

# ELECTRONICS IN BIOMEDICAL AND INSTRUMENTATION

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## ABSTRACT:

*The Biomedical Electronics Technology takes you beyond the basics of electronics and electricity into the world of advanced technical systems associated with medical care. You will find this program valuable if you want to develop the skills and the practical background necessary to inspect, test, calibrate, and repair advanced medical equipment and instrumentation, and to gain the interpersonal skills required to work with medical personnel.*

*The merging of Electronics with Biotechnology promises the advent of a totally new class of devices such as sensors and actuators (MEMS&NEMS) with applications in diagnostics, responsive drug delivery, biocompatibility, self-assembly etc. Proteins and nucleic acid are information rich molecules with structural and electrical properties making their incorporation in the human manufacturing arsenal an attractive proposition. This combination has become possible as today both top-down traditional manufacturing (e.g., MEMS and NEMS) Without biomedical scientists, departments such as accident and emergency and operating theatres could not properly function. The many roles include tests for emergency blood transfusions and blood grouping as well as tests on samples from patients who have overdosed on unknown substances, or may have leukemia or are suspected of having a heart attack. The successful performance of this key role in modern healthcare relies on the accuracy and efficiency of work by biomedical scientists because patients' lives and the treatment of illness depend on their skill and knowledge.*

*Disease-causing microorganisms are isolated for identification and for susceptible to antibiotic therapy. **Biomedical engineering** is the application of engineering principles and techniques to the medical field. This field seeks to close the gap between engineering and medical. It combines the design and problem solving skills of engineering with medical and biological sciences to improve healthcare diagnosis. The course in Biomedical Electronics combines the detailed study of electronics, as the main subjects of an Honors degree course, with a basic education in the physical, chemical, social and biomedical sciences. The structure and function of the human body are taught as an integrated subject*

comprising anatomy, physiology, biochemistry and cell biology. Mathematics is an essential part of each year of the course. Appropriate statistical techniques for this interdisciplinary subject are studied. After an introduction to computers and programming, computer studies continue as an experimental subject, and may continue even further in the final year, since laboratory work in that year is in the form of an open-ended project on some aspect of biomedical electronics, and a student may choose to do a project which requires the use of a computer. A member of staff supervises the project, and there is often an opportunity for liaison with clinical and biological departments outside the University. When this occurs the work acquires an added interest to the student and they develop an appreciation of working as part of a team. The aim of the course is to produce graduates who, being qualified to begin a career as professional electronics engineers, are particularly well equipped to appreciate and to solve the problems that arise in the application of electronics to biomedical situations. It hardly need be pointed out that, even away from human problems, physical, mental and social.

## INTRODUCTION

Recent advances in medical field have been fuelled by the instruments developed by the Electronics and Instrumentation Engineers. Pacemakers, Ultrasound Machine CAT, Medical diagnostic systems are few names which have been contributed by engineers. Now health care industry uses many instruments which are to be looked after by instrumentation engineers. This subject will enable the students to learn the basic principles of different instruments/equipment used in the health care industry. The practical work done in this area will impart skill in the use, servicing and maintenance of these instruments/equipment. Proficiency in this area will widen the knowledge and skill of diploma holders in the field of biomedical instrumentation.

## DETAILED CONTENTS

1. Anatomy and Physiology Elementary ideas of cell structure, heart and circulatory system, control nervous system, Musculo-skeletal system, Respiratory system Body temperature and reproduction system.
2. Classification of Biomedical Equipment  
Diagnostic, therapeutic and clinical laboratory equipment
3. Bioelectric signals and their recording  
Bioelectric signals (ECG, EMG, ECG, EOG & ERG) and their characteristics, Bioelectrodes, electrodes tissue interface, contact impedance, effects of high contact impedance, types of electrodes, electrodes for ECG, EEG and EMG.
4. Transducers for Biomedical Application  
Resistive transducers - Muscle force and Stress (Strain gage), Spirometry (Potentiometer), humidity, (Gammastats), Respiration (Thermistor)  
Inductive Transducers - Flow measurements, muscle movement (LVDT) Capacitive Transducers - Heart sound measurement, Pulse pickup  
Photoelectric Transducers - Pulse transducers, Blood pressure, oxygen Analyses  
Piezoelectric Transducers - Pulse pickup, ultrasonic blood flowmeter  
Chemical Transducer - Ag-Agfallas (Electrodes, PH electrode)
5. Bioelectric Signal recording machines  
Physiological pre-amplifier and specialized amplifiers, ECG lead systems details of ECG, EMG, and EEG machines
6. Patient Monitoring system  
Heart rate measurement pulse rate measurement, respiration, rate measurement, blood pressure measurement, microprocessor applications in patient monitoring
7. X- Ray Machine  
Basic X-Ray components and circuits, types of X-ray machines e.g. general purpose, dental image intensifier system, table shooting and maintenance of X- Ray machine
8. Safety Aspect of Medical  
Gross current, Micro Current shock, safety standards rays and considerations, safety testing instruments, biological effects of X-rays and precautions

## BIOMEDICAL ELECTRONICS

The Biomedical Electronics Technology takes you beyond the basics of electronics and electricity into the world of advanced technical systems associated with medical care. You will find this program valuable if you want to develop the skills and the practical background necessary to inspect, test, calibrate, and repair advanced medical equipment and instrumentation, and to gain the interpersonal skills required to work with medical personnel. Job opportunities are available with hospitals, medical equipment companies, and other medical facilities.

**Biomedical engineering** is the application of engineering principles and techniques to the medical field. This field seeks to close the gap between **engineering** and **medicine**: It combines the design and problem solving skills of engineering with medical and biological sciences to improve healthcare diagnosis, monitoring and therapy.

Biomedical engineering has only recently emerged as its own discipline, compared to many other engineering fields; such an evolution is common as a new field transitions from being an interdisciplinary specialization among already-established fields, to being considered a field in itself. Much of the work in biomedical engineering consists of research and development, spanning a broad array of subfields (see below). Prominent biomedical engineering applications include the development of biocompatible prostheses, various diagnostic and therapeutic medical devices ranging from clinical equipment to micro-implants, common imaging equipment such as MRIs and EEGs, biotechnologies such as regenerative tissue growth, and pharmaceutical drugs and biopharmaceuticals.

### Subdisciplines within biomedical engineering

Biomedical engineering is a highly interdisciplinary field, influenced by (and overlapping with) various other engineering and medical fields. This often happens with newer disciplines, as they gradually emerge in their own right after evolving from special applications of extant disciplines. Due to this diversity, it is typical for a biomedical engineer

to focus on a particular subfield or group of related subfields. There are many different taxonomic breakdowns within BME, as well as varying views about how best to organize them and manage any internal overlap; the main U.S. organization devoted to BME divides the major specialty areas as follows

- Biomechatronics
- Bioinstrumentation
- Biomaterials
- Biomechanics
- Bionics
- Cellular, Tissue, and Genetic Engineering
- Clinical Engineering
- Medical Imaging
- Orthopaedic Bioengineering
- Rehabilitation engineering
- Systems Physiology
- Bionanotechnology
- Neural Engineering

### **Biotechnology and pharmaceuticals**

Biotechnology (see also relatedly bioengineering) can be a somewhat ambiguous term, sometimes loosely used interchangeably with BME in general; however, it more typically denotes specific products which use "biological systems, living organisms, or derivatives thereof." [2] Even some complex "medical devices" (see below) can reasonably be deemed "biotechnology" depending on the degree to which such elements are central to their principle of operation. Biologics/Biopharmaceuticals (e.g., vaccines, stored blood product), genetic engineering, and various agricultural applications are some major classes of biotechnology.

Pharmaceuticals are related to biotechnology in two indirect ways: 1) certain major types (e.g. biologics) fall under both categories, and 2) together they essentially comprise the "non-medical-device" set of BME applications. (The "Device - Bio/Chemical" spectrum is an imperfect dichotomy, but one regulators often use, at least as a starting point.)

### **Tissue engineering**

Tissue engineering is a major segment of Biotechnology.

One of the goals of tissue engineering is to create artificial organs (via biological material) for patients that need organ transplants. Biomedical engineers are currently researching methods of creating such organs. Researchers have grown solid jawbones[3] and tracheas from human stem cells towards this end. Several artificial urinary bladders actually have been grown in laboratories and transplanted successfully into human patients.[4] Bioartificial organs, which use both synthetic and biological components, are also a focus area in research, such as with hepatic assist devices that use liver cells within an artificial bioreactor construct.[5]

Micromass cultures of C3H-10T1/2 cells at varied oxygen tensions stained with Alcian blue. [edit] Genetic Engineering

Genetic engineering, recombinant DNA technology, genetic modification/manipulation (GM) and gene splicing are terms that apply to the direct manipulation of an organism's genes. [1] Genetic engineering is different from traditional breeding, where the organism's genes are manipulated indirectly. Genetic engineering uses the techniques of molecular cloning and transformation to alter the structure and characteristics of genes directly. Genetic engineering techniques have found success in numerous applications. Some examples are in improving crop technology (not a medical application per se; see BioSystems Engineering), the manufacture of synthetic human insulin through the use of modified bacteria, the manufacture of erythropoietin in hamster ovary cells, and the production of new types of experimental mice such as the oncomouse (cancer mouse) for research.

[edit] Neural Engineering

Neural engineering (also known as Neuroengineering) is a discipline that uses engineering techniques to understand, repair, replace, or enhance neural systems. Neural engineers are uniquely qualified to solve design problems at the interface of living neural tissue and non-living constructs.

[edit] Pharmaceutical engineering

Pharmaceutical Engineering is sometimes regarded as a branch of biomedical engineering, and sometimes a branch of chemical engineering; in practice, it is very much a hybrid

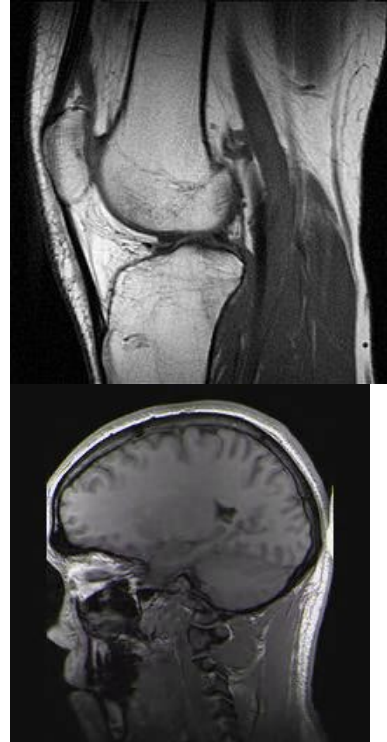
sub-discipline (as many BME fields are). Aside from those pharmaceutical products directly incorporating biological agents or materials, even developing chemical drugs is considered to require substantial BME knowledge due to the physiological interactions inherent to such products' usage.

## MRI

Magnetic resonance imaging (MRI), nuclear magnetic resonance imaging (NMRI), or magnetic resonance tomography (MRT) is a medical imaging technique used in radiology to visualize detailed internal structures. MRI makes use of the property of Nuclear magnetic resonance (NMR) to image nuclei of atoms inside the body.

An MRI machine uses a powerful magnetic field to align the magnetization of some atoms in the body, and radio frequency fields to systematically alter the alignment of this magnetization. This causes the nuclei to produce a rotating magnetic field detectable by the scanner—and this information is recorded to construct an image of the scanned area of the body.[1]:36 Strong magnetic field gradients cause nuclei at different locations to rotate at different speeds. 3-D spatial information can be obtained by providing gradients in each direction.

MRI provides good contrast between the different soft tissues of the body, which make it especially useful in imaging the brain, muscles, the heart, and cancers compared with other medical imaging techniques such as computed tomography (CT) or X-rays. Unlike CT scans or traditional X-rays MRI uses no ionizing radiation.



## ECG

Electrocardiograph (ECG, or EKG [from the German Elektrokardiogramm]) is a transthoracic interpretation of the electrical activity of the heart over time captured and externally recorded by skin electrodes.[1] It is a noninvasive recording produced by an electrocardiographic device. The etymology of the word is derived from the Greek *electro*, because it is related to electrical activity, *cardio*, Greek for heart, and *graph*, a Greek root meaning "to write". In English speaking countries, medical professionals often write EKG (the abbreviation for the German word *elektrokardiogramm*) in order to avoid confusion with EEG.[citation needed]

The ECG works mostly by detecting and amplifying the tiny electrical changes on the skin that are caused when the heart muscle "depolarizes" during each heart beat. At rest, each heart muscle cell has a charge across its outer wall, or cell membrane. Reducing this charge towards zero is called de-polarization, which activates the mechanisms in the cell that

cause it to contract. During each heartbeat a healthy heart will have an orderly progression of a wave of depolarisation that is triggered by the cells in the sinoatrial node, spreads out through the atrium, passes through "intrinsic conduction pathways" and then spreads all over the ventricles. This is detected as tiny rises and falls in the voltage between two electrodes placed either side of the heart which is displayed as a wavy line either on a screen or on paper. This display indicates the overall rhythm of the heart and weaknesses in different parts of the heart muscle.

Usually more than 2 electrodes are used and they can be combined into a number of pairs (For example: Left arm (LA), right arm (RA) and left leg (LL) electrodes form the pairs: LA+RA, LA+LL, RA+LL). The output from each pair is known as a lead. Each lead is said to look at the heart from a different angle. Different types of ECGs can be referred to by the number of leads that are recorded, for example 3-lead, 5-lead or 12-lead ECGs (sometimes simply "a 12-lead"). A 12-lead ECG is one in which 12 different electrical signals are recorded at approximately the same time and will often be used as a one-off recording of an ECG, typically printed out as a paper copy. 3- and 5-lead ECGs tend to be monitored continuously and viewed only on the screen of an appropriate monitoring device, for example during an operation or whilst being transported in an ambulance. There may, or may not be any permanent record of a 3- or 5-lead ECG depending on the equipment used.

It is the best way to measure and diagnose abnormal rhythms of the heart, particularly abnormal rhythms caused by damage to the conductive tissue that carries electrical signals, or abnormal rhythms caused by electrolyte imbalances.[3] In a myocardial infarction (MI), the ECG can identify if the heart muscle has been damaged in specific areas, though not all areas of the heart are covered. The ECG cannot reliably measure the pumping ability of the heart, for which ultrasound-based (echocardiography) or nuclear medicine tests are used. It is possible to be in cardiac arrest with a normal ECG signal (a condition known as pulseless electrical activity).

## History

Alexander Muirhead is reported to have attached wires to a feverish patient's wrist to obtain a record of the patient's heartbeat while studying for his Doctor of Science (in electricity) in 1872 at St Bartholomew's Hospital.[5] This activity was directly recorded and visualized using a Lippmann capillary electrometer by the British physiologist John Burdon Sanderson.[6] The first to systematically approach the heart from an electrical point-of-view was Augustus Waller, working in St Mary's Hospital in Paddington, London.[7] His electrocardiograph machine consisted of a Lippmann capillary electrometer fixed to a projector. The trace from the heartbeat was projected onto a photographic plate which was itself fixed to a toy train. This allowed a heartbeat to be recorded in real time. In 1911 he still saw little clinical application for his work.

### Einthoven's ECG device

An initial breakthrough came when Willem Einthoven, working in Leiden, Netherlands, used the string galvanometer that he invented in 1903. [8] This device was much more sensitive than both the capillary electrometer that Waller used and the string galvanometer that had been invented separately in 1897 by the French engineer Clément Ader.[9] Rather than using today's self-adhesive electrodes Einthoven's subjects would immerse each of their limbs into containers of salt solutions from which the ECG was recorded.

Einthoven assigned the letters P, Q, R, S and T to the various deflections, and described the electrocardiographic features of a number of cardiovascular disorders. In 1924, he was awarded the Nobel Prize in Medicine for his discovery.

Though the basic principles of that era are still in use today, there have been many advances in electrocardiography over the years. The instrumentation, for example, has evolved from a cumbersome laboratory apparatus to compact electronic systems that often include computerized interpretation of the electrocardiogram.

## ECG graph paper

The output of an ECG recorder is a graph (or sometimes several graphs, representing each of the leads) with time represented on the x-axis and voltage represented on the y-axis. A dedicated ECG machine would usually print onto graph paper which has a background pattern of 1mm squares (often in red or green), with bold divisions every 5mm in both vertical and horizontal directions. It is possible to change the output of most ECG devices but it is standard to represent each mV on the y axis as 1 cm and each second as 25mm on the x-axis (that is a paper speed of 25mm/s). Faster paper speeds can be used - for example to resolve finer detail in the ECG. At a paper speed of 25 mm/s, one small block of ECG paper translates into 40 ms. Five small blocks make up one large block, which translates into 200 ms. Hence, there are five large blocks per second. A calibration signal may be included with a record. A standard signal of 1 mV must move the stylus vertically 1 cm, that is two large squares on ECG paper.

Layout

By definition a 12-lead ECG will show a short segment of the recording of each of the 12-leads. This is often arranged in a grid of 4 columns by three rows, the first columns being the limb leads (I,II and III), the second column the augmented limb leads (aVR, aVL and aVF) and the last two columns being the chest leads (V1-V6). It is usually possible to change this layout so it is vital to check the labels to see which lead is represented. Each column will usually record the same moment in time for the three leads and then the recording will switch to the next column which will record the heart beats after that point. It is possible for the heart rhythm to change between the columns of leads.

Each of these segments is short, perhaps 1-3 heart beats only, depending on the heart rate and it can be difficult to analyse any heart rhythm that shows changes between heart beats. To help with the analysis it is common to print one or two "rhythm strips" as well. This will usually be lead II (which shows the electrical signal from the atrium, the P-wave, well) and shows the rhythm for the whole time the ECG was recorded (usually 5–6 seconds). Some ECG machines will print a second lead II along the very bottom of the paper in addition to the output described

above. This printing of Lead II is continuous from start to finish of the process.

The term "rhythm strip" may also refer to the whole printout from a continuous monitoring system which may show only one lead and is either initiated by a clinician or in response to an alarm or event.

## LEADS

The term "lead" in electrocardiography causes much confusion because it is used to refer to two different things. In accordance with common parlance the word lead may be used to refer to the electrical cable attaching the electrodes to the ECG recorder. As such it may be acceptable to refer to the "left arm lead" as the electrode (and its cable) that should be attached at or near the left arm. There are usually ten of these electrodes in a standard "12-lead" ECG.

Alternatively (and some would say properly, in the context of electrocardiography) the word lead may refer to the tracing of the voltage difference between two of the electrodes and is what is actually produced by the ECG recorder. Each will have a specific name. For example "Lead I" (lead one) is the voltage between the right arm electrode and the left arm electrode, whereas "Lead II" (lead two) is the voltage between the right limb and the feet. (This rapidly becomes more complex as one of the "electrodes" may in fact be a composite of the electrical signal from a combination of the other electrodes (see later). Twelve of this type of lead form a "12-lead" ECG

To cause additional confusion the term "limb leads" usually refers to the tracings from leads I, II and III rather than the electrodes attached to the limbs.

## Placement of electrodes

Ten electrodes are used for a 12-lead ECG. The electrodes usually consist of a conducting gel, embedded in the middle of a self-adhesive pad onto which cables clip. Sometimes the gel also forms the adhesive.[12] They are labeled and placed on the patient's body as follows

### Electrode label and placement

**RA** On the right arm, avoiding thick muscle.

**LA** In the same location that RA was placed, but on the left arm this time.

**RL** On the right leg, lateral calf muscle

**LL** In the same location that RL was placed, but on the left leg this time.

**V1** In the fourth intercostal space (between ribs 4 & 5) just to the right of the sternum (breastbone).

**V2** In the fourth intercostal space (between ribs 4 & 5) just to the left of the sternum.

**V3** Between leads V2 and V4.

**V4** In the fifth intercostal space (between ribs 5 & 6) in the mid-clavicular line (the imaginary line that extends down from the midpoint of the clavicle (collarbone)).

**V5** Horizontally even with V4, but in the anterior axillary line. (The anterior axillary line is the imaginary line that runs down from the point midway between the middle of the clavicle and the lateral end of the clavicle; the lateral end of the collarbone is the end closer to the arm.)

**V6** Horizontally even with V4 and V5 in the midaxillary line. (The midaxillary line is the imaginary line that extends down from the middle of the patient's armpit.)

### Waves and intervals

Detail of the QRS complex, showing ventricular activation time (VAT) and amplitude.

A typical ECG tracing of the cardiac cycle (heartbeat) consists of a P wave, a QRS complex, a T wave, and a U wave which is normally visible in 50 to 75% of ECGs. The baseline voltage of the electrocardiogram is known as the isoelectric line. Typically the isoelectric line is measured as the portion of the tracing following the T wave and preceding the next P wave.

**RR interval-** The interval between an R wave and the next R wave. Normal resting heart rate is between 50 and 100 bpm 0.6 to 1.2s.

**P wave-** During normal atrial depolarization, the main electrical vector is directed from the SA node towards the AV node, and spreads from the right atrium to the left atrium. This turns into the P wave on the ECG. 80ms

**PR interval-** The PR interval is measured from the beginning of the P wave to the beginning of the QRS complex. The PR interval reflects the time the electrical impulse takes to travel from the sinus node through the AV node

and entering the ventricles. The PR interval is therefore a good estimate of AV node function 120 to 200ms

**PR segment-** The PR segment connects the P wave and the QRS complex. This coincides with the electrical conduction from the AV node to the bundle of His to the bundle branches and then to the Purkinje Fibers. This electrical activity does not produce a contraction directly and is merely traveling down towards the ventricles and this shows up flat on the ECG. The PR interval is more clinically relevant. 50 to 120ms

**QRS complex-** The QRS complex reflects the rapid depolarization of the right and left ventricles. They have a large muscle mass compared to the atria and so the QRS complex usually has a much larger amplitude than the P-wave. 80 to 120ms

**J-point-** The point at which the QRS complex finishes and the ST segment begins. Used to measure the degree of ST elevation or depression present. N/A

**ST segment-** The ST segment connects the QRS complex and the T wave. The ST segment represents the period when the ventricles are depolarized. It is isoelectric. 80 to 120ms

**T wave-** The T wave represents the repolarization (or recovery) of the ventricles. The interval from the beginning of the QRS complex to the apex of the T wave is referred to as the absolute refractory period. The last half of the T wave is referred to as the relative refractory period (or vulnerable period). 160ms

**ST interval-** The ST interval is measured from the J point to the end of the T wave 320ms

**QT interval-** The QT interval is measured from the beginning of the QRS complex to the end of the T wave. A prolonged QT interval is a risk factor for ventricular tachyarrhythmias and sudden death. It varies with heart rate and for clinical relevance requires a correction for this, giving the QTc. 300 to 430ms[citation needed]

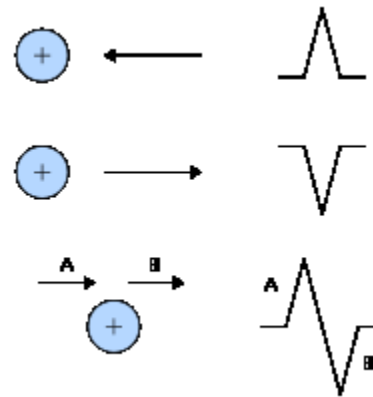
U wave The U wave is not always seen. It is typically low amplitude, and, by definition, follows the T wave.

**J wave-** The J wave, elevated J-Point or Osborn Wave appears as a late delta wave following the QRS or as a small secondary R wave. It is considered pathognomonic of hypothermia or hypocalcemia.

There were originally four deflections, but after the mathematical correction for artifacts

introduced by early amplifiers, five deflections were discovered. Einthoven chose the letters P, Q, R, S, and T to identify the tracing which was superimposed over the uncorrected labeled A, B, C, and D.

In intracardiac electrocardiograms, such as can be acquired from pacemaker sensors, an additional wave that can be seen is the H deflection, which reflects the depolarization of the bundle of His.[26] The H-V interval, in turn, is the duration from the beginning of the H deflection to the earliest onset of ventricular depolarization recorded in any lead.



## Vectors and views

Graphic showing the relationship between positive electrodes, depolarization wavefronts (or mean electrical vectors), and complexes displayed on the ECG.

Interpretation of the ECG relies on the idea that different leads (by which we mean the ECG leads I,II,III, aVR, aVL, aVF and the chest leads) "view" the heart from different angles. This has two benefits. Firstly, leads which are showing problems (for example ST segment elevation) can be used to infer which region of the heart is affected. Secondly, the overall direction of travel of the wave of depolarisation can also be inferred which can reveal other problems. This is termed the cardiac axis . Determination of the cardiac axis relies on the concept of a vector which describes the motion of the depolarisation wave. This vector can then be described in terms of its components in relation to the direction of the lead considered. One component will be in the direction of the lead and this will be revealed in the behaviour of the QRS complex and one component will be at 90 degrees to this (which will not). Any net positive deflection of the QRS complex (i.e. height of the R-wave minus depth of the S-wave) suggests that the wave of depolarisation is spreading through the heart in a direction that has some component (of the vector) in the same direction as the lead in question. Diagram showing how the polarity of the QRS complex in leads I, II, and III can be used to estimate the heart's electrical axis in the frontal plane.

The heart's electrical axis refers to the general direction of the heart's depolarization wavefront (or mean electrical vector) in the frontal plane. With a healthy conducting system the cardiac axis is related to where the major muscle bulk of the heart lies. Normally this is the left ventricle with some contribution from the right ventricle. It is usually oriented in a right shoulder to left leg direction, which corresponds to the left inferior quadrant of the hexaxial reference system, although  $-30^\circ$  to  $+90^\circ$  is considered to be normal. If the left ventricle increases its activity or bulk then there is said to be "left axis deviation" as the axis swings round to the left beyond  $-30^\circ$ , alternatively in conditions where the right ventricle is strained or hypertrophied then the axis swings round beyond  $+90^\circ$  and "right axis deviation" is said to exist. Disorders of the conduction system of the heart can disturb the electrical axis without necessarily reflecting changes in muscle bulk.

**CONCLUSION-** Hence we can say that electronics plays an important role in biomedical instrumentation as most of the biomedical equipments are composed of electronic devices and circuits. With the help of electronics the biological signals are converted into electrical signals and then it is compared with the standard signal and finally gives results.

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