.

4-2 device components:

The ECG device working on DC voltage consists of following devices:

Fig. (4-1) represents ECG Sensor Module

4-2-1 ECG Sensor module:

The ECG sensor is used to measure the electrical activity of the heart. This electrical activity can be mapped as an electrocardiogram. ECG is used to help diagnose various heart diseases. Cost-effective panel used to measure the electrical activity of the heart. This electrical activity can be plotted as an EKG and output as a representative reading. ECGs can be very noisy, with a single heart rate monitor acting as a speakerphone to help get a clear indication of relationship breaks.

Fig. (4-2) represents Nextion display screen

4-2-2 Screen type: Nextion display screen 2.8'':

It is a touch screen that works to display the data it receives from the Arduino.

4-2-3 Arduino UNO:

Arduino Uno is an open source microcontroller board based on the Microchip ATmega328P microcontroller and developed by Arduino.cc The board is equipped with combinations of digital and analog input/output (I/O) pins that can be connected to various expansion boards (shields) and other circuits. The board has 14 digital I/O ports (six of which are PWM capable), and 6 analog I/O ports, and is programmable using the Arduino IDE (Integrated Development Environment), via a USB Type-B cable. Powered via a cable USB or via an external 9V battery, although it accepts voltages between 7 and 20V. It is similar to Arduino Nano and Leonardo.

Fig. (4-3) represents Arduino UNO.

4-2-4 Lithium Battery

Fig. (4-4) represents Lithium Battery

It is a lithium-ion battery that is rechargeable 3.7V / 4800mAh. The user must have a proper understanding of lithium-ion batteries before working on them. Use caution when working with and using lithium-ion batteries as they are very sensitive to charging properties and may explode, burn, or cause a fire if misused or mistreated.

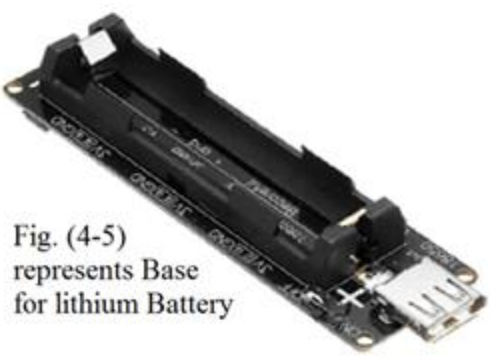

Fig. (4-5) represents Base for lithium Battery

4-2-5 Base for lithium battery:

A charger for lithium-shield battery contains a base with a circuit to protect the battery from high or low charging level The input voltage is from 5 to 8 volts on three outputs and three other outputs. It can be used with Arduino and Raspberry Pi.

4-2-6 A key to open and close the circuit:

Fig. (4-6) represents the Key of device.

A switch is a component that controls whether it is open or closed electrical circuit. It allows controlling the flow of electric current

Through circuits (without having to manually connect or unplug).

Switchgear is an important component of any electrical circuit

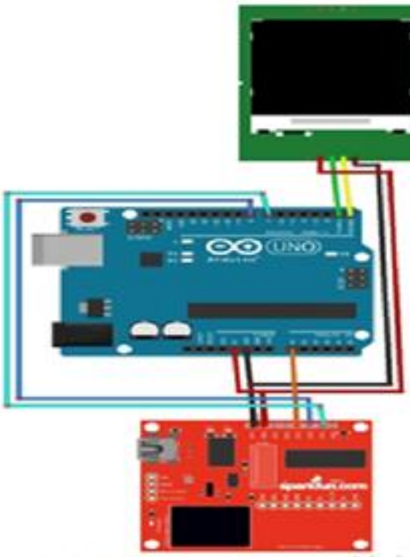

Fig. (4-7) represents the electrical circuit connections.

Require user interaction or control.

4-3 How to connect the circuit:

The figure (4-7) represents the electrical circuit of a portable ECG device.

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