CHAPTER 10

Introduction to Biomedical Instruments

LEARNING OBJECTIVE

In this Chapter, a student can learn and understand the working principle, usage, limitations and applications of the following biomedical instruments:

- Electrocardiograph (ECG)
- Electroencephalograph (EEG)
- Blood Pressure (BP) Monitor
- Pulse oxi-meter
- Tread Mill Test (TMT)
- Glucometer
- Endoscopy
- Ultrasound Scanner
- Computed Tomography (CT) Scanner
- Magnetic Resonance Imaging (MRI)
- Positron Emission Tomography (PET)

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CONTENT

Introduction

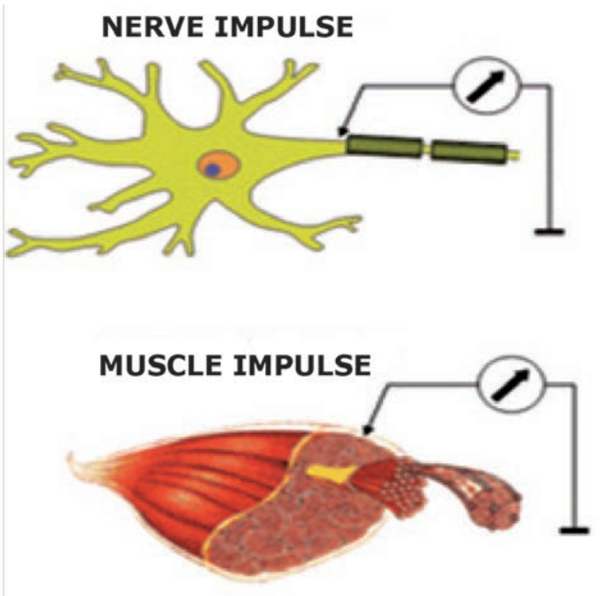


FIGURE 10.1 Biopotential from nerve and muscle

Human body consists of biological, chemical, physical, electrical, thermal, hydraulic, pneumatic, acoustical, magnetic and mechanical systems, all interacting with each other. It also contains a powerful computer (brain), several types of communicating systems (nerves), and a great variety of control systems (muscles).

Human body is a source of various biopotential signals, which are most useful for estimating the physiological, clinical, therapeutic and biological activities of living body. These signals can be picked up from the surface of the body or from within the body. Figure 10.1 shows the biopotential recorded from nerve and muscle, respectively. The biopotential was first recorded in 1786, by an Italian Physician Dr. Luigi Galvani. Later on, several advancements in electronics, material science and computing technology shaped the biomedical instruments in various forms like dedicated, portable, wearable, PC-based, MEMS/NEMS-based and wireless based devices.

Definition of Biopotential

1. An electric potential that is measured between points in living cells, tissues, and organs, which accompanies all biochemical processes.
2. Ionic voltages produced as a result of the electrochemical activity of excitable cells.

DO YOU KNOW? **The difference between the electric current and bioelectric current?**

Electric current is due to the movement of electrons in a circuit, whereas bioelectric current is due to movement of ions across the cell membrane.

Characteristics of Biopotential signals

The important characteristics of a biopotential signals recorded from our body are summarized in Table 10.1

TABLE 10.1 Types of Biopotential Signals and their characteristics

Parameter	Signal Characteristics
Electro cardiogram (ECG)	Frequency range: 0.05 to 500 Hz 0.05 to 120 Hz is adequate Typical signal voltage: 1 mV Voltage range: 10μV to 5 mV
Electro encephalogram (EEG)	Frequency: 0.1 to 100 Hz 0.5 to 70 Hz is adequate Voltage: 2 to 200 μV Typical voltage: 50 μV
Electromyogram (EMG)	Frequency: 5 to 2000 Hz Voltage: 25 to 5000 μV
Electro retinogram (ERG)	Frequency: DC to 20 Hz Voltage: 0.5μV to 1mV Amplitude: 0.5 mV
Electro culogram (EOG)	Frequency: DC to 100 Hz Voltage: 10 to 3500 μV Amplitude: 0.5 mV

Measurement of Biopotential

Using transducers, the ionic potential generated by our body is converted into electrical potential. Bioelectric potential waveforms generally end with the suffix gram. For example, Electrocardiogram, Electroencephalogram. Instruments used to measure biopotential generally ends with the suffix graph, e.g., Electrocardiograph, Echocardiograph. Biomedical instruments are devices that can be used to make measurements of biologic or medical quantities and give quantitative (or sometimes qualitative) results. Have you ever seen a biomedical instrument? Some of the simple biomedical instruments everybody knows are thermometer, stethoscope, etc. as shown in Figure 10.2.

FIGURE 10.2 Basic Medical Instruments

Components of Biomedical Instrument

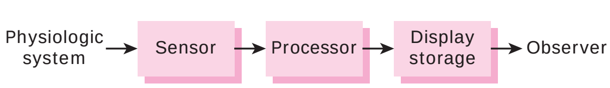


FIGURE 10.3 Basic Component of a Biomedical instrument

Figure 10.3 shows the basic components of a biomedical instrument. Any biomedical instrument comprises of sensor that senses the physiological parameter of interest such as temperature, blood pressure, pulse rate, etc. The sensor's output signal is of low-amplitude and comprises of unwanted signals called noise, artifacts, etc. Therefore, the sensor output signal is processed in the processor unit, which may be an electronic circuit, or a computer with related software. The processed output signal can be either stored in the memory for future usage or it can be shown in a display for monitoring/ diagnosis. In this Chapter, some of the basic biopotential as well as biomedical imaging instruments and their working principles are discussed.

10.1 Electrocardiograph

Have you ever seen an Electrocardiogram (ECG) record? Whenever you have suspected any problem about the normal functioning of the heart, the Physician advised to take an electrocardiogram for diagnosing the functionality of your heart. Then, the questions arises naturally are, How Electrocardiogram is recorded? What is the working principle of electrocardiograph machine? How it is used by the physician for diagnosis? What is the difference between Electrocardiograph and Electrocardiogram? In this chapter, we will try to answer these questions and to understand the concepts related with the working and usage of ECG.

Electrocardiograph is an instrument to record the electrical activity associated with the heart. Electrocardiogram is the graphical or waveform representation of the voltage versus time that is recorded using Electrocardiograph instrument. They are used to assist the Physician in diagnosing or treating some types of heart disease, determining a patient's response to drug therapy, and reveal trends or changes in heart function.

Electrocardiograph records small voltages of about one millivolt (mV) that appear on the skin as a result of cardiac activity. The voltage differences between electrodes are measured; these differences directly correspond to the heart's electrical activity. The first ECG machine developed by Augustus Waller in the year 1887 using capillary electrometer is shown in Figure 10.4. Later, the physician standardized the ECG machine, which comprises of 12 standard leads for knowing the different perspective of the heart's electrical activity. The ECG waveforms consist of P waves, QRS complex, and T waves, which are vary in amplitude and polarity. Typical 12-lead ECG waveforms are shown in Figure 10.5.

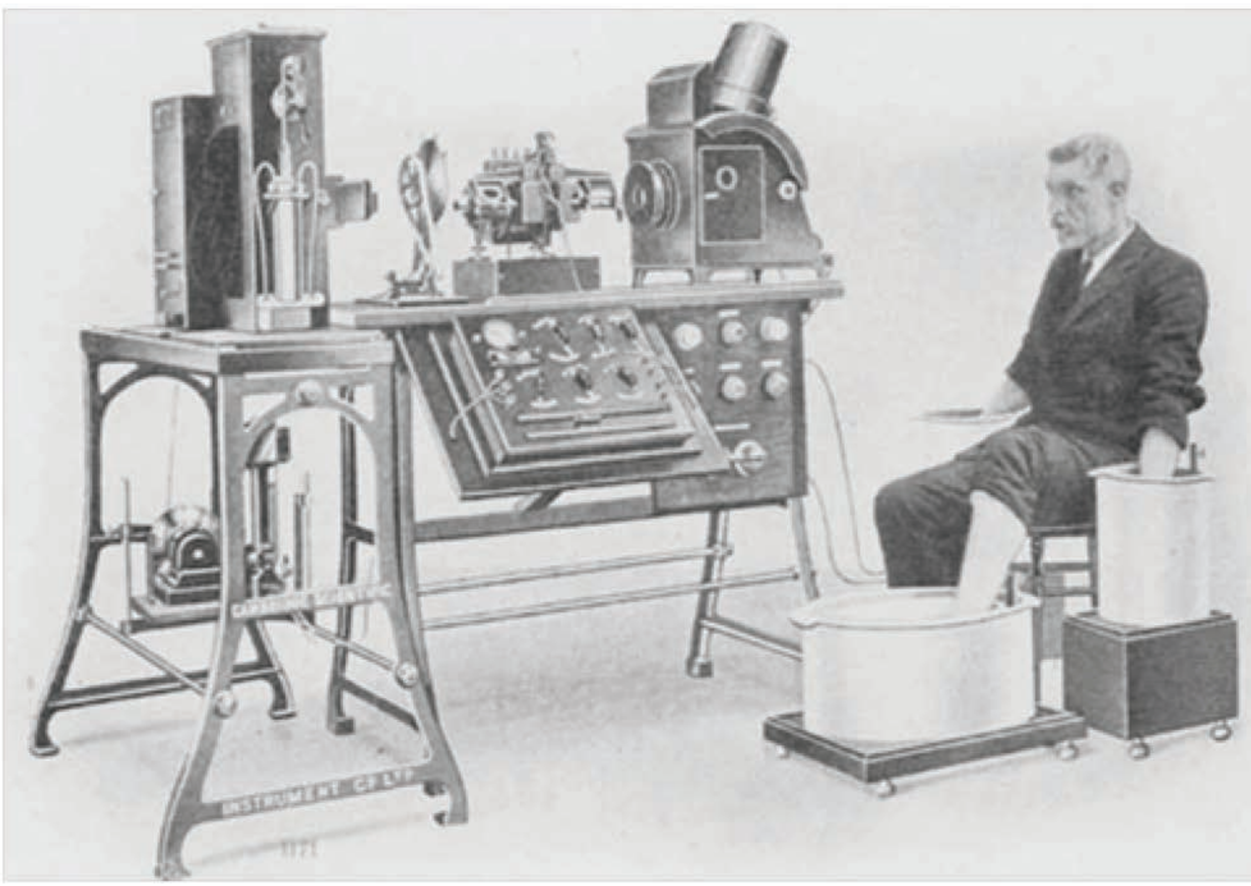


FIGURE 10.4 First ECG machine

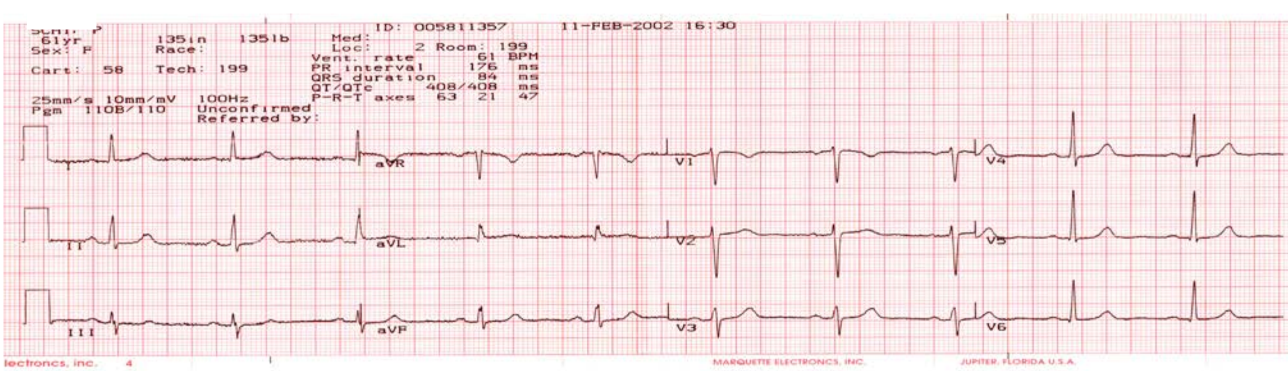
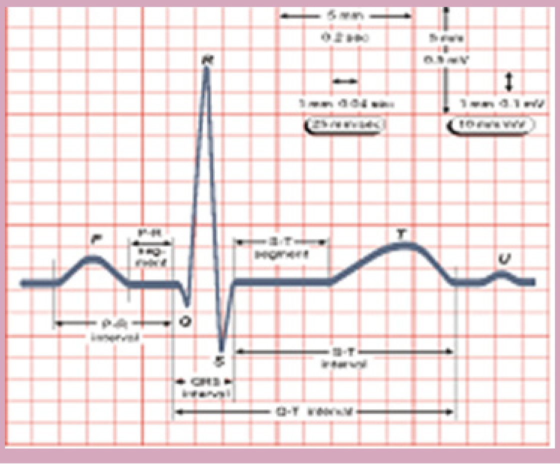


FIGURE 10.5 Standard 12 leads ECG recordings

DO YOU KNOW? **The components of ECG and their relationship with cardiac activity?**

ECG comprises of P, QRS, T and U waves. P wave represents the contraction of the atria or the depolarization of atria, QRS complex corresponds to relaxation of the atria and initiation of ventricular contraction or the depolarization of ventricle, T wave corresponds to ventricular relaxation and the U wave origin is unknown.



Working Principle of Electrocardiograph Machine

Figures 10.6(a) shows a 12 lead ECG machine, Figure 10.6(b) depicts the various electrodes and Figure 10.6(c) illustrates the block diagram of the ECG machine, respectively. For acquiring the ECG signal from human body, four electrodes are placed on the four arms of the body viz., Right Arm (RA), Left Arm (LA), Right Leg (RL) and Left Leg (LL).

The signals picked up by the four electrodes are fed into a resistor/switching network to select one of the 12 leads viz., Lead I, Lead II, Lead III, aVR, aVL, aVF, V1, V2, V3, V4, V5, and V6. The selected/acquired signals from the switching network has very low-amplitude and is amplified by an instrumentation amplifier. In analog type of ECG machines, further processing like noise removal, base line correction and final amplification are performed using complicated circuits. But, in the digital ECG machine the signal from the instrumentation amplified is digitised using Analog-to-Digital Converter (ADC) and stored in digital form. The digitized ECG data is further processed for noise removal, base line correction and final amplification using signal processing hardware or software. The processed ECG data is stored for future use or displayed on the monitor or printed as hardcopy.

Typical applications

Diagnosis of

1. Ischemia
2. Arrhythmia
3. Conduction defects

(a) 12 Lead ECG Machine

(b) Different types of ECG electrodes

FIGURE 10.6

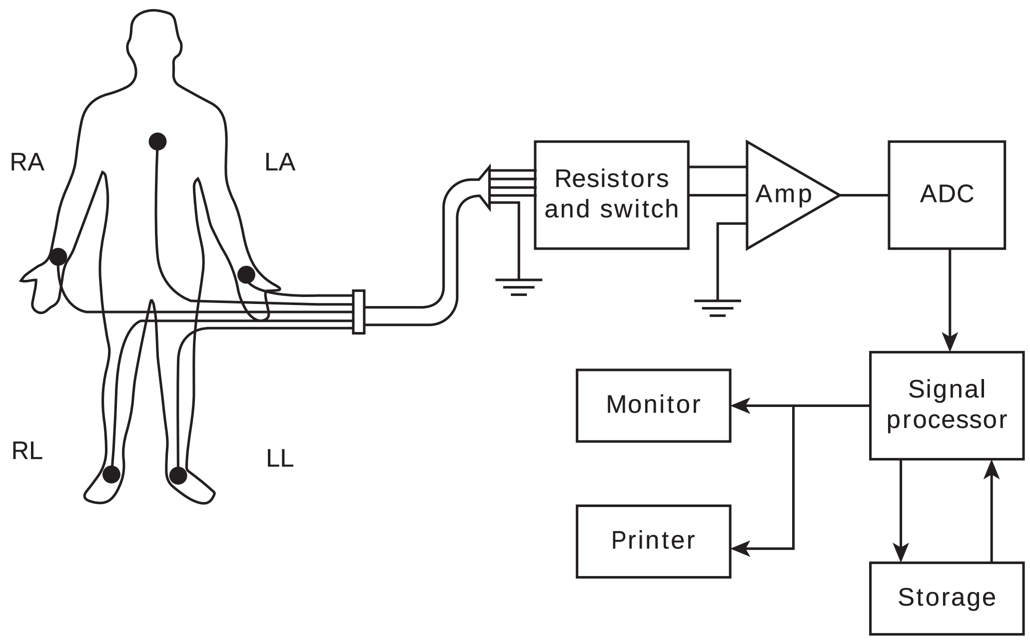


FIGURE 10.6 (c) Block Diagram of Electro cardiograph

10.2 Electro Encephalo Graph (EEG)

This instrument is used to study the activity of the human brain. Electroencephalograph (EEG) is a standard non-invasive method of recording the electrical activity of the brain. Electroencephalogram consists of curves that relate to the spontaneous electrical activity of millions of neural cells of the brain. The recording lasts for 20-40 min and is printed on paper or displayed on monitor. The voltage range of EEG signal on the surface of the brain is 1-10 mV, whereas on the surface of the skull it is 1-100 μV in the frequency range of 0.5 to 3000 Hz. EEG signal consists of alpha, beta, theta and delta waves and are shown in Figure 10.7 shows EEG machine and its electrodes arrangement on the head of a man. Figure 10.8 illustrates the various EEG waveforms.

The characteristics of these waves are given in Table 10.2.

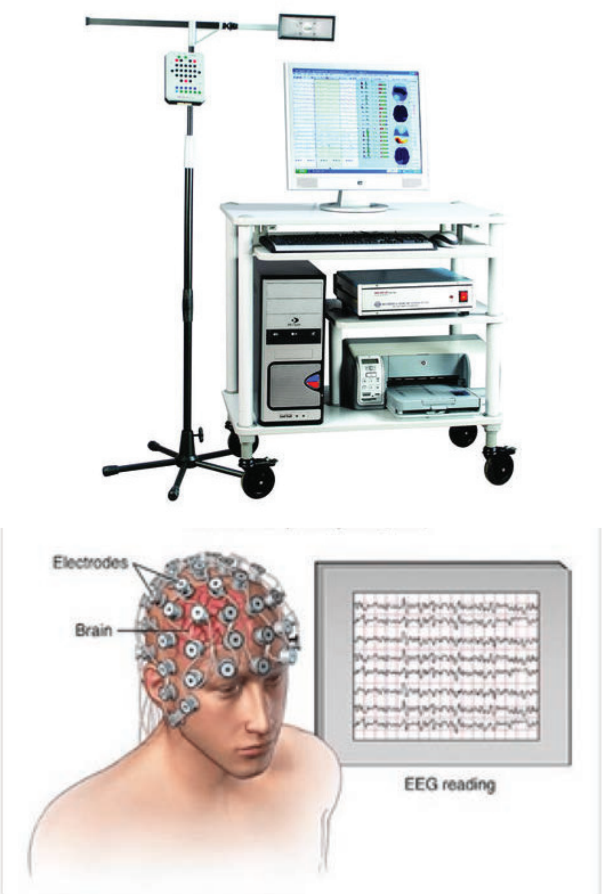


FIGURE10.7 EEG machine and the electrodes arrangements on the head

Application of EEG

The EEG is used to diagnose the following diseases

1. Level of consciousness

TABLE 10.2 EEG signal Characteristics		
Name of the waveform	Frequency range	Occurrence
Alpha	8 to 13 Hz	Normal persons awake in a resting state and disappear during sleep.
Beta	14 to 30 Hz	May go up to 50Hz in intense mental activity. Beta I waves: frequency about twice that of the alpha waves and are influenced in a similar way as the alpha waves. Beta II waves appear during intense activation of the central nervous system and during tension.
Theta	4 to 7 Hz	During emotional stress
Delta waves	Below 3.5 Hz	Deep sleep or in serious organic brain disease

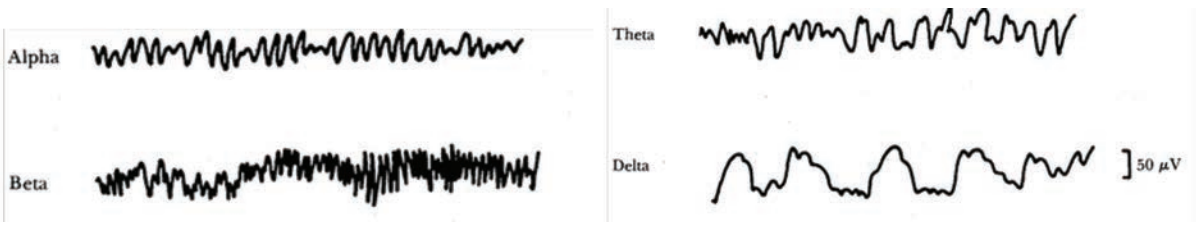


FIGURE 10.8 Components of EEG waveform

2. Sleep Disorders
3. Brain death
4. Epilepsy
5. Multiple Sclerosis

10.3 Blood Pressure Monitor

The abbreviated term 'BP' become very familiar in our life. In every one's mind a question may arise. Why the blood needs pressure. Dear students to understand this, just you think about the water supply system in your town or a city. Houses are located in various places and in various elevations and in different ground levels. But, the water has to reach all the houses. Without giving necessary pressure, is it possible to send the water to all the houses? No. Certainly we need some pressure to send the water to all the houses. To do this, we are pumping the water by using a powerful motor. Just like this, the blood in our body has to reach each and every part and corner of our body. To perform this, it needs some pressure. This is called Blood Pressure (BP). Here the task of giving enough pressure is done by our vital and important organ "The Heart".

Blood transports O_2 and nutrients to the cells and carries the metabolic waste and CO_2 gas from the cells through a pressurized vessel system comprising of arteries, vein, arterioles, venuoles and capillaries (covering approximately 1,00,000 km distance). The pressure is provided by the mechanical pump called, heart. Measuring this pressure at various locations of our body reveals significant clinical information. The Blood Pressure (BP) is measured as Systolic (Pressure exerted by the heart during pumping) and Diastolic pressure (Pressure exerted when the heart relaxes between beats). The optimal values of Systolic and Diastolic pressure for an adult should be 120 mm Hg and 80 mm Hg, respectively. BP can

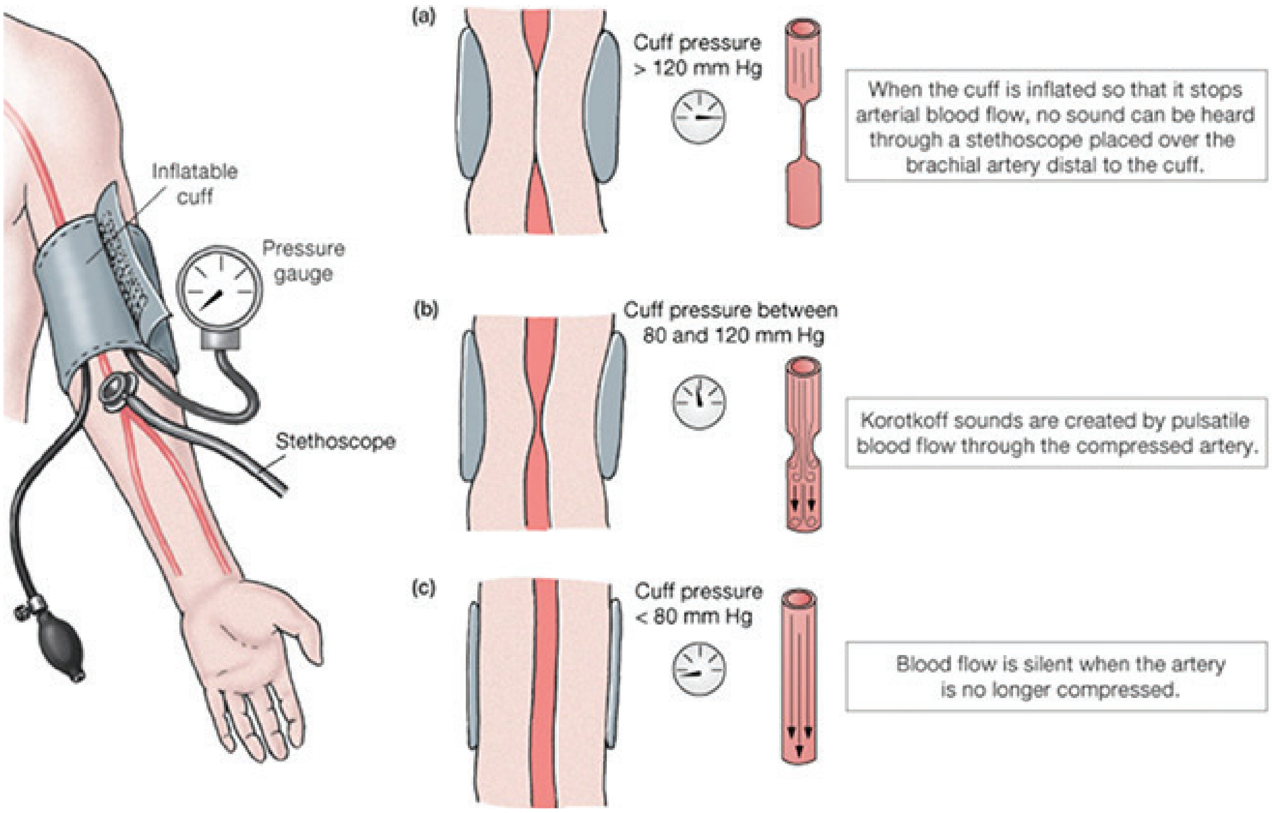


FIGURE 10.9 Working Principle of Sphygmomanometer

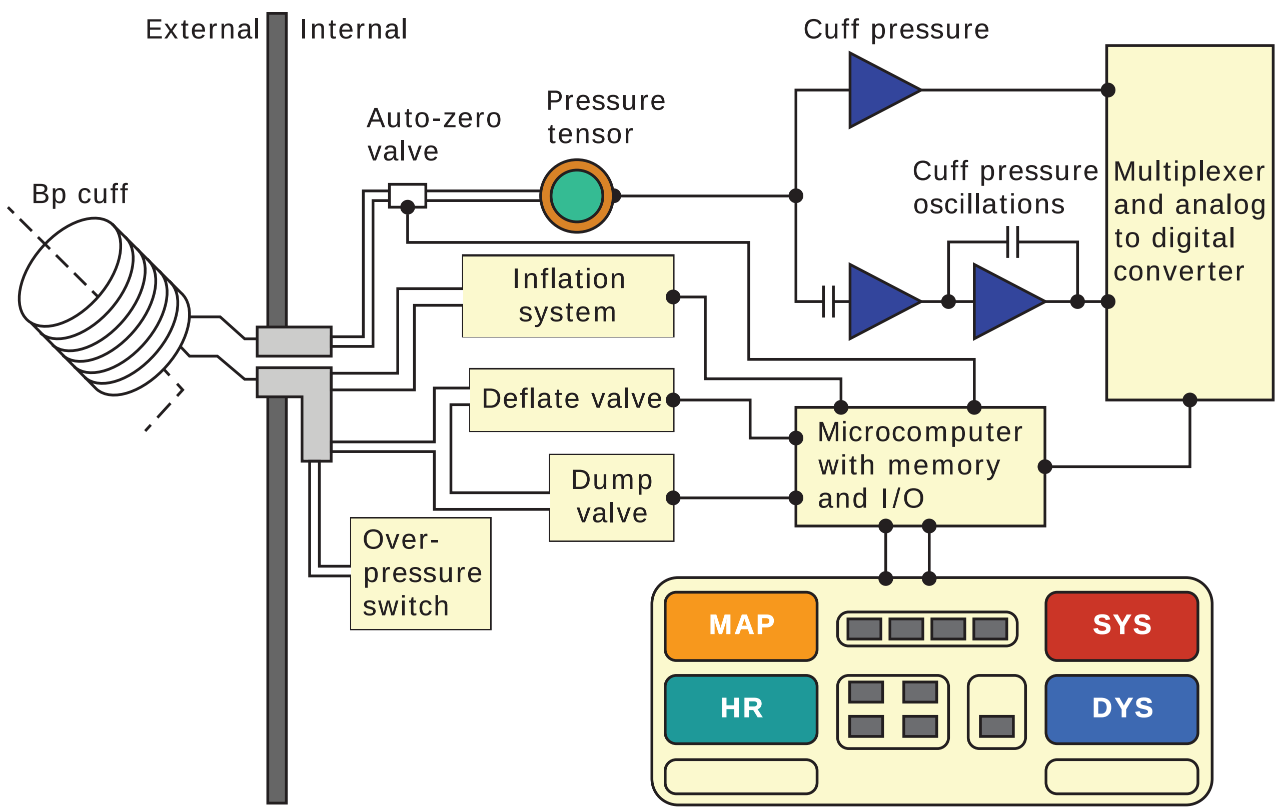


FIGURE 10.10 Components of Automatic BP Monitor: Here, MAP-Mean Average Pressure, SYS-Systolic Pressure, DYS-Diastolic Pressure and HR- Heart Rate

be measured using direct (invasive) or indirect (non-invasive) methods.

1. Invasive – Catheter with external or internal sensor
2. Non-invasive – Sphygmomanometer and Ultrasound Doppler method

In this Section, the BP measurement using Sphygmomanometer is presented. Figure 10.9 shows the Sphygmomanometer comprises of an inflatable cuff, needle valve, pressure gauge, mechanical pump and Stethoscope. During measurement of BP, the cuff is inflated using the mechanical pump and the heart sound called Korotkoff sound is heard, which is listened using a stethoscope placed on the hand below the cuff. In the inflation phase, if the korotkoff sound is not heard, the physician stops pressurizing the cuff. Then, the needle value is opened for deflation and pressure across cuff decreases and once again the korotkoff sound is heard in the stethoscope. This point is noted and the reading in the pressure gauge is noted, which corresponds to the Systolic pressure. This will continue a while and once again the korotkoff sound is not heard, that point in the pressure gauge is noted as a diastolic pressure. In the case of automatic Sphygmomanometer, inflation, deflation, pressure sensing, etc., are controlled by a microcomputer with respective sensors and electronic circuitry as shown in Figure 10.10.

10.4 Pulse Oximeter

This is the most important instrument to identify and diagnose the real situation of the patient. Oxygen is carried in the blood by hemoglobin which has two forms: Hb and HbO_2. These two forms have different absorptions at different wavelengths in the red to infra–red frequency band. By measuring the absorption of the two different wavelengths and taking appropriate ratios it is possible, in theory, to evaluate the percentage of hemoglobin carrying oxygen. The principle of pulse oximetry is based on the red and infrared light absorption characteristics of oxygenated and deoxygenated hemoglobin. Oxygenated hemoglobin absorbs more infrared light and allows more red-light to pass through, whereas deoxygenated hemoglobin absorbs more red-light and allows more infrared light to pass through. Red-light is in the 600-750 nm wavelength light band, whereas infrared light is in the 850-1000 nm wavelength light band. The figure 10.11(a) shows the image of Pulse

FIGURE 10.11 (a) Pulse Oximeter

Oximeter and figure 10.11(b) shows the absorption relationship of Hb and HbO_2.

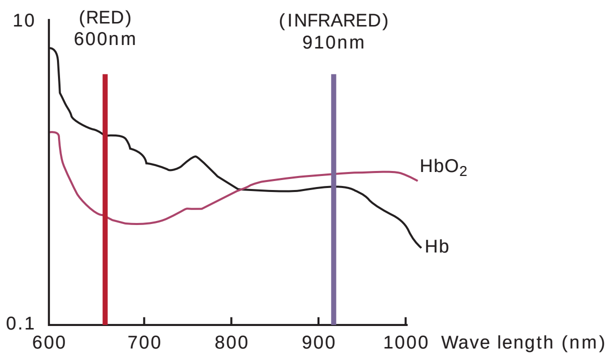


FIGURE 10.11 (b) Absorption Characteristics of HbO2 and Hb

Principle of Operation of Pulse Oximeter

Figure 10.12 shows the functional block diagram and circuit Diagram of simple Pulse Oximeter. Its operations are summarized as follows

1. Shine light through the finger or ear lobe. Red (~660 nm) and Near Infra–Red (NIR, ~940 nm) LEDs are used to generate the respective wavelengths, since LEDs are small and emit light at appropriate wavelengths. However, standard

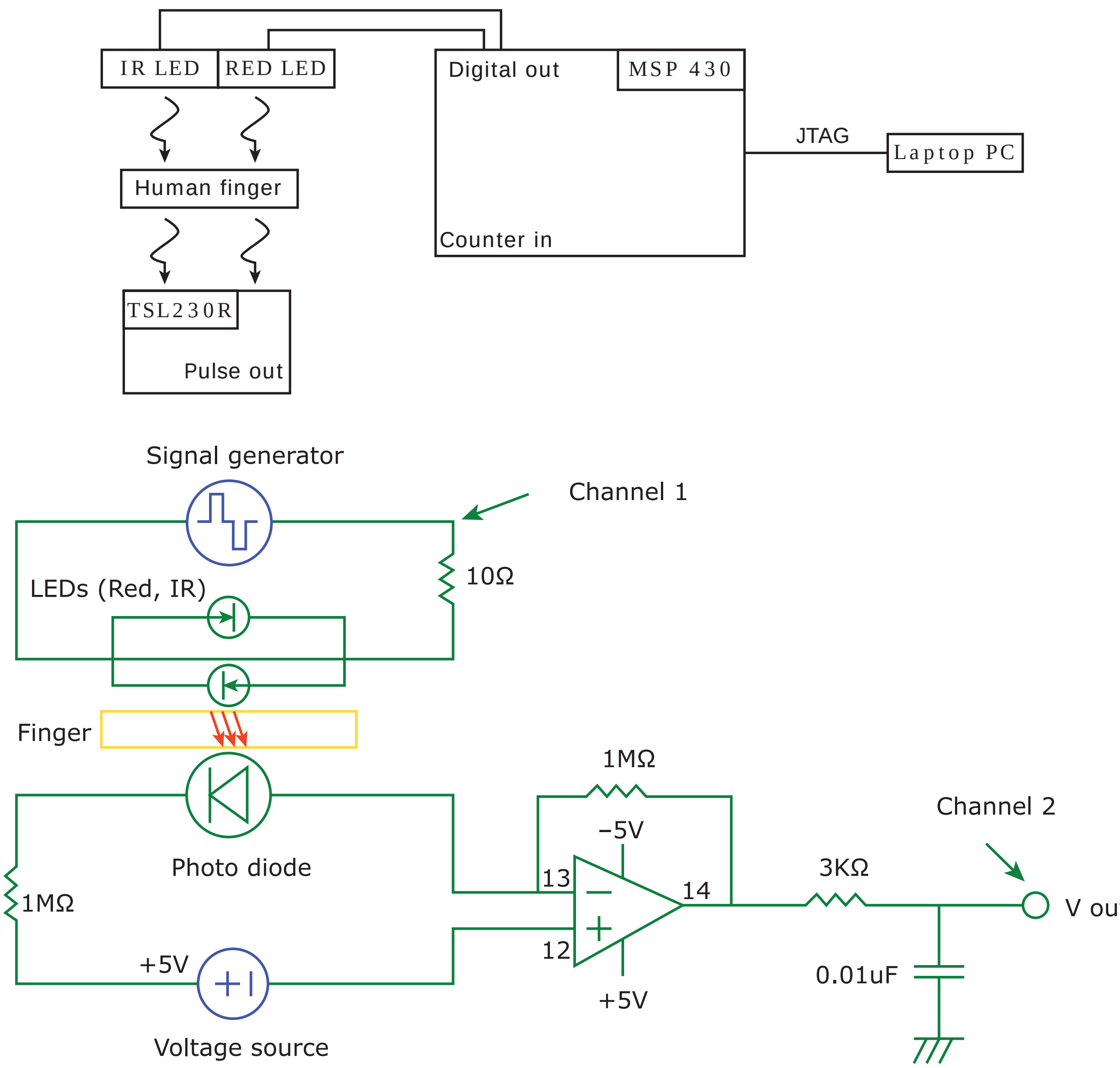


FIGURE 10.12 Block diagram and Circuit Diagram of a simple Pulse Oximeter

LEDs are not sufficiently powerful, therefore, special purpose LEDs have been designed with internal lensing to give a high intensity output. In order to increase the peak power of these LEDs and to use single photo-detector for both the LEDs, the LEDs are operated in a pulsed manner using timing and pulsing circuits.

2. The transmitted light through the tissue is received by a photo-diode, since photodiodes are the simplest solid–state optical detectors. When light falls on the p–n junction region, an electron–hole pair is generated. The hole and the electron are swept in opposite directions. The resulting light current is seen as a large increase in the reverse current. This light current can be converted into a voltage using a single op–amp.
3. Here, a single photo-detector (TSL230R) is being used to provide two pieces of information. Therefore, it is important to know when it is giving information about absorption of the red and the NIR wavelengths, respectively. Some form of sample–and–hold circuitry is used to perform this task.
4. Further, the amplitude of the transmitted light is controlled using Automatic Gain Control (AGC) circuitry, because it allows the frequency response of the photodiode to be 'corrected', keeps the ac signal (which varies between 0.1% and 2% of the total signal) within a pre–defined range and allows the dc level of both the NIR and the red signals to be kept at the same level (say 2 V).
5. Filters are used to perform the necessary noise reduction (possibly using averaging).
6. Finally, the microprocessor (MSP 430) analyses the light absorption of the tissues at each wavelength and determines the respective concentrations of the oxyhemoglobin and deoxyhemoglobin by calculating the value of an index R and estimating the saturation of O_2 (SPO_2) using a lookup table stored in the microprocessor.

Figure 10.13 shows the waveform displayed in the pulseoximeter.

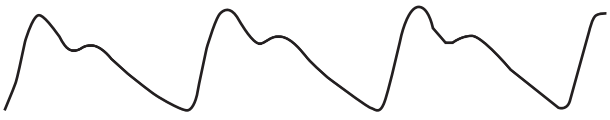


FIGURE 10.13 Pulse Oximeter displays the waveform

Applications of Puloximeter

The SpO_2 values are used to diagnose the conditions such as Apnea, Bronchopulmonary dysphasia and cardiac diseases. For normal patients, the SpO2 will be in the range of 95-100 %, for Mild Hypoxemia, it will be in the range of 91-94%, for Moderate Hypoxemia, it will be in the range of 86-90% and for severe Hypoxemia, it will be in the range of <85%.

10.5 Treadmill Stress Test (TMT)

Treadmill is an exercise machine that allows the user to walk or run in order to monitor some of the vital physiological functions of the person. Figure 10.14 shows the snapshot of a Treadmill machine. A Treadmill Stress Test measures one's heart rhythm when the heart is stressed by exercise, such as walking or running on a treadmill. TMT is used to detect the changes in rhythm of heart, while the patient is walking or exercising on a treadmill. Any change in the rhythm indicates the problem associated with the blood supply of the heart. The total TMT duration should be 10 to 15 minutes. In the beginning of the test, the patient will walk at a slow speed and every 2 to 3 minutes the patient will have to walk faster with more uphill posture of the walking treadmill belt. The TMT will stop when the heartbeat reaches a certain speed or when the patient becomes very short of breath or having pain in the chest. The components of the Treadmill are listed below:

Alternating Current (AC) Motor

An AC motor of capacity 2.5 to 3 HP is used to move the treadmill belt at the required speed. Continuous Duty Horsepower, often referred to as simply CHP, motor is common in today's treadmills. It is much quieter and the actual number signifies the amount of power a motor can generate under normal usage. The industry standard CHP recommended for TMT application is 3.0 CHP. It drives the belt in the specified speed.

Belt (Treadmill Belt)

Belts can differ in size and strength but a 2" ply with a black polyurethane top layer is common.

Deck

The treadmill manufacture will list the running surface as the "deck size". The size of the deck can differ substantially but a 20" x 55" is a common size.

Drive Train

The mechanical system that transmits power or torque from one place to another. Specifically, the drive train on a treadmill is composed of the running belt, drive belt, rollers and motor.

Heart Rate Monitor

A built-in heart-rate monitor with associated program acquires the pulse signal from the user body, calculates the heart-rate and displays on the console.

Incline

It is displayed as a percentage (or in other cases "levels") that a treadmill will point vertically in order to create the experience of running up a hill.

LCD

It is used to display all the details of the test with waveform and results for reference.

Pulse Grips

It allows users to wrap their hands around the grip and in turn get a read-out of their BPM.

Tracking

It is a little adjustment that allows the users to keep the belt centered on the treadmill. Several other adjustment screws or bolts are available, which are used to further adjust the belt.

Quick Controls

Quick controls usually consist of one-touch buttons that will increase/decrease speed, incline and/or resistance. They are considered ideal for workouts on the fly when there is a need to make several speeds and/or incline adjustments.

FIGURE 10.14 Snapshot of a Treadmill Machine

10.6 Glucometer

A glucose meter or glucometer is a medical device used for measuring the approximate level of glucose in the blood, which comprises of a test strip and a read-out device. The glucose meter, determines the concentration of glucose in the solution. Most glucose meters are based on electrochemical technology, they use electrochemical test strips to perform the measurement. Glucose strips are used for glucose monitoring from blood, which is shown in Figure 10.15.

Testing Procedure

A small drop of the solution (blood) to be tested is placed on a disposable test strip and inserted into glucose meter. In each test strip, there is an enzyme called glucose oxidase. This enzyme reacts with the glucose in the blood sample and creates an acid called gluconic acid. The gluconic acid then reacts with another chemical in the testing strip called ferricyanide. The ferricyanide and the gluconic acid then combine to create ferrocyanide. Once ferrocyanide has been created, the device sends an electronic current through the blood sample on the strip. This current is then able to read the ferrocyanide and determine how much glucose is in the sample of blood on the testing strip. Finally, the estimated glucose value is displayed on the screen of the glucose testing meter.

Factors affecting Glucose Measurement

The glucose measurement made using Glucometer may be vulnerable to the parameters such as temperature, humidity, altitude, etc., due to the changes in rate of the enzyme reaction.

10.7 Biomedical Imaging Instruments

The earliest medical images used light to create photographs, either of the anatomic structures, or of the histological specimens using microscopes. Light is still an important source for the creation of images. However, visible light does not allow us to see inside the body. X-rays were first discovered in 1895 by Wilhelm Conrad Roentgen, who was awarded the 1901 Nobel Prize in physics for this achievement. This discovery caused worldwide excitement, especially in the field of medicine, since then, diagnostic X-ray technology has evolved from film-based to completely digital where images are manipulated and viewed in a digital data format. Advanced imaging modalities such as computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET) were developed late in the 20th century and in the 21st century.

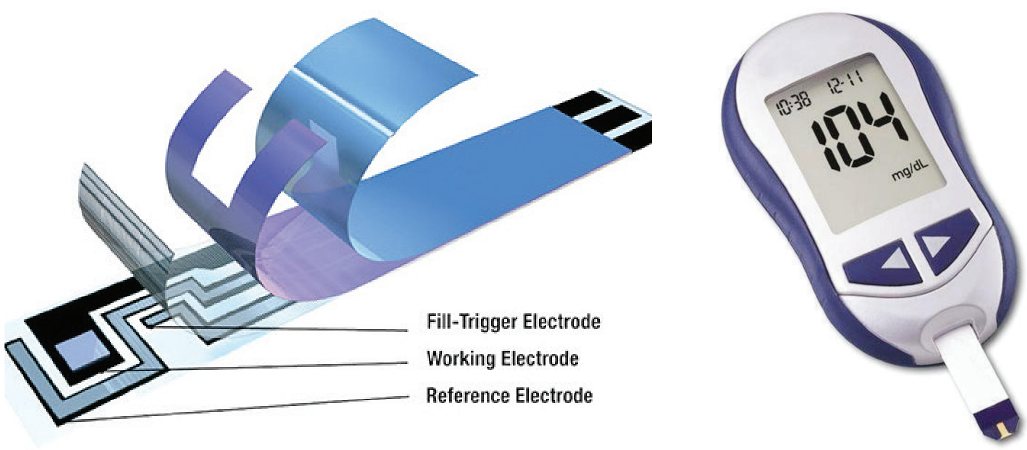


FIGURE 10.15 Components of Glucose Strip and Glucometer

DO YOU KNOW?

What is the first X-ray taken by Rontgen?

The first X-ray image of Rontgen's wife was taken in the year 1985 and is shown here.

In this Section, some of the important imaging modalities like Endoscopy, Ultrasound scanner, Magnetic Resonance Imaging (MRI), Computed Tomography (CT) and Positron Emission Tomography are discussed.

10.7.1 Endoscopy

Endoscopy is the insertion of a long, thin tube directly into the body to observe an internal organ or tissue in detail. The first real endoscope was developed by Phillip Bozzini in the year 1805 to examine the urethra, the bladder and vagina. It can also be used to carry out other tasks including imaging and minor surgery. Endoscopes are minimally invasive and can be inserted into the openings of the body such as the mouth or anus.

FIGURE 10.16 Endoscopy machine and its components

Alternatively, they can be inserted into small incisions, for instance, in the knee or abdomen. Surgery can be completed through a small incision and assisted with special instruments, such as the endoscope, is called keyhole surgery. Since modern endoscopy has relatively few risks, which delivers detailed images in a reasonably quicker time and hence it has proven incredibly useful in many areas of medicine.

Components of an Endoscopy

The endoscope consists of a slender, flexible or rigid tube equipped with lenses and a light source. CCDs are used as detector to acquire the video from the respective organs and display in a monitor. Through the accessory channels of the endoscope, water and air is supplied to wash and dry the surgical site. Also, it has a channel through which surgeons can manipulate tiny instruments, such as forceps, surgical scissors and suction devices. A variety of instruments can be fitted to the endoscope for different purposes. Figure 10.16 shows the various components of an Endoscope.

Types

Endoscopy is the most useful for investigating many systems within the human body and is named based on the applications. They are summarized in Table 10.3.

TABLE 10.3 Types of Endoscopy

Name of the Endoscopy	Application
Gastroscopy	To see the gullet, stomach and upper small intestine.
Colonoscopy	To see the large intestine.
Laparoscopy	To see the "stomach cavity" and the organs therein.
Proctoscopy	This is used to check for piles and other conditions of the anus and rectum.
Cystoscopy	To see the urinary bladder.
Bronchoscopy	To see the air passages to the lungs.
Laryngoscopy	To see the larynx or voice box.
Nasopharyngoscopy	To see the nose and related cavities.
Arthroscopy	To see inside joints such as the knee joint.
Thoracoscopy	To see inside the chest cavity.

DO YOU KNOW?

The meaning of the word "Endoscopy"?

The word endoscopy is derived from the Greek words "Endo" meaning "inside" and "skopeein" meaning "to see". It is a word used in medicine to describe the procedure used to see inside of the various parts of the body.

DO YOU KNOW?

The role of fibre-optics in Endoscopy?

Medical endoscopy really came into force in diagnostic and surgery applications after the invention of fibre-optic technology. Fibre-optic endoscopes use bundles of thin glass fibres to transmit light to and from the organ being viewed. These fibres use the principle of total internal reflection to transmit almost 100 % of the light entering one end to the other end.

DO YOU KNOW?

What is Capsule Endoscopy?

Recently a disposable flash camera slightly larger than a vitamin pill was devised to perform imaging of the small intestine. This procedure is called capsule endoscopy in which the patient swallows the minicam, which then takes pictures inside the small intestine. On its journey through the digestive tract, the tiny tumbling camera transmits images that are stored in a recorder that the person wears around the waist. After 8 hours, the camera's battery runs out, and the capsule is eliminated in the faeces.

10.7.2 Ultrasonography

Ultrasonography is a medical imaging technique that uses high frequency sound waves and their echoes. These frequencies are between 1 MHz and 10 MHz and such frequencies cannot be heard by humans. The technique is similar to the echolocation used by bats, whales and dolphins, as well as SONAR used by submarines.

Principle of Ultrasonography

The typical image of Ultra sound scanner is shown in the Figure 10.17(a). The ultrasound machine transmits high-frequency (1 to 10 MHz) sound pulses into the body using a probe. The sound waves travel into the body and hit a boundary between tissues (e.g. between fluid and soft tissue, soft tissue and bone). Some of the sound waves get reflected back to the probe, while some travel on further until they reach another boundary and get reflected. The reflected waves are picked up by the probe and relayed to the machine. The machine calculates the distance from the probe to the tissue or organ (boundaries) using the speed of sound in tissue (1,540 m/s) and the time of the each echo's return (usually on the order of millionths of a second). The machine displays the distances and intensities of the echoes on the screen, forming a two dimensional image like the one shown in Figure 10.17(b).

FIGURE 10.17(a) Ultrasound Scanner, (b): Ultrasound image of a growing foetus inside a mother's uterus.

Components of Ultrasound Machine

Figure 10.18 shows the components of a basic ultrasound Machine and the functions of each component are described below:

1. **Transducer probe** - The transducer probe generates and receives sound waves using a principle called the piezoelectric (pressure electricity) effect, which was discovered by Pierre and Jacques Curie in 1880. The probe also has a sound absorbing substance to eliminate back reflections from the probe itself, and an acoustic lens to help focus the emitted sound waves. When an electric current is applied to these crystals, they change shape rapidly and the vibrations of the crystals produce sound waves that travel outward. Conversely, when sound or pressure waves hit the crystals, they emit electrical currents. Therefore, the same crystal can be used as transmitter and receiver of the sound waves.

2. **Central processing unit (CPU)** - The CPU is basically a computer that contains the microprocessor, memory, amplifiers and power supplies for the microprocessor and transducer probe. The CPU sends electrical currents to the transducer probe to emit sound waves, and also receives the electrical pulses from the probes that are created from the returning echoes. The CPU does all of the calculations involved in processing the data. Once the raw data are processed, the CPU forms the image on the monitor. The CPU

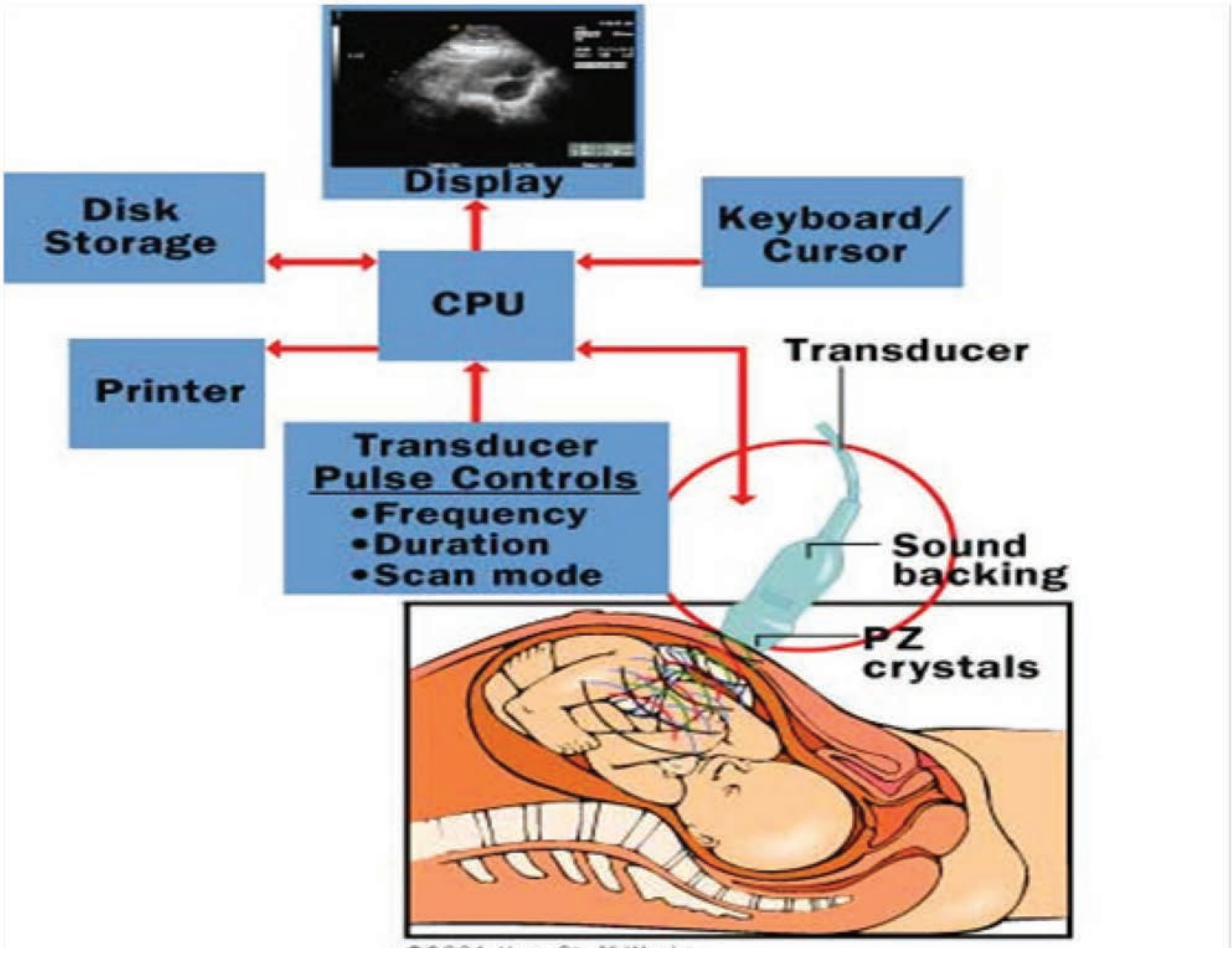


FIGURE 10.18 Components of a Basic Ultrasound Scanner

can also store the processed data and/or image on disk.

3. **Transducer pulse controls** - The transducer pulse controls allow the operator, called the ultrasonographer, to set and change the frequency and duration of the ultrasound pulses, as well as the scan mode of the machine. The commands from the operator are translated into changing electric currents that are applied to the piezoelectric crystals in the transducer probe.
4. **Display** - The display is a computer monitor that shows the processed data from the CPU. Displays can be black-and-white or color, depending upon the model of the ultrasound machine.
5. **Keyboard and Cursor** - Ultrasound machines have a keyboard and a cursor, such as a trackball, built in. These devices allow the operator to add notes and to take measurements from the data.
6. **Disk storage device** - The processed data and/ or images can be stored on the disk. The disks can be hard disks, floppy disks, compact discs (CDs) or digital video discs (DVDs).
7. **Printer** - Many ultrasound machines have thermal printers that can be used to capture a hard copy of the image from the display.

Uses of Ultrasonography

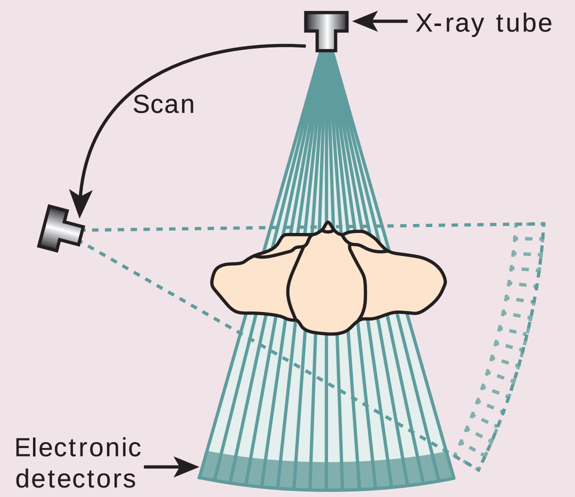
Ultrasound has been used in a variety of clinical fields including obstetrics and gynecology, cardiology and cancer detection. The main advantage of ultrasound is that certain structures can be observed without using radiation. Ultrasound can also be done much faster than X-rays or other radiographic techniques.

10.8 Computed Tomography Scanner

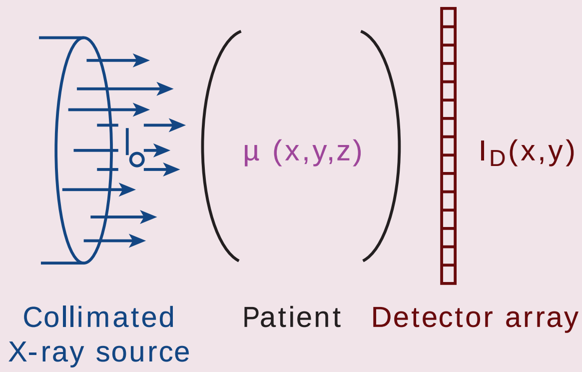
Tomography is imaging by sections or sectioning. A device used in tomography is called a tomograph, while the image produced is a tomogram. Computed Tomography (CT) or Computed Axial Tomography (CAT), utilizes X-ray technology and sophisticated computers to create images of cross-sectional "slices" of the human body. CT produces cross-sectional images and also has the ability to differentiate tissue densities, which creates an improvement in contrast resolution.

FIGURE 10.19(a) CT-Scanner

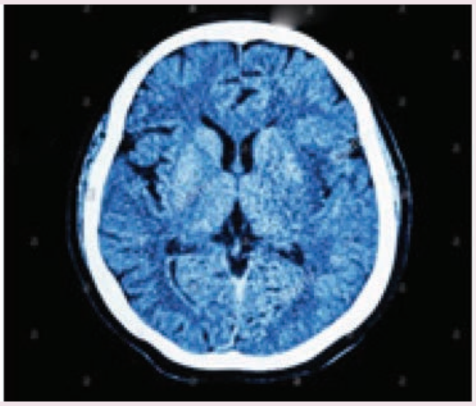
Figure 10.19(a) shows the image acquired from a CT-Scanner. Figure 10.22(b) shows the principle of operation and the image of CT. In CT, the X-ray source is tightly collimated to interrogate a thin slice through the patient. The source and detectors rotate together around the patient, producing a series of one-dimensional projections at a number of different angles. The basic processes of CT consist of for steps viz., Data acquisition, Image reconstruction, Image display and Image archiving (recording). After placing the patient in the proper position of the scanner, the operator selects the correct protocols and technical parameters and starts running the machine. At the initialization of the scan, X-rays passing through the patient are attenuated depending on the tissue type. A detector system located opposite to the X-ray tube measures the attenuation values as an analogue signal. This signal is transmitted to the Analogue to digital converter (ADC), which converts the signal of attenuated values from analog to digital form and sending to computer for further processing. The computer reads this digital data and employs a mathematical formula, called a reconstruction algorithm, to generate the cross-sectional image. The mathematical basis for reconstruction of an image from a series of projections is the Radon transform. The image reconstruction, involving millions of data points, which is usually performed in less than a second by a group of array processors. The reconstructed image is displayed on a LCD monitor as an image suitable for manipulation by the operator. In the image archiving, three processes such as image manipulation, Archiving on a Picture Archiving and Communication System (PACS) and storage are performed. For this, a wide range of software is available to enhance the image on the monitor before storage. These include altering the density and brightness, changing the plane of the image from axial to sagittal or coronal, producing three dimensional images and demonstrating detailed angiography. Recent developments in spiral and multi-slice CT have enabled the acquisition of full three-dimensional images in a single patient breath-hold.



CT Principle



Operation of CT



CT image of brain

FIGURE 10.19(b) Principle, Operation and Image of the CT

Advantages

- Desired image detail is obtained
- Fast image rendering
- Filters may sharpen or smooth the reconstructed images

Disadvantages

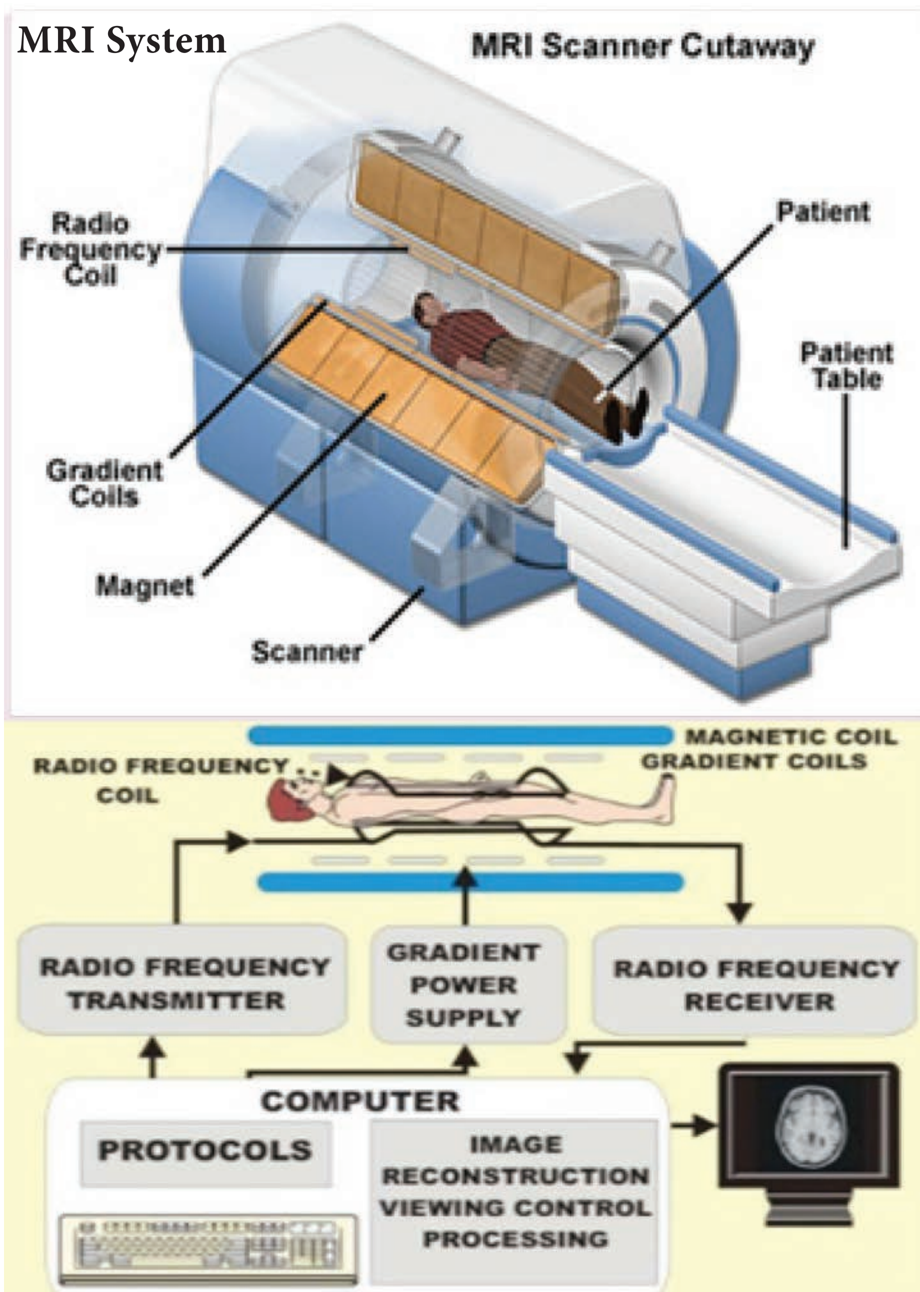
- Multiple reconstructions may be required if significant detail is required from areas of the study that contain bone and soft tissue
- Need for quality detectors and computer software
- X-ray exposure

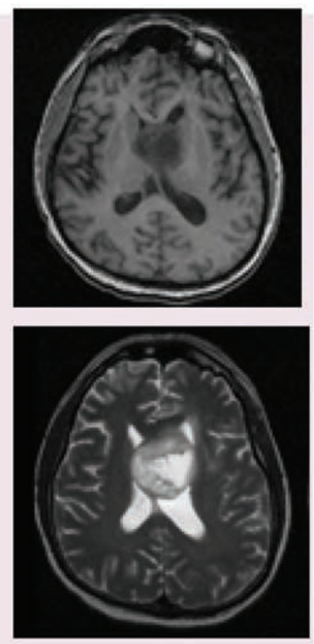
Do you know? Who invented the CT?

In 1950, Allan M. Cormack developed the theoretical and mathematical methods used to reconstruct CT images. In 1972, Godfrey N. Hounsfield and colleagues of EMI Central Research Laboratories built the first CAT scan machine, taking Cormack's theoretical calculation into a real application. For their independent efforts, Cormack and Hounsfield shared the Nobel Prize in medicine and physiology in 1979.

10.9 Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging (MRI) is a non-ionizing technique with full three-dimensional capabilities, excellent soft-tissue contrast, and high spatial resolution (about 1mm). Figure 10.20 shows the MR instrumentation setup and the MR images. MRI machines look like a large block with a tube running through the middle of the machine, called the bore of the magnet. The bore is where the patient is located for the duration of the scan. A radio frequency electromagnetic field is briefly





MRI images

FIGURE 10.20 MRI system and MR images

turned on, causing the protons to absorb some of its energy. When this field is turned off the protons release this energy at a resonance radio frequency, which can be detected by the scanner. The frequency of the emitted signal depends on the strength of the magnetic field. The position of protons in the body can be determined by applying additional magnetic fields during the scan which allows an image of the body to be built up. These are created by turning gradients coils on and off which creates the knocking sounds heard during an MR scan. The MR signal from a human is predominantly due to water (hydrogen) protons. Since these protons exist in identical magnetic environments, they all resonate at the same frequency. Hence, the NMR signal is simply proportional to the volume of the water. The MRI machine picks points in the patient's body, decides what type of tissue the points define, and then compiles the points into 2-dimensional and 3-dimensional images. Once the 3-dimensional image is created, the MRI machine creates a model of the tissue. This allows the clinician to diagnose without the use of invasive surgery. The scan can last anywhere from 20-30 minutes.

DO YOU KNOW?

The magnet strength of the MRI machine and our earth?

The largest and most important components of the MRI machine are the magnets. The magnet strength is measured in units of Tesla or Gauss (1 Tesla = 10,000 Gauss). Today's MRI machines have magnets with strengths from 5000 to 20,000 Gauss. To give perspective on the strength of these magnets, the earth's magnetic field is about .5 Gauss, making the MRI machine 10,000 to 30,000 times stronger.

Applications

MRI is used to diagnose or monitor the conditions such as:

- Tumours and other cancer related abnormalities.
- Certain types of heart problems.
- Blockages or enlargements of blood vessels
- Diseases of the liver, such as cirrhosis, and that of other abdominal organs.
- Diseases of the small intestine, colon, and rectum

Advantages of MRI

- MRI uses no ionizing radiation; there is little risk of tissue damage from repeated scans.
- MRI acquires images directly in any orientation.
- MRI better differentiates contrast between different kinds of soft tissue.
- MRI generates images with different tissue contrast properties, with or without the use of contrast agent injection.

10.10 Positron Emission Tomography

PET is a non-invasive, nuclear diagnostic imaging technique for measuring the metabolic activity of cells in the human body. It was developed in the mid-1970s and it was the first scanning method to give functional information about the brain. PET produces images of the body by detecting the radiation emitted from radioactive substances. These substances are injected into the body, and are usually tagged with a radioactive atom (C-11, Fl-18, O-15 or N-13) that has short decay time. These radioactive atoms are formed by bombarding normal chemicals with neutrons to create short-lived radioactive

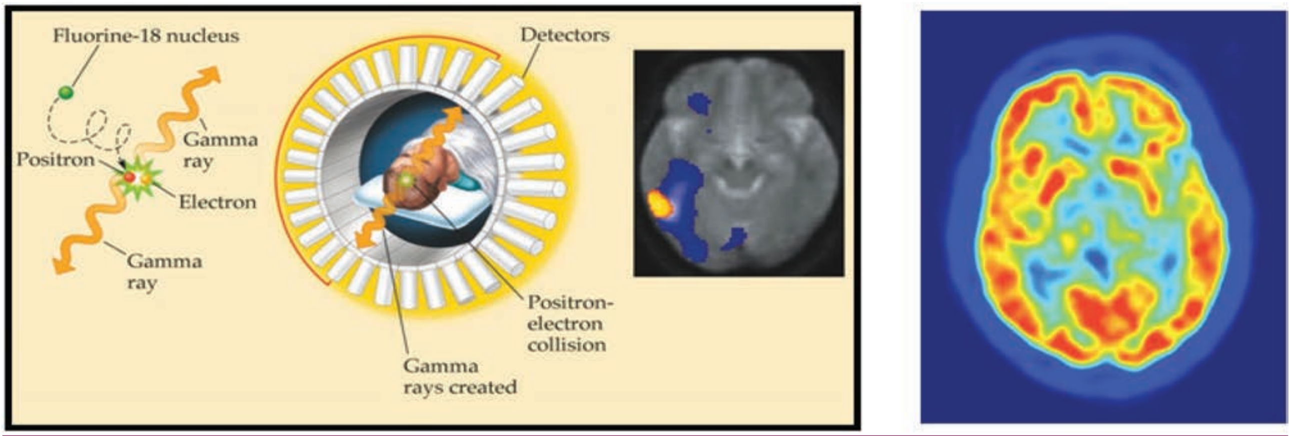


FIGURE 10.21 PRINCIPLE OF PET AND ITS IMAGE

isotopes. PET detects the gamma rays given off at the site where a positron emitted from the radioactive substance collides with an electron in the tissue. The results are evaluated by a trained expert.

Figure 10.21 shows the principle of PET imaging. PET imaging starts with the injection of metabolically active tracer – a biologic molecule that carries with it a positron emitting isotope.

Applications

- Detect cancer.
- Determine whether a cancer has spread in the body.
- Assess the effectiveness of a treatment plan, such as cancer therapy.
- Determine if a cancer has returned after treatment.
- Determine blood flow to the heart muscle.
- Determine the effects of a heart attack, or myocardial infarction, on areas of the heart.
- Evaluate brain abnormalities, such as tumors, memory disorders and seizures and other central nervous system disorders.
- Map normal human brain and heart function.

Limitations

- Time-consuming.
- The resolution of structures of the body with nuclear medicine may not be as clear as with other imaging techniques, such as CT or MRI.
- PET scanning can give false results if chemical balances within the body are not normal.
- Because the radioactive substance decays quickly and is effective for only a short period of time, it is important for the patient to be on time for the appointment and to receive the radioactive material at the scheduled time.
- A person who is very obese may not fit into the opening of a conventional PET/CT unit.

LEARNING OUTCOME

A student will understand the working principle of the following instruments after reading this Chapter.

1. Electrocardiograph (ECG)
2. Electroencephalograph (EEG)
3. Blood Pressure (BP) Monitor
4. Pulseoximeter
5. Tread Mill Test (TMT)
6. Glucometer
7. Endoscopy
8. Ultrasound Scanner
9. Computed Tomography (CT) Scanner
10. Magnetic Resonance Imaging (MRI)
11. Positron Emission Tomography (PET)

GLOSSARY

Biopotential	Potential generated at the cell level due to mobility of ions across cell membrane
Electrocardiograph	Instrument used to measure the electrical activity of the heart
Electroencephalogram	Instrument for measuring the electrical activity of the brain
Blood Pressure Monitor	Instrument to quantify the pressure of the Blood
Pulseoximeter	Instrument used to measure the oxygen saturation of blood
Tread Mill Test	Instrument used to test vital parameters of the human being during exercise
Glucometer	Instrument used to quantify the amount of glucose level in blood
Endoscopy	Instrument used to capture the image of the internal organs like stomach, intestine, etc.
Ultrasound Imaging	Instrument used to capture the image of the internal organs and tissues using ultrasound
Computed Tomography	Instrument used to image soft tissues and bones using X-ray
Magnetic Resonance Imaging	Instrument used to image soft tissues and bones using magnetic and radio frequency waves
Positron Emission Tomography	Instrument used to image the brain and its functions using gamma rays

QUESTIONS

Part – A (1 Mark)

I Multiple choice Questions

1. Bioelectric waveforms and Instruments ends with the suffixes ----------- and ----------- respectively
   (a) Graph, gram
   (b) Gram, graph
   (c) Graphy, gramy
   (d) Gramy, graphy
2. Lead I, II and III in ECG are
   (a) Bipolar Leads
   (b) Unipolar Leads
   (c) Monopolar Leads
   (d) Tripolar Leads
3. Brain waves comprise of
   (a) Alpha, Beta, Theta and Delta waveform patterns
   (b) Alpha, Theta, Zeta and Delta waveform patterns
   (c) Beta, Theta, gamma and Delta waveform patterns
   (d) Alpha, Beta, gamma and Delta waveform patterns
4. Ultrasound transducers are made from (a)
   (a) Piezoelectric material
   (b) Photovoltaic material
   (c) Thermoelectric material
   (d) None of the above
5. Magnetic resonance imaging (MRI) is a ……………. Technique
   (a) Ionizing
   (b) non-ionizing
   (c) nuclear
   (d) radiation
6. In PET imaging, a biologic molecule that carries a positron emitting isotope is called as ………………
   (a) Tracer
   (b) Tracker
   (c) dyer
   (d) verifier
7. In CT machines, which source is used?
   (a) Gamma Ray
   (b) X-ray
   (c) ultrasound
   (d) infrared
8. PET is a non-invasive, nuclear diagnostic imaging technique for measuring the …….. activity of cells in the human body.
   (a) metabolic
   (b) electric
   (c) magnetic
   (d) transport
9. A glucose meter or glucometer is a medical device used for measuring the approximate level of ……….. in the blood.
   (a)RBC
   (b) cholesterol
   (c) potassium
   (d) Glucose
10. Sphygmomanometer is used to estimate blood ……….

(a)Sugar
(b) Sodium
(c) pressure
(d) flow

Part – B (3 Marks)

II Answer in one or two sentences

1. Define bioelectric current.
2. State the value of blood pressure for a normal adult.
3. What are the applications of ECG?
4. Name any four types of Endoscopy.
5. What are the types of electrodes used in EEG?
6. Enumerate the purpose of a Pulseoximeter.
7. List the applications of PET.
8. Mention the advantages of MRI.
9. State the uses of ultrasonography.
10. State the principle of operation of TMT.

Part – C (5 Marks)

III Answer in a paragraph

1. Briefly explain the principle of operation of an Electrocardiograph with a neat sketch.
2. Explain the functions of Treadmill Test Machine.
3. Write a short note on the operations of a Blood Pressure Monitor.

Part – D (10 Marks)

IV Answer in One Page (Essay type Question)

1. Discuss in detail the working principle and testing procedure of a Glucometer with neat sketch.
2. Explain about Electro Encephalo Graph and its uses.
3. Describe the operating principle of CT scan using functional block diagram.

ANSWERS

1 (a)	2 (a)	3 (a)	4 (a)	5 (b)
6 (a)	7 (a)	8 (a)	9 (d)	10 (c)