Chapter 15

ELECTROCARDIOGRAPHS

OBJECTIVES

- Explain the origin of ECG signal and the relationships between the waveform and cardiac activities.
- Explain projection of the three-dimensional cardiac vector and analyze the relationships between the ECG leads.
- Define 12-lead ECG, the electrode placements, connections, and their relationships.
- Differentiate between diagnostic and monitoring ECG and explain the effects of changing bandwidth on the display waveform.
- Identify and analyze the functional building blocks of an ECG machine.
- Study typical specifications of an electrocardiograph.
- Evaluate causes of poor ECG signal quality and suggest corrective solution.

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1. Introduction
2. Origin of the Cardiac Potential
3. The Electrocardiogram
4. ECG Lead Configurations
5. Standard 12-Lead ECG and Vectorcardiogram
6. Fundamental Building Blocks of an Electrocardiograph
7. Typical Specifications of Electrocardiographs
8. ECG Data Storage, Network, and Management
9. Common Problems

INTRODUCTION

The class of medical instrumentation to acquire and analyze physiological parameters is called diagnostic devices. This chapter introduces an important diagnostic medical device to monitor and analyze the heart condition through collecting and evaluating electrical potential generated from cardiac activities. This medical device is called electrocardiograph, and the record of the electrical cardiac potential as a function of time is called the electrocardiogram. The first ECG came into clinical use in the 1920s using electron vacuum tube amplification, an oscilloscope for display, and a string galvanometer for recording. ECG has since evolved into a group of highly sophisticated devices to acquire cardiac potentials, perform diagnostic analysis and interpretation, as well as provide information storage and communication.

ORIGIN OF THE CARDIAC POTENTIAL

The natural pacemaker of the heart is a small mass of specialized heart muscle cells called the sinoatrial (SA) node. The SA node generates electrical impulses that travel through specialized conduction pathways in the atrium (Figure 15-1). As a result of this electrical activation, the atrial muscle contracts to pump blood from the atria through the two atrioventricular valves into the ventricles.

While causing the atrial muscle to contract, this electrical impulse continues to travel and eventually reaches another specialized group of cells called the atrioventricular (AV) node. In the AV node, the electrical impulse is delayed by about 100 ms before it arrives at the Bundle of His and its two major divisions, the right and left bundle branches. These branches then break into the Purkinje system, which conducts the electrical impulse to the inner wall of the ventricles, causing the ventricles to contract and pump blood from the right ventricle into the lung and from the left ventricle to the rest of the body. The time delay of the electrical impulse in the AV node allows blood to be emptied from the atria to the ventricles before the ventricular contraction. This coordinated contraction of the atria and ventricles maximizes the throughput of the cardiac contraction. Figure 15-2 shows the time delay of the electrical stimulation reaching different locations of the heart conduction pathway.

The contraction and relaxation of the heart due to synchronized polarization and depolarization of the cells in the cardiac muscles produce an electric current that spreads from the heart to all parts of the body. The spread-

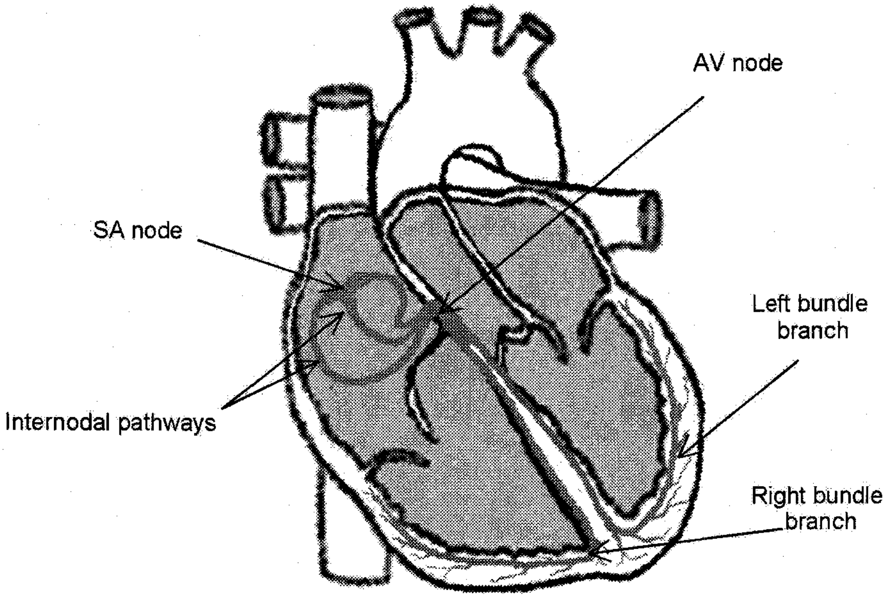


Figure 15-1. The Heart's Electrical Conduction Pathways.

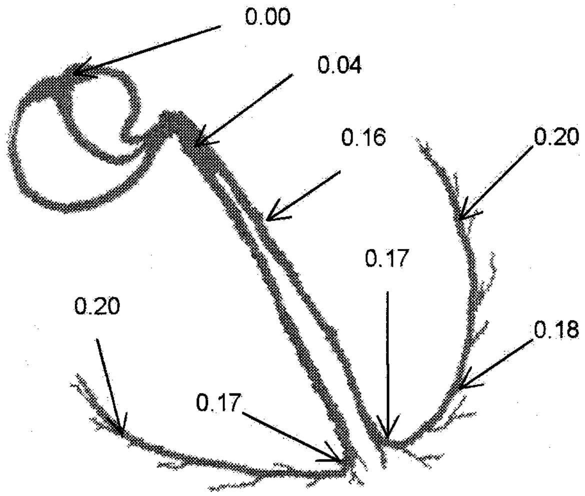


Figure 15-2. Time Delay (sec) of Cardiac Conduction.

ing of this current creates differences in potential at various locations on the body. Figure 15-3a shows a typical action potential plotted against time obtained from a pair of electrodes placed on a ventricular muscle fiber bundle under normal cardiac activity. It shows rapid depolarization (contraction) and then slow repolarization (relaxation) of the muscle fiber. As there are many fiber bundles contracting and relaxing at slightly different times in a cardiac cycle, the result of these electrical potential forms a cardiac vector of changing magnitude moving in three dimensions with time. The potential difference measured using a pair of electrodes placed on the surface of the body is the projection of the cardiac vector to the line joining the two electrodes. The waveform obtained by plotting this potential difference between a pair of electrodes placed on opposite sides of the heart as a function of time is called the electrocardiogram (or ECG).

THE ELECTROCARDIOGRAM

An ECG obtained from electrodes placed on the surface of the body (or skin) is called a surface ECG. A typical surface ECG is shown in Figure 15-3b. It consists of a series of waves (P, Q R, S, and T) corresponding to different phases of the cardiac cycle. Roughly speaking, the P wave corresponds to the contraction of the atria, the QRS complex marks the beginning of the contraction of the ventricles, and the T wave corresponds to the relaxation of the ventricles. In a normal heart, relaxation of the atria occurs at the same time as the contraction of the ventricles. The voltage variation due to atrial relaxation is not visible because of the large amplitude of the QRS complex. The amplitude of the R wave for surface ECG is about 0.4 to 4 mV. Typical amplitude is 1 mV with a cycle time of 1 second (60 beats per minute). Figure 15-4 shows the relationship between the surface ECG and the depolarization of the heart. In a normal cardiac cycle:

- The P wave precedes the depolarization of the atria.
- The PQ (or PR) interval is a measure of the elapsed time from the onset of atrial depolarization to the beginning of ventricular depolarization.
- The QRS complex marks the start of the depolarization of the ventricles.
- The QT interval marks the period of depolarization of the ventricle.
- The T wave reflects ventricular repolarization.

Delay due to total interruption or nonresponsiveness of some part of the pathway causes changes in the ECG. For example, if a large nonconductive area develops in the wall of the ventricle, the shape or duration of QRS will be altered. Any marked cardiac abnormality such as problems with the SA or AV nodes or in the ventricular conduction pathways will be reflected by changes in amplitude and shape of the ECG waveform. Surface ECG is an important diagnostic tool for clinicians to gain insight into different abnor-

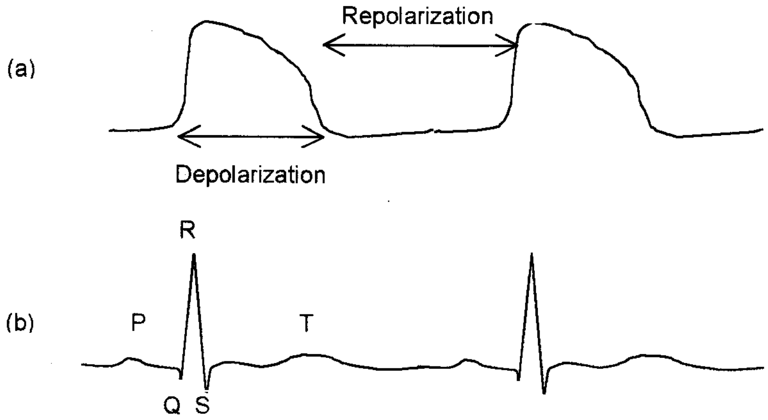


Figure 15-3. (a) Action Potential of a Cardiac Fiber Bundle and (b) Surface ECG.

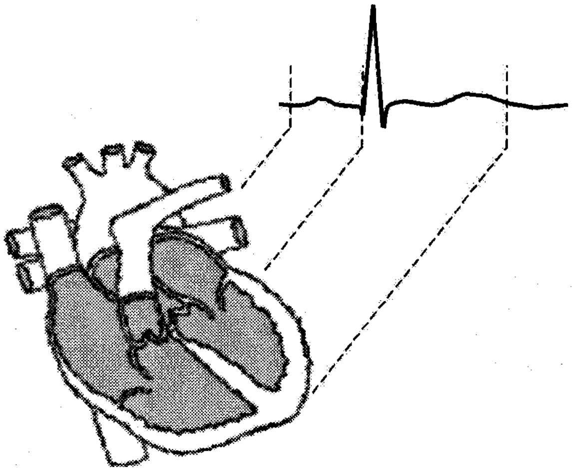
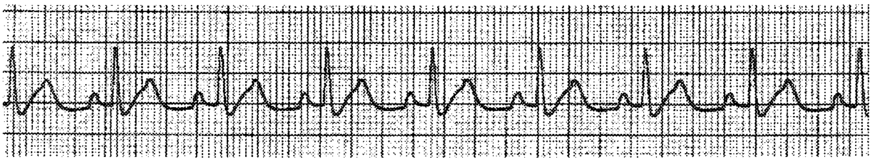


Figure 15-4. Surface ECG and the Cardiac Cycle.

mal heart conditions. Examples of some cardiac arrhythmias (abnormal heart rhythms) revealed in diagnostic ECG are shown in Figure 15-5.

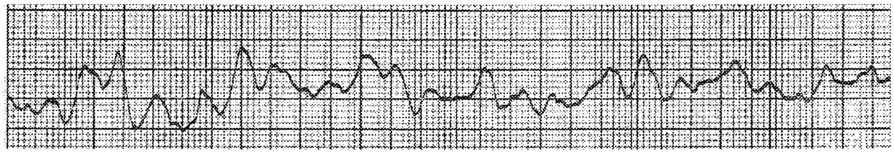
An electrocardiogram can be used to diagnose physiological conditions of the heart (e.g., to track heart rhythm and heart rate). Figure 15-5b reviews a premature ventricular contraction caused by an ectopic focus from the ventricles. Figure 15-5c is the most severe consequence of ventricular condition, which occurs when each muscle fiber within the myocardium contracts and relaxes at its own pace with no coordination. In ventricular fibrillation, the heart loses its ability to pump blood into the circulatory system.

ECG is an important diagnostic tool of the heart. An ECG stress test



a) Normal Heart Rhythm.

b) Premature Ventricular Contraction (PVC).



c) Ventricular Fibrillation.

Figure 15-5. Normal and Arrhythmic ECG.

(ECG taken when the patient is exercising) is an example of a diagnostic ECG. When a patient's heart rhythm is monitored while staying in a hospital, it is called monitoring ECG. In general, diagnostic ECG contains more information than monitoring ECG due to two major factors:

1. The bandwidth of diagnostic ECG (e.g., 0.05 Hz to 120 Hz) is wider than that of monitoring ECG (e.g., 0.5 Hz to 40 Hz).
2. There are more leads (projection of the cardiac vector) taken simultaneously in diagnostic ECG than monitoring ECG.

The effects of machine bandwidth and lead configurations on ECG will be discussed in more detail later in this chapter.

In a critical care area in a hospital, monitoring of a patient's ECG provides the following information:

- Early warning signs of more major arrhythmias that may follow
- Immediate detection of potentially fatal arrhythmia by means of alarms
- Feedback on the effectiveness of a treatment intervention
- Correlation between cardiac rhythm and treatment variables
- Permanent record of ECG waveform on a routine basis

When an out-patient's ECG must be monitored over an extended period of time, an ambulatory ECG (or sometimes called Holter ECG) is used.

An ambulatory ECG can record the patient's heart rhythm continuously during normal daily activities, say, 24 hours. During monitoring, the patient wears a small ECG machine with a built-in magnetic tape recorder or a semiconductor memory. ECG is acquired from skin electrodes attached to the patient and stored in the memory. After the acquisition period, the memory is downloaded to a reader terminal by a cardiology technologist and the ECG is read and interpreted by a cardiologist.

ECG LEAD CONFIGURATIONS

In earlier discussion, we learned that the cardiac vector has a varying magnitude and pointing to different directions with time; also, an ECG is the potential difference measured against time from the projection of the cardiac vector into a direction according to the placement of the pair of electrodes. If ECG electrodes are connected to the right arm (RA), left arm (LA), and left leg (LL) of the patient, one projection of the cardiac vector can be obtained by connecting the electrodes attached to the left leg and right arm to the input terminals of a biopotential amplifier. A different projection of the same cardiac vector can be measured between the left arm and the right arm electrodes and similarly another projection between the left leg and right arm. These projections (or lead vectors) in the patient's frontal plane can be approximated by an equilateral triangle called the Einthoven's triangle. Figure 15-6 shows the projections of the cardiac vector at a certain time instant on the Einthoven's triangle.

The ECG obtained between the limb electrodes LA (+) and RA (-) is called lead I (Figure 15-7), between LL and RA is called lead II, and

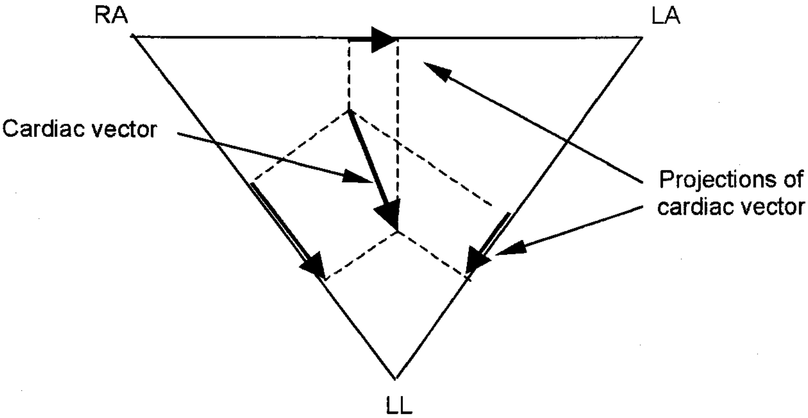


Figure 15-6. Projection of Cardiac Vector in the Frontal Plane.

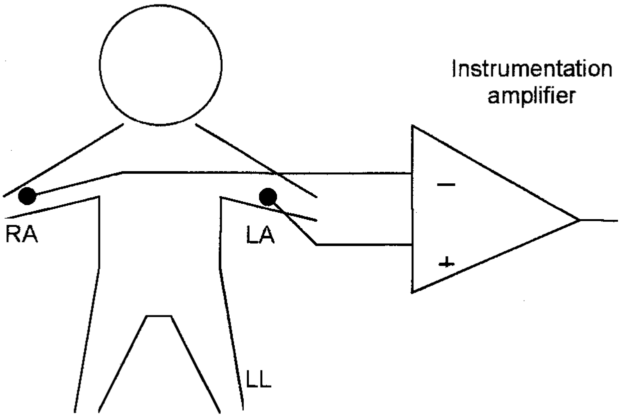


Figure 15-7. ECG Lead I Measurement.

between LL and LA is called lead III. Figure 15-8 shows the configurations of these limb leads. Note the polarities of the electrodes.

If the potential is measured across a limb electrode and the average of two other limb electrodes, the ECG obtained is called an augmented limb lead. Figure 15-9 shows the connections of the augmented limb leads aVR

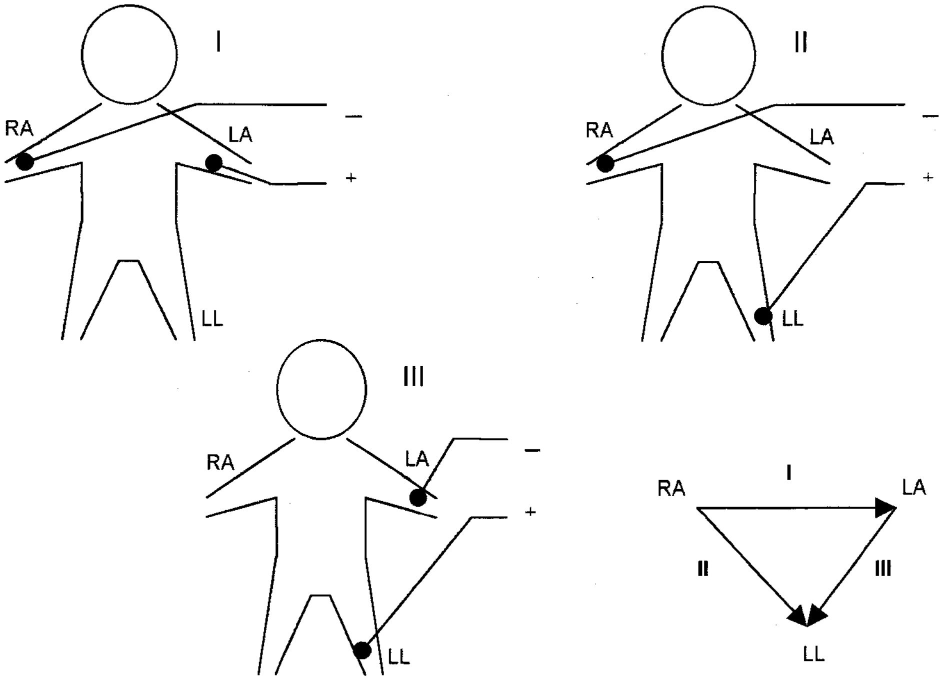


Figure 15-8. ECG Limb Leads.

aVL, and aVF (note that R stands for right, L stands for left, and F stands for foot). The average of the limb potentials is obtained by connecting two identical value resistors to the limb electrodes and then connected to the inverting input of the instrumentation amplifier. The limb leads (I, II, and III) and the augmented limb leads (aVR, aVL, and aVF) together are called the frontal plane leads.

The frontal plane leads represent the projection of the three-dimensional cardiac vector onto the two-dimensional frontal plane. In order to reconstruct the entire cardiac vector, the cardiac potential projected onto another plane is required. Figure 15-10 shows the position of the electrode placements on the chest of the patient to obtain the precordial leads (or the chest leads). The precordial leads represent the projection of the cardiac vector on the transverse plane of the patient. To measure the precordial leads, potential of each of the chest electrodes is referenced to the average of the three limb electrodes (that is why they are sometimes referred to as unipolar leads). Figure 15-11 shows the connections to obtain the chest leads. Note that all resistors to the limb electrodes are of equal value. Which precordial lead is being measured depends on the position of the electrode on the chest of the patient (Figure 15-10). The six frontal plane leads and the six precordial leads form the standard 12-lead ECG configuration. A summary of the electrode positions for the standard 12-lead ECG is shown in Table 15-1.

Note that altogether nine electrodes (three on the frontal plane and six on the transverse plane) are necessary to obtain the 12-ECG leads simultaneously. In practice, a tenth electrode attached to the patient's right leg is used either as the reference (grounded) or connected to the right-leg-driven circuit for common mode noise reduction (see Chapter 11). Figure 15-12 shows the characteristic ECG waveform from a standard 12-lead measurement.

Table 15-1.
Standard 12-Lead ECG Electrode Placement.

Lead	*Electrode Placement*	
	Positive Polarity	*Negative Polarity*
I	left arm (LA)	right arm (RA)
II	left leg (LL)	right arm (RA)
III	left leg (LL)	left arm (LA)
aVR	right arm (RA)	1/2 (LA + LL)
aVL	left arm (LA)	1/2 (RA + LL)
aVF	left leg (LL)	72 (RA + LA)
V1 through V6	chest positions	1/3 (LA + RA + LL:

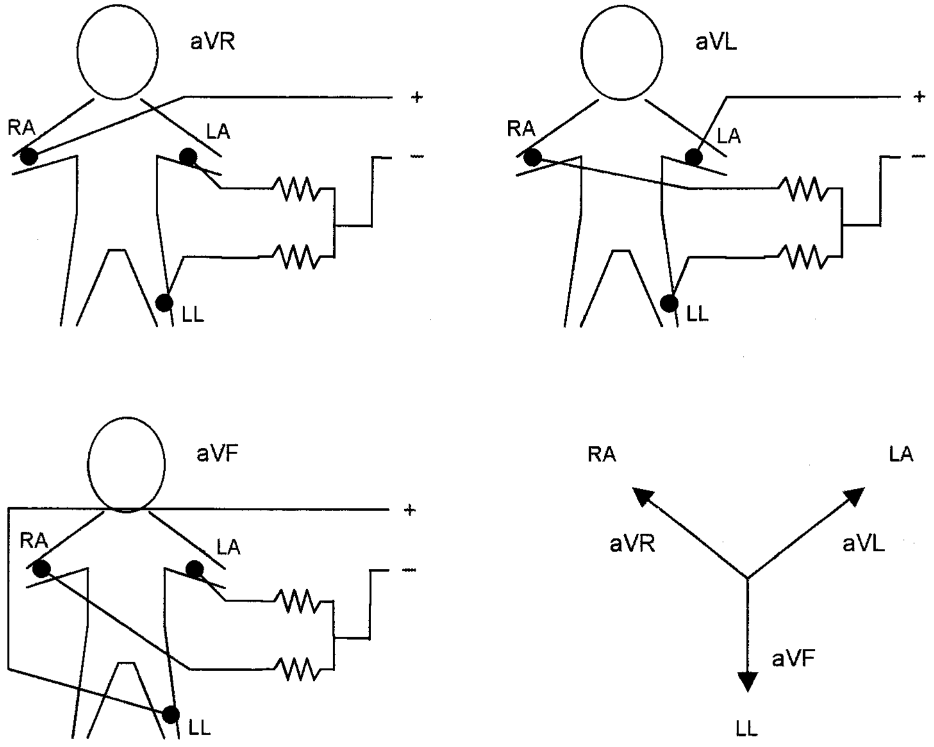
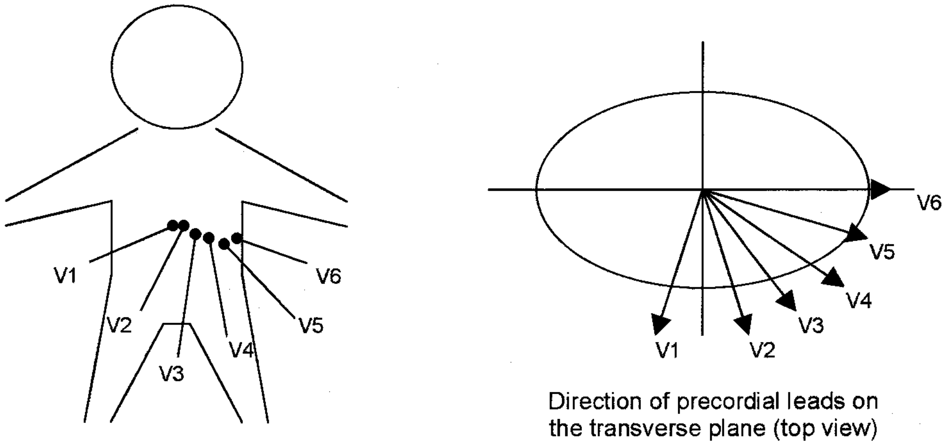


Figure 15-9. ECG Augmented Limb Leads.



Positions of electrodes on chest wall

Direction of precordial leads on the transverse plane (top view)

Figure 15-10. ECG Precordial Leads.

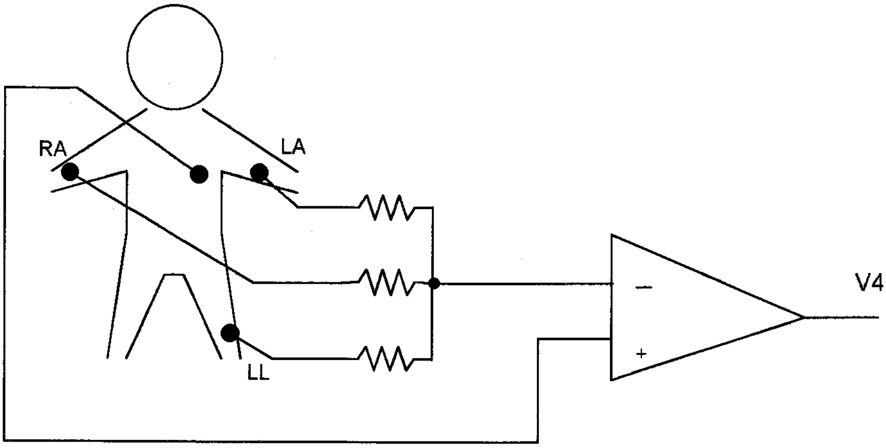


Figure 15-11. Connections for the Chest Leads.

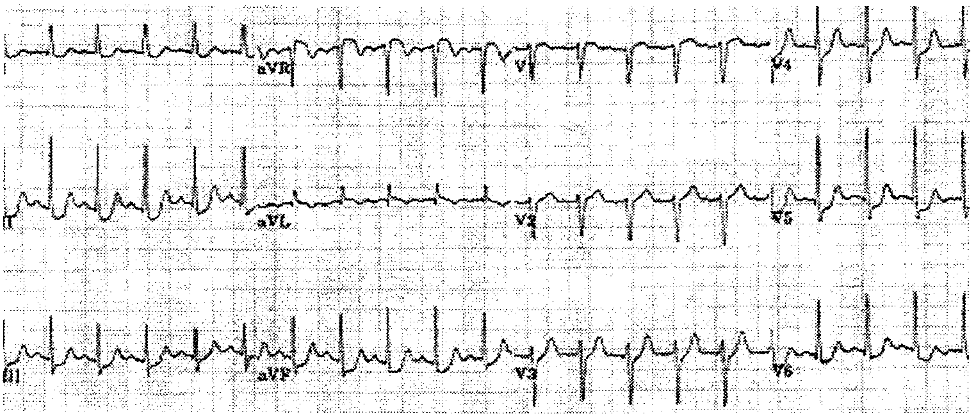


Figure 15-12. Standard 12-Lead ECG Waveform.

STANDARD 12-LEAD ECG AND VECTORCARDIO GRAM

From the definition of the limb leads, lead I is the difference in potential between the electrodes attached to the left arm and the right arm. That is: lead I = ELA - ERA, similarly lead II = ELL - ERA, and lead III = ELL - ELA.

The sum of Lead I and Lead III equals to Lead II:

Lead I + Lead III = (ELA - ERA) + (ELL - ELA) = ELL - ERA = Lead II

This result agrees with the vector relationships between lead I, lead II, and lead III shown in Figure 15-8.

For the precordial lead VI, where *n*= *1* to 6,

$$V_n = E_n - \frac{E_{RA} + E_{LA} + E_{LL}}{3}$$

For the augmented limb leads,

$$aVR = E_{RA} - \frac{E_{LA} + E_{LL}}{2} = \frac{2E_{RA} - E_{LA} - E_{LL}}{2} = -\frac{(E_{LL} - E_{RA}) + (E_{LA} - E_{RA})}{2}$$

Since lead I (or I) = $E_{LA} - E_{RA}$ and lead II (or II) = $E_{LL} - E_{RA}$,

$$aVR = -\frac{II + I}{2}$$, similarly, one can show that

$$aVL = E_{LA} - \frac{E_{RA} + E_{LL}}{2} = \frac{I - III}{2}, \text{ and}$$

$$aVF = E_{LL} - \frac{E_{RA} + E_{LA}}{2} = \frac{II + III}{2}.$$

Furthermore, augmented leads can be obtained by subtracting the average potential of the three limb electrodes from one of the limb electrode potential:

$$E_{LL} - \frac{E_{RA} + E_{LA} + E_{LL}}{3} = \frac{2E_{LL}}{3} - \left(\frac{E_{RA}}{3} + \frac{E_{LA}}{3}\right) = \frac{2}{3}\left(E_{LL} - \frac{E_{RA} + E_{LA}}{2}\right) = \frac{2}{3}aVF.$$

Similarly, one can show that

$$E_{LA} - \frac{E_{RA} + E_{LA} + E_{LL}}{3} = \frac{2}{3}aVL, \text{ and}$$

$$E_{RA} - \frac{E_{RA} + E_{LA} + E_{LL}}{3} = \frac{2}{3}aVR.$$

Consider the Wilson network shown in Figure 15-13. If the corners of this triangular resistive network are connected to electrodes on the right arm, left arm, and the left leg of the patient, *V-, VR-, Vi-,* and *VF-* are equal to:

$$V_{-} = \frac{E_{RA} + E_{LA} + E_{LL}}{3}$$

$$V_{R-} = \frac{E_{LA} + E_{LL}}{2}$$

$$V_{L-} = \frac{E_{RA} + E_{LL}}{2}$$

$$V_{F-} - \frac{E_{RA} + E_{LA}}{2}.$$

These terminals on the network can therefore be used as the negative reference to measure the augmented and precordial ECG leads. The Wilson network allows using only one electrode connection at each location. It also avoids the need to remove and reconnect lead wires and electrodes during ECG measurement. Figure 15-14 shows the connections to obtain lead I, lead aVR, and a chest lead. Typical resistance values of R and R1 in the network (Figure 15-13) are 10 kΩ and 15 kΩ, respectively.work (Figure 15-13) are 10 kΩ and 15 kΩ, respectively.

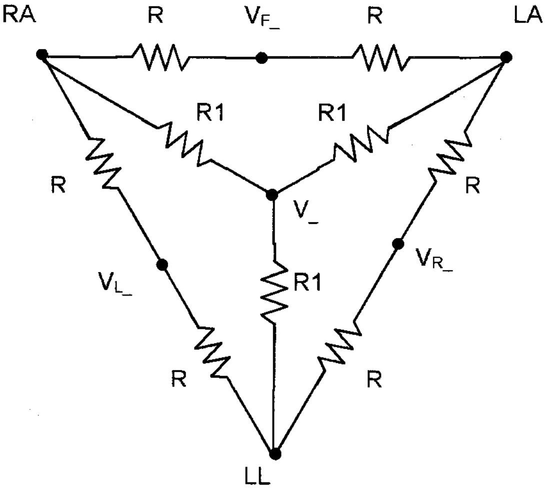


Figure 15-13. Wilson Network.

Figure 15-15 shows the acquisition block (or patient interface module) of a single channel 12-lead ECG machine. During operation, it uses a multiplexer or a number of mechanical switches to select which two input combinations of electrodes are connected to the instrumentation amplifier. Note that for this machine only one lead can be measured at a time. In a fully digital machine, the Wilson Resistor Network may be eliminated. The lead signals from such a digital system are derived mathematically from the electrical potentials from the individual electrodes using the lead relationships derived previously.

In order to simultaneously measure more than one ECG lead, more than one instrumentation amplifiers are usually required. Figure 15-14 shows a three-channel ECG machine measuring lead I, lead aVR, and one chest lead simultaneously. In general, to measure all 12 leads simultaneously, the electrocardiograph will need to have 12 sets of instrumentation amplifiers as well as 12 display channels. Some machines are using sampling and time-division multiplexing techniques.

Other than the standard 12-lead ECG, other lead systems or lead loca-

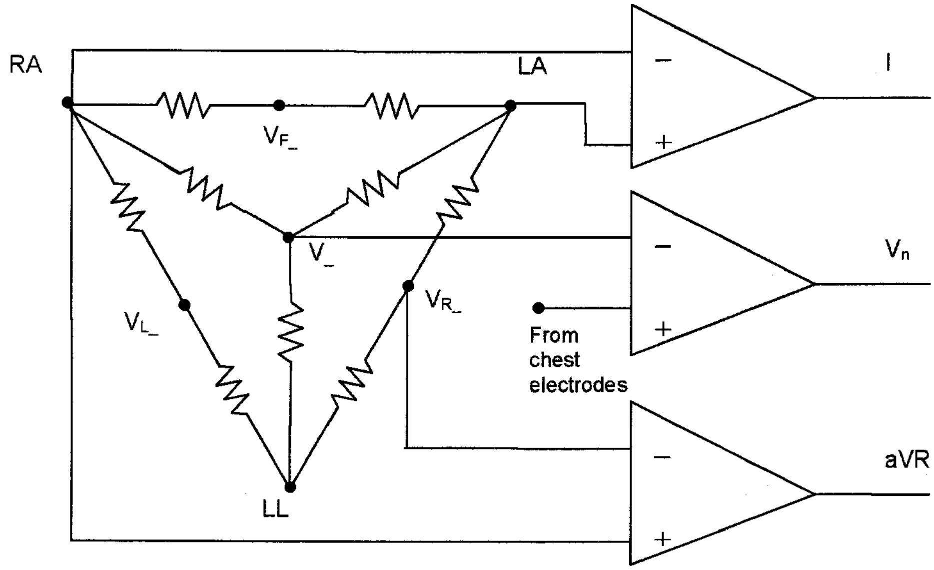


Figure 15-14. Use of Wilson Network in ECG Measurement.

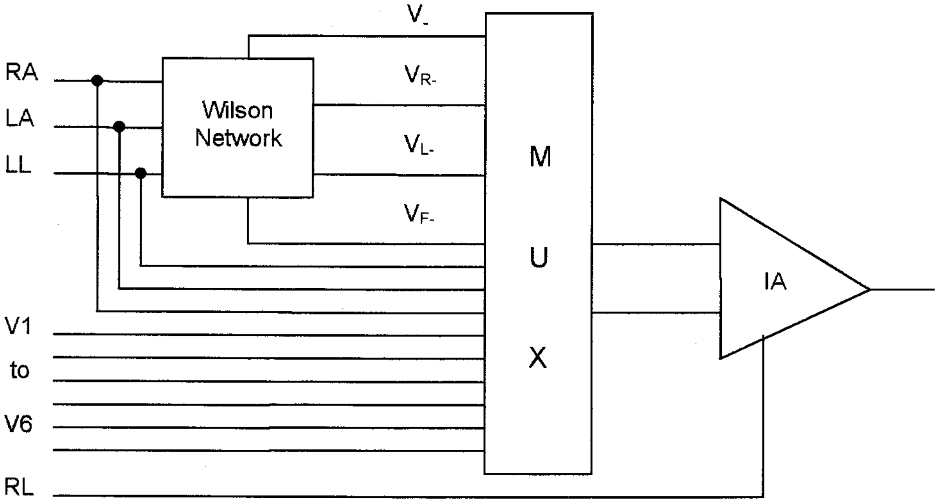


Figure 15-15. A Single Channel 12-Lead ECG Front End.Figure 15-15. A

lions are used in diagnostic electrocardiography. One such commonly used lead is the esophageal lead, which is obtained by swallowing an electrode into the esophagus so that the electrode is directly behind and close to the heart of the patient. The esophageal electrode is often referenced to the average of the limb leads.

Another interpretation of the electrical cardiac activity is the vectorcardiogram. It was discussed earlier that the cardiac vector changes in both magnitude and direction (in three dimensions) as the electrical impulse spreads through the myocardium. A vectorcardiogram depicts these changes as a function of time during the cardiac cycle. Figure *15-16* show the magnitude and direction of the cardiac vector projected onto the frontal plane at five different time intervals during the QRS complex (i.e., ventricular contraction). The vector at ti is zero, which corresponds to the quiescent time before the ventricle starts to contract. When the current starts to flow toward the apex of the heart, causing the ventricle to contract, the cardiac vector starts to grow in magnitude as well as change in direction. The vectors at time intervals t2 to is are shown in Figure *15-16*. The elliptical figure (or loop) traced by the cardiac vector during the QRS interval using the quiescent point as reference is called the QRS-vectorcardiogram. A smaller loop, referred to as the T-vectorcardiogram, is also produced by the T wave. As the magnitude of the T wave is about *0.2* to *0.3* mV and happens about *0.25* second after the QRS, it is a much smaller loop that appears about *0.25* second after the disappearance of the QRS-vectorcardiogram. A still smaller P-vectorcardiogram can be recorded during atrial depolarization. Like the conventional electrocardiogram, the vectorcardiogram can be used in the diagnosis of certain heart conditions.

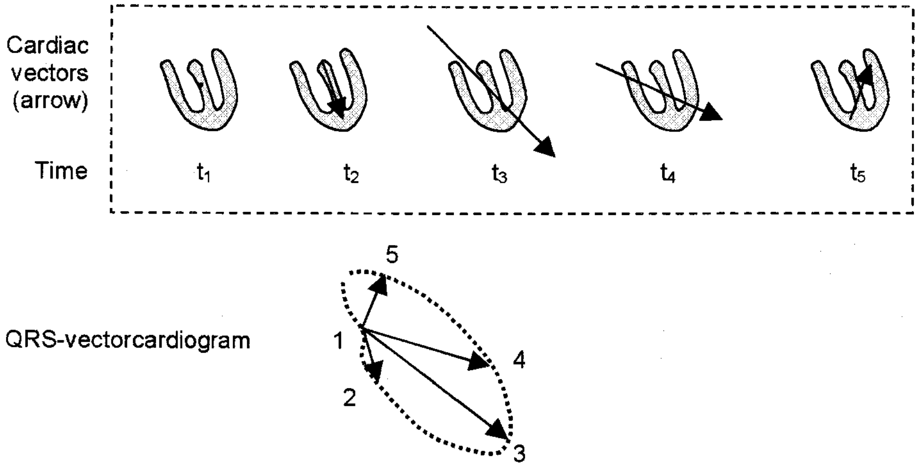


Figure 15-16. QRS-Vectorcardiogram.

FUNDAMENTAL BUILDING BLOCKS OF AN ELECTROCARDIOGRAPH

Figure 15-17 shows the functional block diagram of a typical electrocardiograph. The function of each block is described below.

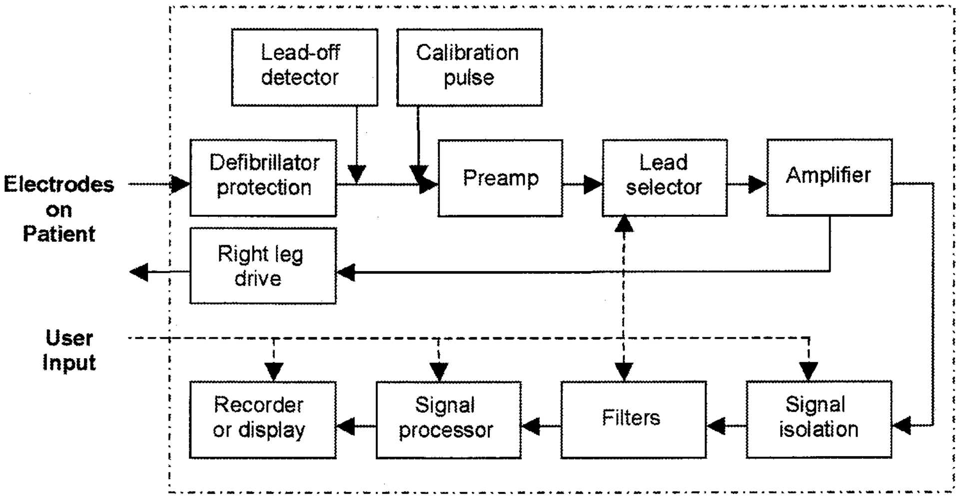


Figure 15-17. Functional Block Diagram of an Electrocardiograph.

Defibrillator Protection

As the ECG electrodes are connected to the patient's chest, they will pick up the high-voltage impulses during cardiac defibrillations. Gas discharge tubes and silicon diodes are used for defibrillator protection (see Chapter 11, Figs. 11-17 and 11-18) to prevent the high-voltage defibrillation discharge from damaging sensitive electronic components.

LeadOff Detector

When an electrode or lead wire is disconnected, the output of the ECG may display a flat baseline with noise. This may be misinterpreted as asystole. A lead-off (or lead fault) detector can prevent such misinterpretation. A simple lead-off detector is shown in Figure 15-18. In this design, a very large value resistor (>100 MΩ) is connected between the positive power supplyvalue resistor (>100 MΩ) is connected between the positive power supply and a lead wire to allow a small DC current to flow via the electrode through the patient to ground. Under normal situation, due to the relatively small electrode/skin impedance, the DC voltages created at the input terminals of the operation amplifier are very small and almost of equal value. However, if an electrode or a lead wire comes off from the patient, the amplifier will be saturated since the voltage at one input of the amplifier will rise to the level of the power supply. In this case, the lead-off LED will turn on to alert the user to a lead fault.

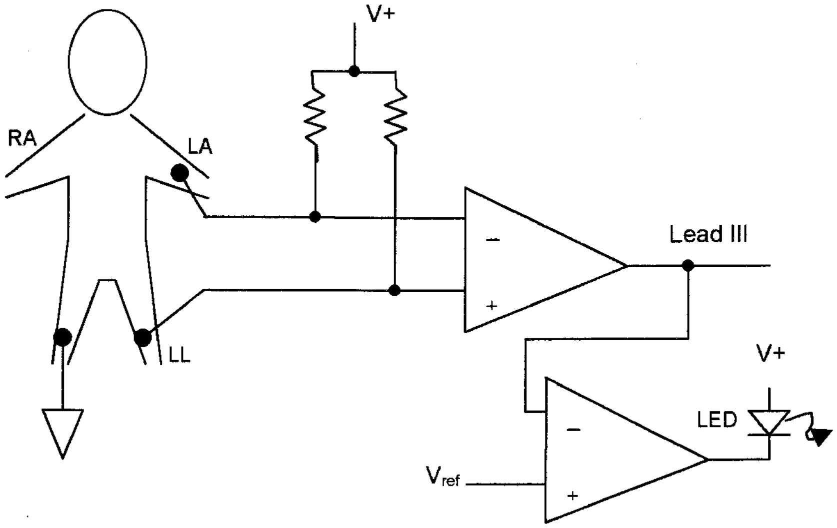


Figure 15-18. Lead-Off Detector.

Preamplifier

The magnitude of surface ECG is from 0.1 to 4 mV. A system, especial-

The magnitude of surface ECG is from 0.1 to 4 mV. A system, especially one with long unshielded lead wires, may pick up noise of up to several mV through electromagnetic coupling. Therefore, it is important to amplify this small signal as close to the source as possible before it is corrupted by noise. Most ECG machines amplify the potential signals picked up by the electrodes in a preamp module or patient interface module located near the patient.

Lead Selector

The lead selector selects the ECG lead to be displayed or recorded. In a multichannel machine, the lead selector also configures the sequence and format of the display or printout.

Amplifier

Typically the magnitude of the ECG at the surface of the body is about 1 mV, but this value may vary substantially from patient to patient. For example, the ECG of a critically ill patient may be as low as 0.1 mV or as high as 3 mV. The electrocardiography must have some means of controlling the size of the ECG waveform. This is also called SIZE, GAIN, or SENSITIVITY adjustment. Typical sensitivity settings are 5, 10, or 20 mm/mV.ITY adjustment. Typical sensitivity settings are 5, 10, or 20 mm/mV.

RightLegDriven Circuit

Electrical equipment and wiring near the electrocardiograph may induce common mode signal of several mV magnitude on the patient's body. The right-leg-driven circuit is to suppress this common mode signal so that it will not mask the ECG signal (see Chapter 11).

Calibration Pulse

A built-in reference voltage of 1 mV is applied to the input of the electrocardiograph. This reference signal is displayed on the screen and on the printout to inform the user that the machine is functioning properly and that it has the necessary gain to display the ECG signal coming from the patient.

Signal Isolation

The function of the signal isolation circuit is to reduce the leakage current to and from the patient through the electrode/lead connection for microshock prevention. A module consisting of a FM modulator, an opto-isolator, and a demodulator is commonly used to serve this purpose.

Filter

The frequency bandwidth for a diagnostic quality ECG is from 0.05 to 150 Hz. Such diagnostic mode bandwidth allows accurate presentation of the electrical activities of the patient's heart. Monitoring mode is used where a gross observation of the electrical activity of the patient's heart is necessary but requires little analysis or details. Interference and baseline drift can be reduced by a bandwidth less than that required for a diagnostic-quality ECG. For monitoring, a bandwidth of 1 to 40 Hz is reasonable and will allow recognition of common arrhythmias, while providing reasonable rejection of artifacts and power frequency (60 or 50 Hz) interference. However, some distortion of the ECG will occur. Most electrocardiographs have built-in upper and lower cutoff frequency selection to allow the user to choose the optimal bandwidth for the situation. A power frequency rejection filter optimal bandwidth for the situation. A power frequency rejection filter (notch filter) can also be switched on or off by the user to minimize power frequency interference.

Signal Processor

Signal processing functions in ECG machines can range from simple heart rate detection to sophisticated arrhythmia analysis and classification. Some common features for signal processing are:

- Heart rate detection and alarm
- Pacemaker pulse detection
- Waveform measurement: PR interval, QRS duration, etc.
- Arrhythmia analysis and classification: e.g., occurrence and frequencyof PVC
- Diagnosis and interpretation

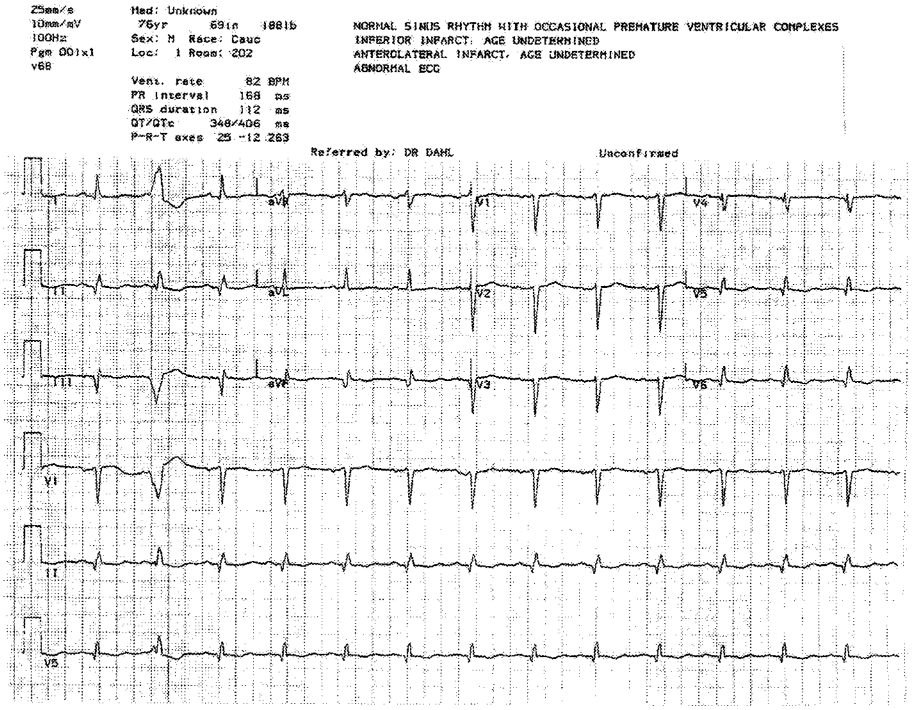
Recorder or Display

The acquired waveform of diagnostic ECG can be displayed on a monitor (LCD or CRT) or printed out from a paper chart recorder. In either case, the speed of the waveform traveling across the screen of the monitor or the speed of the paper in the chart recorder can be adjusted. Typical speeds are 12.5, 25, and 50 mm/s. For a multichannel ECG machine, the display format can be selected to display a combination of ECG leads. For example, a "3 X 4 + 3R" print format from a six-channel paper chart recorder is shown in can be selected to display a combination of ECG leads. For example, a "3 X 4 + 3R" print format from a six-channel paper chart recorder is shown in Figure 15-19. In this format, the 12 ECG leads are displayed in three rows of 4 ECG leads. Each of the leads is displayed for 2.5 seconds. In addition, three leads selected by the user are displayed for the entire 10 seconds.

TYPICAL SPECIFICATIONS OF ELECTROCARDIOGRAPHS

The specifications of a typical 12-lead electrocardiograph are:

- Input channels: simultaneous acquisition of up to 12 ECG leads
- Frequency response: -3dB @ 0.01 to 105 Hz
- CMRR: >110 dB
- Input impedance: >50 M’Ω
- A/D conversion: 12 bits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Med: Unknown
76yr 69in 188lb
Sex: M Race: Cauc
Loc: 1 Room: 202

Vent. rate 82 BPM
PR interval 168 ms
QRS duration 112 ms
QT/QTc 348/406 ms
P-R-T axes 25 -12 263

NORMAL SINUS RHYTHM WITH OCCASIONAL PREMATURE VENTRICULAR COMPLEXES
INFERIOR INFARCT: AGE UNDETERMINED
ANTEROLATERAL INFARCT, AGE UNDETERMINED
ABNORMAL ECG

Referred by: DR DAHL

Unconfirmed

Figure 15-19. A "3 X 4 + 3R" Printout of a 12-Lead ECG.Figure 15-19. A "3 X 4 + 3R" Printout of a 12-Lead ECG.

- Sampling rate: 2,000 samples/sec per channel
- Writer type: thermal digital dot array with 200 dots per inch vertical resolution
- Writer speed: 1, 5, 25, and 50 mm/sec, user selectable
- Sensitivities: 2.5, 5, 10, and 20 mm/mV, user selectable
- Printout formats: 3, 4, 5, 6, and 12 channels, user selectable channel, and lead configurations
- Dimensions: 200 (H) X 40 (W) X 76 (D) cm
- Power requirements: 90 VAC to 260 VAC, 50 or 60 Hz
- Certifications: IEC 601

ECG DATA STORAGE, NETWORK, AND MANAGEMENT

With the advancement in electronic data storage and computer network technologies, modern ECG machines are capable of electronically stored and shared information through computer networks. In a hospital, wireless ECG telemetry, diagnostic review stations, ECG machines, and electronic storage can be integrated into an "ECG data management system" via a local area network (LAN). Multiple hospitals, through wide area network (WAN), can also be configured to communicate and share resources such as mass storage or archive. In a paperless cardiology, ECG data can be readily stored, retrieved, transferred, and viewed at any designated location.

COMMON PROBLEMS

Abnormality in ECG waveform may be grouped into the following three categories:

1. Artifacts due to electrode problems may be caused by

- Improper positioning of electrodes on the patient
- Loose contact between the electrode and the patient
- Dried-out electrode gel
- Bad connection between the lead wire and the electrode
- Failure to properly prepare (clean, shave, and abrade) the patient site for electrode attachment

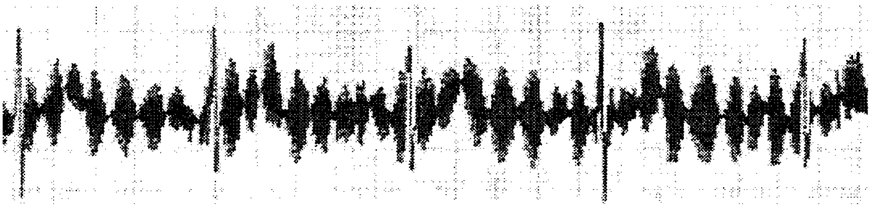
2. Artifacts due to physiological interference may be caused by

- Skeletal muscle contraction
- Breathing action
- Patient movement
- Involuntary muscle contraction (e.g., tremor)

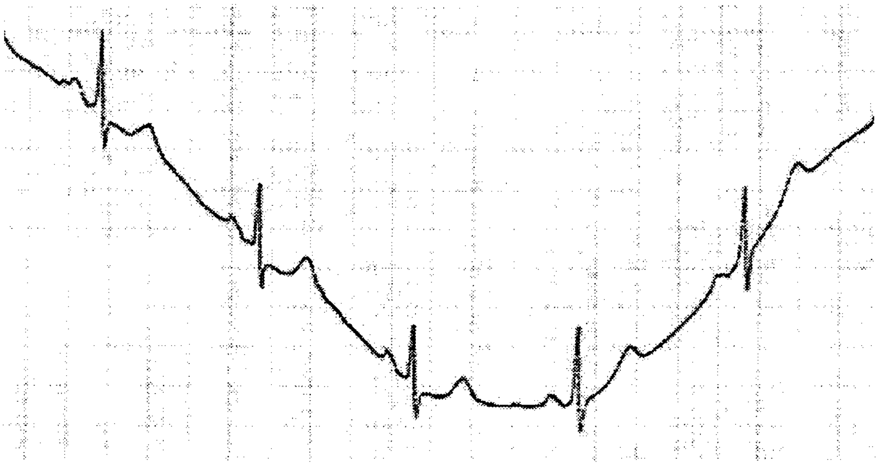
3. Artifacts due to external interference may be caused by

- Power frequency interference coupled to the lead wires or as common mode voltage on the patient (60 Hz interference in North America)
- Radiated electromagnetic interference from other equipment (e.g., 500 kHz interference from an electrosurgical unit)
- Conductive interference from the power line or ground conductor (e.g. high-frequency noise from switching power supplies)
- Interfering signals from other equipment connected to the patient (e.g., pacemaker or neural stimulator pulses)
- Power interruption and supply voltage fluctuation

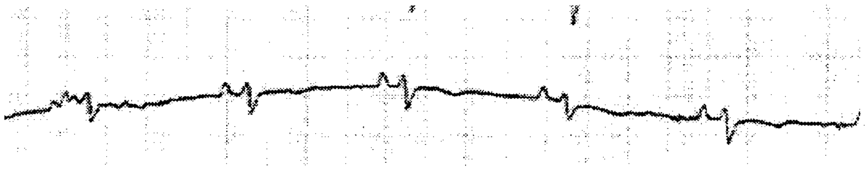
Figure 15-20 shows some common artifacts in ECG acquisitions. Figure 15-20a shows a typical ECG waveform with power frequency interference. One can see 60 even, regular spikes in a 1-second interval if the timescale is expanded. Severe 60 Hz interference is often caused by improper patient or equipment grounding. It may also occur when the ECG lead wires are placed too close to power cables or improperly grounded electrical equip-



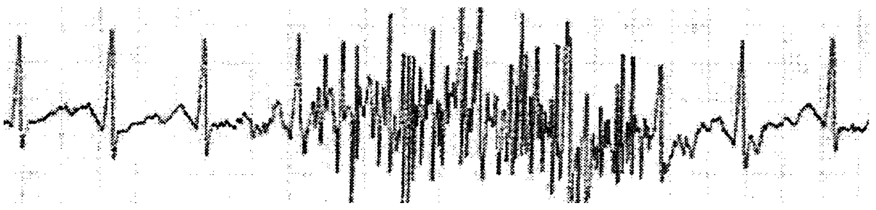
a) Power Frequency (60 Hz) Interference.



b) Baseline Wander.



c) Low Amplitude.



d) Muscle Contraction.

Figure 15-20. Common ECG Artifacts.

rent. Turning on the built-in 60 Hz notch filter (if available) can eliminate such interference. Grouping the lead wires may reduce the interference amplitude. Figure 15-20b shows an ECG with wandering baseline. This can be caused by poor skin preparation, bad electrode contact, dried-out or expired electrode, patient movement, or patient's respiratory action. Figure 15-20c shows an ECG waveform with abnormally small amplitude. Poor skin contact, improperly prepared skin, or dried-out electrode may be the cause. Figure 15-20d shows ECG artifacts due to skeletal muscle contraction. Muscle artifacts will usually disappear when the patient is relaxed and calmed down.