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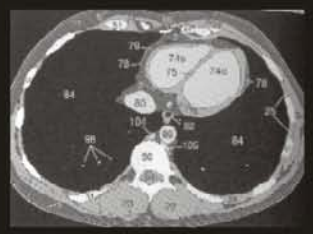
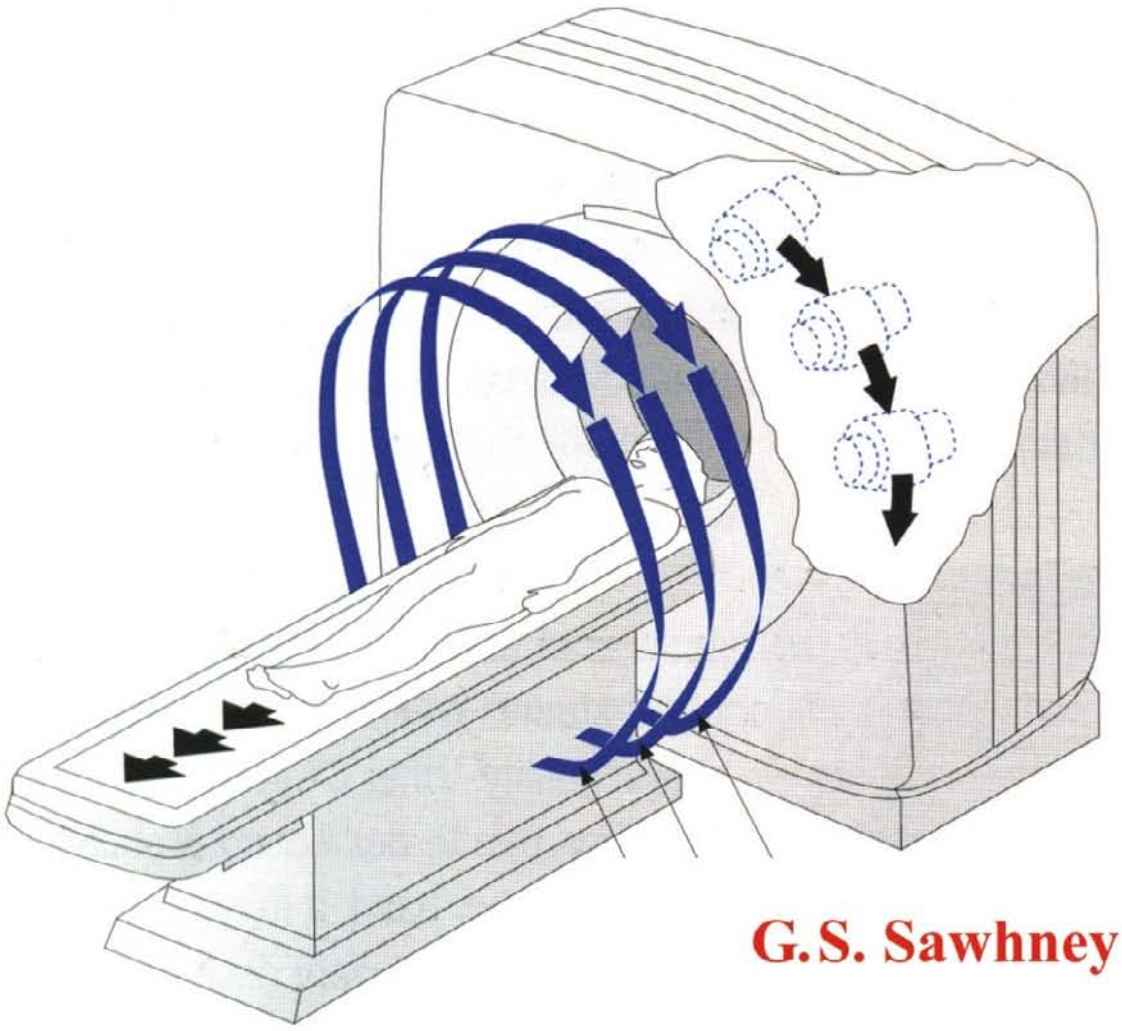
Fundamentals of Biomedical Engineering





G.S. Sawhney

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Fundamentals of Biomedical Engineering

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PREFACE

'Bio' denotes all things which are connected with life. Firstly man has learnt the use of herbs for treatment and the knowledge of botany becomes essential for the *practitioner* of medicine. Gradually man has learnt to apply laws of physics and chemistry to living things which has led to the evolution of sciences of biophysics and biochemistry. In recent years, there has been rapid progress in the field of the health care. The need to effectively utilize high technology equipment and systems in the health care necessitates the expertise of clinical engineers, hospital physicians and computer scientists. Hardly any patient today would pass through a hospital or even a family physician's chamber without the use of this technology.

The knowledge of basic engineering and the need of biomedical engineers in health care is increasingly accepted. The biomedical engineering is the inter marriage of engineering and medicine. The biomedical engineering as a subject has been introduced in the engineering courses to equip the engineering graduates to work in the health care industry. It is, therefore, essential for engineering students of almost all disciplines to have a sound knowledge of biomedical engineering. This book is designed to explain the fundamentals of biomedical engineering in the areas of biomechanics, biofluid flow, biomaterials, bioinstrumentations and in use of computing in biomedical engineering. Though this book is chiefly based on the syllabus of Uttar Pradesh Technical University, but an effort has been made to cover the syllabus of several other universities as well as based on my experience of teaching.

I have endeavoured to present a systematic explanation of the basic concepts of the biomedical engineering by firstly introducing the topics of anatomical terms and planes, terms related to movements medical terminology, histology and physiological systems of the body. A large number of objective type questions are included to enhance the understanding of the principles of theory.

I express my gratitude to Dr. Jasdev Singh Sawhney, FRCR and Dr. Pooja Sachdev Sawhney MRCP for their valuable suggestions which have helped me immensly in conceptualizing and writing this book. I am also thankful to my doctoral guide, Dr. S. Prasad, NIET Greater Noida for moral support. I am also thankful to Dr. Sujay K.Guha, SMS, IIT kharagpur who has been my inspiration in the field of biomedical engineering.

I am also thankful to Dr. V.K. Goswami and the faculty of GNIT, Greater Noida specially Mr. Devraj Tiwari of Mechanical, Prof O.P. Sharma and Mr. Manish of Information Technology, Mrs. Minakshi Awasthi of Physics and Mr. S.D. Nautyal of library for their contributions.

Above all, I wish to record my sincere thanks to my wife, Jasbeer Kaur for her patience shown throughout the preparation of this book. I am also thankful to the staff of New Age Publishers

who have associated with the completion of this book. Last but not least, I want to thank Mr. K.K. Aggarwal, chairman and Dr. A.M. Chandra, Director of Lord Krishna College of Engineering, Ghaziabad where I joined recently for their constant encouragement.

I would appreciate receiving constructive suggestions and objective criticism from students and teachers alike with a view to further enhancing the usefulness of the book by e-mailing at channi_sawhney@hotmail.com

G.S. SAWHNEY

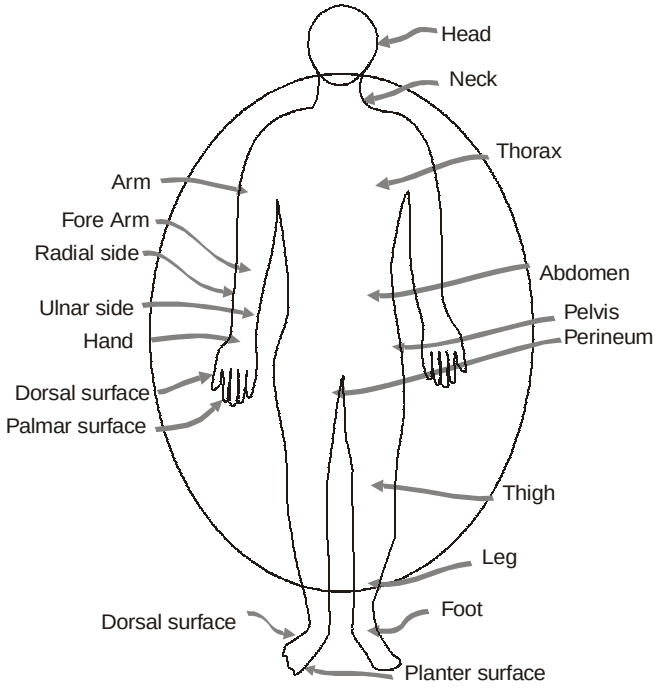
CONTENTS

INTRODUCTION 1

If only tool in your bag is a hammer then every problem in the world appears to be a nail.

ANATOMICAL TERMS AND PLANES

1. The body is made up of the head, trunk and limbs. The trunk consists of the neck, thorax (chest) and abdomen (belly). The lower part of the abdomen is the pelvis. This word is also used for the bones of the pelvis. The lowest part of the pelvis or in other words the lowest part of the trunk is the perineum. The central axis of the trunk is the vertebral column, and the upper part of it (cervical part) supports the head.



Anatomical Terms

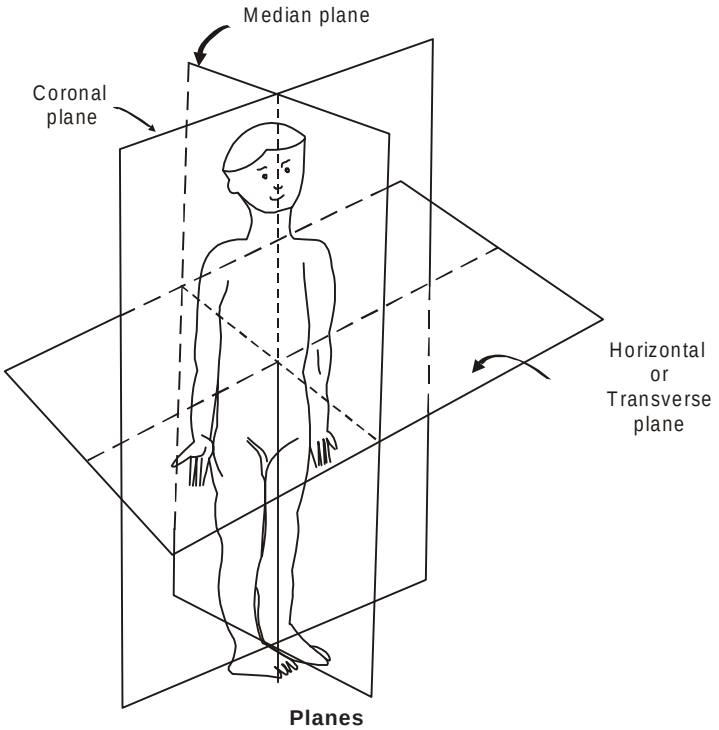
2. The main parts of the upper limb are the arm, forearm and hand. Arm in strict anatomical term means the upper arm (the part between the shoulder and elbow) however, this word is commonly used for the whole of the upper limb.

3. The main parts of the lower limb are the thigh, leg and foot. Here also leg in strict anatomical form means the lower leg (the part between the knee and foot) but the word is commonly used for whole of the lower limb.

4. In order to describe the positions of structure in human anatomy, the body is assumed to be standing upright with the feet together and the head and eyes looking to the front with the arms straight by the side and the palms of the hands facing forwards. This is the anatomical position and structures are always described relative to one another using this as the standard position. This is also applicable even when the body is lying on the back to bed or when lying on a dissecting table.

5. The 'Median plane' is an imaginary vertical longitudinal line through the middle of the body from front to back, dividing the body into right and left halves. The 'sagittal plane' is any plane that is parallel to the median plane. The adjective 'medial' means nearer to the median plane, and 'lateral' means farther from it. Thus we can say in anatomical position, the little finger is on the medial side of the hand and the thumb is on the lateral side, similarly the great toe is on the medial side of the foot and the little toe on the lateral side. If we consider forearm which has two bones with radius bone on the lateral side and ulna bone on the medial side, then the adjective 'radial' and 'ulnar' can be used instead of lateral & medial. Similarly in the lower leg where there are two bones, the fibula on the lateral side and the tibia on the medial side, the alternative adjectives 'fibular' and 'tibial' can be used.

6. 'Coronal planes' are imaginary planes at right angles to the median plane. Horizontal or transverse planes are at right angles to both the median and coronal planes.



Planes

7. The terms 'anterior' and 'posterior' are used to indicate the front or back of the body respectively. Therefore we have anterior and posterior view of the body or any part of body or organ. It is also used to describe the relationship of two parts. One is said to be anterior or posterior to the other if it is closer to anterior or posterior to the body surface. Hence on the face, the nose is anterior to the ears and the ears are posterior to the nose. Sometimes 'ventral' is used instead of posterior.

8. In describing the hand, the term 'palmar' and 'dorsal' surfaces are used instead of anterior and posterior. Similarly in describing the foot, the 'plantar' and 'dorsal' surfaces, are used instead of lower and upper surfaces.

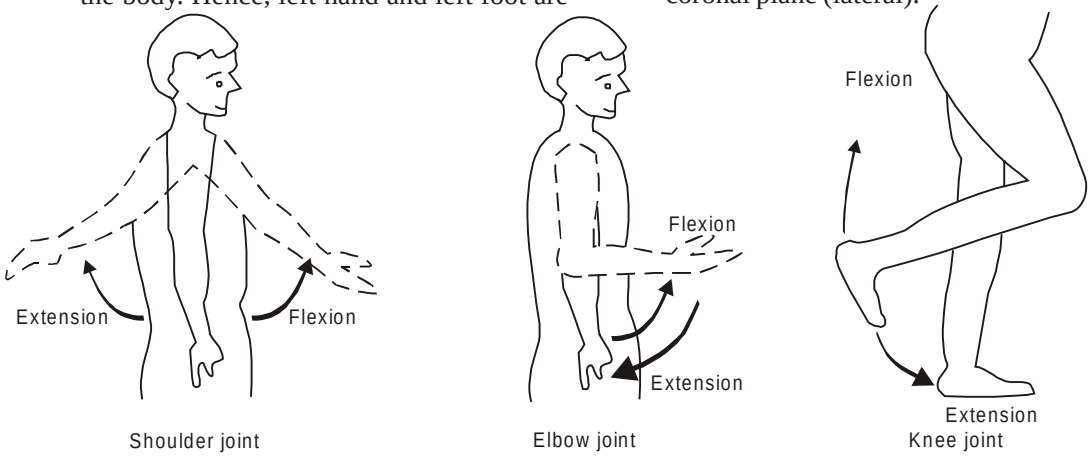
9. The terms 'proximal' and 'distal' describe the relative distances from the roots of the limbs. The arm is proximal to the forearm and the hand is distal to the forearm.

10. The terms 'superior' and 'inferior' means nearer the upper or lower end of the body respectively. Hence the nose is superior to the mouth and, inferior to the forehead. 'Superficial' means near the skin surface and 'deep' means farther away from the surface. The terms 'internal' and 'external' are used to describe the relative distance of a structure from the centre of an organ or cavity. 'Ipsilateral' and 'contra-lateral' are used for parts on the same side or not of the body. Hence, left hand and left foot are ipsilateral while the left biceps branchii muscle and the right rectusfemoris muscle, are contralateral. The 'supine' position of the body is lying on the back and the 'prone' position is lying face downward.

TERMS RELATED TO MOVEMENTS

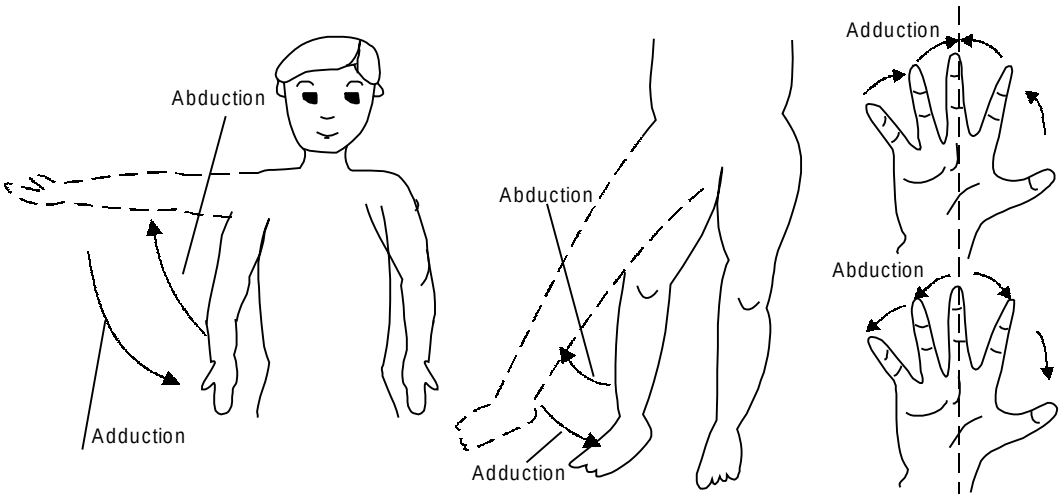
1. Wherever two or more bones meet, it is known as a joint. The degree of mobility varies from joint to joint. Some joints have no movement (as in bones of skull), some have only slight movement (as in vertebrae) and some are freely morable. These movements are made in any of three planes as explained above. Different terms are used to describe the movements as explained below.

2. 'Flexion' is a movement that takes place in a sagittal plane. It is infact folding of the bones so as they may come nearer. For example, flexion of the elbow joint bring the anterior surface of the forearm to the anterior of the arm. It is usually an anterior movement but it can be posterior movement also as in the case of the knee joint. 'Extension' means unfolding or straightening the joint. The movement usually takes place in a posterior direction. However, flexion and extension of trunk takes place in the coronal plane (lateral).



Flexation and Extension

3. 'Abduction' of a limb is the movement away from the midline of the body in the coronal plane. 'Adduction' of a limb is the movement towards the body in the coronal plane. In the fingers and toes abduction signifies the spreading of these parts and adduction indicates the drawing together of these parts.



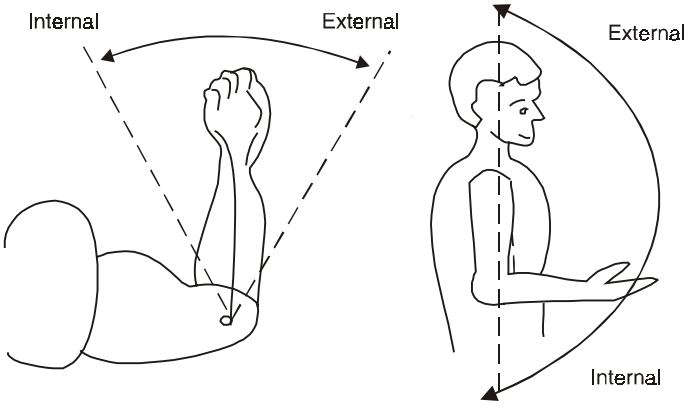
Shoulder **Hip Joint** **Fingers**

Abduction and Adduction

4. 'Rotation' is a term applied to the movement of a part of the body around its long axis. It can be.

(*a*) 'Medial rotation', which is the movement that takes place in the anterior surface of the part when facing medially.

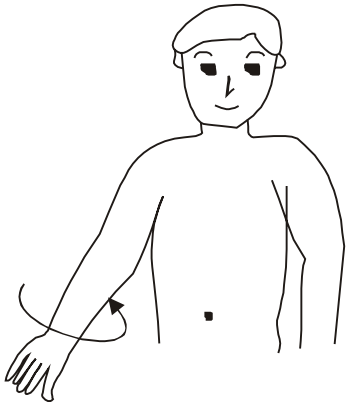
(*b*) 'Lateral rotation' is the movement that takes in the anterior surface of the part facing laterally.



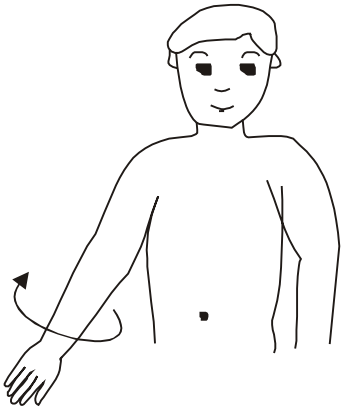
Medical Rotation of Shoulder **Rotation of Shoulder**

(*c*) 'Pronation of the forearm' is medial rotation of the forearm in such a manner that the palm faces posteriorly.

(*d*) 'Supination of the forearm', is a lateral rotation of forearm from the pronated position so that palm of the hand comes to face anteriorly.



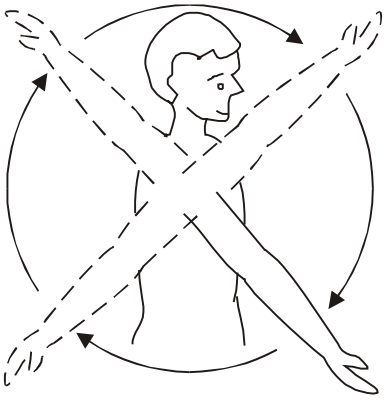
Pronation of Forearm



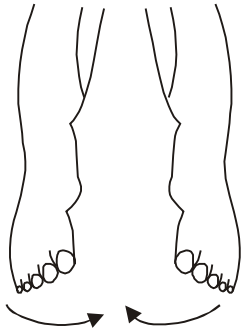
Supination of Forearm

5. 'Circumduction', is the combination of four movements which is in sequence of the movements of flexion, extension, abduction and adduction.

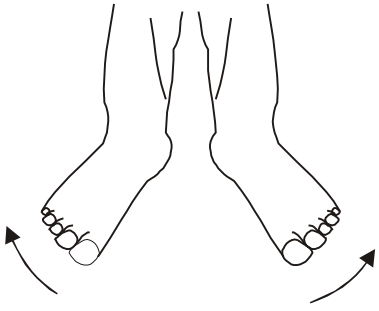
6. Inversion is the movement of the foot so that the sole faces in a medial direction while eversion is the opposite movement of the foot so that the sole faces in a lateral direction.



Circumduction of Shoulder Joint



Inversion of Foot



Eversion of Foot

MEDICAL TERMINOLOGY

1. Engineers and technicians working in medical field have to learn enough physiology, anatomy and medical terminology to be able to discuss problems intelligently with members of medical profession. They face great difficulty in learning medical terminology. However with a few simple rules, medical terminology, can be understood more easily. Most medical words have been derived from latin and Greek. Most words consist of a root or base which is modified by a prefix or suffix or both. The root is often abbreviated when the prefix or suffix is added.

PREFIXES

Prefix	*Stands for*	*Prefix*	*Stands for*
a	without or not	mat	bad
ab	away from	medio	Middle
ad	toward	meta	beyond
an	absence of	micro	small
ante	before	ortho	straight, correct
antero	in front	para	beside
		oxy	containing oxygen
anti	against	patho	disease
bi	two	peri	outside
dia	through	poly	many
dys	painful	pseudo	false
endo	within	retro	backward
epi	upon	sub	beneath
eu	good	supra	above
ex	away from	tachy	fast
exo	outside	trans	across
hyper	over		
hypo	under or less	tri	three
infra	below	ultra	beyond
intra	within	uni	single, one

SUFFIXES

Suffix	*Stands for*	*Suffix*	*Stands for*
algia	pain	emia	blood
centeses	puncture	iasis	a process
clasia	remedy	itis	inflammation
ectasis	dilation	oma	swelling, tumor
ectomy	cut	sclerosis	hardening
edema	swelling		

ROOTS

Roots	*Stands for*	*Roots*	*Stands for*
adon	gland	gaster	stomach
arteria	artery	haemo/hemo	blood
arthros	joint	hepar	liver
branchion	arm	hydro	water
branchus	windpipe	larynx	throat
cardium	heart	nephros	kidney
cephalos	brain	neuron	neuron
colon	intestine	odynia	pain
costa	rib	os/osteon	bone
Cranium	head	ren	kidney
derma	skin	spondylos	vertebra
epithelium	intestine	stoma	mouth
ostium	orifice, mouth	thorax	chest
pharynx	throat	trachea	windpipe
phlebos	vein	vene	vein
pleura	chest	vesica	bladder
psyche	mind		
pulmones	lungs		
pyelos	pelvis		

2. Examples of synthesis of words

(*a*) peri + cardium = pericardium
= outside the heart

(*b*) an + emia = anemia
= absence of blood

(*c*) hypo + oxygen = hypoxia
= lack of oxygen

(*d*) hyper + ventilation = hyperventilation
= over breathing

(*e*) tachy + cardia = tachycardia
= rapid heart action

(*f*) intra + venous = Intravenous
= within vein

(*g*) Intra + vascular = intravascular
= within blood vessel

(*h*) arthros + itis = arthritis
= inflamation of joint

(*k*) hyper + tension = hypertension
= high arterial blood pressure

(*l*) patho + phobia = pathophobia
= fear of disease

(*m*) sclero + dermatitis = sclerodermatitis
= hardening of skin

(*n*) gastroenteritis = gastro + intestine + ities
= inflammation of the mucous membranes of both stomach and intestine

(*o*) Arteries = Aeir (air) + tercm (to keep). It is a greek word. After death the arteries (blood vessels to take blood to organs) are usually empty of blood whereas the veins (blood vessels to take blood to heart) are full of clotted blood. The ancient concluded from this, that the arteries carried air. Hence the name given to these vessels as arteries.

(*p*) Robotic = Robota (Slave) + ic (Like). In 1921, Czech dramatist, KAREL CAPEK published ROSSUM's UNIVERSAL ROBOTS. Based on this, the word "robot" has been coined for something working as slave. A Robot is any mechanical device operated automatically to perform in seemingly human way. Current research efforts focus on creating a smart robot that can hear, touch, taste & consequently make decision. Robots do not have to look like humans and it is functions, not form which matters. Robots have capability to interact with humans via synthesised speech. They have vision sensors to identify obstructions, road blocks and detect motion in the environment. They can navigate and make documentation. They can be programmed to make decisions. Robotic intensive care cart is being used in intensive care unit. Robots can be used as device to provide technical aids to the handicapped.

MEDICAL GLOSSARY

1. In this book many medical words have been used which are unfamiliar to the readers. The glossary of medical words which will be used in this book is presented in alphabetical order.

A

Anatomy – A study of the structure of the body and the relationship of its constituent parts to each other.

Alveoli – Air sacs in the lungs formed at the terminals of a bronchiole. It is the thin membrance of the alveoli that allows oxygen to enter the blood stream.

Aorta – The great trunk artery that carries blood from heart to be distributed by branch arteries throughout the body.

Aortic valve – Outlet valve from left ventricle to the aorta.

Arrhythmia – An alteration in rhythm of the heart beat either in time or force.

Arteriole – One of the small terminal branch of an artery that ends in capillaries.

Artery – A vessel through which the blood is pumped away from the heart.

Atrio ventricular – Located between an atrium and ventricle of the heart.

Atrium – A main chamber of the heart into which blood returns from circulation

Auscultation – The act of listening for sounds in the body.

Axon – A never cell process which conducts impulse away from the cell body of a neuron.

B

Bifurcation – Branching as in blood vessel.

Bioelectricity – Electrical phenomenon that appear in living tissue.

Brachial – Relating to the arm or a comparable process.

Bradycardia – A slow heart rate.

Bronchus – Bronchial tubes, (air passage) *i.e.*, two branches of trachea going into the right and the left lungs.

Bundle of His – A small band of cardiac muscle fibers transmitting the wave of depolarization from the atria to the ventricles during cardiac contraction.

C

Capillaries – Smallest vessels of the blood vascular system connecting arterioles with venules and forming or network throughout.

Cardiac – Pertaining to the heart

Cardiology – The study of the heart about its action and diseases

Cardiovascular – Relating to the heart and blood vessels.

Catheter – A tubular device inserted in any passage of body to keep it open or to inject or withdraw fluid.

Cell – A smallest living matter capable of functioning as an independent unit.

Cerebellum – A part of brain to coordinate muscle and to maintain equilibrium.

Collagen – Literally meaning is glue producing. The major portion of the white fibers of connective tissue and bone.

Computerised Axial tomography (CAT) : A technique combining X-ray and computer technology for visualisation of internal organs and body structure.

Coronary artery and sinus – vessels carrying blood to & from the walls of the heart itself.

Cortex – Outer part of an organ or body structure.

Cranium – The part of the head that encloses the brain.

D

Defibrillation – The correction of rapid irregular contraction of the heart

Diastole – Dilation of the cavities of the heart as they fill with the bood.

Diastolic – Pertaining to the diastole. Diastolic blood pressure is lower.

Dicrotic – Second expansion of artery that occurs during the diastole of the heart (a dicrotic notch in the blood pressure wave)

E

Electro cardiogram (ECG) – A record of the electrical activity of the heart.

Embryo – An organism in early stages from conception.

Enzyme – A protein secreted by cells that acts as a catalyst to induce chemical changes in other substances and itself remains unchanged by the process.

Epilepsy – A disorder marked by disturbed electrical rhythms of the nervous system.

F

Fluoroscopy – Process to observe internal structure by X-ray.

H

Hemorheology – The science of rheology of the blood, the relation of pressure, flow volume and resistance to blood vessels.

Heparin – An acid in tissue which make the blood incoaguable.

Hormone – A chemical substance formed in one organ and carried in blood to another organ. Depending on the speciality of their effects, hormones can alter the functional activity and sometimes structure of one or more organs.

Hypoxia – Lack of oxygen.

I

Inferior vena cava – Main vein feeding back to the heart from systemic circulation below the heart.

In-vivo – In living body chemical process occuring within cell.

Ischemic – A localized anaemia due to an obstructed circulation.

Isometric – Having same length. A muscle acts isometrically when it applies force without changing its length.

Isotonic – having same tone. A muscle acts isotonically when it changes length without changing much the force it exerts.

K

Korotkoff sounds – Sounds produced by sudden pulsation of blood being forced through a partially occupied artery and heard during ausculatory blood pressure determination.

L

Latency – Time delay between stimulus and responses

Liver – the largest gland of the body lying beneath the diaphragm. It is irregular in shape and weight from 3 to 3 ½ pounds or about 1/40 the weight of the body. It secretes the bile and it is also of great importance in both carbohydrate & protein metabolism.

Lung – The organ of respiration in which aeration of the blood takes place.

M

Membrane – A thin layer of tissue that covers a surface or divides a space or organ

Metabolism – The sum of all the physical and chemical processes by which the living organised substance is produced and maintained.

Mitral valve – Valve between the left atrium and ventricle of the heart.

Motor – A muscle, nerve or centre that effects or produces movement.

Myelin – A fat like substance forming a sheath around certain nerve fibers

Myocardium – The walls of the chamber of the heart which contain the musculature which acts during the pumping of blood.

Myograph – An apparatus for recording the effects of the muscular contraction

N

Necrosis – Death of tissue

Nerve – A cord like structure that conveys impulse from one part of the body to another.

Neuron – A nerve cell.

O

Orthosis – Making straight, the correction of maladjustment.

Oxyhaemoglobin – A compound of oxygen and haemoglobin which is formed in lungs whereby oxygen is carried through the arteries to the body tissue.

P

Pathology – The science and study of disease, its causes and cure.

Perfuse – To pour over or through.

Permeate – To pass through the pores

Pneumograph – The recording of the thoractic movement or volume change during respiration.

Prosthesis – Artificial substitution of a missing or diseased part the like lower limb.

Protein – Part of cell and each cell is three-fourth protein.

Pulmonary – Associated with lungs

Pulse pressure– The difference between systolic and diastolic blood pressure.

R

Radioisotope – An isotope that is radioactive produced artificially from the basic element by the action of neutrons, protons, deutrons or alpha particles in cyclotron by chain reaction. These are used as tracer with stable element (labeled) by injecting in body to study the functioning of organs.

Radiology – The chief X-rays methods used in the examination of the chest which are fluoroscopy, radiography, tomography and bronchography.

S

Semi lunar pulmonary valve – Outlet valve from the right ventricle into the pulmonary artery.

Sinoatrial – The pacemaker of the heart, cardiac muscle which is responsible for initiating each cycle.

Sphygmomanometer – Instrument for measuring blood pressure (arterial).

Spirometer – Instrument for measure air which is entering and leaving the lungs.

Spleen – It is a blood forming organ in early life. It is storage organ for corpuscles and because of large number of macrophages acts as a blood filter.

Stenusis – Narrowing of a duct or canal.

Stroke volume – Amount of blood pumped during each heartbeat.

Superior vena cava – Main vein feeding back to the heart from systemic circulation above the heart.

Systemic – Pertaining to or affecting the body as a whole.

Systole – The contraction specially of ventricles during which blood is forced into the aorta and the pulmonary trunk.

T

Tachycardia – Rapid heart action.

Tendon – A fibrous cord or band that connects a muscle to a bone. It consists of tissue fascicles of very densely arranged almost parallel collagenous fibres.

Thorax – The part of the body between neck and abdomen.

Thrombus – Clotting of blood within a blood vessel

Tissue – Similar cells united in the performance of a partcular function.

Trachea – The main trunk of the system of tubes by which air goes in or comes out of the lungs.

Tricuspid valve – The valve connecting right atrium to right ventricle.

V

Ventricle – A chamber in heart which receives blood from atrium and forces it into arteries.

Venule – A small vein.

HISTOLOGY

1. All organs of the body are formed of tissues. A tissue is a collection of similar type of cells, which are associated with some intercellular matrix (ground substance) governed by some laws of growth and development. These cells are adopted to perform the same function or functions. Tissues are usually classified into four main categories:
   (*a*) Epithelial tissue
   (*b*) Connective tissue
   (*c*) Muscular tissue
   (*d*) Nervous tissue
2. **Epithelium :** It is a lining or covering tissue. It is a sheet of cells that cover external surface or lines of internal surface of the body. It can be simple, pseudostratified or stratified epithelium.
3. **Connective tissue:** It has few cells and a large amount of non living ground substance or matrix. It can be:
   (*a*) Connective tissue proper
   (*b*) Skeletal tissue
   (*c*) Fluid connective tissue
4. Connective tissues proper as name suggests, connect and anchor parts and give support to the body and its organs. For this reason, connective tissue is also known as supporting tissue. Connective tissue and skeletal tissue (cartilage and bone) have to perform mechanical functions.
5. The skeletal tissue includes the cartilages and the bones which form the structure of the body skeleton. The bones and cartilages have considerable rigidity. This is a feature which enables them to act as levers which is of great importance in the movement of limbs. The bones and the cartilages also provide surfaces for the attachment of muscles which provide force for the movement. Skeleton also protects the internal organs besides giving shape to the body. Cartilages are four types. Hyaline cartilage is bounded by fibrous membrane which is supplied by blood vessels and through it nutritive substances diffuse into the cartilage. Cartilage grows by the addition of new layers on the outside. Hyaline cartilage occurs at the ends of the long bones. It has great resistance wear and covers the articular surfaces of nearly all synovial joints. Yellow elastic cartilage has great elasticity due to the presence of large number of yellow elastic fibers. It is found at the end of the nose and in the pinna of the ear. Calcified cartilage has its matrix impregnated with calcium salts. It is found in the pelvis and at the head of the humerus and femur bones. White fibrous cartilage has a large number of white fibers. It is found in the discs of vertebral hyaline cartilage and fibrocartilage found to calcify or even ossify in later life. Bone is a connective tissue in which the matrix is inpregnated with various salts which contribute to about two third of its weight. Bone is developed by two methods (1) membranous (2) endochondral. In first method the bone is developed directly from a connective tissue membrane. For example, the bones of the vault of the skull are developed rapidly by the membranous method in the embryo. In the second, a cartilagious model is laid down which is replaced by bone. The long bones of the limbs are developed by endochondral ossification. Bones have fine canals which join with blood vessels and bone marrow. At birth, the marrow of all the bones of the body is red and hematopoietic (forming blood cells). The blood forming activity gradually lessens with age and red marrow is replaced by yellow marrow.
6. **Fluid connective tissue:** Blood is liquid connective tissue. It is red coloured fluid. It consists of liquid portion which is called plasma and of three different kinds of cells which are red blood corpuscles (erythrocytes), white blood corpuscles

(leucocytes) and platelets (thrombocytes). Plasma is the liquid portion of the blood of which it forms about two-third and contains about 80% of water. It is almost colourless clear fluid and contains an everchanging variety of substances in solution and suspension. Among the various substances present in the plasma are gases, absorbed food material, inorganic salts, vitamins, metabolic waste products, hormones, anti toxin and a soluble blood protein called fibrinogen. The cytoplasm of red corpuscles contains a pigment, the haemoglobin which makes these cells appear red. In bulk these cells give blood its red colour. The haemoglobin combines readily with oxygen to form an unstable compound, oxyhaemoglobin. In the tissues it breaks up releasing the oxygen. Here it combines with carbondioxide to form an unstable compound, carboxy haemoglobin, which breaks up in the lung, releasing carbondioxide for expiration. Haemoglobin, therefore, transports the gases and as such plays a vital part in respiration. The red corpuscles are formed in liver and spleen which also destroy the worn out corpuscles. As these are nucleated, they live for a pretty long time. The white blood corpuscles (leucocytes) are small, semitransparent, nucleated and amoeboid cells. These can crawl out between neighbouring endothelial cells and hence are found in every nook and corner of the body. At part of body having infections, they accumulate in very large numbers and serve to defend the body against the disease germs. They are able to eat bacteria and other germs in an amoeba like manner. This process is known as phagocytosis and hence they are known as phagocytes. Some of the WBC are killed by bacterial acids. Thus they may accumulate at the seat of infection as living or dead bacteria, leucocytes and disintegrating cells. All these form a whitish or yellow mass which is called pus. Leucocytes are also useful in transporting waste particles and fat globules. These are produced in the bone marrow and lymphatic glands and are destroyed in the lymph organs. Thrombocytes or platelets contain a chemical which plays an important role in the clotting of blood. The various functions of blood are :

(*a*) *Transport of gases* : RBC combines with oxygen to form oxyhaemoglobin which breaks up and release oxygen in tissues. In tissues, RBC combines with carbon-di-oxide to form carboxy haemoglobin which breaks up in the lungs to release carbondioxide for expiration.

(*b*) *Transport of food material:* All the absorbed food circulated by the blood till it is taken up and used by tissue cells.

(*c*) *Transport of substances:* Many other substances such as enzymes, hormones and anti toxins are transported by the blood to the places where they are required.

(*d*) *Defence against disease:* This is effected in two ways. Firstly the white blood corpuscles feed on disease germs. Secondly blood possesses certain antioxins which unite chemically with toxins and then neutralize them.

(*e*) *Equalization of the body temperature:* As the blood circulate throughout the body, it brings about an equalization of the body temperature by transferring heat from one part to another.

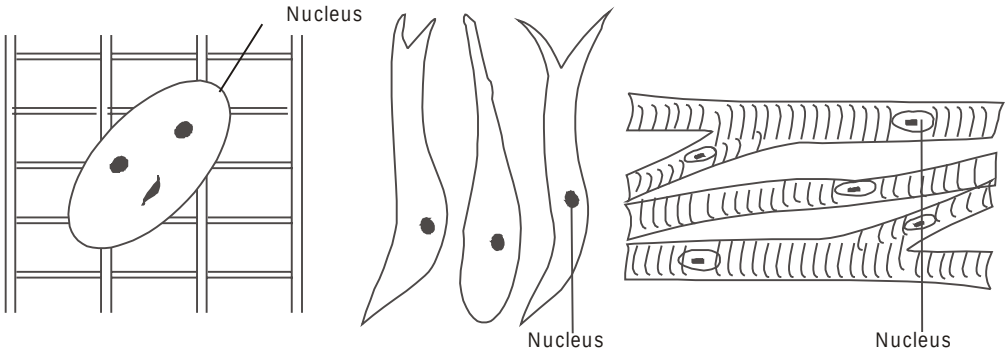
(*f*) *Transport of metabolic wastes:* The nitrogenous waste material is carried by the blood to the liver where it is converted into urea. The later is now carried by the blood to the kidney where it is removed out along with the urine.

(*g*) *Clotting of blood:* Blood has a soluble solution called fibrinogen which is converted into a mesh work of fine

threads of insoluble fibrins. In the mesh of fibrins, various types of corpuscles get entangled to form a blood clot which is also known as coagulation. The conversion of fibrinogen into fibrin is affected by the action of an enzyme called thrombin. Free thrombin is not present in the blood but it is formed by its precursor (inactive enzyme prothromboplastin) in presence of calcium ions. Calcium ions are present in blood but free thromboplastin is absent in blood. However it is present in other solid tissues. Hence when an injury occurs, thromboplastin is released by the injured tissues. The thromboplastin then acts with calcium upon the prothrombin, changing it to thrombin. The thrombin then acts upon the fibrinogen and converts it to fibrin.

7. **Muscular tissue:** It consists of cells in the shape of fibres of different lengths. Inter-cellular elements are almost absent. The muscular tissues are of three types :
   (1) *Striped or voluntary*
   (2) *Unstriped or involuntary*
   (3) *Cardiac*

   The striped muscles are under the control of 'will' and they are wide and nontapering. In the striped muscle, fibres are united in parallel bundles which is continuous with the connective tissue sheath surrounding the tendons that unite the muscle to the skeleton. Unstriped muscles are made of elongated, spindle shaped, flattened fibres which are rarely forked at the ends. The number of unstriped muscle fibres are united together by a minute quantity of intercelluar substance into a thin and flat band and a number of such bands are bound together by connective tissues into a larger bundle. The unstriped muscles are not in the control of 'will' and they are found in the alimentary canal, the lungs and the blood vessels. The cardiac muscles are found only in the wall of the heart. The structure is somewhat inbetween striped and unstriped muscles. These muscles contract rhythmically and these muscles are immune to fatigue.



Striped Muscle **Unstriped Muscle** **Cardiac Muscle**

8. **Nervous tissue:** They consists of
   (1) nerve cell
   (2) nerve fibre.

   Nerve cells are known as neurons. Each neuron consists of a cell body from which arises a system of branching fibres. The number of fibres is variable. On this basis, neurons are classified into three types:

(1) neurons with many processes are called multipolar.

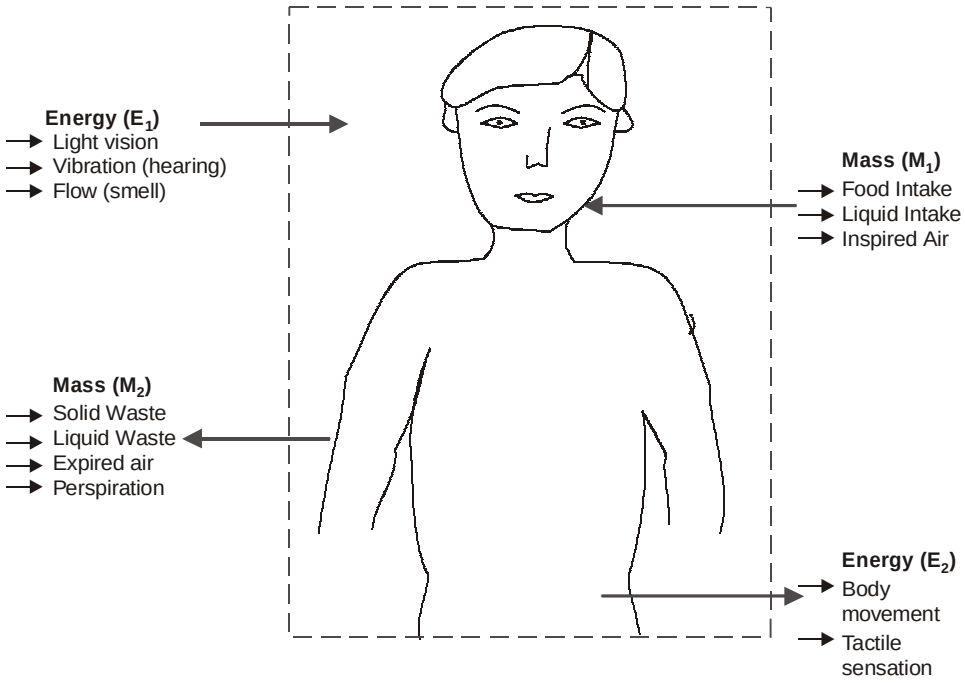
(2) neurons with two procesess arising at opposite poles are known as bipolar.

(3) neurons having two processes arising from the same pole are known as unipolar. The cytoplasm of each neuron contain a large and spherical nucleus, large number of dark staining minute particles (Nissl Granules) and numerous cytoplasmic strands known as neurofibrillae. Neurofibrillae help in the passage of the nerve impulse.

PHYSIOLOGICAL SYSTEMS OF THE BODY

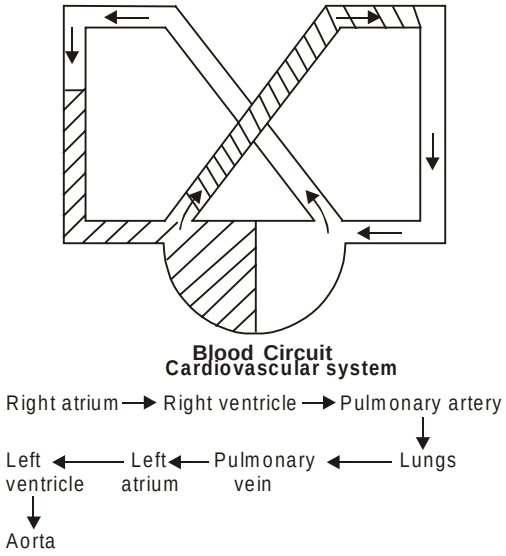
1. In our body, we have mechanical, electrical, chemical, thermal, pneumatic, hydraulic and many other types of system. Each system communicates internally with other systems of the body and externally it communicates with surroundings. We have a multi level control system with its communication network which organises these internal systems to perform many complex functions. We are able to sustain our lives due to organised operations of all these internal systems and their various subsystems. In medical terms, a study of the structure of the body and the relationship of its constituents parts to each other is known as 'Anatomy' while the study of function of these parts as a system is known as physiology. The major functional physiological systems of the body are:

(*a*) The cardiovascular system
(*b*) The biochemical system
(*c*) The respiratory system
(*d*) The nervous system
(*e*) The excretory system
(*f*) The locomotor system
(*g*) The digestive system

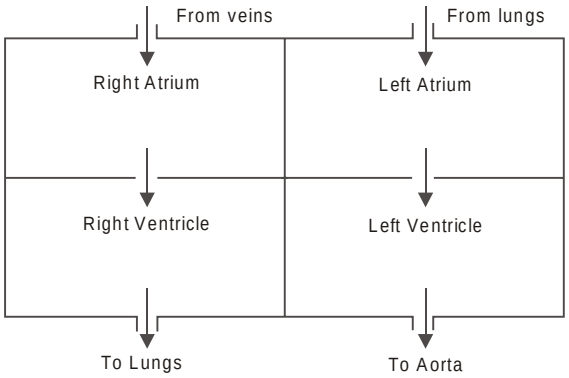


Communication with Energy and Mass Transfer with Surroundings

2. The cardiovascular system: The cardiovascular system is a closed hydraulic system. It has heart and blood vessels. The heart works as a four chamber pump. The blood vessels are flexible and sometimes elastic tubing of varying sizes. The tubings



change their sizes to control blood pressure, for example arteries and arterioles. Certain tubings act as reservoirs as they can control their volume as per the requirements by a system of valves and variable resistance to flow by constriction and dilation of the control blood tubings. These tubings are veins and they take blood back to heart. The heart acts as two functionally isolated two stages pumps working in parallel. In first stage of each pump, the blood is taken into the reservoirs (atriums) from the system and it is pumped into second stage reservoirs (ventricles). The action of the second stage is so well coordinated that the blood is pumped into the system immediately when it is received from the first stage. The circuit of the blood is shown in the diagram. Right side of the heart collects blood from the hydraulic system through veins and pumps it to the lungs for oxygenation. The left side of the heart receives blood from the lungs (oxygenation system), and pumps it into the main hydraulic system which is formed by the various organs of the body. The heart rate and stroke volume are constantly changed to control the flow of the blood in the system to meet the requirements of body parts. The blood performs all functions as elaborated in para 25 of this chapter. The blood flows in laminar manner. Superior vena cava is a large venous channel which collects blood from the upper half of the body and delivers into the right atrium. It has no valve. The inferior vena cava (larger than superior vena cava) also opens into right atrium. It returns the blood to the heart from the lower half of the body. Since the blood in the inferior vena cava has to flow against gravity at times, special one way valves are located in it to prevent gravity from pulling blood against the direction of flow. The cardiac output flow rate and volume of the fluid at various places in the body are important indicators for proper functioning of the system.



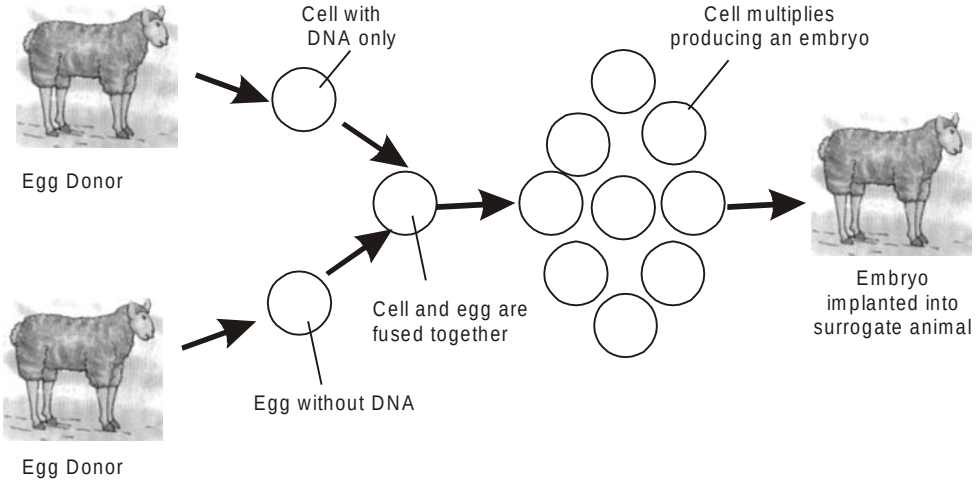
Heart Works a Pump

3. **The biochemical system:** There are many chemical systems in our body that produce energy for the functioning of our body. The energy is required for growth, body functions and body repairs. These chemical systems are interconnected and these can be considered as the subsystems of a very efficient chemical factory. There is a single point intake of fuel (food, water and air) for this factory which is also source for all chemical reactions which are taking place inside the body. This chemical factory also contains all monitory devices which are essential to carry out necessary control for each chemical operation. The waste disposal system is also a part of this biochemical system.
4. **The respiratory system:** The respiratory system is a pneumatic system which ensures exchange of gases by a biological process which is termed respiration. The body requires oxygen to combine with carbon, hydrogen and other nutrients to produce heat and energy for sustenance of life. The entire process of taking inside oxygen from surroundings, transporting it to body cells, removing the carbondioxide from the cells and pushing out the carbondioxide into surrounding is called respiration. Air enters the lungs through air passages which include the nasal cavities, pharynx, larynx, trachea, bronchi and bronchioles. The lungs are elastic bags located in a closed cavity, called the thorax. The diaphragm is a special bell shaped muscle located at the bottom of the closed cavity. When this diaphragm contracts, thorare is pulled downward, enlarging the closed cavity. The resultant increase in the volume of the closed cavity, a negative pressure (vacuum) is created which is relieved by air entering the lungs from the surroundings. When the diaphragm moves up and reduces the volume of the thorax, the used air with carbon dioxide is pushed out of the lungs. Oxygen is taken into the blood from the incoming air in about 300 million alveoli present in the lungs. The oxygen and haemoglobins in blood form oxyhaemoglobins and carbondioxide removed from the blood is pushed out from lungs to the surroundings. An automatic control system maintains pneumatic pump operation (rate of contraction of diaphragm) at a speed that is adequate to supply oxygen and to remove carbondioxide as required by body. It is also possible to accelerate or deacelerate the operation of the pneumatic pump by manual control whenever it is required. Automatic control returns whenever manual control is not applied.
5. **The nervous system:** The nervous system consists of control and communication network which coordinates the functions of all parts of the body. The brain is the central information processor and it works as a computer. It has memory, power to compute, capability to make decisions and innumerous input, and output channels for communication. These channels form complicated networks with many interconnections (nodes) which take singnals from a large number of sensory devices (each sensory device detects light, sound, pressure, heat and chemicals) to the brain (computer) for analysis. Some network is again used to take the output control signals from the brain to the motor units of the muscles to carryout the desired motion or to exert force. The nerves form signal lines to carry signals (informations) generated by the nerve action potentials (sensory devices) to the brain and same signal lines are used to carry control signals generated by the brain for the motor units. In addition to the control of the brain, a large number of simple decision making devices in the form of spinal reflexes are present in the body to control independently some motor devices from certain sensory inputs. Example of this is

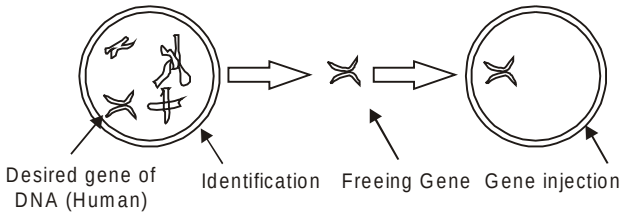
the Portal system which consist of vein and capillary network.

6. **The excretory system :** It consists of all organs that are responsible for the removal of waste products formed by metabolism in the organisms. The kidneys are the major excretory organs in man. The left kidney is located at slightly higher level than right kidney, one on each side of the vertebral column. The kidneys have 'bean' shape and they are also called renes from which it is known as rent. The renal tubules act as filters to remove from the blood (1) Excess water (2) Urea and uric acid (3) Excess mineral salts (4) Yellow pigments from the bile. The mixture of these substances forms urine. When the human kidneys fail to function, the urine accumulates in the blood resulting death of the person from toxic poisoning.
7. **The locomotor system:** The system provides locomotion or movement to the body. Bones and joints play an important role for this system. Statics and dynamics of the musculoskeletal system; forces and motions acting in the skeletal system; forces and movements within the body; behaviour of bones, tendons, ligaments and cartilages for stress and strains; and prosthesis design etc. will be covered in details in later chapters.
8. **The digestive system:** It includes all organs that help in ingestion, digestion, absorption and egestion of undigested food. It includes the alimentary canal and asociated glands like liver and pancreas etc. The liver is the largest gland in the body. It is located on the right side, just under the diaphragm. It has irregular shape and it weighs 3 to 3 ½ pounds (1/40th the weight of the body). It secretes bile juice which plays an important role in metabolism of both carbohydrate and protein. The nitrogenous waste material is carried by the blood to the liver where it is converted into urea. Bile pigments are derived from the breakdown of hemoglobin from worn out red blood corpuscles. Bile pigments colour undigested food. The other important gland is pancreas which secrete digestive pancreatic juice and discharge it into intestine. This is done by exocrine part of the pancreas. The endocrine part secretes hormones like insulin. Insulin promotes glucose utilization, protein synthesis and the formation and storage of neutral lipids. Insulin is given to the persons suffering from diabetes.
9. **Cell, DNA and atoms:** Our body possess numerous cells (almost 10,000 trillion) of almost some few hundred varities. Each cell performs an important role to keep us fit. All activities like standing, walking, talking and playing are possible through these cells. The cells extract nutrients from food, distribute the energy and remove the waste from the body. They also fight against becteria and billion of cells die daily in this process.
10. Inside every cells is a nucleus which has 46 chromosomes (23 come from father and 23 come from mother). Chromosomes carry all instructions necessary for our growth and to maintain us. They contain long strands of chemical called DNA.
11. In microscopic level, each cell of our body is made of atoms. We have in our body about 63% by hydrogen atoms, 25.5% oxygen atoms, 9.5% carbon atoms, 1.5% nitrogen atoms and only 0.5% atoms of other atoms (Iron, Cobalt, Sodium and Potasium etc). When we die our atoms will dissemble and move off to form new uses elsewhere as atoms can not be destroyed. Some atoms may form a part of a flower or other human being or a drop of rain. It is also possible that we may be having atoms in our body which once belonged to Budha, Gandhi or Nehru.

12. **Cloning:** Cloning occurs in nature for simple organisms (bacteria and viruses) which reproduce by splitting when their DNA has replicated itself. Cloning can also be done in humans and other animals when a single fertiliged egg divides and separates to form two or more identical individuals. Gene cloning is generally done in the laboratory by means of the polymerisation chain reaction which enables to reproduce millions of identical gene in short time. In animal cloning, the donor's DNA is introduced into egg of another animal of same species after egg's DNA has been removed. The egg is then inserted into surrogate animal's womb and pregnancy procceds as normal. Another genetic advancement is the creation of transgenic animals which can be used for the production of human compatible organs such as hearts. Pigs are being used for this purpose.



Cloning of Animal



Creating Transgenic Animal

OBJECTIVE TYPE QUESTIONS

Fill up the gaps

1. The body is made up of the head, _____ and limbs. ((*a*) arms (*b*) trunks)
2. The vertebral column is _____axis of trunk. ((*a*) central (*b*) middle)
3. The upper limbs by the sides of the trunk is _____ position ((*a*) erect (*b*) anatomical)
4. Sagittal plane is parallel to _____ plane. ((*a*) median (*b*) lateral)
5. Horizontal plane is also known as _____ plane. ((*a*) median (*b*) transverse)
6. The adjective medial means _____ to median plane. ((*a*) nearer (*b*) farther)
7. The adjective radial and 'ulnar' can be used instead of _____. ((*a*) medial and lateral (*b*) lateral and medial)
8. The terms 'anterior' and 'posterior' are used to indicate _____ of the body respectively. ((*a*) back and front (*b*) front and back)
9. Nose is _____ to the ears. ((*a*) anterior (*b*) posterior)
10. The term 'palmer' and 'dorsal' surfaces of the hand. ((*a*) anterior and posterior (*b*) posterior and anterior)
11. The arm is _____ to the forearm. ((*a*) distal (*b*) proximal)
12. The mouth is _____ to the nose. ((*a*) superior (*b*) infevior)
13. If a person is lying, them he is in _____ position. ((*a*) supine (*b*) prone)
14. Flexion is the _____ of the bones and extension is _____ of the bones. ((*a*) unfolding, folding (*b*) folding, unfolding)
15. Flexion and extension of trunk takes place in the _____ plane. ((*a*) medial (*b*) lateral)
16. _____ of the limb is the movement away from the midline of the body in the coronal plane while _____ of the limb is the movement towards the body in the coronal plane. ((*a*) adduction, abduction (*b*) abduction, adduction)
17. Rotation is a term applied to the movement of a part of the body around its _____ axis. ((*a*) central (*b*) long)
18. _____ is the movement of the foot so that the sole faces in medial direction while _____ is the opposite movement so that the sole faces in a lateral direction. ((*a*) Eversion, Inversion (*b*) Inversion, Eversion)
19. Blood is _____ tissue. ((*a*) Epithelial (*b*) Connective)
20. _____ tissue has to perform mechanical function. ((*a*) skeletal (*b*) fluid connective)
21. All organs of the body are formed of _____. ((*a*) flesh (*b*) tissue)
22. Tissue is a collection of similar type of _____. ((*a*) fibres (*b*) cells)
23. Epithelium is _____ tissue. ((*a*) covering (*b*) connecting)
24. Cartilages and bones are _____ tissues. ((*a*) supporting (*b*) skeletal)
25. Blood consists of liquid portion (plasma) and _____ different kinds of cells. ((*a*) two (*b*) three)
26. The haemoglobin is the pigment in _____ corpuscles which makes the blood red. ((*a*) erythrocytes (*b*) leucocytes)
27. Transport of gases (oxygen and carbon dioxide) is done by _____ of RBC (Red blood corpuscles). ((*a*) haemoglobin (*b*) platelets)
28. The haemoglobin combines with oxygen to form oxyhaemoglobin in _____. ((*a*)lungs (*b*) tissues)
29. The haemoglobin combines with carbon dioxides to form carboxy haemoglobin in _____. ((*a*) lungs (*b*) tissues)

30. The corpuscles which are able to eat bacteria and other germs so as to defend the body against disease are _____.((*a*) RBC (*b*) WBC

31. The clotting of blood is done by ____. ((*a*) thrombocyctes (*b*) leucocytes)

32. Striped muscle tissues are _____ the control of 'will'. ((*a*) under (*b*) not under)

33. The muscles of joints are _____ muscles. ((*a*) striped (*b*) unstriped)

34. The alimentary canal, the lungs and the blood vessels have _____ muscles. ((*a*) unstriped (*b*) striped)

35. The _____ muscle is found only in the wall of heart. ((*a*) unstriped (*b*) cardiac)

36. The study of the parts of the body is ____ and the function of the parts is _____. ((*a*) physiology, anatomy (*b*) anatomy, physiology)

37. The vascular system is a closed _____ system. ((*a*) hydraulic (*b*) pressure)

38. The heart works as ____ chambers pump. ((*a*) two (*b*) four)

39. The heart can be considered as _____ stages pumps. ((*a*) two (*b*) four)

40. The respiratory system is a ____ system. ((*a*) air (*b*) pneumatic)

41. The _____ is the central information processor of the nervous system. ((*a*) motor units (*b*) brain)

42. The _____ is the major organ of the excretory system. ((*a*) liver (*b*) kidney)

43. The filtering of the blood for removal of wastage is done in ____. ((*a*) liver (*b*) kidney)

44. The digestive system includes ____ and associated glands. ((*a*) stomach (*b*) alimentary canal)

45. The digestive pancreatic juice and insulin is secreted by _____. ((*a*) liver (*b*) pancreas)

46. Red blood cells are formed in the _____. ((*a*) liver (*b*) bone marrow)

47. The valves are found in only _____ ((*a*) artery (*b*) vein)

48. Artery takes the blood _____ and vein takes the blood _____ the heart. ((*a*) away, towards (*b*) towards, away)

49. A portal system is _____. ((*a*) vein (*b*) vein and capillary network)

50. An artery has _____ wall than a vein. ((*a*) thicker (*b*) thinner)

ANSWERS

1. (*b*)	**2.** (*a*)	**3.** (*b*)	**4.** (*a*)	**5.** (*b*)	**6.** (*a*)	**7.** (*b*)	**8.** (*b*)
9. (*a*)	**10.** (*a*)	**11.** (*b*)	**12.** (*b*)	**13.** (*a*)	**14.** (*b*)	**15.** (*b*)	**16.** (*b*)
17. (*b*)	**18.** (*b*)	**19.** (*b*)	**20.** (*a*)	**21.** (*b*)	**22.** (*b*)	**23.** (*a*)	**24.** (*b*)
25. (*b*)	**26.** (*a*)	**27.** (*a*)	**28.** (*a*)	**29.** (*b*)	**30.** (*b*)	**31.** (*a*)	**32.** (*a*)
33. (*a*)	**34.** (*a*)	**35.** (*b*)	**36.** (*b*)	**37.** (*a*)	**38.** (*b*)	**39.** (*a*)	**40.** (*b*)
41. (*b*)	**42.** (*b*)	**43.** (*b*)	**44.** (*b*)	**45.** (*b*)	**46.** (*b*)	**47.** (*b*)	**48.** (*a*)
49. (*b*)	**50.** (*a*)						

CONCEPTS OF PHYSICS, MECHANICS AND FLUID MECHANICS

2

Difficult we shall do now, Impossible we shall take afterwards.

INTRODUCTION

1. Physics is the study of nature and law. Nature governs with laws and to explain the laws, the science of physics is developed. Physics is concerned with the basic rules which are applicable to all objects whether innert or living. Therefore understanding of physics helps us to apply these laws in the study of bio and medical sciences. No one has been given authority to frame the laws of physics. These laws were discovered while observing the events happening in nature. A falling apple from a tree gave Newton an idea of law of gravitation. Mathematics has given us a concept of induction and deduction reasoning. When a person makes observations or experiments and on their basis, reaches a conclusion, then it is said to be inductive reasoning. Deductive reasoning on other hand, proceeds from assumptions rather than observations. It is usually by inductive reasoning that mathematical results are discovered while they are proved by deductive reasoning.

MECHANICS

1. Mechanics is a science which deals with the state of rest or the state of motion of body under the action of forces. The application of this science to actual problems is called applied mechanics. Statics is the branch of mechanics which relates to bodies at rest. Dynamics is the other branch of mechanics which deals with bodies in motion. The analysis of force system on bodies is based on some of basic laws which are fundamental laws of mechanics. First law of motion states that a body tends to stay in state of rest or of uniform motion unless an external force is applied. Second law of motion states that the rate of change of momentum of a body is directly proportional to the applied force and in same direction *i.e.,* force = mass × acceleration.Third law of motion states that for every action, there is an equal and opposite reaction.

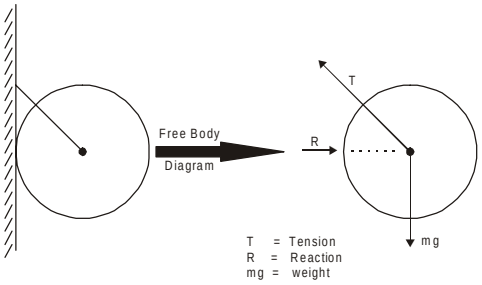
2. If all the forces in a system lie in single plane, then it is called a coplanar force system. If the line of action of all forces lie along a

single line, then it is called a collinear force system. If all forces pass through a single point, it is called a concurrent force system.

3. Moment of a force about a point is the measure of its rotational effect. It is the product of the magnitude of the force and the perpendicular distance of the point from the line of action of the force. The point from where the moment taken is called "moment centre" and the perpendicular distance of the point from the line of action of the force is called "moment arm"

4. Forces on a body can be applied forces and non applied forces. Non applied forces are self weight and reactions. Self weight always act vertically downward and it is equal to the product of mass and gravitational acceleration. Reactions are self adjusting forces developed by other bodies or surfaces which are equal and opposite to forces (actions) exerted by the body. For smooth contact, the direction of reaction is normal to the surface of contact.

5. Free body diagram of a body is a diagram in which the body under consideration is freed from all the contact surfaces with reaction forces and diagram of the body is shown with applied forces and reaction forces at points where body was making contact with other surfaces. Reaction at joints and muscles forces are worked out by drawing free body diagrams.



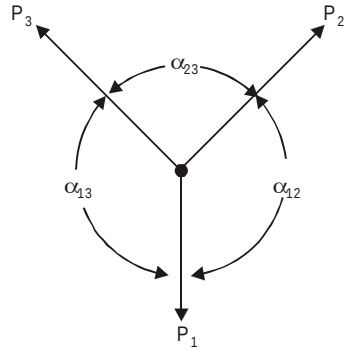
6. A body is said to be in equilibrium under a system of coplanar forces if $\Sigma P_x = 0$ and $\Sigma P_y = 0$. The resultant of coplanar *concurrent forces* not in equilibrium is given by

$$R = \sqrt{(\Sigma px)^2 + (\Sigma py)^2}$$

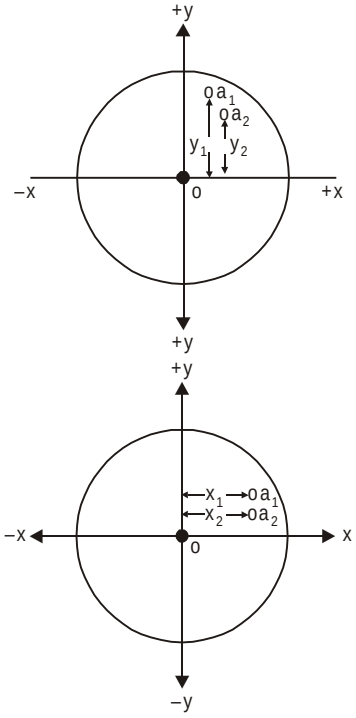
and angle of inclination is given by $\tan^{-1} \frac{\Sigma P_y}{\Sigma P_x}$ where Σpx and ΣP_y are sum of resolved forces in x and y directions.

7. A body is said to be in equilibrium under coplanar force system if $\Sigma P_x = 0$, $\Sigma P_y = 0$ and $\Sigma M = 0$. Hence we see that the condition of equilibrium gives three equations to find only three unknowns. A system of forces is determinate incase it has three unknowns only, otherwise it is indeterminate. Lami's theorem of equilibrum can be applied for three concurrent forces. According to it, the forces are proportional to sine of the angle between other two forces.

Hence, $\frac{p_1}{\sin \alpha_{23}} = \frac{p_2}{\sin \alpha_{13}} = \frac{p_3}{\sin \alpha_{12}}$



8. Friction : When a body moves or tends to move over another body, a force opposing the motion is developed at contact surface. Friction force = coefficient friction force is always less than static friction. Friction can be reduced by lubricating the contacting surface. Dry surface friction is always greater than wet surface friction. Friction can always be reduced if contact between the surfaces can be avoided by keeping a layer of liquid in between the surfaces. Synovial joints in our body work on same principle.



9. Bending and torsonal stresses: The bending equation is applicable where shear force is zero and it is given by $\frac{M}{I} = \frac{E}{R} = \frac{\sigma}{y}$ where M = applied moment, I = moment of inertia, R = radius and curvature, σ = bending stress, E = Young's modulus and y = layer from centre where bending stress is being analysed. Moment of inertia is nothing but second moment of area or mass. Moment of inertia of a lamina is

(a) Moment of inertia about $x - x$

$= I_x = a_1 y^2_1 + a_2 y_2^2 \ldots\ldots = \Sigma a y^2$

(b) Moment of inertia about $y - y$

$= I_y = a_1 x_1^2 + a_2 x^2_2 \ldots\ldots = \Sigma a x^2$

(c) Moment of inertia of circular section =

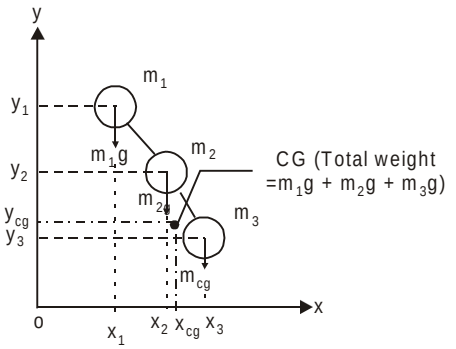
$$I_{xx} = I_{yy} = \frac{\pi D^4}{64}$$

(d) Moment of inertia of hollow circular section

$$= I_{xx} = I_{yy} = \frac{\pi}{64}(D^4 - d^4)$$

Similarly for pure torsion we can apply $\frac{T}{I_p} = \frac{\tau}{r} = \frac{G\theta}{l}$ where T = Torque, I_p = polar moment of inertia, τ = shear stress r = radius, G = rigidity modulus, l = length and θ = angle of twist.

10. Centre of gravity: The entire mass of a body is assumed to be concentrated at a point and the force of gravity acts at this point which is called the centre of gravity. The centre of gravity of a body is located at a point about which sum of moments of weights of all its particles is zero. Hence if the body is supported at its centre of gravity, the body will remain in rotational equilibrium as the moment of weight of all its particles about the point of support will be zero.



Centre of Gravity of Particles

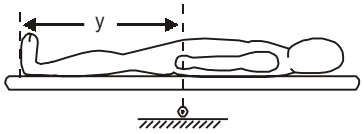
Consider a body with three particles only with masses as m_1 m_2 and m_3. The moment of three particles at point '0' about $y - y$ axis is equal to $m_1 g$ $x_1 + m_2 g\ x_2 + m_3\ g\ x_3$. Total mass of the body at centre of gravity (CG) is $m_1 + m_2 + m_3$ and moment of inertia is equal to $(m_1 + m_2 + m_3)\ g \times x_{cg}$.

Hence, $$x_{cg} = \frac{m_1 x_1 + m_2 x_2 + m_3 x_3}{m_1 + m_2 + m_3}$$

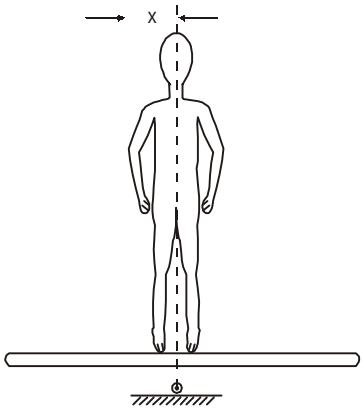
$$= \Sigma \frac{m_i x_i}{\Sigma m_i}$$

and $y_{cg} = \Sigma \frac{m_i y_i}{\Sigma m_i}$. There is another method to find the centre of gravity by actually balancing the body

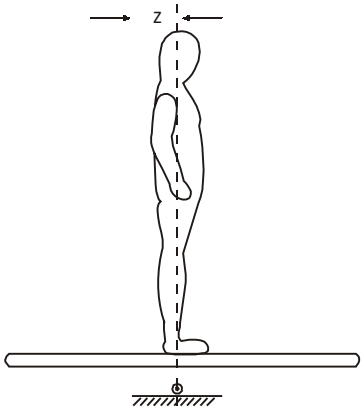
on a knife edge in three planes *i.e.*, median plane, coronal plane and horizontal plane. The point of balance will give the line in that plane on which the centre of gravity of the body is lying. The intersection of these three lines will give the actual centre of gravity of the body from a point in space. Statistical method can also be used for finding



Horizontal Plane



Median Plane

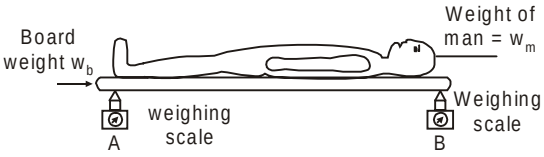


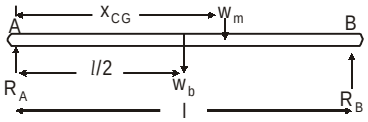
Coronal plane

the centre of gravity. A man (weight = w_m) is lying supine on a board (weight = w_b) and reaction force R_A and R_B are read from the measuring scale. The length of board is '*l*' and its weight will act at $l/2$ while weight of the man acts at x_{cg} from point *A*. The free body diagram of the body is shown in the figure. Now $\Sigma P_y = 0$, therefore $R_A + R_B = w_m + w_b$ and w_m can be found out. Similarly $\Sigma M_A = 0$, therefore,

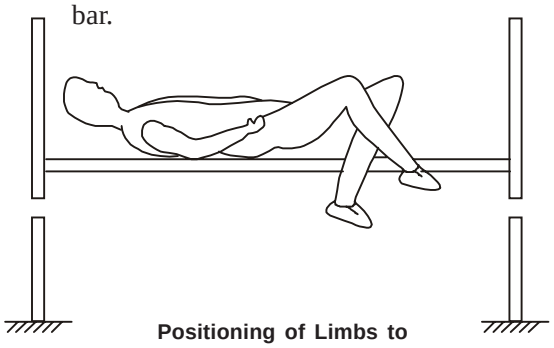
$$\frac{l}{2} \times w_b + x_{cg} \times w_m - l \times R_B = 0, \text{ and } x_{cg}$$

can be found out. Similarly y_{cg} and z_{cg} can be found out.





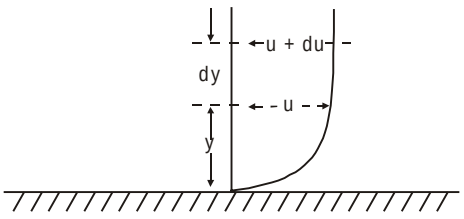
11. The centre of gravity of a man depends on the relative position of his limbs (lower and upper) as compared to the anatomical position. Locations of the centre of gravity of upper and lower limbs will change depending upon their positions which will change the overall centre of gravity of the man. If knee is flexed backwards, the centre of gravity of leg as well as that of the man will shift backwards. Smilarly, the centre of gravity of arm as well as the man shifts forward if the elbow is flexed. An athletic can take full advantage by positioning his limbs so as to shift his centre of gravity as high as possible while jumping over the high bar.



Positioning of Limbs to Help While Jumping

FLUID MECHANICS

1. **Viscosity :** It is defined as the property of a fluid which determines its resistance to shearing stresses. It is a measure of internal fluid friction which exerts resistance to flow, It is primarily due to cohesion and molecular momentum exchange between fluid layers which appears as shearing stresses between the moving layers of the fluid when the flow takes place. An ideal fluid one which has no viscosity. But no fluid is exists which can be classified as an ideal fluid having zero viscosity. However fluids with very small viscosity can be considered as ideal fluids. In the figure, a fluid flow is shown on a solid boundary when two layers are '*dy*' apart and moving one over the other with different velocities, say '*u*' and '*u* + *du*'. The top layer causes a shear stress on the adjacent lower layer and this lower layer also cause a shear stress on the layer lower to it and this goes on. According to Newton's law of viscosity, the shear strees (τ) on a fluid element layer is directly proportion to the rate of shear strain or the rate of change of velocity $\left(\frac{du}{dy}\right)$.



Solid Boundary

$$\tau \propto \left(\frac{du}{dy}\right)$$

$$\tau = \mu\left(\frac{du}{dy}\right)$$

μ = dynamic viscosity

or $\mu = \dfrac{\tau}{(du/dy)} = \dfrac{\text{stress}}{\text{strain}}$

The viscosity can be defined as shear stress required to produce unit rate of shear strain. The unit of viscosity

$$= \frac{\text{Force} \times \text{Time}}{(\text{length})^2}$$

$$= \frac{\text{Newton Second}}{(\text{meter})^2}$$

and one poise = 1/10 Ns/m^2. Kinematic viscosity is defined as the ratio between the dynamic viscosity and density of the fluid.

Hence, $$v = \frac{\text{Viscosity}}{\text{density}} = \frac{\mu}{\rho}$$

and it has unit = $\dfrac{(\text{metre})^2}{\text{second}} = \dfrac{m^2}{s}$.

One stoke $= 10^{-4}\dfrac{m^2}{s}$. The fluids which follow Newton's law of viscosity are known as Newtonian fluid. Hence fluids can be classified as :

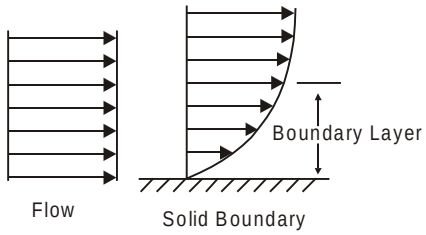
(*a*) *Newtonian fluids :* These fluids follow Newton's viscosity equation. For such fluids, μ does not change with rate of deformation. Water, kerosene and air are Newtonian fluids.

(*b*) *Non Newtonian fluids :* Fluids which do not follow the linear relationship between shear stress and rate of deformation are termed as non Newtonian fluids. Solutions, suspensions (slurries), mud flows, polymer solutions and blood are examples of non Newtonian fluids. These fluids are generally complex mixture and they are studied under rheology (a science of deformation and flow).

(*c*) *Plastic fluid :* Non Newtonian fluid in which initial yield stress is to be exceeded to cause a continuous deformation.

(*d*) *Ideal fluid :* Fluid is incompressible and has zero viscosity. Stress is zero regardless of motion of the fluid.

2. **Boundary layer:** When a real fluid flows past a solid boundary, the fluid particles adhere to the boundary and the condition of no slip occurs. It means that the velocity of fluid close to the boundary will be same as that of the boundary. In case the boundary is stationary, the fluid velocity at the boundary will be zero. As we move further away from the boundary, the velocity of the fluid will be higher. Due to variation of velocity as we move away from the boundary, a velocity gradient (*du/dy*) will exist. The velocity of the fluid increases from zero velocity on the stationary boundary to free stream velocity (*u*) of the fluid in the direction normal to the boundary (*y*). The theory dealing with boundary layer flow is called boundary layer theory.



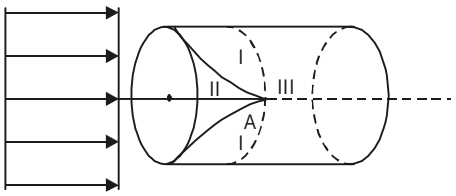
Boundary Layer

According to this, the flow in the neighbourhood of the solid boundary may be divided into two regions :

(*a*) A very thin layer of fluid called the boundary layer is in the immediate neighbourhood of the solid boundary where the variation of velocity exists from zero at solid boundary to free stream velocity in the direction normal to the boundary. In this region, a velocity gradient = *du/dy* exists and hence the fluid exerts a shear stress on the boundary in the direction of flow. τ (shear stress) = μ *du/dy* where μ = viscosity.

(*b*) The velocity of the fluid outside the boundary layer is constant and equal to the free stream velocity. There is no velocity gradient in this region and hence shear stress is also zero in this region.

3. **Flow in tube:** When a fluid enters a tube/ pipe from a large reservoir where the velocity is uniform and parallel to the axis of the tube (as shown in the figure), the velocity profile is a flat surface at the entry. Immediately on entry, the fluid velocity in vicinity of the surface of the tube is affected by friction force. However, the velocity profile far from the surface and near the axis of the tube remains still flat (same as free flow). As the fluid moves further in the tube, flat portion decreases and some distance after, a paraboloidal velocity profile for the fully developed flow is reached. The flow at the inlet and flow beyond point A (region III) is called fully developed flow.



Flow Tube and Entry Length

The entry length is defined as the length in which 99% of the free flow velocity is attained. The flow in the entry length portion consists of two parts:

(1) the flow in region I near the tube surface is called boundary layer flow.

(2) the flow in the region II is called core flow (plug flow)

4. **Laminar and turbulent flow:** The particles move in curved unmixing layers or streams and follow a smooth continuous path in the laminar flow. The paths of fluid movement are well defined and the fluid particles retain

their relative positions at successive cross sections of the flow passage in the laminar flow. There is no transverse displacement of fluid particles. Soldiers marching in orderly manner is an analogy to laminar flow. In turbulent flow, the motion of fluid particles is irregular. The fluid particles move along erratic and unpredictable paths. The velocity of fluid particle fluctuates both along the direction of flow and also perpendicular to the flow. A crowd of commuters on a railway station rushing for boarding a train is an analogy.

The Reynolds numbers is a dimensionless number which is used to predict whether the flow is laminar or turbulent in a tube. The Reynold's number = Inertial force/ viscous force = $\rho u^2D^2/\ \mu uD = \rho uD/\mu = uDv$, where μ = viscosity, v = kinematic viscosity = μ/ρ, ρ = density, u = velocity and D = diameter of tube. If inertia force is much higher than viscous force, Reynolds number will be more and less chance for the flow to be laminar. In a tube, turbulent flow occurs when Reynolds number > 6000. For laminar flow in a tube, following are applicable:

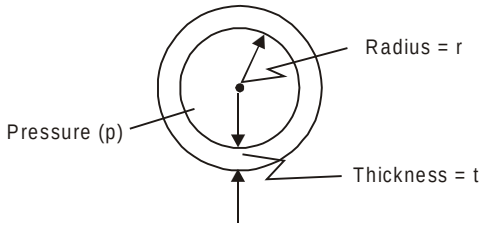
(*a*) Strear stress $\tau = -\frac{\partial P}{\partial x} \cdot \frac{r}{2}$ where r = radius of layer and $\frac{\partial P}{\partial x}$ = Pressure gradient along direction of flow.

(*b*) Velocity $u = -\frac{1}{4\mu}\frac{\partial P}{\partial x}(R^2 - r^2)$ where R = radius of tube, r = radius of layer

(*c*) Ratio of maximum velocity to average velocity = 2

(*c*) Loss of pressure head = $\frac{32\,\mu\bar{u}\ L}{\rho\ g\ D^2}$ where $\bar{u} = \frac{\text{Flow}}{\text{Area}}$ and L = Length of flow.

5. The tube must have same thickness of the wall depending upon the pressure of the fluid. Thickness (t) = $\frac{Pr}{\sigma_p}$ where P = pressure, r = radius and σ_p = permissible stress

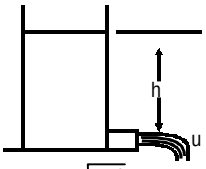


Thin Tube

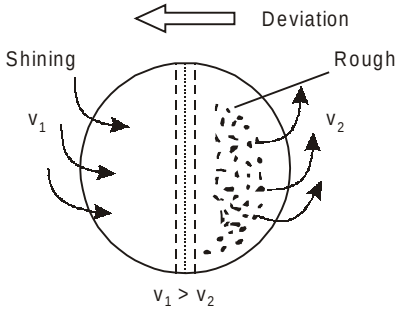
6. Equation of continuity and Bernaulli's equation. The total mass of fluid going inside the tube through any cross section remains same. Therefore the equation of continuity is $A_1u_1 = A_2\ u_2$, where A stands for cross sectional area and u stands for velocity. As per Bernaulli's equation, the total head of the fluid remains constant at every cross section of the tube. The Bernoulli's equation is $P + \frac{1}{2}\ \rho u^2 + \rho gh$ = constant where P = pressure, ρ = density, g = coefficient of gravity, h = height of cross section from a datum line and u = velocity of the fluid.

7. Applications of Bernaulli's equation. The speed of liquid coming out through a hole in a tank at a depth 'h' below the free surface is the same as that of a particle falling freely through the height 'h' under gravity *i.e.*, $u = \sqrt{2gh}$. This is known as Torricelli's theorem. When a person is bleeding, we try to reduce 'h' so that blood flow can be reduced. Other application is Aspirator pump which works on the principle that the pressure of fluid decreases where ever its speed increases. As shown in the figure, the air is pushed through a narrow opening at

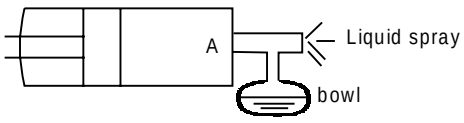
'*A*' resulting in drop of pressure. The liquid in the bowl is raised by the pressure drop and liquid is sprayed with the expelled air. A cricket ball having a shining side and rough a side on the left and right as shown in the figure will deviate towards the shining side as air passing over the shining side will face less resistance and gain more speed resulting in lower pressure as compared to the rough side. Similarly, an aerofoil has longer distance at the top surface as compared to the bottom surface which makes the air move at higher speed at the top surface as compared to the bottom surface resulting in lower pressure at top the surface and higher pressure at the bottom surface which provides a lift to the aerofoil. A venturi tube is used to measure the flow of speed of a fluid in a tube. The tube has a constriction (throat) which makes the fluid flow at higher speed resulting in drop of pressure at throat. The pressure $P_1 - P_2 = \rho g\ (h_1 - h_2)$ as shown in the figure. Also $v_2^2 - v_1^2 = 2g(h_1 - h_2)$ where v_1 and v_2 are velocities. Knowing $A_1$and A_2 (areas), the rate of flow of liquid past a cross-section can be found out.



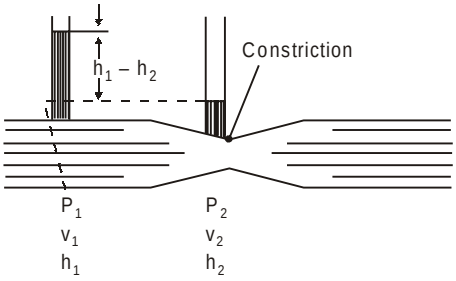
Torricell's Theorem



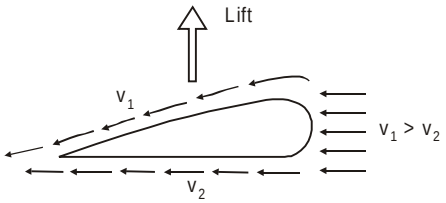
Cricket ball



Aspirator Pump

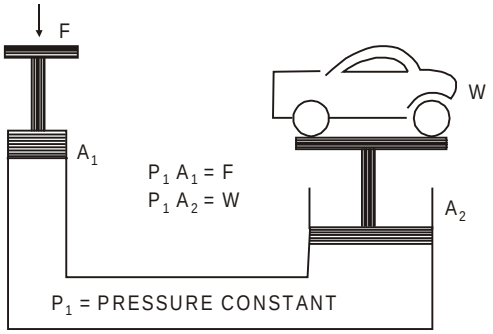


Venturi Tube



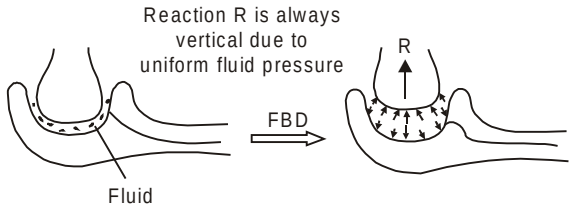
Aerofoil

8. Pascal's law : If the pressure in a liquid is changed at particular point, the change is transmitted to the entire liquid without being diminished in magnitude. Pascal's law has several applications like hydraulic lift and reaction force at the joints of our body as shown in the figure.



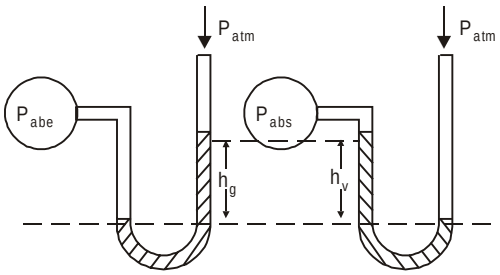
Area $A_2 >> A_1$ $\therefore W >> F$

Hydraulic Lift



Reaction Force at Joint

9. Gauge pressure : The standard atmospheric presure is defined as the pressure produced by a column of mercury of 760 mm high. Hence $P_{atm} = \rho gh = (13.6 \times 10^3) \times 9.8 \times \frac{760}{1000} = 1.01 \times 10^5$ pascal = 1.01 bar. Pressure of the vessel can be higher or lower than atmospheric pressure. Pressure is measured by a manometer. Manometer is a U-tube with one end opens to atmosphere and other is connected to vessel.



$P_{abs} = P_{atm}$ + Gauge Pr
$= P_{atm} + \rho_{HG} \times h_g \times g$
Where h_g = height

$P_{abs} = P_{atm}$ – Vacuum Pr
$= P_{atm} - \rho_{HG} \times h_v \times g$
where h_v = vacuum height

If pressure in vessel (P_{abs}) is lower than P_{atm}, mercury is forced into the limb connected to vessel. Higher than atmospheric pressure is known as gauge pressure while lower pressure than atmospheric pressure is called vacuum pressure. The flow in cardiovascular system is higher than atmospheric pressure and flow at various places is given by gauge pressure only. The blood pressure of a healthy person is 120/80mm Hg (gauge pressure) during systole/diastole.

TEMPERATURE

1. Temperature is an intensive property of a system (intensive property does not depend upon mass) and indicates relative hotness or coldness from the reference states. Boiling point and freezing point of water are acceptable reference states. Thermometer is a temperature measurement system which can show some change in its characteristics (termed as thermometric property) due to heat interaction taking place with the body whose temperature is being measured. Temperature is measured either in centrigrade or fahrenheit for human body. The relation between these two thermometers is $\frac{T_c}{100} = \frac{T_f - 32}{180}$ where T_c = temperature in centrigrade, and T_f = temperature in fahrenheit. Both theromometers are mercury scale thermometers in which length of mercury column is proportion a to temperature of the body. The normal oral (mouth) temperature of a healthy person is about 37°C or 98.6°F. The underarm temperature is one degree lower, whereas the rectal temperature is one degree higher than that of oral temperature. The temperaure of body is controlled by the body so that it remains constant as 37°C. However during fever, the temperature of body increases as temperature control mechanism fails, thus causing additional metabolism because higher temperature inside the body accelerates the chemical reactions. During fever, shivering takes place as the blood does not flow to skin and muscle tissues which is essential to keep them warm. When body temperature falls to normal temperature, increased sweating takes place as additional heat is eliminated.

OBJECTIVE TYPE QUESTIONS

Fill up the gaps

1. Static is the branch of mechanics which relates to bodies in _____. ((*a*) rest (*b*) motion)

2. If all the forces in a system lie in single plane, then it is called a ____ force system. ((*a*) coplanar (*b*) concurrent)

3. If all the forces in a system pass through a point it is called a _____ force system. ((*a*) coplanar (*b*) concurrent)

4. Lami's theorem can be applied for three _____ force system. ((*a*) coplanar (*b*) concurrent)

5. The condition of equilibrium in a coplanar force system gives ____ equations. ((*a*) Three (*b*) two)

6. The fluids which follows $T = \mu\, du/dy$ are called _____ fluids. ((*a*) Ideal (*b*) Nowtonian)

7. Blood is a _____ fluid. ((*a*) Newtonian (*b*) non Newtonian)

8. Ideal fluid has _____ viscosity. ((*a*) unit (*b*) zero)

9. The ratio of Inertia force and viscous force is _____ number. ((*a*) Rayleigh (*b*) Reynold)

10. Turbulent flow has _____ value of Reynold number. ((*a*) lower (*b*) higher)

11. The _____ is used for measuring gauge or vacuum pressure. ((*a*) manometer (*b*) pressure meter)

12. The blood pressure is always given in _____. ((*a*) gauge height (*b*) vacuum height)

13. $P + \frac{1}{2}\,\rho u^2 + \rho g h$ = constant is known as _____ equation. ((*a*) hydraulic (*b*) Bernoulli)

14. $A_1 u_1 = A_1\, u_2$ wher A = area and u = velocity is known as _____equation. ((*a*) continuity (*b*) constant)

15. $\frac{M}{I} = \frac{E}{R} = \frac{\sigma}{y}$ is called _____equation. ((*a*) Bending moment (*b*) Torsion)

ANSWERS

1. (*a*)	**2.** (*a*)	**3.** (*b*)	**4.** (*b*)	**5.** (*a*)
6. (*b*)	**7.** (*b*)	**8.** (*b*)	**9.** (*b*)	**10.** (*b*)
11. (*a*)	**12.** (*a*)	**13.** (*b*)	**14.** (*a*)	**15.** (*a*)

BIOMEDICAL ENGINEERING

3

Good things come to those who wait, but better things come to those who try.

INTRODUCTION

1. Prefix "bio" denotes something connected with life. When basic science of physics and chemistry have been applied to living things, this intermarriage has been named as biophysics and biochemistry. Hence, marriage of discipline of medicine and engineering is called biomedical engineering. The aim of biomedical engineering is the application of the methodology and technology of physical sciences and engineering to the problem of the living systems with emphasis on diagnosis, treatment and prevention of diseases in man.
2. Access to adequate health care is comparable to the fundamental rights of a human being. The view has led to the development of large and sophisticated health care systems. The components of health care include preventive medicine, diagnosis, therapy and rehabilitation. The critical element in this chain is diagnosis. Once a physician makes a diagnosis and institutes therapy, diagnostic procedures are used then to monitor therapy and to assess its adequacy to maintain or modify the therapy. High technology medical equipments are being introduced in health care industry as this industry is growing at fast rate. High technology equipments normally require more skills. To control the correct functioning of these equipments, one has to understand its basic operating principles and be able to apply some performance assurance tests for that purpose. The physicians utilizing the results produced with these equipments need to understand the limitation of the technology. Hence physicians and biomedical engineers can not work in isolation.

ADVANCED MEDICAL EQUIPMENT AND SYSTEMS

1. Science and technology are evolving rapidly. This creates the potential for applying these innovations also to health care products. Improved and cheaper version of old medical equipment and new equipment have been emerging as a consequence of this. Advanced medical equipment mean innovative products which may be technologically simple or complicated. Examples of these include :

   (*a*) Artificial organs, such as heart valves, hip joints and implanted pacemakers. More research in medical science to ensure reliability and durability.

(*b*) Patient-monitoring equipment which use sophisticated transducers together with microelectronics, microprocessor and software for processing the measured signals.

(*c*) Information system for patient data management and for decision support integrating various sources of patient data and incorporating knowledge based techniques (artificial intelligence, expert system) for the interpretation of the compiled data.

(*d*) Imaging of the anatomy and functions of the human body. The technology for obtaining and storing the images is changing from film to digital integration of the various image sources with "picture archiving and communicating system" (PACs) and image processing stations is the present practice.

(*e*) Automated laboratory equipment for the processing of patient samples (blood, urine etc). It has cut down the cost by making tests simpler, accurate and faster. Information systems are extensively used to manage the process, for quality control and for producing laboratory reports, for archiving or for display to treating physicians.

(*f*) Technical aids for the handicapped (and for the elderly) comprising both simple and complex devices. Development in information technology and in robotics, have opened up new possibilities to provide technical aids to the handicapped both at home and at work. (More on robotic refer chapter1)

REQUIREMENT FOR ADVANCED MEDICAL EQUIPMENT

1. The effective utilization of high technology equipment and systems necessitates the technical expertise of clinical engineers, hospital physicists and computer scientists. The efficient and cost effective utilization of a new technology also requires careful planning in organisation and ways of operation. Any new equipment introduced would require engineers to operate and to maintain it. Regular service and regular preventive maintenance combined with performance assurance procedure is more cost effective. The installation of new equipment can be expensive in terms of both actual purchasing and installation costs; and additional technical staff requirements to operate and maintain.

BIOMEDICAL ENGINEERING

1. As name suggests, biomedical engineering is interaction of medicine and engineering Hence biomedical engineering can be defined as application of the knowledge gained by a cross fertilization of engineering and the biological sciences so that both will be more fully utilized for the benefit of man.

SPECIALITY AREA OF BIOMEDICAL ENGINEERING

1. The field of biomedical engineering is ever expanding as new engineering applications in medical field are emerging. A tendency has been seen to describe the personnel working in different speciality areas of bio engineering with the name of the area. A tendency has arisen to call the biomedical engineer as person working in the interface area of medicine and engineering whereas the practitioner working with physician and patient is called a clinical engineer. Similarly titles of hospital engineer, medical engineer, bioinstrumentation engineer, biomaterial engineer and rehabilitation engineer are being used depending upon personnel working in different speciality areas of biomedical engineering. Speciality areas are :

(*a*) *Bioinstrumentation:* It implies measurements of biological variables which help the physicians in diagnosing

and treatment. For the measurement of biological variables, applications of electronics and measurement techniques necessitate understanding and knowledge to operate the devices. In order to handle data, computers are essential part of bioinstrumentation. Large amount of information in medical imaging system can be processed by a computer.

(*b*) *Clinical engineering:* It is application of engineering knowledge to health care in hospitals.Clinical engineer with physician, nurses and other staff form a health care team so that health care facilities (patient monitoring equipment, diagnosing equipment, technical aids for the handicapped) can be effectively utilised and computer data base can be maintained.

(*c*) *Biomaterial engineering:* Bomaterials include both living tissues and artificial developed materials which are suitable for implantation. Materials can be metal alloys, ceramics and polymers which must be chemically inert, stable and mechanically strong to withstand the repeated forces for a lifetime.

(*d*) *Cellular, tissue and genetics engineering:* With advancement in biomedical field, it is possible to tackle the biomedical problems at microscopic and nenoscopic level. The anatomy biochemistry and mechanics of cellular and subcellular structure are studied to understand disease process and to find out suitable therapy to overcome malfunctioning.

(*e*) *Medical imaging engineering:* There are many techniques to generate the image of organs inside the body. Various rays and radiations like ultrasound, X-rays and nuclear radiation with physical phenomenons like magnetism, sound, fluorescence and reactions on photographic film, can be used to generate or display internal image of the body. These images can be digitized so that data can be handled by the computer.

(*f*) *Rehabilitation engineering:* Rehabilitation relates to both handicapped and elderly persons. Rehabilitation engineering aims to enhance the capabilities and to improve the quality of life of personnel having physical and cognitive impairment. The development of prosthesis for amputees, provision of proper wheel chair to paraplegic which permits regular exercise for fitness so that regular assessment of the functional capacity can be made and assistive devices for elderly persons are some of the contributions of rehabilitation engineering.

(*g*) *Orthopadic biochemistry:* It is the field in which malfunctioning of bones, muscles and joints is studied so that artificial joints for replacement can be designed.

(*b*) *System physiology:* It is the field in which engineering techniques and tools are used to gather a comprehensive understanding of the function of living organisms ranging from bacteria to human body. Computer is used to model physiological systems for analysis and understanding.

2. Biomedical engineer is a professional who has expertise both in biological sciences and engineering field so as to effectively and safely manage medical devices and instruments, for an overall enhancement of health care. He can use engineering expertise to analyse and solve problems in biology and medicine providing an overall improvement of health care. Other definitions by various committes are :

(*a*) A clinical engineer is a professional who brings to health care facilities a level of education, experience and accomplishment which will enable him to responsibly, effectively and safely manage and interface with medical devices, instruments and systems and

the use of these for patient care, because of high level of competence and responsibly. He can directly serve the patient, physician, nurse, and other health care professionals to use of the medical instrumentations.

(*b*) Biomedical engineer is a person working in research or development in the interface area of medicine and engineering whereas the practitioner working with physician and patient is called a clinical engineer.

(*c*) Biomedical engineer is a professional who applies knowledge gained by a cross fertilization of engineering and the biological sciences so that both will be more fully utilized for the benefit of man.

(*d*) A biomedical equipment technician is an individual who is knowledgeable about the theory of operation, the underlying physiologic principles, and the practical, safe clinical applicaton of biomedical equipment. His capabilities may include installation, calibration, inspection, preventive maintenance and repair of general biomedical and related technical equipment as well as operation or supervision of equipment control, safety and maintenance programmes and systems.

3. With the need of sophisticated health care system and advent of advanced medical equipment, there is a growing demand of biomedical engineers. There is a growing demand for them in these places:

(*a*) In hospital as clinical engineer

(*b*) In industry involving manufacturing biomedical equipment

(*c*) In research facilities of educational medical institutions.

(*d*) In government regulatory system for product testing and safety

(*e*) In performance testing of a new product or existing product in hospital

(*f*) In establishing safe standards for devices

(*g*) In managerial position as technical advisor in marketing department

(*h*) In creating design to understand living system and technology

(*j*) In coordinating and interfacing function using background in engineering as well as medical field

(*k*) In university and in teaching institutions. Biomedical engineers can effectively supervise laboratories and equipment in research institutions

OBJECTIVE TYPE QUESTIONS

Fill up the gaps

1. Access to adequate health care is comparable to the _____ right (*a*) fundamental (*b*) human

2. High _____ medical equipment are being introduced in health care industry (*a*) finish (*b*) technology

3. Proper working of the equipment is indicated by performance _____ tests (*a*) assurance (*b*) quality

4. Marriage of discipline of medicine and engineering is called _____ (*a*) medical engineering (*b*) biomedical engineering

5. Bioinstrumentation measures _____ variable (*a*) physical (*b*) biological

6. Biomaterial are used for _____ (*a*) implantation (*b*) instruments

7. Preventive medicine, diagnosis, therapy and rehabilitation are the components of _____ (*a*) medicine (*b*) health care

8. High technology equipments normally require more _____ (*a*) skill (*b*) men

9. Physicians and biomedical engineers _____ work in isolation (*a*) can (*b*) cannot

10. Information system integrate patient data and _____ based techniques for the interpretation of the compiled data (*a*) knowledge (*b*) technical

11. Storage of images is changing from film to _____ (*a*) digital (*b*) written

12. Development in _____ has opened up new possibilities to provide technical aids to handicapped both at home and at work (*a*) robotics (*b*) treatment

13. Total cost of new equipment include both equipment cost and cost of _____(*a*) technical staff (*b*) additional technical staff

ANSWERS

1. (*a*)	**2.** (*b*)	**3.** (*a*)	**4.** (*b*)	**5.** (*b*)
6. (*a*)	**7.** (*b*)	**8.** (*a*)	**9.** (*b*)	**10.** (*a*)
11. (*a*)	**12.** (*a*)	**13.** (*b*)		

BIOMECHANICS OF BONE

4

To see and understand the big picture, You've got to meet the master painter

INTRODUCTION

1. Bone is a living tissue capable of altering its shape and mechanical behaviour by changing its structure to withstand the stresses to which it is subjected. Bones form the body's hard, strong skeletal framework. Each bone has a hard, compact exterior surrounding a spongy, lighter interior. Long bone has a central cavity containg bone marrow. Bone is composed chiefly of calcium, phosphorous and a fibrous substance collagen.Like other connective tissues, it has cells fibres and ground substance (for more details refer chapter1). It has also inorganic substances in the form of mineral salts which contribute about two third of its weight. As explained earlier, bone is developed by two methods *viz* membranous and endochondral. Bone is the primary structural element of the human body. Bones form the building blocks of the skeletal system (see the figure) which protects the internal organs, provides kinematic links, provides muscle attachment sites, and facilitates muscle actions and body movements. Bone is hard due to presence of inorganic substances but it has a degree of elasticity due to the presence of organic fibres. Since bone is a living tissue, it can repair itself if it is properly aligned after fracture. The major factors that decides the stress bearing capacities of bone are:

1. The composition of bone.
2. The mechanical properties of the tissues comprising the bone.
3. The size and geometry of the bone,
4. The rate of applied loads with magnitude and direction.

CLASSIFICATION OF BONES

1. The skeleton is made of 206 bones. Although individual bones are rigid but the skeleton is flexible and allows the human body a huge range of movement. Bones can be classified as per their shapes as :

1. long and short bones
2. irregular bones
3. flat bones and
4. sesamoid bones

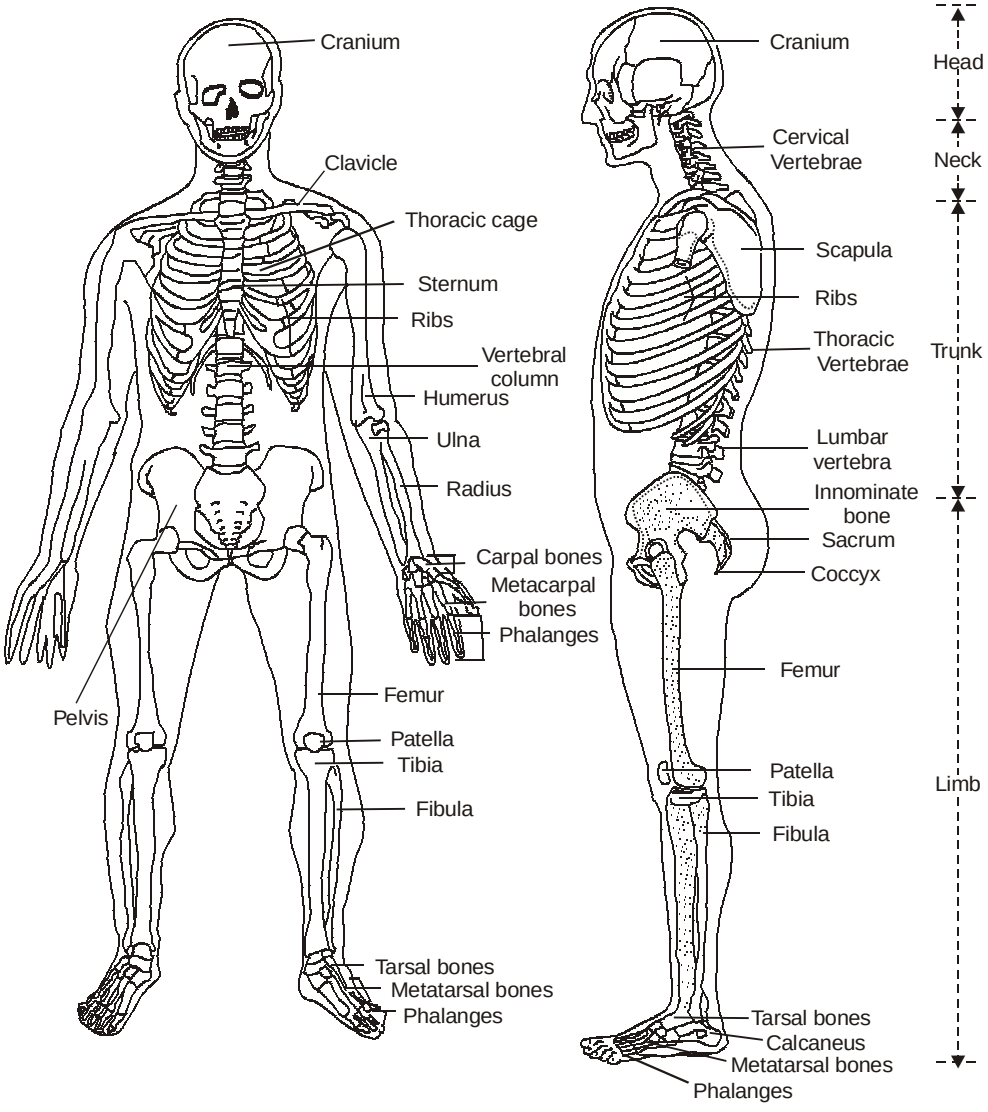
The locations of these types of bones are:

(*a*) *Long and short bones:* They are in the limbs. For examples, humerus in upper arm, radius and ulna in forearm; femur, tibia and fibula in lower limb are long bones while metacarpal and

metatarsal bones of hand and foot respectively are small bones (refer to figure of skeleton)

(*b*) Flat and irregular bones are in the skull, back bone and the limb girdles.

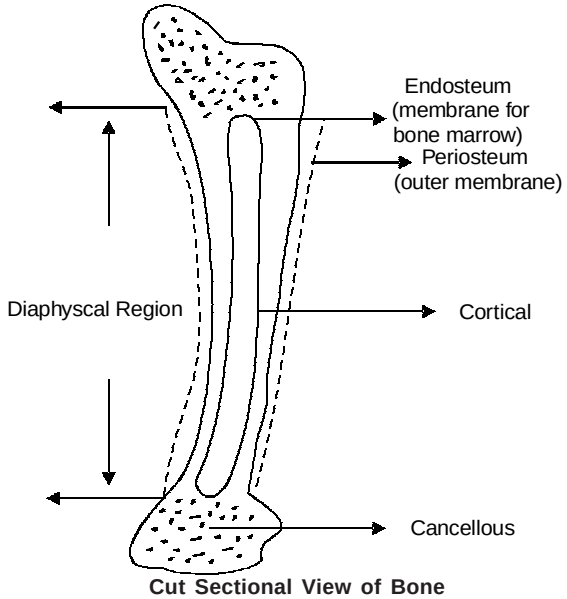
(*c*) Sesamoid bone is buried in the tendon and free surface is covered with articular cartilage. It has two functions (1) to reduce friction when it rubs over bony surface, (2) to alter the pull of tendon to which it is attached. The largest sesamoid bone is 'patella' of the knee joint.



Skeletal System

COMPOSITION OF BONE

1. All organs of the body are formed of tissues. A tissue is a collection of similar type of cells which are associated with some intercellular matrix (ground substance) governed by some laws of growth & development. Bone is made of connective tissue. Bone binds together various structures of the body. Bone is a composite material with various solid and fluid substances, besides cells, an organic mineral matrix of fibres and a ground substance, it has inorganic substances in the form of mineral salts which make it hard and relatively rigid. However, organic components provide flexibility and resilience. The density and composition of bone varies with age and disease which results into degrading of mechanical properties.
2. The bones consist of two types of tissues as shown in 'cut section view'. The compact bone tissue is a dense material forming the outer shell of bones and the diaphyscal region of long bones. The outer shell is called cortical. The other tissue consists of thin plates (trabeculae) in a loose mesh which is enclosed by the cortical bone tissue. This is called cancellous, trabecular or spongy bone tissue. A dense fibrous membrane surrounds the bone and it is called periosteum (epithelium tissue as explained in chapter 1) the periosteum membrane covers the entire bone except the joint surfaces which are covered with articular cartilage. It is the most sensitive part of the bone.

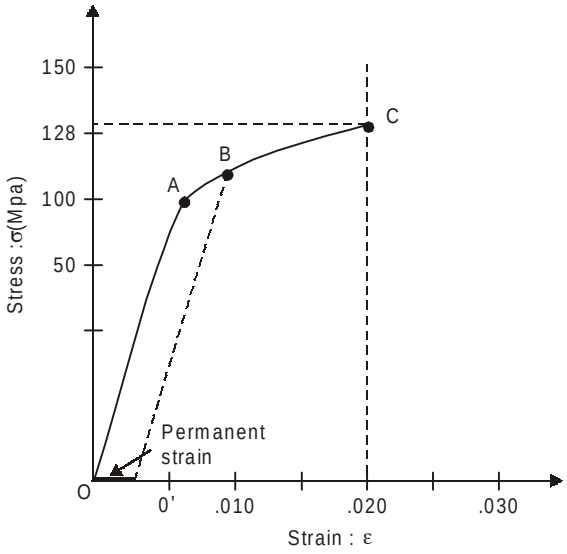


Cut Sectional View of Bone

MECHANICAL PROPERTIES OF BONE

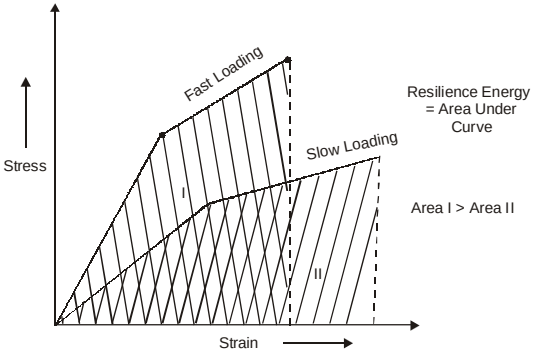
1. Material can be homogeneous or non-homogeneous. Homogenous material has same composition in all directions. Bone is a non homogeneous material as it has different compositions in different directions as it consists of various cells, organic and inorganic substances laid in uniform manner. Material can be isotropic having mechanical properties same in all directions or anisotropic with mechanical properties different in different directions. Bone is anisotropic material as its mechanical response depends upon the direction of the applied load. For example compressive strength is more than tensile strength and tensile load capacity is more than transverse load capacity of the bone. Bone has both liquid and solid constituent, hence it has viscoelastic properties which is time dependent *i.e.*, the mechanical response of the bone is dependent on the rate of loading of the bone. Bone can stand rapidly applied loads much better than gradually applied loads.
2. Mechanical properties of metals, concrete and polymers are found out by testing the specimen under tensile, compression and bending load by universal testing machine and torsional load by torsion testing machine. Similar tests can be performed on bone specimen for bulk properties. It can also be performed separately for cortical and cancellous part of the bone.
3. The stress and strain diagram for the cortical bone under tensile loading is shown in the figure. The stress and strain diagram has

three distinct regions. The part 'OA' is elastic region and the slope of this line is equal to the elastic modulus (*E*) of the bone which is 17 GPa (10^9 pascal). In the intermediate region (AB), the bone exhibits non linear elasto-plastic material behaviour. Now the bone does not retains its original length on removal of load (possible in region OA) and a permanent yielding takes place. On removal



Stress and Strain of Cortical Bone: Tensile Loading

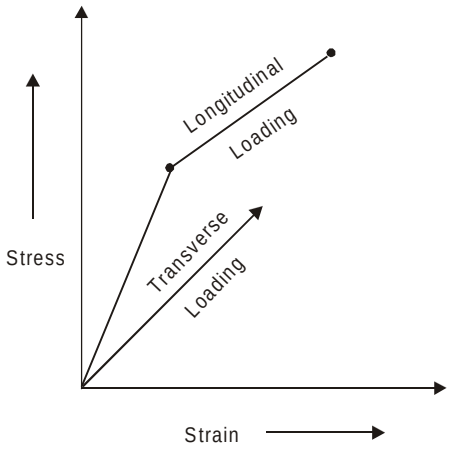
of load, the specimen follows path BO' instead BAO and there is a permanent strain of OO′. On loading the specimen will now follow path O′B which amounts to higher strength. This is known as strain hardening. The bone exhibits a linearly plastic material behaviour in region BC after yield strength (Point B). The bone fractures when tensile stress is about 128 MPa (10^6 Pascal) for which the tensile strain is about 0.020. The stress and strain diagram of the cortical bone depends upon strain rate and the diagram is drawn for the strain rate of 0.05 per second. It has been seen that a specimen of bone which is loaded rapidly, has a greater elastic modulus and ultimate strength than a specimen which is loaded slowly. This has been shown in the figure. We also know that resilience energy is the area under the stress and strain diagram. Hence absorbed energy increases with rapidly loading. It has been seen that bone tissues are subjected to a strain rate of about 0.01 per sec during normal activities.



Fast and Slow Loading

Fast and Slow Loading

4. Bone is an anisotropic material. Hence its stress-strain behaviour depends upon the orientation of bone with respect to the direction of loading. Bone is stronger (larger ultimate strength) and stiffer (larger elastic modulus) in longitudinal direction (along long axis) than transverse direction (vertical to long axis).



Longitudinal and Transverse Loading

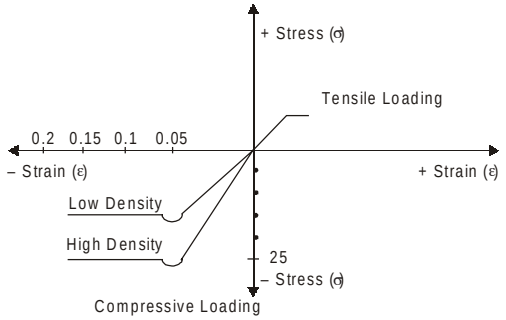
Bone fails in brittle manner at lower load during transverse loading as compared to

the longitudinal loading. Stress and strain diagram for these loadings is given in the figure. The values of ultimate strength and elastic modulus are given in the table.

ULTIMATE STRENGTH, E AND G OF BONE

LOADING MODE	*ULTIMATE STRENGTH*	*ELASTIC MODULUS*
LONGITUDINAL		→ 17 GPa
× TORSION	133 MPa	
× COMPRESSION	193 MPa	
× SHEAR	68 MPa	
TRANSVERSE		→ 11.5 GPA
× TENSION	51 MPa	
× COMPRESSION	133 MPa	→ SHEAR MODULUS (G)= 3.3 GPa

5. Cancellous bone: The distinguishing characteristics of the cancellous bone is its porosity. Hence cancellous bone has lower density depending upon porosity. The stress-strain of cancellous bone depends upon porosity and the mode of loading. In compressive loading, stress and strain in elastic region varies linearly upto a strain about 0.05 and after this yielding occurs when the trabeculaes begin to fracture. Yielding occurs at constant stress until fracture, showing a ductile material behaviour. However on tensile loading, cancellous bone fractures abruptly, showing a brittle material behaviour. The capacity to absorb energy is higher in compressive loading than in tensile loading.



Compressive and Tensile Loading

6. Factors affecting strength: Factors affecting the strength or structural integrity of bone are:

(*a*) *Area:* Larger is the bone, the larger is area upon which the internal forces are distributed and the smaller is the intensity of stresses.

$$\text{stress } (\sigma) = \frac{\text{Force}}{\text{Area of bone}}$$

or Force = σ × Area of bone Hence, bone with larger area can withstand more force for a given value of maximum permissible stress.

(*b*) *Geometry of bone:* The bone can be solid or hollow tube. The moment of inertia & polar moment of inertia of solid and hollow tube are:

$$(I)_{\text{Solid}} = \frac{\pi D^4}{64},$$

$$(I_P)_{\text{Solid}} = \frac{\pi D^4}{32}$$

$$(I)_{\text{hollow}} = \pi\frac{(D^4 - d^4)}{64}$$

$$\text{and } (I_P)_{\text{Hollow}} = \pi\frac{(D^4 - d^4)}{32}$$

Hence for equal cross sectional area $I_{\text{Solid}} < I_{\text{Hollow}}$ and $(I_p)_{\text{Solid}} < (I_p)_{\text{Hollow.}}$ According to bending moment equation, applied bending moment

$$(M) = \frac{I \times \sigma_{\text{permissible}}}{D/2}$$

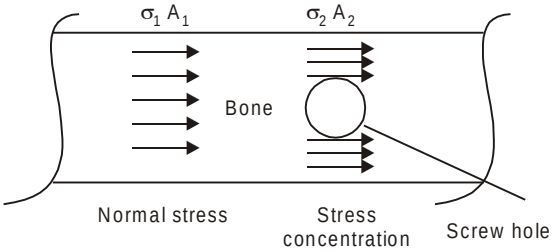
$$\text{or } M \propto I$$

which shows that hollow bone can take more bending load for given σ permissible. Similarly, applied torsion

$$T = \frac{I_P \times \tau_{\text{perm}}}{D/2}$$

which shows that hollow bone can take more torsion load for given τ permissible as compared to solid bone.

(*c*) *Reduction in Density:* The strength of bone decreases with reduction of density which may result due to skeletal conditions such as osteoporosis, with ageing or after period of disease. Certain surgical treatments may alter the geometry of the normal bone which may reduce the strength of the bone. Screw holes or other defects in the bone also reduce the load bearing capacity of the bone as stress concentration at these locations of defects increases loading to failure.



$\sigma_1 A_1 = \sigma_2 A_2$
As $A_1 > A_2$
$\therefore \sigma_1 < \sigma_2$

Stress Concentration

BONE FRACTURES AND TRACTION

1. When a bone is subjected to an external load, it develops internal force to counteract by some elastic deformation which disappears on the removal of the load and the bone regains its original shape. If the applied load is high and it generates stresses in the bone which are larger than the ultimate strength of the bone, the bone fractures. Fractures caused by pure tensile loads are observed in bones having a large proportion of cancellous bone tissues. On other hand, fractures caused by compressive loads are seen in the verterbrae of an aged person whose bones have weakened due to ageing. Such fracture are generally seen in the diaphyscal regions of long bones. Bones have oblique fracture pattern under compressive fracture. Long bone fractures are usually caused by bending or torsional loading. Bones have spiral oblique fracture pattern when they are fractured under excessive torsional loading. Bending fractures are usually identified by the formation of butterfly fragments. Professionals like athletes and distant runners generally suffer bone fractures caused by fatigue. Fatigue fracture of bone occurs when the wear and tear caused by repeated mechanical stress is more than the natural ability of the bone to repair itself. Bone failure can be (1) Fracture–loss of continuity of a bone (2) Dislocation– loss of continuity between the articulating surface of a joint (3) Subluxation–early stage which may lead to dislocation (4) Sprain– a partial tear of a ligament.

2. Fracture can be classified as under:

(*a*) Depending on plane of the fracture
- (*i*) transverse fracture
- (*ii*) spiral fracture
- (*iii*) oblique fracture: angle with long axis
- (*iv*) commuted fracture: more fragments
- (*v*) compression fracture: eg fracture of thoracis spine results in decreased length

(*b*) Communication with exterior
- (*i*) Simple or closed: No communication with exterior through the skin
- (*ii*) Open or compound: There is a communication between fracture and the skin or mucous membrane

(*c*) According to the cause of fracture
- (*i*) Traumatic fracture
- (*ii*) Pathological fracture due to weakness resulting from tumour or infection
- (*iii*) Stress or fatigue fracture–due to repeated stress

(*d*) According to number of fracture
- (*i*) single
- (*ii*) multiple

(*e*) According to wholeness

(*i*) complete

(*ii*) incomplete

3. The treatment of fractured bone can be done by:

(*a*) *Reduction:* It is to bring the fractured segments in alignment. It can be

(*i*) *Closed reduction:* It is performed from outside the body. The methods are (1) Closed manipulation (2) Gravity: The application of plaster of Paris increases weight and provides side to side stability (3) Traction provides both reduction and immobilization.

(*ii*) *Open reduction:* where closed reduction is impossible.

(*b*) *Retention:* It is to immobilse a fracture. The methods are :

(*i*) *Traction:* It can be (1) traction by gravity (2) skin traction (3) skeletal traction. Traction is always opposed by counter-traction, that is the pull must be exerted by something, so that traction can actually work, otherwise it will simply drag the patient down instead of providing traction to the fractured bone. The methods of skeletal tractions are (1) fixed traction (2) continuous or sliding traction (3) combined traction.

(*ii*) *Plaster:* Plaster of paris is used for encasing in plaster the whole circumference of limb.

(*c*) *Rehabilitation:* The main aim of fracture treatment is not only to provide complete union of the fractured segments but also to bring back the normal function of the limb as soon as possible. Proper exercise, crutches and physiotherapy are used for rehabilitation of the patient.

4. In cases of complete fractures, bone screw plates or rods of compatible metals (cobalt, silicon) are used for holding in place two parts of the bone as shown in the figure. The size of screw should be sufficient to withstand the shear stress developed due to weight of the patient. Formula for diameter (*d*) of screw can be calculated by formula:: permissible $\tau = \frac{\text{Weight}}{\pi d^2}$ where τ is shear stress.

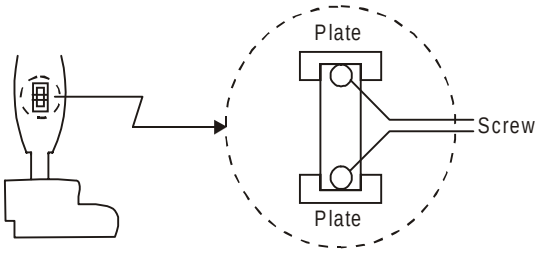
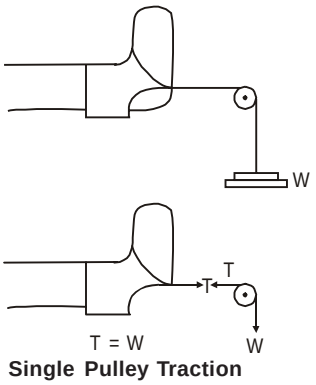


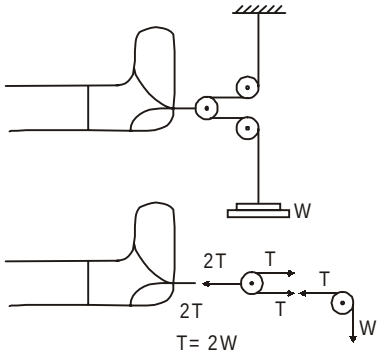
Plate for Bone Reduction

5. Different arrangements of rope and pulleys are used as traction devices. The single rope- pulley arrangement gives a traction device which pulls the leg towards right by applying a horizontal force on the leg as shown in the figure. In this case, the traction force in horizontal direction is equal to W = mxg, where *m* is mass in pan and *g* is coefficient of acceleration due to gravity [9.81 metre/sec].



Single Pulley Traction

The three pulleys arrangement as shown in figure, exerts a horizontal force whose magnitude is twice that of weight put in the pan.



Three Pulleys Traction

6. Single and three pulleys arrangement provides traction in one direction only. However there are requirements when traction is to be given in two directions of the fracture at two places. The two such arrangement of cable-pulleys system have been shown in the figures. Each arrangement is nothing but the system of coplanar force system. Each system is in equilibrium which gives three equations of equilibrium. Using these equations, three unknowns can be found out.

7. Two direction traction (Method I): First consider the free body diagram of leg (AB) as shown in above figure with assumption that AB is horizontal and point B is also centre of gravity of leg (weight W_1) having distance 'l' from A. Now applying the equations of equilibrium, we have

$$\Sigma P_x = 0, \quad T_1 \cos \beta = T_2 \quad .... (i)$$

$$\Sigma P_Y = 0, \quad T_1 \sin \beta = W_1 \quad ...(ii)$$

If we consider pulley near point A

$$\Sigma P_x = 0, \quad T_2 = 2T_1 \cos \alpha \quad ...(iii)$$

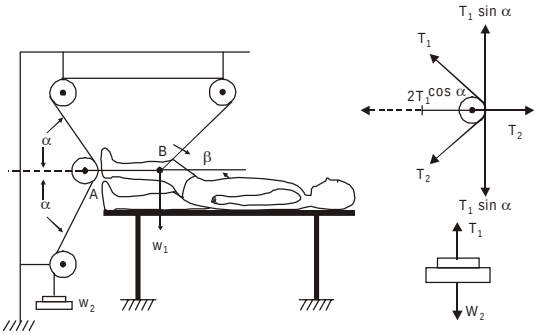
If we consider weight pan

$$\Sigma P_Y = 0, \quad T_1 = W_2 \quad ...(iv)$$

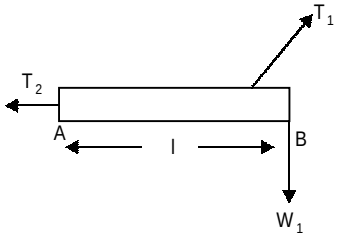
From equation (*i*) and (*iii*), we have

$T_1 \cos \beta = 2T_1 \cos \alpha$ or $\cos \beta = 2 \cos \alpha$

As angle α is fixed and known, angle β can be found out. Also W_2 is known, we can find out T_1 and T_2 from equation (*iii*) amd (*iv*).



Two Direction Traction (Method I)



Free Body Diagram

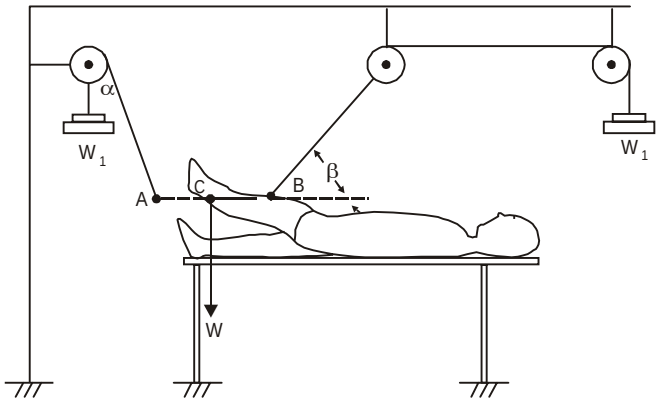
8. Two direction traction (Method II): For analysis of the coplanar force system of the above two directions traction, consider AB is horizontal, weight of leg is W with length l and centre of gravity at c as 'l_1', from point A.

$$\Sigma P_x = 0, \; T_1 \cos \alpha = T_2 \cos \beta \quad ... (i)$$

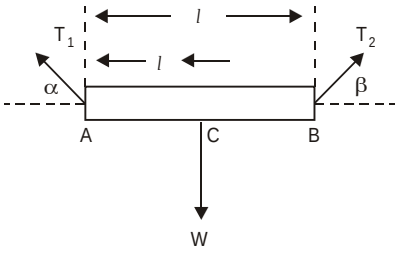
$$\Sigma P_y = 0, \; T_1 \sin \alpha + T_2 \sin \beta = W \quad ... (ii)$$

$$\Sigma M_A = 0, \; Wl_1 = T_2 \sin \beta \times l \quad ...(iii)$$

If b is given and also values of W, l, and l_1 are known, T_2 can be found out from equation (*iii*), T_1 can be also found out from remaining equations.



Two Direction Traction (Method II)



Free Body Diagram of Leg

OBJECTIVE TYPE QUESTIONS

Fill up the gaps

1. Bone is a _____ tissue
(*a*) strong (*b*) living

2. Bone has also ---------- substance which is not present in the cells of soft tissues (*a*) inorganic (*b*) organic

3. Hardness of bone is due to ---------- substance while elasticity is due to --------- substance. (*a*) inorganic and organic (*b*) organic and inorganic

4. Bone _____ repair itself
(*a*) cannot (*b*) can

5. Patella is a ---------- bone (*a*) sesamoid (*b*) irregular

6. Skull has ---------- bones
(*a*) irregular (*b*) short

7. Outer shell of bone is ---------- (*a*) cortical (*b*) endosteum

8. ---------- tissues are the ends at the bone (*a*) cancellous (*b*) endosteum

9. Bone is a ---------- material (*a*) homogeneous (*b*) non homogeneous

10. Bone is a ---------- material (*a*) isotropic (*b*) anisotropic

11. Bone can absorbs---------- energy during rapid loading (*a*) more (*b*) less.

12. Bone has ---------- strength in longitudinal loading as compared to transverse loading (*a*) more (*b*) less

13. Bone has ---------- strength in tension as compared to compression.
(*a*) more (*b*) less

14. Bone strength ---------- with density (*a*) increases (*b*) decreases

15. Solid bone has ---------- strength in bending and torsional loading as compared to hollow bone for some cross sectional area. (*a*) more (*b*) less

16. Strain hardening give--------- yield strength to the bone (*a*) less (*b*) more

17. ---------- is to bring the fractured segments in alignment (*a*) reduction (*b*) abduction

18. ---------- is to immobile a fracture (*a*) retention (*b*) detention

ANSWERS

1. (*b*)	**2.** (*a*)	**3.** (*a*)	**4.** (*b*)	**5.** (*a*)	**6.** (*a*)
7. (*a*)	**8.** (*a*)	**9.** (*b*)	**10.** (*b*)	**11.** (*a*)	**12.** (*a*)
13. (*b*)	**14.** (*a*)	**15.** (*a*)	**16.** (*b*)	**17.** (*a*)	**18.** (*a*)

BIOMECHANICS OF SOFT TISSUES 5

Keep your face toward the light and the darkness will never be able to close in on you.

INTRODUCTION

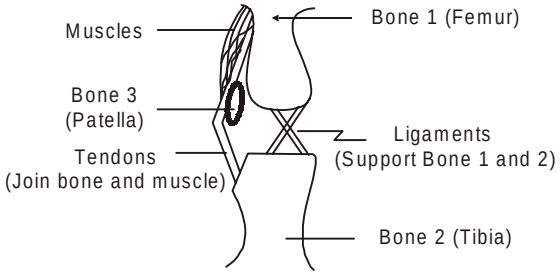
1. Soft tissues include skin, cardiovascular tissues, articular cartilage, muscles, tendons and ligaments. All soft tissues are composite materials. Collagen and elastin fibers are the common components of soft tissues and they have most important properties affecting the overall mechanical properties of the soft tissues in which they exist. Collagen is a protein in shape of crimped fibrils which are joined together into fibers. Fibril can be considered as a spring and every fibre as an assemblage of fibril springs. The function of collagen is to withstand axial tension. As collagen fibers have high aspect ratio (length to diameter ratio), they are not effective to withstand compressive loads. collagen fiber acts like a mechanical spring as it stores the energy supplied to it by stretching the fiber. When the load is removed, the stored energy is used to return to the unstretched state. The individual fabrics of the collagen fibers are submerged in a gel-like ground substance consisting largely of water. Since collagen fibers consists of solid and water substance, it shows viscoelastic mechanical properties.

2. Elastin is another fibrous protein and its properties are similar to the properties of rubber. Elastin fibers consists of elastin and microfibril. Elastin fibers are highly extensible and the extension is reversible even at high strain. In other words elastin fibers have a low elastic modulus. The mechanical properties of soft tissues depend upon the geometric configuration of collagen fibers and there interaction with elastin fibers. Collagen fibers have comparatively higher modulus and show viscoelastic mechanical behaviour.

TENDONS AND LIGAMENTS

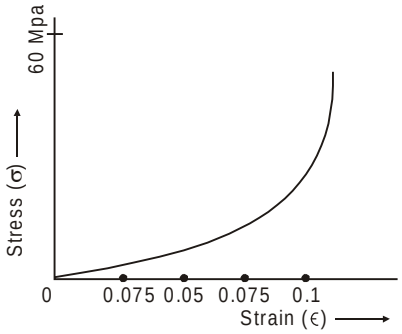
1. Both tendons and ligaments are fiberous connective tissues (Refer to para 23 of chapter 1). Ligaments are supporting tissues. They join bones and provide support to the joints for stability. Tendons are connective tissues and they join muscles to the bones. Another function of tendons is to help in executing joint motion by transmitting mechanical force from muscles to bones. Both tendons and ligaments are passive tissues *i.e.*, they can not generate force by contraction as done by muscles.

2. Tendons have higher modulus of elasticity (Stiffer) to stand higher stresses with small strain. They also have higher tensile strength. Hence at joints where space is limited, tendons enable the attachments of muscles with the bones. Since tendons can support large loads with small strains, hence tendons enable the muscles to transmit forces to the bones without wasting energy in its stretching.



Attachment: Tendons and Ligaments (Knee Joint: Femur, Tibia and Patella)

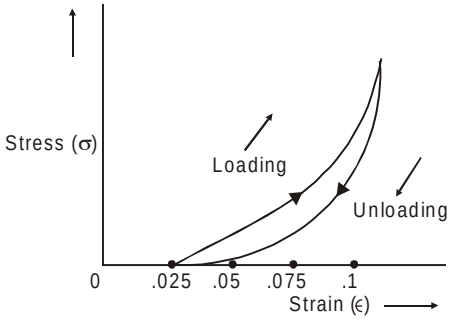
3. The mechanical behaviour of both tendons and ligament depends upon their composition which vary considerably in each direction of loading. The stress and strain diagram for a typical tendon is as shown in the figure. As collagen fibers of tendon require very little force to straighten and rubber like elastin fibers of tendon also do not require very high force, we get a large strain (upto 0.05) with a small applied force. The curve is flat in this portion. The tendon becomes stiffer after this as the crimp is straightened. Hence stiff and viscoelastic nature of the collagen fibers begin to take higher load with slight strain. Tendons are tested to function in the body upto ultimate strains of about 0.1 and ultimate stresses of about 60 MPa.



Stress-strain Diagram : Tendon in Tension

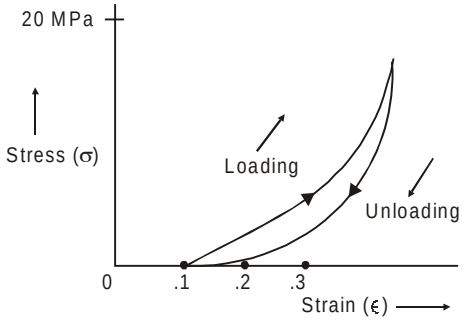
As the area under the curve is small, hence a tendon does not absorb much energy of muscles and maximum energy is passed on to the bones.

4. As a tendon has a viscoelastic nature, its properties are dependent upon the rate of loading. When a tendon is stretched rapidly, there is less time for the ground substance to flow, hence a tendon becomes stiffer. However, a tendon can release to original shape in a slow manner on unloading. Tendon takes more energy on stretching during rapid loading and releases less energy on slow unloading. The hysteresis loop of loading and unloading is shown in the figure. Some energy is dissipated in tendon during loading & unloading process.



Hysteresis Loop – Loading and Unloading

5. Ligaments are also composite materials containing crimped collagen fibers surrounded by ground substance. Ligaments contain a greater properties of elastics (elastic fibers) which contribute to their higher extensibility but lead to lower strength and stiffness. Ligaments are viscoelastic like tendons and exhibit hysteresis on loading & unloading. Ligaments rupture at a stress of about 20 MPa, yield at about 5 MPa and deform at strain of about 0.25. Some energy in ligament is dissipated in causing the flow of fluid within the ground substance.

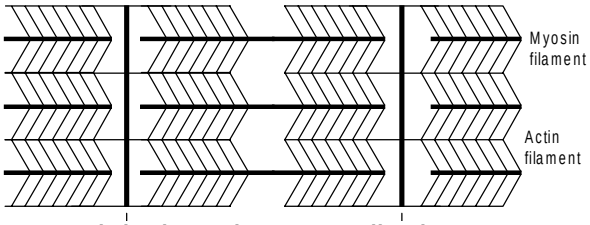


Hysteresis Loop : Ligaments

SKELETAL MUSCLES

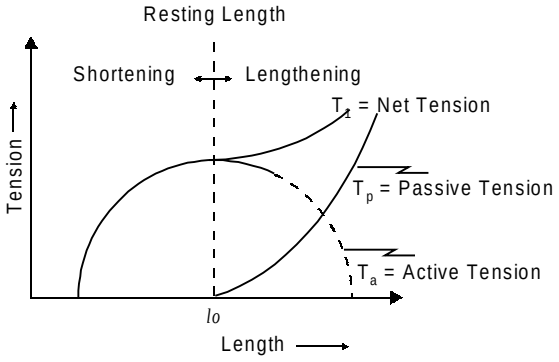
1. Muscles are connective tissues and they are three types. Skeletal, smooth and cardiac (refer chapter1). Smooth muscles (unstriped & involuntary) line the internal organs and cardiac muscles form the heart.Skeletal muscle (striped & voluntary) is attached to at least two bones via tendons in order to cause and control the movement of one bone with respect to other bone. When muscle fibers contract under the stimulation of a nerve, the muscle exerts a pull on the bones to which it is attached. The development of tension in the muscle has been possibly only due to contraction of muscle fibers. The muscle contraction can take place as a result of muscle shortening (concentric contraction), or muscle lengthening (eccentric contraction) or without any apparent change in length of the muscle (static or isometric interaction).

2. The contractile element (motor unit) consists of many sarcomere elements connected in a series arrangement as shown in the figure.



Skeletal Muscle : Contractile Element

The muscle force is generated within these sarcomeres by lengthening or shortening of the muscle. The force and torque developed by a muscle depend upon number of sarcomeres (motor units) within muscle, number of sarcomeres utilized, the manner of change of length of muscle, the velocity of muscle contraction and length of the lever arm of the muscle force. Two different forces are generated in a muscle. The contractable elements of the muscle produce active tension due to the voluntary muscle contraction. The passive tension is developed within the connective muscle tissues when the muscle length surpasses its resting length. The net force is the resultant of these two forces. A typical tension versus muscle length diagram is given in the figure.



Active, Passive and Tension Versus Muscle Length

At resting, length to the number of cross-bridges between filament is maximum. Hence active tension (Ta) is maximum & passive tension (Tp) is Zero. On lengthening of muscle, the filaments are pulled apart resulting in reduction of number of bridges. Hence active tension (Ta) reduces. At full extended position, active tension (Ta) becomes zero.

3. The outcome of muscle contraction is always tension. Hence a muscle can only exert a pull and it can not exert a push. A muscle is also named according to the function it performs. A muscle is called 'agonist' if it causes movement through concentric contraction. An 'antagonist' muscle controls the movement by eccentric contraction. Hence the biceps during flexion of the fore arm is 'agonist' as the length of muscle decreases and the bicep during extension of the forearm is 'antagonist' as the length of the muscle increases.

OBJECTIVE TYPE QUESTIONS

Fill up the gaps

1. All soft tissues are ---------materials (*a*) composite (*b*) complex

2. Collagen and ---------- fibers are the common component of soft tissues (*a*) elastin (*b*) rubber

3. Skin, cardiovascular, articular cartilage, muscle, tendon & ligament are ---------- tissues (*a*) soft (*b*) ductile

4. Collagen fiber acts like a mechanical-------- (*a*) lever (*b*) spring

5. Collagen fiber shows---------- mechanical properties (*a*) elastic (*b*) viscoelastic

6. Tendon and ligament are fiberous -------- tissues (*a*) connective (*b*) elastic

7. Ligaments are ---------- tissues (*a*) supporting (*b*) active

8. Muscles are joined to bone through ---------- (*a*) ligaments (*b*) tendons

9. Tendon and ligament give ---------- loop during loading and unloading (*a*) complex (*b*) hysteresis

10. The outcome of muscle contraction is always---------- (*a*) compression (*b*) tension

11. Muscle is ---------- if it causes movement by concentric contraction (*a*) agonist (*b*) antagonist

12. Muscle is --------- if it controls movement increasing its length (*a*) agonist (*b*) antagonist

13. Muscle force is generated in ------- (*a*) sacromere (*b*) nerves

14. Muscle can exert -------- force only (*a*) pull (*b*) push

ANSWERS

1. (*a*) **2.** (*a*) **3.** (*a*) **4.** (*b*) **5.** (*b*) **6.** (*a*) **7.** (*a*)

8. (*b*) **9.** (*b*) **10.** (*b*) **11.** (*a*) **12.** (*b*) **13.** (*a*) **14.** (*a*)

SKELETAL JOINTS 6

Though, God's ways of operating may perplex us at times, if we trust, in due time, we will understand.

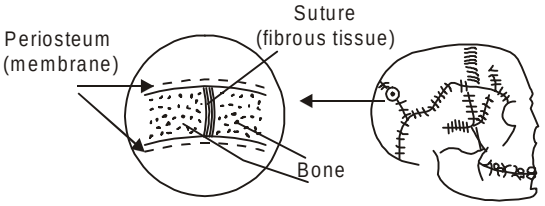
INTRODUCTION

1. The site where two or more bones come together whether or not there is movement between them, is called a joint. The primary function of joints is to provide mobility to the musculoskeletal system. In addition to providing mobility, a joint must also possess a degree of stability. Different joints have different functions to perform. Therefore, the joints have varying degree of mobility and stability depending upon functions to be performed. Joints are formed to give required mobility. Mobility can be triaxial (motion in all three planes) or uniaxial (motion in only one plane). Shoulder joint (ball and socket) is a triaxial joint, Here high mobility is achieved at the cost of low stability. Elbow joint (pivot joint) is a uniaxial joint. It has less mobility (one plane only) but more stability (less vulnerable to dislocation). A joint may have no mobility, The connecting bones of the skull form such joints and they have extreme stability.

TISSUES BETWEEN JOINTS

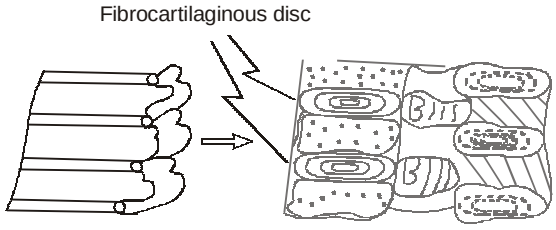
1. Joints can be classified according to tissues that lie between the bones.

(*a*) *Fibrous joints:* The articulating surfaces of the bones are joined by fibrous tissues. The joint has very little movement which depends on the length of the collagen fibers connecting the bones. The connecting bones of the skull form such joints.



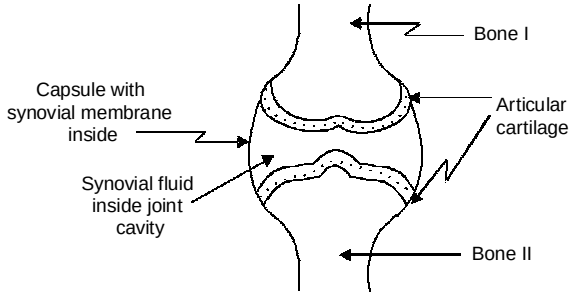
Fibrous Joint

(b) Cartilaginous joints : It can be primary or secondary. A primary cartilaginous joint is one in which the bones are united by a plate of hyaline cartilage (For this type of cartilage, refer chapter 1). The joint between the first rib and manubrium is a primary cartilaginous joint. A secondary cartilaginous joint is one in which the bones are united by a disc of fibrocartilage and the articulator surface of the bones covered with a thin layer of hyaline cartilage. Intervertebral joints are secondary cartilginous joints. The amount of movement possible depend on the physical qualities of the fibrocartilage.



Intervertebral Joint (Cartilaginous Joint)

(*c*) *Synovial joints :* The articular surface of the bones are covered by a thin layer



Synovial Joint

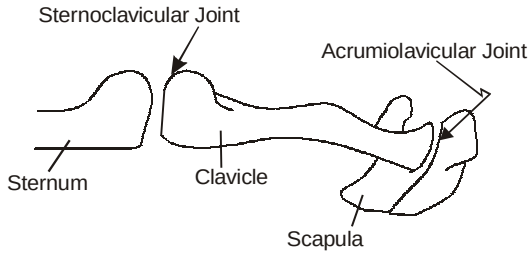
of hyaline cartilage separated by a joint cavity. This arrangement permits great degree of freedom of movement. The cavity of the joint is lined by synovial membrane which covers the one end of the articular surface of the first bone to that of the second bone. The synovial membrane is protected on the outside by a tough fibrous membrane which is called the capsule of the joint. The articular surfaces are lubricated by a viscous fluid which is called synovial fluid. In certain synovial joints like knee joint, discs or wedges of fibrocartilage are interposed between the articulating surfaces of the bones which are called articular discs.

2. Joints can also be classified according to the relative motion between the bones forming a joint, synarthrodial joint does not permit any motion and it is a fibrous joint. Amphiorthrodial joint allows slight relative motions between the bones and it is nothing but a cartilagious joint. Diarthrodial joints permit varying degree of relative motion and they are synovial joints.

TYPES OF SYNOVIAL JOINTS

1. Synovial joints can be classified according to the arrangement of articular surface and nature of movement that are possible by the joints. The joints are:

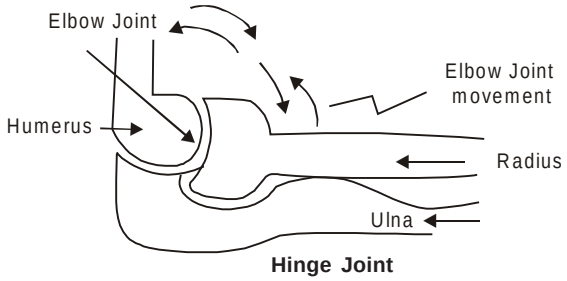
(a) Plane joint: In these joints, the articular surfaces of the bones are flat which permit the bones to slide one upon other. The sternoclavicular and acromioclavicular joints are plane joints.



Plane Joint

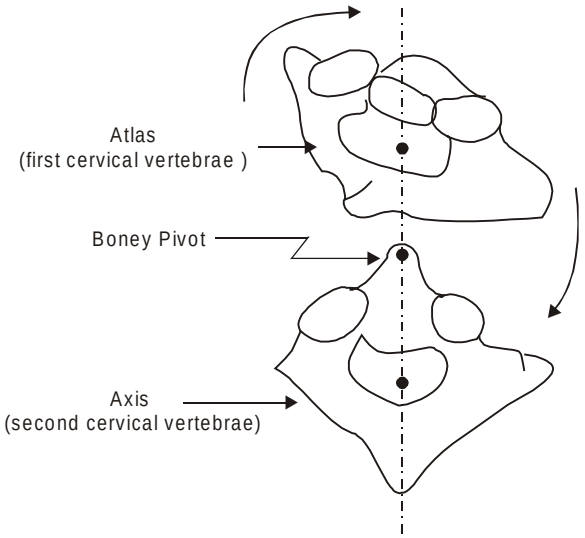
(b) Hinge joint : It is similar to the hinges on a door i.e. the bones fold & unfold

themselves. Flexion is folding of bones (coming nearer) and extension is unfolding of bones (moving away). Elbow, knee and ankle joints are hinge Joints.



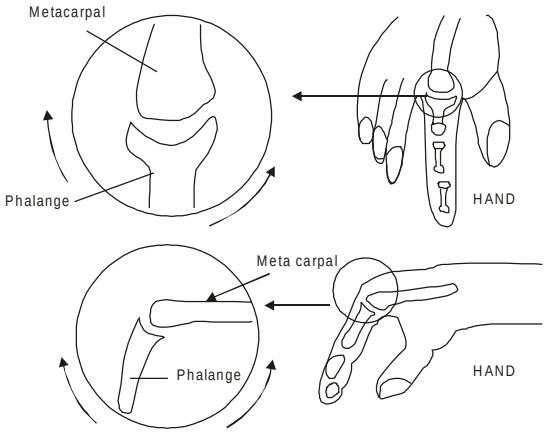
Hinge Joint

(*c*) *Pivot joint :* These joints are like a wheel on an axel. Rotation is the only movement possible in these joints. The atlanto–axial and superior radioulnar joints are pivot joints.



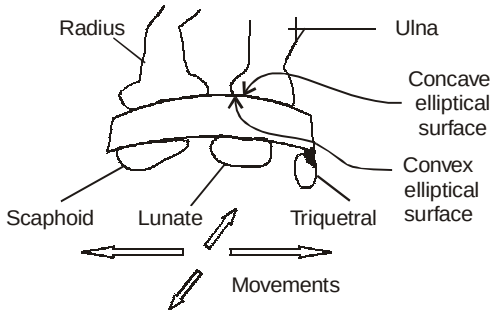
Pivot Joint

(*d*) *Condyloid joints :* The bones have two distinct convex surfaces which articulate with two concave surfaces in these joints. These joints permit flexion, extension, abduction, adduction with small rotational movement. The knuckle joints or metacarpophalangeal joints are condyloid joints.



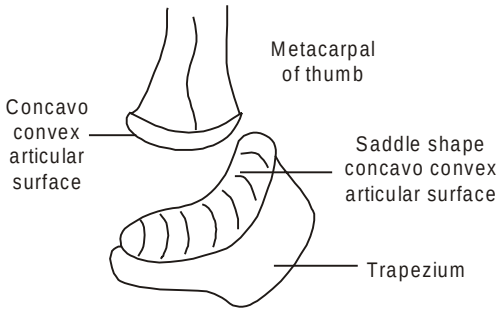
Condyloid Joint

(e) Ellipsoid joints: There is an elliptical convex articular surface that fits into an elliptical concave articular surface in this type of joints. Flexion, extension abduction and adduction can take place in these joints. The wrist joint is a ellipsoid joint.



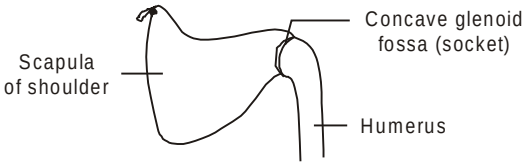
Ellipsoid Joint

(f) Saddle joints: The joint resembles a saddle on a horse's back. The articular surfaces are concavo-convex. Flexion, extension, abduction, adduction and rotation are possible in this joint. Carpometacarpal joint of the thumb is a saddle joint.



Saddle Joint

(*g*) *Ball & socket joints:* In this joint, one bone has a ball shaped head and other bone has a socket like cavity in which the head of first bone fits. The joint permits all movements like flexion, extension, abduction, adduction, medial rotation, lateral rotation and circumduction. Shoulder and hip joints are ball and socket joints.



Ball and Socket Joint

OBJECTIVE TYPE QUESTIONS

Fill up the gaps

1. A site where two or more bones come together, whether or not there is a movement between them is called---------- (*a*) skeleton (*b*) joint

2. The primary function of a joint is to provide -------- to musculoskeletal system (*a*) safety (*b*) mobility

3. Joint is required to provide -------- besides mobility (*a*) stability (*b*) safety

4. Motion in all time planes is called--------
(*a*) trimotion (*b*) triaxial

5. Motion in one plane is called---------
(*a*) monomotion (*b*) uniaxial

6. The connecting bones of the skill form a ---- joint (*a*) fibrous (*b*) fixed

7. Cartilage joint has bones united by a ------- of fiberocartilage (*a*) ligament (*b*) disc

8. Synovial joint has articular bone surfaces separated by a --------- filled with synovial fluid (*a*) cavity (*b*) pouch

9. ------- fluid reduces wear and tear of articular bone surfaces (*a*) lubricating (*b*) synovial

10. Intervertebral joint is a -------- joint
(*a*) cartilaginous (*b*) fibrous

11. Synovial joint has ------- degree of freedom of movement (*a*) greater (*b*) lesser

12. Amphiorthrodial joint permits------- relative motion between bones (*a*) slight (*b*) varying degree of

13. Diorthrodial joint permits ------- relative motion between bones (*a*) slight (*b*) varying degree of

14. Synovial joint of plane variety has the articular surfaces of the bones which are ------- (*a*) flat (*b*) sliding

15. A joint which is like a wheel on an axel is ------ joint (*a*) hinge (*b*) pivot

16. A saddle joint has reciprocally -------- articular surfaces (*a*) convex (*b*) concavo-convex

17. A ellipsoid joint has--------- articular surfaces (*a*) concavo-convex (*b*) elliptical

18. A condyloid joint has two distinct ------- surfaces which articulate with two distinct ------ surfaces
(*a*) flat, flat (*b*) convex, concave

ANSWERS

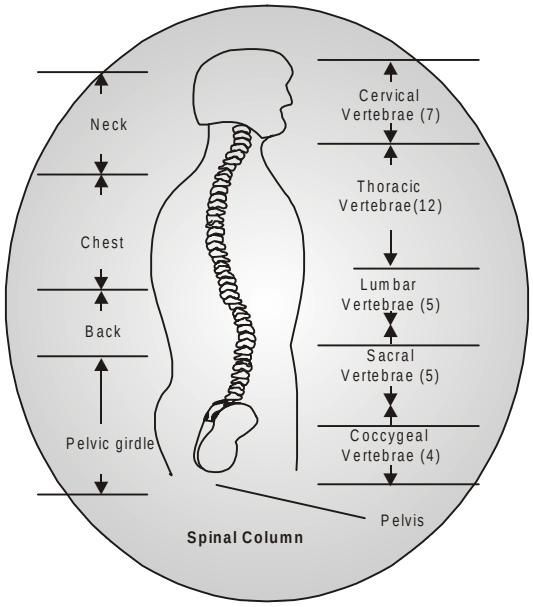
1. (*b*)	**2.** (*b*)	**3.** (*a*)	**4.** (*a*)	**5.** (*b*)	**6.** (*a*)
7. (*b*)	**8.** (*a*)	**9.** (*b*)	**10.** (*a*)	**11.** (*a*)	**12.** (*a*)
13. (*b*)	**14.** (*a*)	**15.** (*b*)	**16.** (*b*)	**17.** (*b*)	**18.** (*b*)

MECHANICS OF THE SPINAL COLUMN 7

There is always some good in every situations, all you have to do is look for it.

INTRODUCTION

1. The vertical column is also known as spine, spinal column or back bone. It is the control axis of the body. It supports the body weight and transmits it to the ground through the lower limbs. It is the most complex part of the human muscleoskeletal system. Its principal functions are to protect the spinal cord, to support the head, neck and upper limbs; to transfer loads from the head and trunk to the pelvis; and to provide flexibility to carry out a variety of movements. It can be divided into five regions viz. cervical (neck), thoracis (chest), lumbar (lower back), sacral and coccygeal regions. The thoracis and lumbar regions of spinal column form the trunk of the body while sacral and coccygeal regions join with pelvis and form parts of pelvic girdle.



ANATOMY OF SPINAL COLUMN

1. The vertical column is made up of 33 vertebraes which include 7 cervical, 12 thoracic, 5 lumbar, 5 sacral and 4 coccygeal. In the thoracic, lumbar and sacral regions, the number of vertebrae corresponds to the number of spinal nerves and each nerve lying below the corresponding vertebrae. In cervical region, then are eight nerves, the upper seven lying above the corresponding vertebrae and the eight below the 7^{th} vertebrae. In the coccygeal region there is only one coccygeal nerve.

2. The vertebrae are also grouped according to their mobility. The moveable or true vertebrae include 7 of cervical, 12 of thoracic and 5 of lumbar vertebrae which have intervertebrae disks in between for facilating rotating movement. Hence these are 24 movable (true) verterbrae and nine unmovable (false) verterbrae which are in sacrum and coccyx region. Twelve thoracic verterbrae have ribs attached to them.

3. There are 24 movable verterbrae and they form amphiarthrodial joints with the fibrocartilaginous interposed between each pair of vertebrae. The fibrocartilaginous discs perform following functions.

(1) Sustains loads transmitted from segments above

(2) Act as shock absorbers

(3) Eliminate bone to bone contact

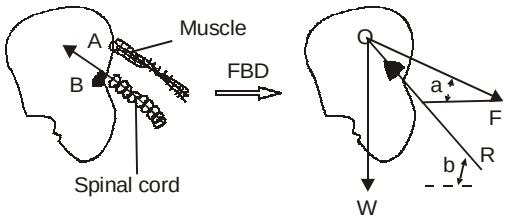
(4) Reduce the effects of impact forces by preventing direct contact between the verterbraes. The intervertebrae disc permits articulation of each verterbrae with the adjacent verterbrae in these planes. Hence the entire spinal column functions like a single ball and socket joint. Flexion and extension, lateral flexion and rotation of body is possible due to the structure of spinal column.

4. At the superior end, spinal column has two important joints with head. The atlanto-occipital joint is the joint between the first cervical vertebrae (called atlas) and the occipital bone of the head. This is a double condyloid joint (refer chapter 6) The joint permits movement of the head in the sagittal plane and lateral plane. The atlanto axial joint is the joint between the atlas and the axis (first and second verbetrae). This is a pivot joint which permits head to rotate in the transverse plane.

5. The movement of head and neck is provided, controlled and coordinated by a muscle group viz. prevertebrals (anterior), hyoids (anterior) sternocleidomastoid (anterior lateral) scalene (lateral), levator scapulae (lateral) suboccipital (posterior) and spleni (posterior). The spine gets its stability from the inter vertebral discs and from the surrounding ligaments and muscles. The discs and ligaments provide passive stability while muscles give active support. The muscles of the spinal column exist in pairs. The anterior portion of spine is connected to abdominal muscles viz. the rectus abdominis, external obligue and internal obligue. These muscles can do flexion & maintain the spine in proper position. There are three layers of posterior trunk muscles viz. the erector spine, the semispinalis and the deep posterior spinal muscle groups. These muscles provide trunk extension as they are located at posterior position of the spine. The effect of gravity is also overcome by these muscles. The quadratus lumborum muscle helps in lateral trunk flexion. The pelvis and lumbar spine is stabilized by this muscle. The lateral flexion of the trunk is carried out by the abdominal and posterior muscles. The rotational movement of the turnk is controlled by the simultaneous action of anterior & posterior muscles.

ANALYSIS OF FORCE SYSTEM

1. When head flexes in meridian plane, exterior muscles exert force to support the head. There is also compressive force exerted on the first cervical vertebrae at the atlanto-occipital joint.



2. Let F is muscle force & R is reaction at the joint. We get a three forces system which is concurrent at joint O. Hence we can apply Lami's theorem on the force system.

$$\frac{W}{\sin(180-\beta+\alpha)} = \frac{R}{\cos\alpha} = \frac{F}{\sin(90+\beta)}$$

Where α is angle with horizontal of muscle force and β is angle of reaction of joint with horizontal.

$$\frac{W}{\sin(\beta-\alpha)} = \frac{R}{\cos\alpha} = \frac{F}{\cos\beta}$$

$$\therefore \quad R = \frac{W\cos\alpha}{\sin(\beta-\alpha)}$$

$$= \frac{W\cos\alpha}{\sin\beta\cos\alpha-\cos\beta\sin\alpha}$$

$$= \frac{W}{\sin\beta-\tan\alpha\cos\beta}$$

Similarly $$F = \frac{W\sin\beta}{\sin(\beta-\alpha)}$$

$$= \frac{W\cos\beta}{\sin\beta\cos\alpha-\cos\beta\sin\alpha}$$

$$= \frac{W}{\cos\alpha\tan\beta-\sin\alpha}$$

If we have W = 50 N, $\alpha = 30°$ & $\beta = 60°$

Then $$R = \frac{50}{\sin 60-\tan 30\cos 60}$$

$$= \frac{50}{\frac{\sqrt{3}}{2}-\frac{1}{\sqrt{3}}\times\frac{1}{2}}$$

$$= \frac{50\times\sqrt{3}\times 2}{2} = 88 \text{ N}$$

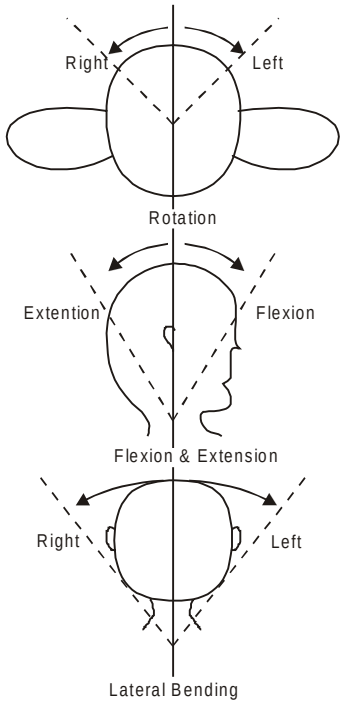
Similarly $$F = \frac{50}{\cos 30\tan 60-\sin 30}$$

$$= \frac{50}{\frac{3}{2}-1/2} = 50 \text{ N}$$

Hence muscles must apply 50 N force to support the head and reaction force developed at the joint is 88 N.

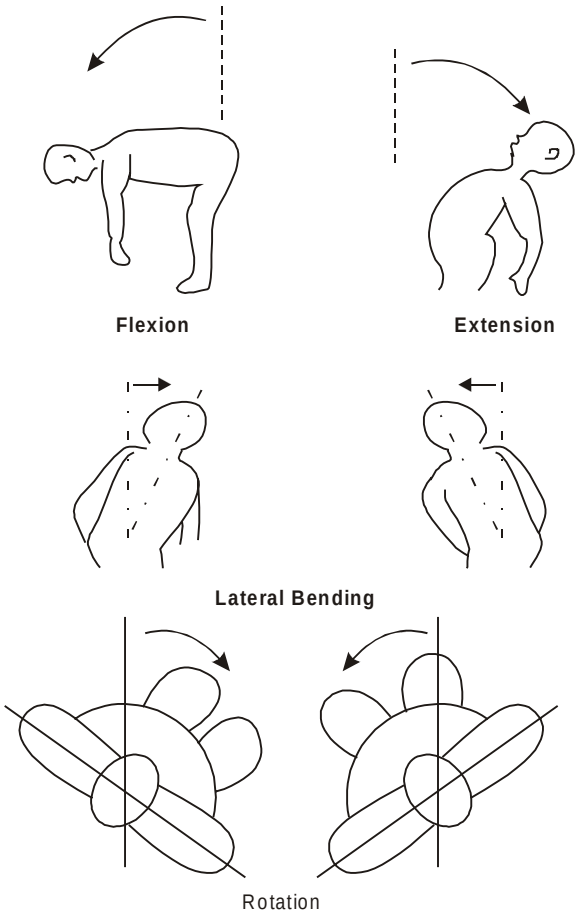
MOVEMENTS OF NECK AND SPINE

1. Neck: It can rotate in horizontal plane. It can do lateral bending. It can also do flexion and extension in meridian plane.



Movements of The Neck

2. Spine: Spine can do flexion and extension in meridian plane. It can also do lateral bending. It can also have rotational movement in horizontal plane.



Movements of Spine

OBJECTIVE TYPE QUESTIONS

Fill up the Gaps

1. The primary function of spinal column is to protect the ----- of the body
(*a*) posture (*b*) spinal cord

2. Neck has ---- cervical vertebraes.
(*a*) six (*b*) seven

3. Chest has -------- thoracic vertebrae
(*a*) Thirteen (*b*) twelve

4. Back has ---- lumbar vertebrae
(*a*) five (*b*) four

5. The spinal column has ---vertebrae
(*a*) 24 (*b*) 33

6. There are -------- movable vertebrae
(*a*) 24 (*b*) 33

7. Each movable vertebrae has fibrocartilaginous --------- interposed between each pair of verterbrae.
(*a*) plate (*b*) disc

8. Movable vertbraes form -------- joints
(*a*) amphiorthrodial (*b*) rotatable

9. Thoracic vertebraes have ------ attached to them. (*a*) ribs (*b*) abdomen

10. The interverbetrae disc permits ----- of each verbetrae with the adjacent vertebrae in three planes. (*a*) articulation (*b*) rotation

11. Entire spinal column functions like a single ------- joint. (*a*) ball and Socket (*b*) plane

12. The joint between first cervical vertebrae and the occipital bone of the head is -----
(*a*) 'atlanto' occipital (*b*) vertebro occipital

13. The atlantoaxial joint is between the first vertebrae and --------- vertebrae
(*a*) 3rd (*b*) 2nd

14. 9 unmovable verterbraes are in -------
(*a*) Back (*b*) Pelvic girdle

15. Chest is ------------ region
(*a*) cervical (*b*) thoracic

16. Back is ---- region. (*a*) thoracic (*b*) lumbar

17. The thoracic and lumbar regions of spinal column form the ------ of the body.
(*a*) chest (*b*) trunk

18. Sacral and coccygeal regions join to form ------- (*a*) shoulder girdle (*b*) pelvic girdle

19. Ligament and discs provide ------- stability
(*a*) active (*b*) passive

20. Muscles provide ------- stability
(*a*) active (*b*) passive

21. The load from head to pelvis is conveyed by -------
(*a*) chest bones (*b*) spinal column

22. The protection to spinal cord is provided by ------- (*a*) chest bone (*b*) back bone

23. Intervertebrae discs permit-------contacts between adjacent vertebrae.
(*a*) smooth (*b*) no

24. In coccygeal region, there is-------nerve/ nerves
(*a*) one (*b*) four

ANSWERS

1. (*b*)	**2.** (*b*)	**3.** (*b*)	**4.** (*a*)	**5.** (*b*)	**6.** (*a*)
7. (*b*)	**8.** (*a*)	**9.** (*a*)	**10.** (*a*)	**11.** (*a*)	**12.** (*a*)
13. (*b*)	**14.** (*b*)	**15.** (*b*)	**16.** (*b*)	**17.** (*b*)	**18.** (*a*)
19. (*b*)	**20.** (*a*)	**21.** (*b*)	**22.** (*b*)	**23.** (*b*)	**24.** (*a*)

MECHANICS OF UPPER LIMBS

8

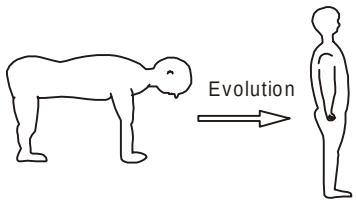
To see and understand the big picture, you've got to meet the Master Painter.

INTRODUCTION

1. The upper and lower limbs were evolved basically for bearing the weight of the body and for locomotion as it is seen in quadrupeds (eg. cows and dogs). Therefore the two pairs of limbs are formed on the similar basic pattern. The evident similarities of upper and lower limbs are :

Upper limbs	*Lower limbs*
1. Shoulder griddle	1. Hip girdle
2. Shoulder joint	2. Hip joint
3. Arm with humerus	3. Thigh with femur
4. Elbow joint	4. Knee joint
5. Forearm with radius and ulna	5. Leg with tibia and fibula
6. Wrist joint	6. Ankle joint
7. Hand with	7. Foot with
(*a*) Carpus	(*a*) Tarsus
(*b*) Metacarpus	(*b*) Metatarsus
(*c*) 5 digit	(*c*) 5 digit

2. Due to the evolution of erect posture in man, the function of weight bearing was taken over entirely by the lower limbs. As a result of this removal of function of load bearing, the upper limbs (specially the hands) became free. Hands were gradually evolved into the organs having greater manipulative skill. The upper limbs started performing different functions. Hence the apparent difference between the upper and lower limbs is as a result of the difference of functions.



Change of Posture

The division of the upper limbs with bones and joints are:

S.No.	*Division*	*Bones*	*Joints*
1.	Shoulder region	1. Clavicle 2. Scapula	1. Sternoclavicular 2. Acromioclavicular
2.	UPPER ARM (Shoulder to elbow)	Humerus	Shoulder joint (scapula humerus)
3.	Forearm (Elbow to wrist)	1. Radius 2. Ulna	1. Elbow joint 2. Radius ulna
4.	Hand	1. Carpus (8 Carpel bones) 2. Metacarpus (5 metacarpal bones) 3. 14 Phalanges (2 for thumbs & 3 for each finger)	1. (*a*) Wrist joint (radio - carpal) (*b*) Inter carpal 2. Carpometacarpal 3. (*a*) Intermetacarpal (*b*) Metacarpophalangeal (*c*) Proximal and distal interphalangeal

3. The forces involved on various joints can be classified as (1) internal forces (2) external forces. Internal forces are developed in muscles and joint reactions. External forces are gravitational force and mechanical applied forces. To apply the principles of statics to analyze the mechanics of human joints, following assumptions are made :

(*a*) Only one muscle groups controls the movement of joint

(*b*) Muscle attachment is at a joint which is known

(*c*) The line of action of muscle tension is known

(*d*) Proper point of joint at which joint can rotate is known

(*e*) Segmental weight of the parts of body with their centre of gravity are known

(*f*) Frictional forces at joints are small & negligible

(*g*) All forces acting on a joint are coplanar

(*h*) Deformation is small and negligible in muscles, bones and tendons etc

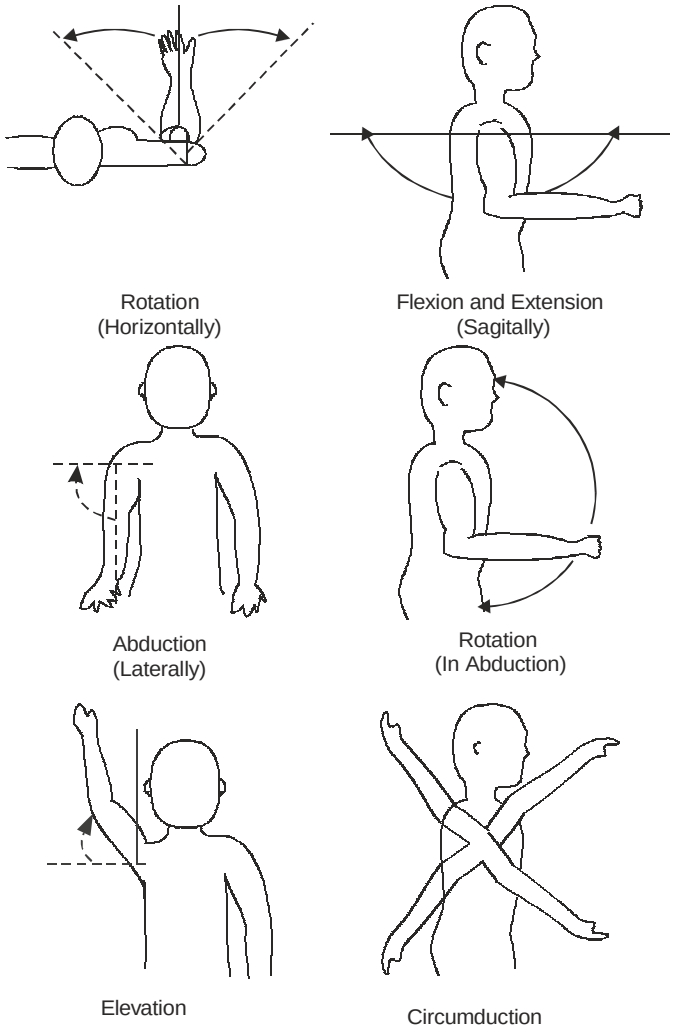
(*k*) Dynamic effect is ignored

MECHANICS OF THE SHOULDER

1. Shoulder joint: It is also called glenohumeral joint between hemispherical humeral head (ball) and the shallowly concave glenoid fossa (socket) of the scapula bone. Hence it is a ball and socket joint which permits variety of movements to the arm. The movements allowed are flexion and extension, abduction and adduction, outward rotation and inward rotation. The configuration of the articular surfaces of this joint makes the joint more susceptible to instability. The stability of the joint is due to the presence of ligaments and muscles. Ligaments are glenohumeral and coracohumeral while the major muscles of the joint are :

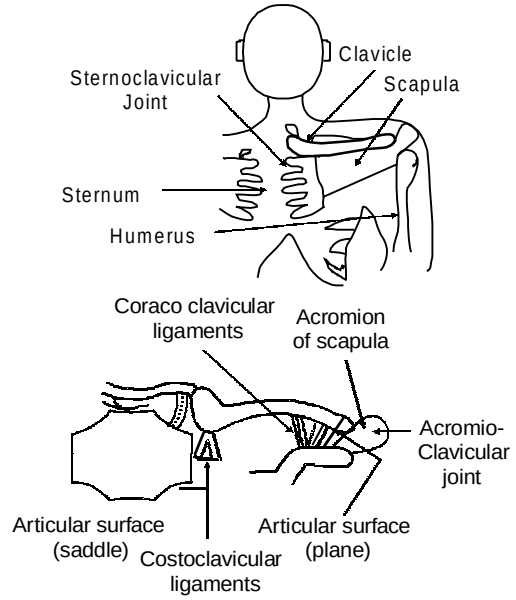
(1) deltoideus
(2) supraspinatus
(3) pectoralis major
(4) coracobrachialis
(5) latissimus dorsi
(6) teres major
(7) teres minor
(8) infraspinatus
(9) subscapularis

Shoulder joint



Movements of the Shoulder

2. The shoulder girdle consists of the clavicle (collarbone) and scapula (shoulder blade). The acromioclavicular joint gives small synovial articulation between acromion of the scapula and the distal clavicle. Coracoclavicular ligaments join these two bones. The sternoclavicular joint is a saddle synovial joint and it gives articulation between sternum and clavicle. Costoclavicle ligaments join these bones and provide stability. Both these joints of clavicle with sternum and scapula have layers of cartilage (called menisci) interposed in between the joints. There are six types of movement possible as shown in the figure. There are 6 muscles that control and coordinate these movements viz. trape = 145, levator scapulae, rhomboid pectoralis minor, serratus anterior and subclavius.

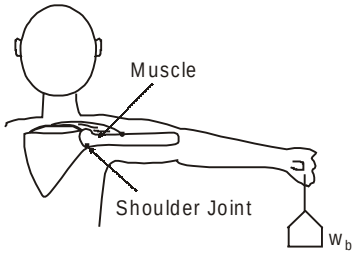


Sternoclavicular and Acromioclavicular Joints

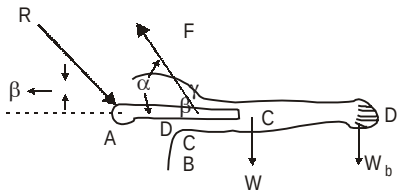
3. The shoulder joint is very susceptible to injuries like dislocation of the joint & the fracture of the humerus bone. As the head of humerus is relativity free to rotate about the articulating surface of the glenoid fossa the freedom of movement is gained by reduced joint stability. The humeral head is likely to be displaced if external loading is more than the strength of the muscles and ligaments.

ANALYSIS OF FORCE ON THE SHOULDER JOINTS

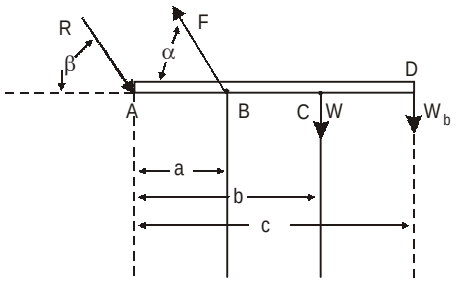
1. Case study 1: Let us take a typical case of arm stretched fully & holding a weight (W_b) as shown in the figure. Free body diagram of the arm is also shown. The shoulder joint is at point A, deltoid muscle is attached at point B; center of gravity of the arm is at point C and weight in hand is acting at point D. The force F is developed by deltoid muscle at point B which makes an angle α with horizontal. The reaction R acts at the joint which makes an angle β with horizontal. The weight of the arm (W) acts vertically downwards at point *C*. The weight held in hand also acts vertically downwards at point D. The mechanical model of the arm is also shown. The distances of point *B*, *C*, & *D* from point A are a, b, and c respectively. Now we have a coplanar force system in equilibrium which gives us three equations of equilibrium *i.e.* $\Sigma Px = O$, $\Sigma P_Y = 0$ & $\Sigma M = O$.



Arm Abducted Horizontally



Free Body Diagram of Arm



Mechanical Model of Arm

$\Sigma Py = 0, -R \sin \beta + F \sin \alpha - W - W_b = 0$ ...(*i*)

$\Sigma Px = O, R \cos \beta = F \cos \alpha$ ...(*ii*)

$\Sigma M_A = 0, -F \sin a \times a + W \times b + W_b \times c = 0$ ... (*iii*)

If we have been given the value of a = 20, b = 40, c = 60, α = 12°, m = 4 Kg (W = 4× g = 4 × 10 = 40 N), m_b= 5 Kg (W_b = 5 ×10 = 50 N) then substituting these values in equations (*i*), (*ii*) and (*iii*)

$-R \sin \beta + F \sin 12 - 40 - 50 = 0$ ... (*iv*)

$R \cos \beta = F \cos 12$ ... (*v*)

$-F \sin 12 \times 20 + 40 \times 40 + 50 \times 60 = 0$

$$\therefore F = \frac{4600}{20 \times \sin 12} = \frac{4600}{20 \times \sin 13} = 1080 \quad ...(vi)$$

From eqn (*v*) $R \cos \beta = F \cos 12$

$= 105.64$ ... (*vii*)

From eqn (*iv*) $R \sin \beta = F \sin 12 - 90$

$= 129.4$ ... (*viii*)

From eqn (*vii*) and (*viii*)

$\tan \beta = 0.123$

$\therefore \beta = 7$

and $$R = \frac{1056.4}{\cos 7} = \frac{1056.4}{0.95}$$

$= 1056.5$

2. **Case study 2:** Consider an athlete is strengthening his shoulder joint by lowering and raising a bar bell with arms straight while lying down as shown in figure below. The weight of the bar bell is W_b at a distance '*b*' from the shoulder joint (point D) and W_a is weight of the arms acting at a distance '*a*' from the shoulder joint. Now we can analyse the force system, when the arm is making an angle θ with horizontal.

$M_0 = W_a \times a \cos \theta + W_b \times b \cos \theta$.

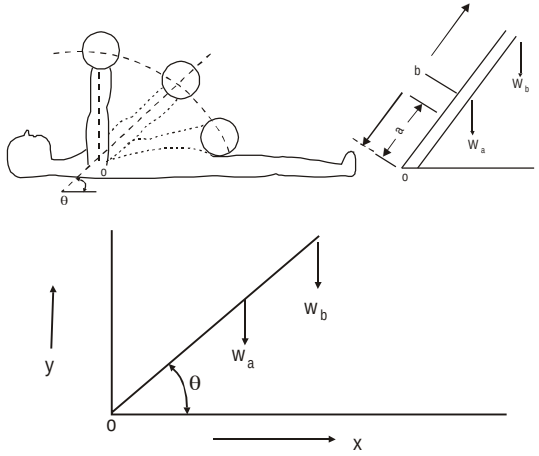
If we take, a = 30 cm, b = 60 cm, W_a = 60 N and W_b = 300 N

$M_0 = 60 \times 0.30 \cos \theta + 300 \times 0.60 \cos \theta$

$= (18 + 18) \cos \theta$

$= 36 \cos \theta$

The moment at the shoulder joint varies as per the angle θ. It is maximum when θ = 0 (arm is horizontal) and zero when θ = 90 (arm is vertical).

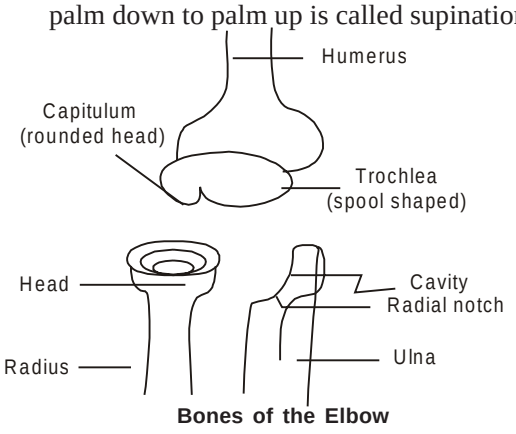


Free Body and Mechanical Model of Arm

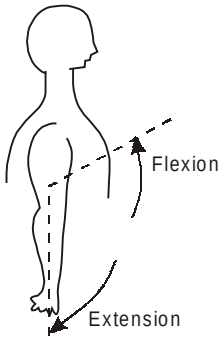
MECHANICS OF THE ELBOW

1. The elbow joint has three bones viz humerus, radius and ulna. Humerus lies in upper arm while radius & ulna lie in forearm. At the distal (far from root) humerus has capitulum (rounded head) and spool shaped trochlea. The humeroulnar joint is a huge joint formed by humerus (distal) and ulna having concave trochlear fossa (cavity) at proximal (root). The joint can make only uniaxial rotation which permits flexion and extension. The humeroradial joint is formed

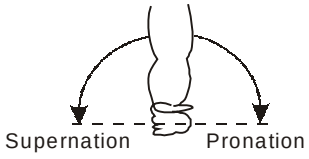
by the capitulum of the distal humerus and head of the radius. It is a also a hinge joint. The third joint in this region is the proximal radioulnar joint which is a pivot joint formed by the head of the radius and the radial notch of the proximal ulna. The joint permits the radius and ulna to make relative rotation about the longitudinal axis of either of the bones. The movement by the joint from the palm-up to the palm down is called pronation while the movement by the joint from the palm down to palm up is called supination.



Bones of the Elbow



Movements of the Elbow



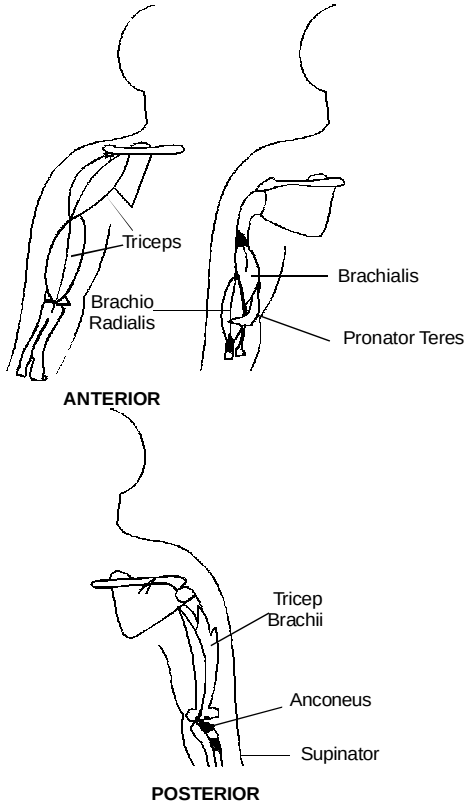
Movements of the Forearm

2. The muscles coordinating & controlling the movement of the elbow joint are:

(*a*) *Bicep brachii:* It is the most powerful flexor of the elbow joint, specially when the joint is in supinated position. On the distal side, the biceps is attached to the tuberosity of the radius and on the proximal side, it has attachments at the top of the coracoid process and upper lip of the glenoid fossa.

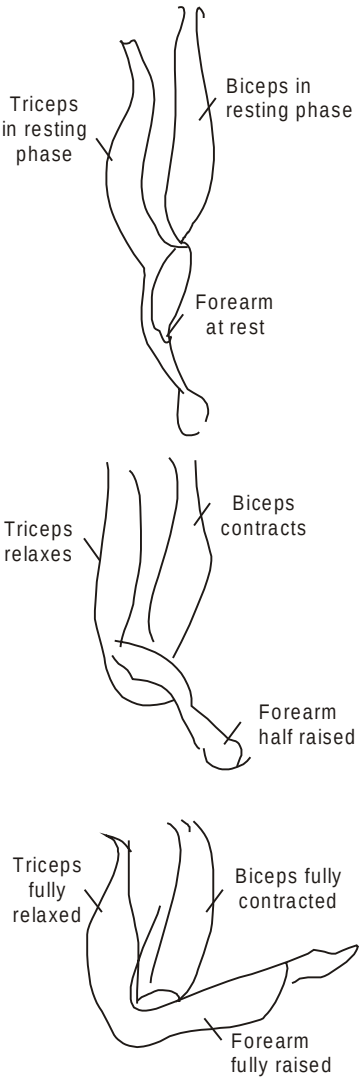
(*b*) *Brachialis muscle:* This flexor has attachments at the lower half of the anterior portion of the humerus & the coronoid process of the ulna.

(*c*) *Triceps brachii:* The muscle controls the extension movements of the elbow. It has attachments of the lower head of the glenoid cavity of the scapula, the upper half of the posterior surface of humerus, the lower two thirds of the posterior surfaces of the humerus and the olecranon process of the ulna.

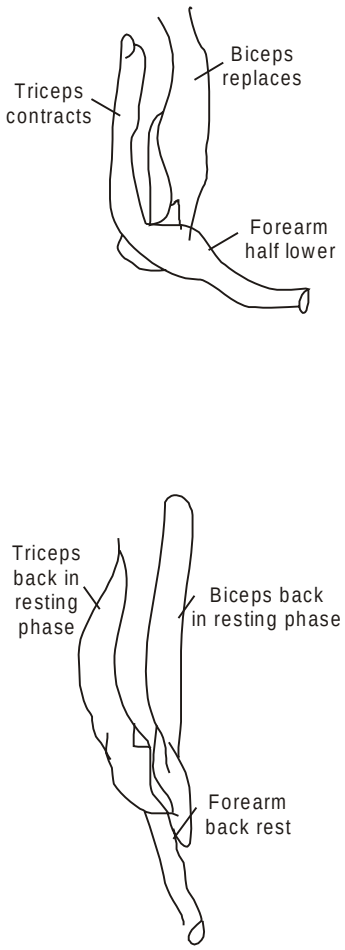


Muscles of the Elbow

(*d*) *Pronator teres and supinator muscles:* The pronator teres is attached to the lower part of the inner condyloid ridge of the humerus, the medial side of the ulna and the middle third of the humerus, the medial side of the ulna and middle third of the outer surface of the radius. As the name suggests, it performs pronation. The supination muscle has attachments at the outer condyloid ridge of the humerus, the neighboring part of the ulna and the outer third of the radius. The muscle controls supination. The coordinated relaxation and contraction of the opposing muscles enables to control movement of the limbs. To raise the forearm, the biceps (two rooted muscle) contracts and shortens while triceps (three rooted muscles) relaxes. To lower the forearm, the reverse occurs.

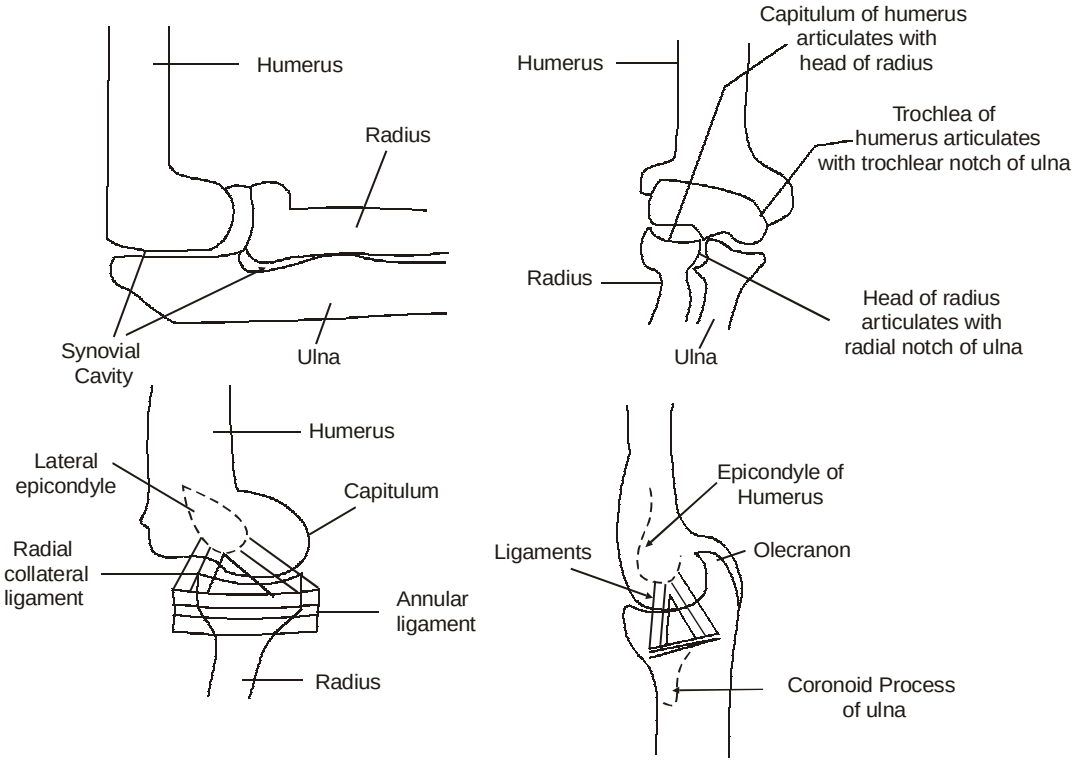


Raising of Forearm



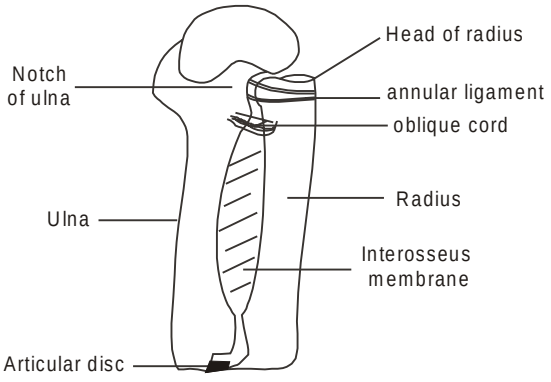
Lowering of Forearm

3. **The elbow joint :** The elbow joint is a synovial joint of the hinge variety. A ligamentous capsule encloses an articular cavity filled with synovial fluid. The synovial fluid is a thick and viscous substance. The primary function of synovial fluid is to provide lubrication to the articulating surfaces which reduces coefficient of friction, thereby frictional forces acting against movements are reduced considerably. The synovial fluid also nourishes the articulating cartilages . Besides above two functions, the synovial fluid helps in distributing the forces acting on the joint to a large area. All forces acting on the fluid are transferred to the fluid as liquid pressure which is uniform in all directions. The components of the fluid pressure along the horizontal get cancelled and the vertical components get added up, resulting into a vertical force on the joint. The elbow joint is continuous with the superior radioulnar joint. The humeroradial, the humeroulnar and the superior radioulnar joints together are known as cubital articulations. The long axis of the arm makes an angle of about 170° with the long axis of the forearm when the forearm is extended and supinated. The elbow joint is susceptible to fractures and dislocations. Fractures occurs at the epicondyles of the humerus and coronoid process of ulna. Another elbow injury that happens frequently is tennis elbow, which occurs due to repeated and forceful pronation and supination movement of the elbow.



Elbow Joint

4. **The radioulnar Joints :** The radius and the ulna are joined to each other at the superior and inferior radioulnar joints. Supination and pronation (rotary movements of the forearm along the long axis) are possible due to these joints,. It is a pivot type synovial joint. Pronation and supination movements are similar to turning a door handle, moving a screw or opening a lock. The head of radius articulates with the radial notch of ulna in the joint.



The Radioulnar Joint

FORCES ON THE ELBOW JOINT

1. Let us take a typical example of the arm in which elbow is flexed to a right angle and an object is held in the hand. The freebody diagram of the forearm is shown indicating forces and reaction acting on it in equilibrium. The mechanical model of the forearm is also shown to convert it to a simple mechanics problem. As shown in the figure, W = weight of the forearm acting at C (Centre of gravity of the forearm), W_b = weight of the body held in the hand at point D, F = Force exerted by the biceps muscle on the radius at point B and R = reaction force at the elbow joint at point A. Let the distance $AB = a$, $AC = b$ and $AD = c$. The force system on the forearm is a coplanar force system and we get three equations of equilibrium

$$i.e.\quad \Sigma Px = 0,\ \Sigma PY = 0 \text{ and } \Sigma M_A = 0$$

$$\Sigma P_Y = 0,\ -R + F = W + W_b \qquad ...(i)$$

$$\Sigma M_A = 0,\ F \times a = W \times b + W_b \times c$$

$$\text{or} \qquad F = \frac{W \times b + W_b \times c}{a}$$

If we take mass of forearm 2 kg ($W = 2\times g \approx 20$ N), mass of object 5 kg ($W_b = 5 \times g \approx 50$ N), $a = 5$ cm, $b = 15$ & $c = 40$ cm

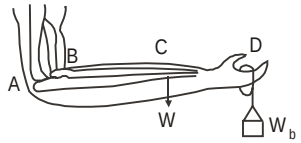
$$\therefore \qquad F = \frac{20\times15 + 50\times40}{5}$$

$$= \frac{300 + 2000}{5} = 460 \text{ N}$$

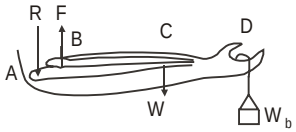
$$\therefore \qquad R = -20 - 50 + 460$$

$$= 390 \text{ N}$$

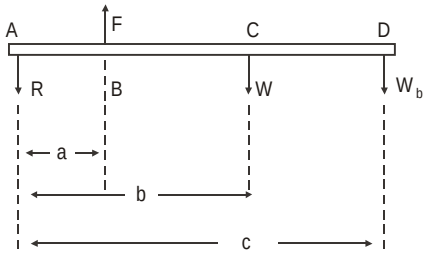
2. The above example indicates that the muscle force and reaction at joint are considerably larger than the weight of the object. Both F & R can be brought down if distance '*a*' is large i.e. distance between joint & point of attachment of the muscles. However nearer attachment of muscle to the joint helps in quick motion of the forearm w.r.t joint.
3. If the muscle force is not acting vertical then muscle force (F) will have a rotational component acting vertically up (as in the previous example) and a translational component (stabilizing or sliding depending on flexed position). If muscle force (F) is acting towards upper arm (making angle θ with vertical) then F cos θ is rotational component and F sin θ is stabilising component acting towards joint. Now if muscle force (F) is acting away from the upper arm (making angle θ with vertical), then F cos θ is rotational component and F sin θ is sliding or destabilising component.



(a) Arm Flexed at right angle



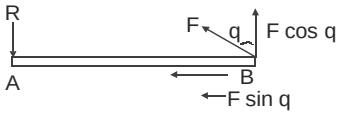
(b) Free body Diagram of Forearm



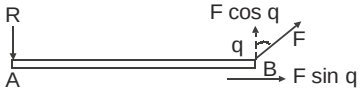
(c) Mechanical Model

Force Analysis of Forearm

F = Rotational effect of A



F cos θ = Rotational effect at A
F sin θ = Stabilising effect at A

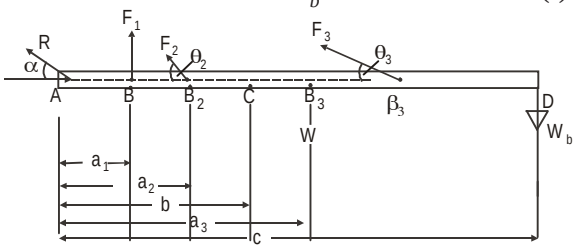


F cos θ = Rotational effect at A
F sin θ = Destabilising effect at A

Rotational and Translation Components

4. In practice, biceps muscle is not the only muscle exerting force on the forearm in the flexed position. The brachialis and the brachioradialis muscles are also exerting forces. The mechanical model of the force system is still a coplanar force system as shown in the figure. As we have three equations of equilibrium, hence the system is determinate for only three unknown. The three equations are $\Sigma P_x = 0$, $\Sigma P_y = 0$, and $\Sigma Ma = 0$

$\Sigma P_y = 0$, $F_1 + F_2 \sin\theta_2 + F_3 \sin\theta_3$
$= R \sin\alpha + W + W_b$ ...(*i*)



$\Sigma P_x = 0$, $R \cos\alpha = F_2 \cos\theta_2 + F_3 \cos\theta_3$..(*ii*)

$\Sigma M_A = 0$, $F_1 \times a_1 + F_2 \sin\theta_2 \times a_2 + F_3 \sin\theta_3 \times a_3$
$= W \times b + W_b \times c$ ...(*iii*)

The muscle forces F_1, F_2, and F_3 are proportion to their areas *i.e.*, A_1, A_2 and A_3

$$F_1 A_1 = F_2 A_2 = F_3 A_3$$

$$F_2 = \frac{A_1}{A_2} F_1 = K_2 F_1$$

$$F_3 = \frac{A_1}{A_3} F_1 = K_3 F_1$$

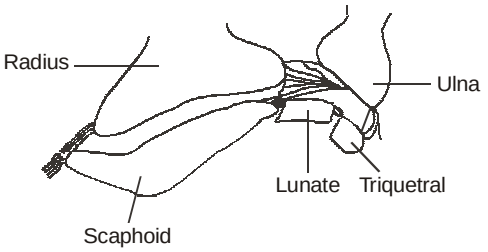
From eqn. (*iii*)

$F_1 \times a_1 + F_1 K_2 \times a_2 \sin\theta_2 + F_1 K_3 x a_3 \sin\theta_3$
$= W \times b + W_b \times c$

$$\therefore \quad F_1 = \frac{W \times b + W_b \times c}{a_1 + K_2 a_2 \sin\theta_2 + K_3 a_3 \sin\theta_2}$$

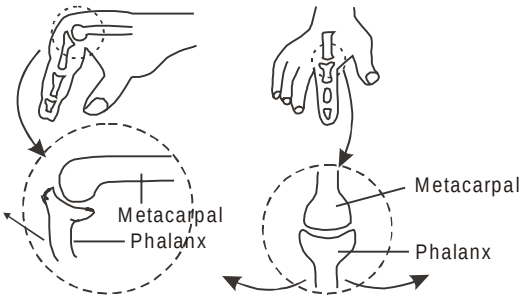
JOINTS OF HAND

1. **The wrist joint:** This is a synovial joint of the ellipsoid variety. It is also called as radio carpal joint. There is an elliptical convex articular surface (formed by triquetral, lunate and scaphoid) that fits into an elliptical concave articular surface (formed by radius and ulna) as shown in the figure. The movement of flexion, extension, abduction and adduction can take place but rotation is impossible.



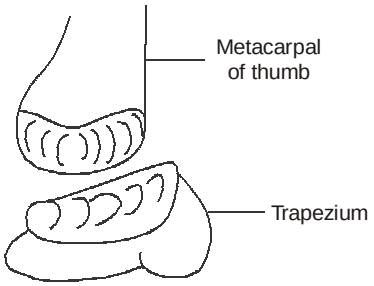
Wrist Joint

2. **The knuckle joint:** It is also called as metacarpophalangeal joint. The joint is a synovial joint of the condyloid variety. The joint has two distinct convex surfaces (on metacarpal bone) that articulate with two concave surfaces (on phalanx). The movements possible are flexion, extension, abduction, adduction and small amount of rotation.



Knuckle Joint

3. **The thumb joint:** It is also called carpometacarpal joint. It is a synovial joint of the saddle variety. The joint has the articular surfaces which are reciprocally concave convex and resemble a saddle on a horse's back. The joint permits flexion, extension, abduction, adduction and rotation.



Thumb Joint

OBJECTIVE TYPE QUESTIONS

Fill up the gaps

1. Upper & lower limbs are formed on -------- basic pattern (*a*) similar (*b*) dissimilar
2. Due to evolution of erect posture in man, the function of weight bearing was taken away by the ----- (*a*) foot (*b*) lower limbs
3. Shoulder region has clavicle and -------bones (*a*) scapula (*b*) humerus
4. Upper arm has ---------- bone
   (*a*) Humerus (*b*) Radius
5. Forearm has radius and ------ bones
   (*a*) humerus (*b*) ulna
6. The joint between humerus and scapula is _____ joint. (*a*) glenoscapular (*b*) glanohumeral
7. The joint between clavicle and scapula is ---------- (*a*) acromioscapular
   (*b*) acromioclavicular
8. Clavicle bone and scapula are also known as ---------- and -------- (*a*) shoulder blade,

collar bone (*b*) collar bone, shoulder blade

9. Clavicle bone & sternum form -----joint
(*a*) Clavicular sternal (*b*) sternoclavicular

10. The primary function of synovial fluid is to provide -------- to the articulating surfaces (*a*) support (*b*) lubrication

11. The synovial fluid also ---------- the articulating cartilages.
(*a*) nourishes (*b*) support

12. The joint between humerus with both radius and ulna is called ------- joint
(*a*) elbow (*b*) radioulnar

13. The joint between radial and ulna is called
-------- (*a*) ulnaradial (*b*) radioulnar

14. The shoulder girdle consists of the collar bone and -------- (*a*) scapula (*b*) clavicle

15. Ligaments are ------- tissues (*a*) passive (*b*) active

16. Muscles are ---------- tissues (*a*) passive (*b*) active

17. The movement of the elbow joint is coordinated & controlled by -------
(*a*) ligaments (*b*) muscles

18. Radius is joined with ------- to ulna (*a*) ligaments (*b*) muscles

19. The radioulnar joint permits---------- movement of the forearm along the long axis (*a*) rotational (*b*) abduction

20. The wrist joint is a synovial joint of ------- variety (*a*) ellipsoid (*b*) condyloid

21. The knuckle joint is a synovial joint of
--------- variety (*a*) ellipsoid (*b*) condyloid

22. The thumb joint is a synovial joint of
---------- variety (a) saddle (*b*) plane

23. Radiocarpal joint is a ---------- joint
(*a*) wrist (*b*) knuckle

24. Metacarpophalangeal joint is a ---------- joint
(*a*) wrist (*b*) knuckle

25. Carpometacarpal joint is a --------- joint
(*a*) knuckle (*b*) thumb

ANSWERS

1. (*a*)	**2.** (*b*)	**3.** (*a*)	**4.** (*a*)	**5.** (*b*)	**6.** (*b*)
7. (*b*)	**8.** (*b*)	**9.** (*b*)	**10.** (*b*)	**11.** (*a*)	**12.** (*a*)
13. (*b*)	**14.** (*a*)	**15.** (*a*)	**16.** (*b*)	**17.** (*a*)	**18.** (*a*)
19. (*a*)	**20.** (*b*)	**21.** (*a*)	**22.** (*a*)	**23.** (*b*)	**24.** (*b*)
25. (*b*)					

MECHANICS OF LOWER LIMBS 9

Knowledge is a collection of facts. Wisdom is knowing how to apply knowledge.

INTRODUCTION

1. The lower limb in its basic design is similar to the upper limb because both of them were used earlier for locomotion. Each limb has a girdle (shoulder or hip girdle) by which it is attached to the axial skeleton. The hip girdle supports three main segments of the lower limb: (*a*) proximal (thigh) (*b*) a middle (leg), (*c*) a distal (foot). Each segment moves at its proximal joint. Lower limb has specialized for support and locomotion. The lower limb is therefore bulkier and stronger than upper limb

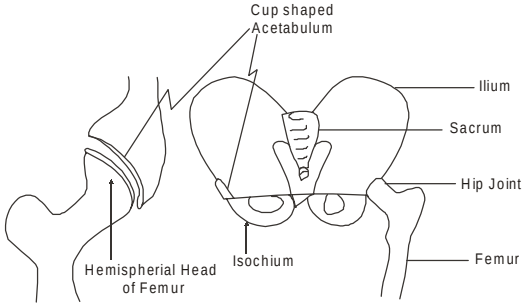
2. The parts of the lower limb are:

S.No.	*Parts*	*Bones*	*Joints*
1.	Gluteal region (covers the side and back of the pelvis)	Hip bone	Hip joint
2.	Thigh (Hip to knee)	1. Femur 2. Tibia 3. Patella 4. Fibula	1. Knee joint 2. Tibia fibular joint
3.	Leg (knee to ankle)	1 Tibia 2 Fibula 3 Talus 4 Calcancus	1. Ankle Joint 2. Subtalar and transverse tarsal joint
4.	Foot (Heel to toes)	1 Tarsus (7 tarsal bones) 2. Metatarsus (5 metatarsals) 3. 14 Phalanges (2 in great toe and 3 in toes (4))	1. Tarsometatarsal (TM) joint 2. Intermetatarsal (IM) joint 3. Metatarsophalangeal (MP) 4. Interphalangeal (IP) joint

3. The hip bone is made of three elements (ilium, pubis and ischium) which are fused at the acetabulum. Two hip bones form the hip girdle which articulates posteriorly with the sacrum at the sacroiliac joints. The bony pelvis includes the two hip bones, a sacrum and a coccyx. Hip joint has articulation between the hip bone and femur.
4. The fibula of the leg does not take part in the formation of knee joint. Patella (knee cap) is a large sesamoid bone developed in the tendon of quadriceps femoris. It articulates with the lower end of femur anteriorly and takes part in the formation of knee joint.

MECHANICS OF THE HIP

1. The pelvis consists of the bones viz. ilium, ischium, pubis and sacrum. At birth, three bones are distinct. In adults these bones are fused and synarthrodial joint is formed which permits no movement. The pelvis is located with spine at centre and one femur bone at each end. Any movement of spine or femur bone will result into the movement of the pelvis. Hence there is no muscle whose primary function is to move the pelvis. Movements of pelvis are resulted by the muscles of the trunk and the hip.
2. The hip joint is formed by the femoral head fitting well in to the deep socket of the acetabulum. The transverse and teres femoris ligaments of the hips support and hold the femoral head in the acetabulum as the femoral head moves. The stability of the hip joint is resulted from its construction which also permits wide range of motions facilitating walking, sitting and squatting. The joint permits flexion and extension, abduction and adduction, and inward and outward rotation. The movement is controlled and coordinated by ligaments, muscles and bony structure, and shape of the hip. The articulating surfaces of the femoral head and the acetabulum are lined with hyaline cartilage. These two form a diarthrodial joint which is a ball and socket joint. Derangement of the hip can produce altered force distributions in the joint cartilage, leading to degenerative arthritis.

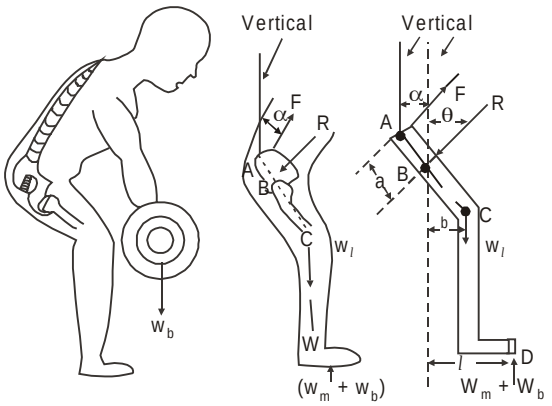


Hip Joint

3. The muscles of the hip joint can be divided into (1) hip flexer (psoas, iliacus, rectus femoris, pectineus and tensor fascia) to carry out activities such as running or kicking (2) hip extensors are gluteus maximus and hamstring muscles (biceps femoris-semitendinosus, semi membranosus). The hamstring muscles also work as knee flexers (3) Hip abductor muscles providing for the inward rotation of the femur. They are gluteus medius and gluteus minimus. The gluteus medius also stabilises the pelvis in the frontal plane (4) Hip adductor muscles are adductor longus, adductor magnus and gracilis muscles (5) Outward rotation of the femur is provided by small deeply placed muscles.

FORCES ON THE HIP JOINT

1. **Case study 1:** To understand the stability of the hip joint, consider a man who is bent forward and lifting a weight (W_b). As shown in the figure, the man's trunk is flexed by an angle α as measured from the vertical.



The forces acting on the lower limb of the man is shown in the figure. Weight (W_m + W_b) is total ground reaction acting at point *D* of the feet where W_m = weight of man and W_b weight being lifted. W_l is the weight of both legs including the pelvis which is acting at point C. F is the force exerted by the erector spinae muscle supporting the trunk and acting at the point A. R is the reaction at the union of the sacrum and the fifth lumbar vertebrae (point B). A mechanical model of man's lower body with forces is illustrated. Assume the force F is acting at angle α to the vertical. Also assume shortest distance of A, C and D from *B* is a, b, and c as shown on the model.

$$\Sigma M_B = 0,\ F \times a + W_l \times b = (W_m + W_b) \times c$$

$$\therefore \qquad F = \frac{(W_m + W_b)c - W_l \times b}{a}$$

Also $R \sin\theta = F \sin\alpha$

and $R \cos\theta = F \cos\alpha - W_l - W_m - W_b$

If $\alpha = 30°$, $a : b : c = 1 : 4 : 6$;

w_1 = 40% of W_m ; and $W_m = W_b$

$$F = \frac{\frac{6}{11}(W_m + W_m) - \frac{4}{11} \times (0.4W_m)}{\frac{1}{11}}$$

$$= 12\ W_m = 1.6\ W_m$$

$$= 10.4\ W_m$$

$$R \sin\theta = F \sin 30 = 10.4 \times W_m \times \frac{1}{2}$$

$$= 5.2\ W_m$$

$$R \cos\theta = 10.4\ W_m \cos 30 - 0.4\ W_m - 2W_m$$

$$= (9.152 - 24)\ W_m$$

$$= 6.752\ W_m$$

$$R = \sqrt{[(5.2)^2 + (6.752)^2]\,W_m^2}$$

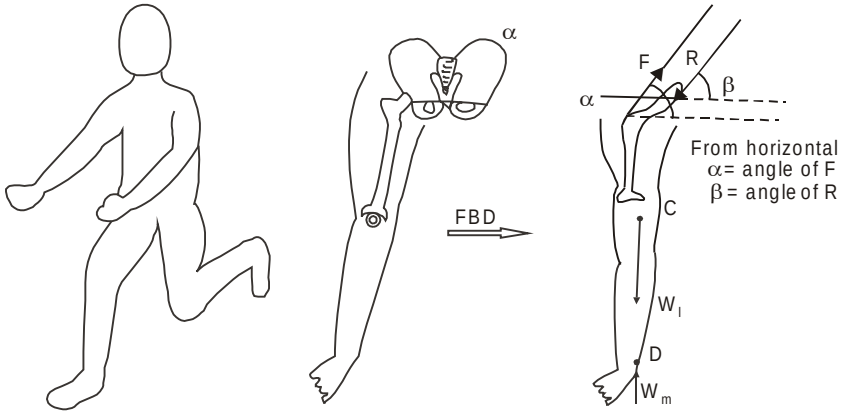
$$= W_m \sqrt{2.7.04 + 45.59}$$

$$= 8.52\ W_m$$

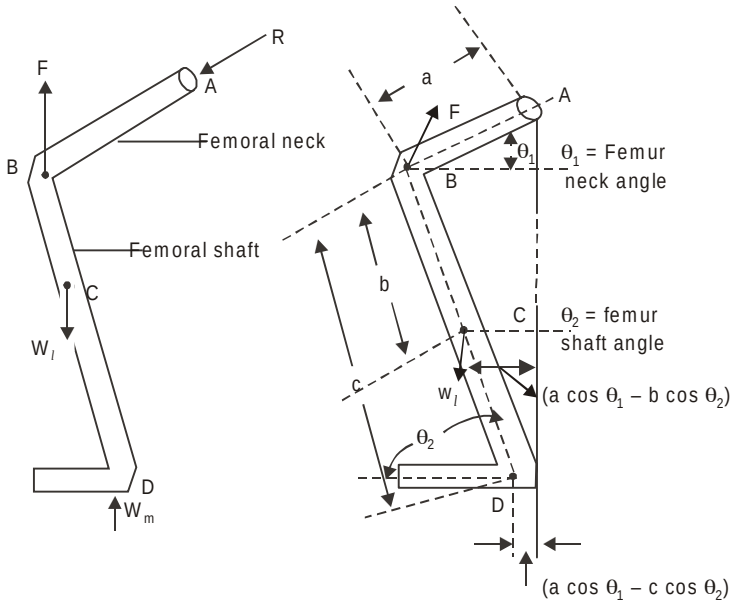
$$\theta = \tan^{-1} 57$$

It can be seen that muscle force (F) is 10.4 times and reaction at joint is 8.52 times the weight of the man when trunk is flexed for 30° from the vertical.

2. **Case study 2:** While walking and running, the body weight is momentarily taken by one leg. For the single leg stance, the forces acting on the leg are shown in the figure. *F* is the muscle force exerted by the abductor muscle. *R* is the reaction force developed by the pelvis on the femur. W_m is the weight of the man which acts on the leg as a normal force by the ground. W_l is the weight of the leg. Let α and β are angles made by *F* and *R* with the horizontal. A mechanical model of the leg with forces acting on it is also shown. A is point of rotation of the hip joint; *B* is point where the hip abductor muscles are attached to the femur; *C* is the centre of gravity of the leg where W_l is acting, and *D* is point where ground reaction force (= W_m) is acting upwards, The distance from point *B* to *A*, *C* and *D* are a, b and c as shown in the figure. α and β are the angles of F and R from horizontal while θ_1 and θ_2 are the angles of femur neck and femur shaft with the horizontal. The forces acting on the leg form a coplanar force system which will give us three equations of equilibrium ($\Sigma Px = 0$, $\Sigma Py = 0$, $\Sigma M = 0$)



One Leg Stance **Forces Acting on a Leg**



Mechanical Model of Leg

$\Sigma M_A = 0$, $F \sin\alpha \times a \cos\theta_1 - F \cos\alpha \times a \sin\theta_1 - W_1 \times (a \cos\theta_1 - b \cos\theta_2) + W_m \times (a \cos\theta_1 - \cos\theta_2) = 0$

$$F = \frac{(cW_m - bW_1)\cos\theta_2 - a\,(aW_m - W_1)\cos\alpha}{a\,(\sin\alpha\cos\theta_1 - \cos\alpha\sin\theta_1)}$$

$$= \frac{(CW_m - bW_1)\cos\theta_2 - a\,(W_m - W_1)\cos\alpha}{a\,\sin(\alpha - \theta_1)}$$

If we take $a : b : c = 1 : 4 : 10$, $\theta_1 = 45°$ $\theta_2 = 80°$, $\alpha = 75°$ and $W_1 = 18\%$ of W_m, then we get

$$F = \frac{\left\{\begin{array}{l}\left(\frac{10}{15}\times W_m - \frac{4}{15}\times 0.18W_m\right)\cos 80 \\ -\frac{1}{15}(W_m - 0.18W_m)\cos 75\end{array}\right\}}{\frac{1}{15}\times\sin(75-45)}$$

$$= \frac{(10 - 0.72)\,0.174 - (1-0.18)\times 0.259}{0.5}\times W_m$$

$$= \frac{9.28\times 0.174 - .82\times 0.259}{0.5} \times W_m$$

$$= \frac{1.6 - 0.21}{0.5} \times W_m$$

$$= 2.78\ W_m$$

Hence force exerted by the abductor muscle is 2.78 times the weight of the man.

$\Sigma Px = 0$, $F \cos\alpha - R \cos\beta = 0$

or $R \cos\beta = F \cos\alpha$

$R \cos\beta = 2.78\ W_m \cos 75 = 0.72$

$\Sigma Py = 0$, $F \sin\alpha - R \sin\beta - W_l + W_m = 0$

$2.78\ W_m - R \sin\beta - 0.18\ W_m + W_m = 0$

or $R \sin\beta = 3.6\ W_m$

$$R = \sqrt{3.6^2 + 0.72^2} \times W_m$$

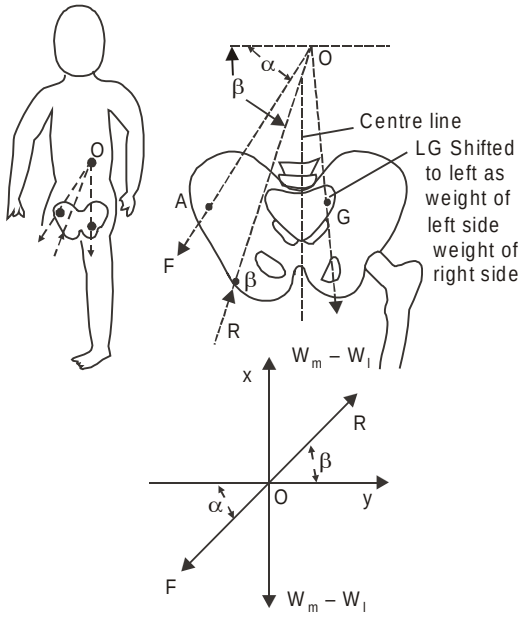
$$= \sqrt{12.96 + 0.52} \times W_m = 3.67\ W_m$$

Also $\tan\beta = \frac{3.6}{0.72} = 5$

or $\beta = 78.7°$

Hence the reaction force at the hip joint is 3.67 times the weight of the man and it makes angle of 78.70 with the horizontal.

3. Case study 3: In the last case study of one leg stance, we have considered the free body diagram of the leg and mechanical model of one leg in solving the magnitude of muscle force (F) and reaction at the joint (R). A simpler approach for finding F and R is to consider the free body diagram of the body minus the right leg (as shown in the figure) with the left leg on the ground.



Single Leg Stance

The weight of the man minus left leg (= $W_m - W_l$) does not act at middle line but now it shifts from centre towards a point at left side of CG point (left side is heavier than right side as shown in the figure). F is muscle force at A and R is reaction at hip joint at point B. Now we get a concurrent force system which meet at point O. We can apply lami's theorem for finding solution.

$$\frac{F}{\sin(90+\beta)} = \frac{R}{\sin(90-\alpha)}$$

$$= \frac{W_m - W_l}{\sin(180+\alpha-\beta)}$$

$$\frac{F}{\cos\beta} = \frac{R}{\cos\alpha} = \frac{W_m - W_l}{\sin(\beta-\alpha)}$$

$$\therefore \quad F = \frac{(W_m - W_l)\cos\beta}{\sin(\beta-\alpha)} \cos\beta$$

$$F = \frac{(W_m - W_l)\cos\alpha}{\sin(\beta-\alpha)}$$

If we take W_l = 18% W_m, $\alpha = 75°$ and $\beta = 78.7°$

$$F = \frac{(W_m - 0.18W_m)}{\sin(78.7-75)} \cos 78.7$$

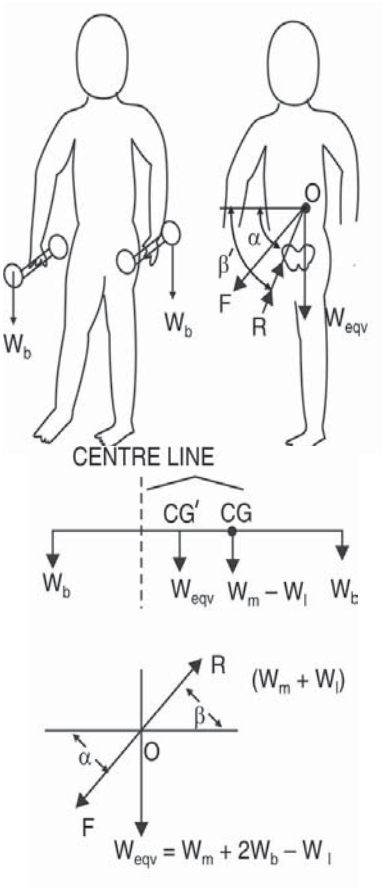
$$= \frac{0.82W_m \times .196}{0.0645}$$

$$= 2.49\ W_m$$

$$R = \frac{0.82\times 0.26}{0.0645} W_m = 3.3\ W_m$$

4. Case study 4: In one leg stance, if a man carries dumb bell in each hand, we can find muscle force (F) and hip joint reaction (R). In the free body diagram of the upper body

with load W_b in each hand and weight = $(W_m - W_l)$ is acting at CG is shown as in earlier case. The force F and reaction R will be having higher value due to extra loads in the hand. If we consider three weights W_b, $(W_m - W_1)$ and W_b as shown in the figures, the equivalent of these three weight $(W_m + 2W_b - W_l)$ will act at point CG′ which will be towards the left of the center line and the right of CG. Now we have three force system viz. *F, R* and $W_{eqv}(W_m + 2W_b - W_l)$ which are concurrent and Lami's theorem can be applied for a solution. If we consider the angle of muscular force makes same angle α with horizontal as in the last case, the new angle β' of the reaction will be greater than β of the last case since *CG′* has shifted towards the right of the man.



Single Leg Stance with Equal Weights in Hands

$$F = \frac{\cos\beta' \times W_{eqv}}{\sin(\beta' - \alpha)}$$

$$= \frac{\cos\beta' \times (W_m + 2W_b - W_l)}{\sin(\beta' - \alpha)}$$

$$R = \frac{\cos\alpha \times W_{eqv}}{\sin(\beta' - \alpha)}$$

$$= \frac{\cos\alpha \times (W_m + 2W_b - W_l)}{\sin(\beta' - \alpha)}$$

It can be seen that carrying loads by using both hands helps in bringing the equivalent weight closer to the midline of the body and it is effective in reducing required musculoskeletal forces.

5. **Case study 5:** In the right leg stance if a man carries dumb bell in the left hand, we can consider upper body less right leg. The weight of the upper body $(W_m - W_l)$ acting at CG′ as explained in earlier cases will shift towards the left of the man (at CG′′) due to the extra load W_b. Hence the length of the lever arm of total gravitational force $(W_m - W_l + W_b)$ with respect to the right hip joint will increase. To counter balance the larger clockwise moment resulting from gravitational force, the abductor muscle has to exert larger force '*F*' so that it gives stabilising anticlockwise movement at the right hip joint. It can be seen that a shift of centre gravity from CG′ to CG′′ towards the left of the man will decrease the angle β' to β'' between R and the horizontal. The free body diagram of the upper body and the action of forces have been shown in the figure. We have now three force system which are concurrent and solution can be worked out by applying Lami's theorem.

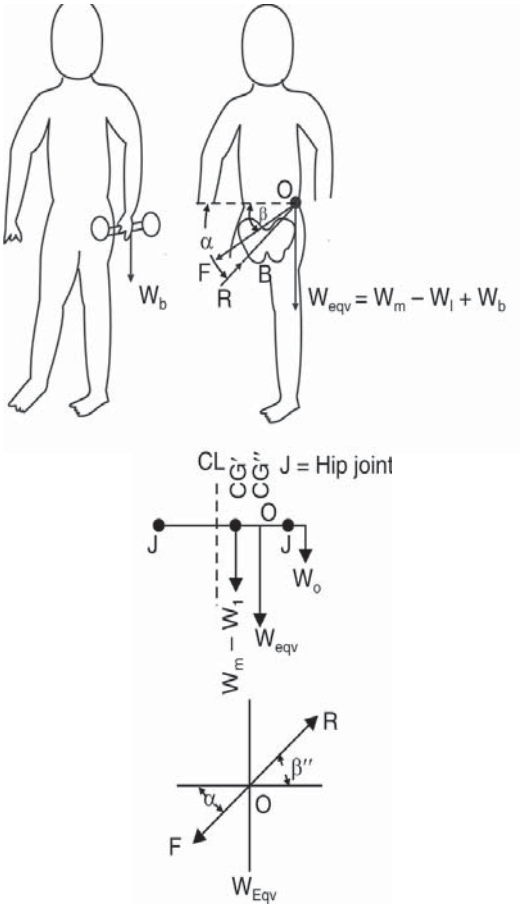
$$F = \frac{\cos\beta''(W_{eqv})}{\sin(\beta'' - \alpha)}$$

$$= \frac{\cos\beta'' \times (W_m + W_b - W_l)}{\sin(\beta'' - \alpha)}$$

$$R = \frac{\cos\alpha\,(W_{eqv})}{\sin(\beta'' - \alpha)}$$

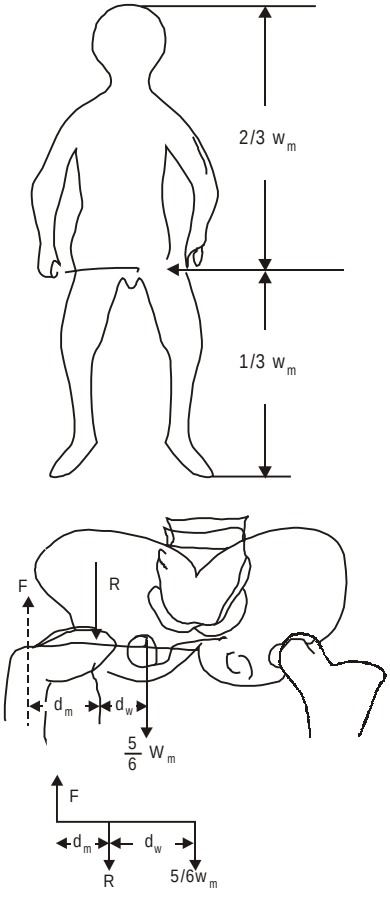
$$= \frac{\cos\alpha\,(W_m + W_b - W_l)}{\sin(\beta'' - \alpha)}$$

It can be seen that shifting of CG′ to CG″ (towards left) will decrease the angle from β′ to β″ for the reaction. The supporting muscle force F required at the hip joint is greater when load is carried on the opposite side of the body as compared to the force required to carry the loads by using both hands. If the load is carried on the same side *i.e.*, right side, the supporting muscle force required at the right hip joint is less but the muscle force required at the left hip joint is greater.



Right Leg Stance

6. **Lever approach:** The lever approach can be used for calculation of hip joint forces. It is an approximation method. Assumptions are:
   (1) all forces are vertical
   (2) all anatomical angles are neglected
   (3) 1/3 of body weight (W_m) consists of lower limbs and upper body consists of 2/3 of the body weight. Hence during single leg stance, the weight of upper body and one leg is equal to $\frac{5}{6}\ W_m$.
   (4) The ratio of d_m (distance of muscle force from the joint) and dw (distance of the point where net weight is acting) equal to 1:3. As shown is in the figure.



Lever Approach : One Leg Stance

$$F \times d_m = \frac{5}{6} W_m \times d_w \text{ or}$$

$$F = \frac{5}{6} \times W_m \times \frac{d_w}{d_m} = \frac{5}{6} \times \frac{3}{1} . W_m$$

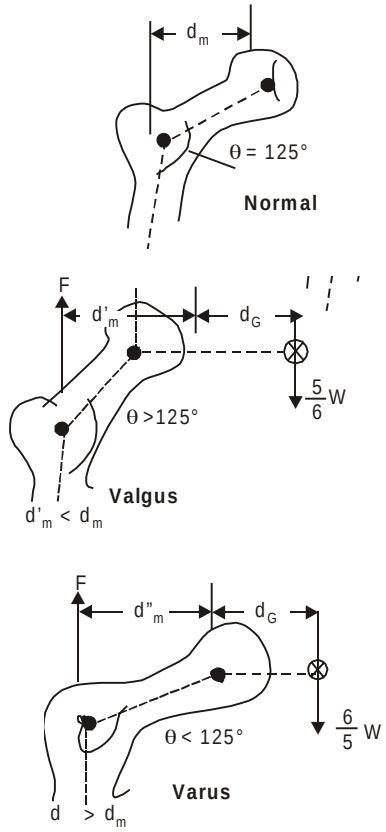
$= 2.5W_m$.

If man weighs 1000 N, Then,

$F = 2.5 \times 1000 = 2500$ N and

$R = 2500 - 1000 = 1500$ N.

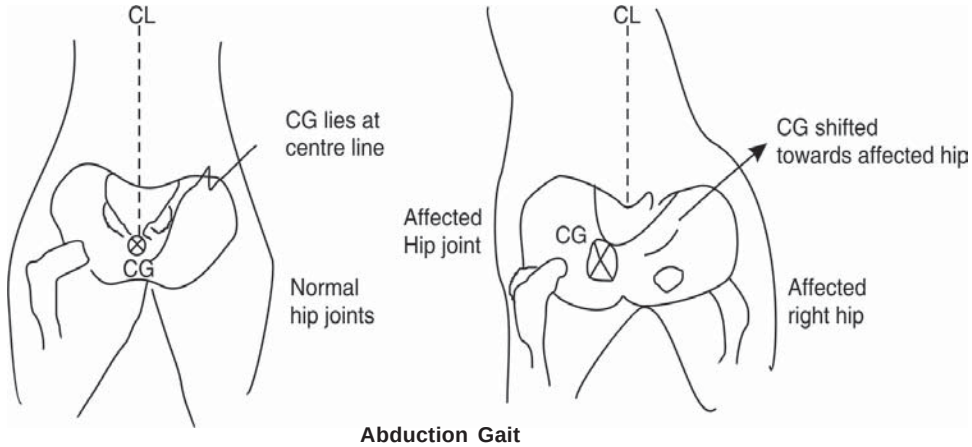
7. Pathological hip joint: The angle of femoral neck from normal is about 125°. In valgus deformity, the femoral neck bends or twists outward and the angle becomes



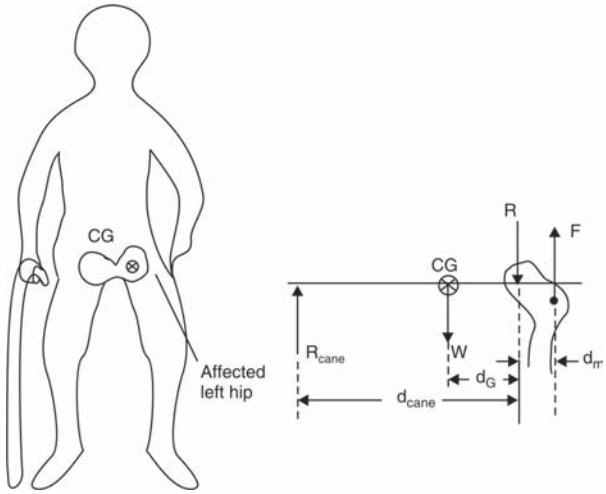
Pathologic Hip Joint

greater than 125°. The moment arm of the muscle force (d_m) decreases to d_m'. Hence abductor muscle force (F) has to increase to provide stabilising moment to balance the moment development by the weight of upper body and one leg during single leg stance as $F \times d_m' - 5/6W \times d_G$. As F has increased while weight does not change, reaction (R) at the joint will also increase. In varus deformity, the femoral neck bends or twists inward and the angle of femur neck with normal becomes less than 125°. This will increase d_m to which will result in decrease of abductor muscle force (F) as $d_m'' \times F = \frac{5}{6} W_m \times d_G$. Similar effect takes place if femoral neck is longer than usual. However bending stresses in the femoral neck increase in various deformity or when femoral neck is longer than usual. Therefore, femoral neck is more susceptible to fracture.

8. Other factors affecting hip joint: People with weak hip abductor muscles or painful hip joints usually lean towards the weaker side and walk with an abductor gait. Leaning the trunk sideways towards the affected hip shifts the centre of gravity of the body closer to the affected joint. The shifting of CG results into the reduction of the moment arm of the body weight. This reduces the rotational action of the moment of the body weight. Hence we require lower magnitude of abductor muscle force (F) to stabilise the movement due to the weight. Abductor gait can also be corrected more effectively with a cane held in the hand opposite to the weak hip joint as shown in figure on next page. The reaction on the cane acts opposite to the body weight and that too with a bigger moment arm from the hip joint. The abductor muscle force (F) reduces as $F \times d_m = W \times d_G - R_{cane} \times d_{cane}$. The lower F means lower hip joint reaction (R).



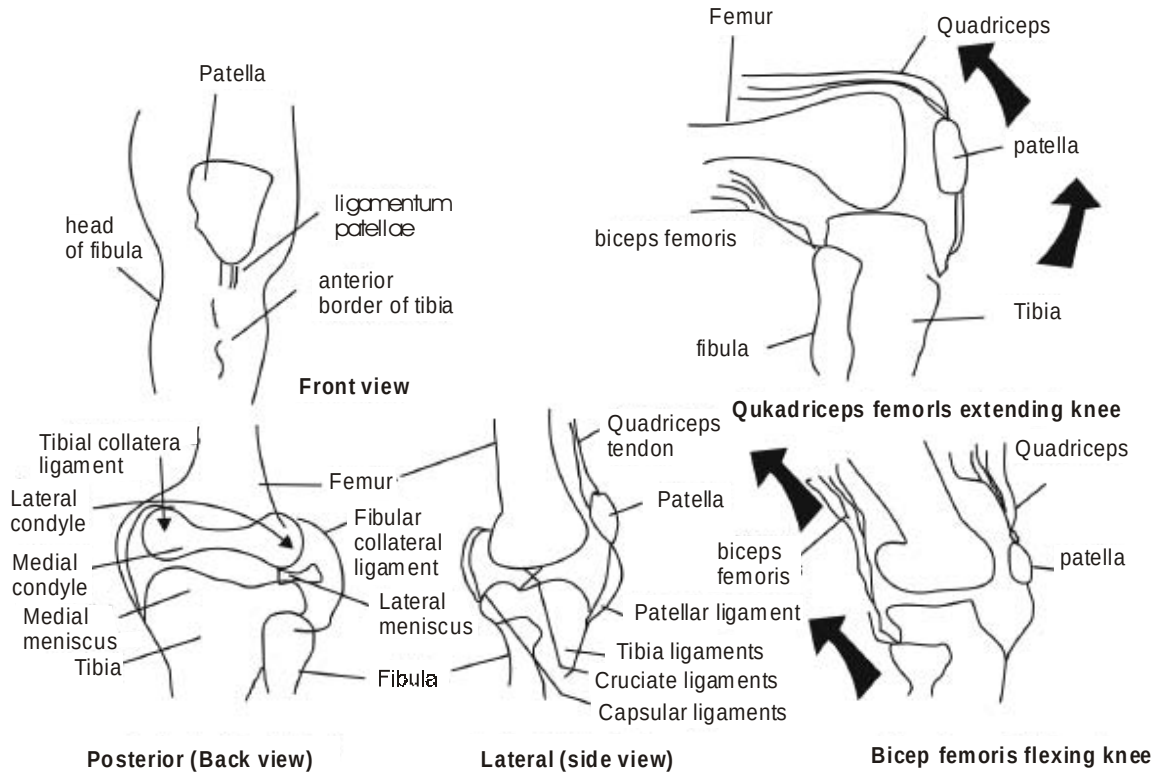
Abduction Gait



Effect of Cane

MECHANICS OF THE KNEE

1. The knee is the largest joint in the body. It is also a most complex joint. The complexity is the result of fusion of three joints in one. It is formed by fusion of the lateral femorotibial, medial femorotibial and femoropatellar joints. It is a compound synovial joint, incorporating two condylar joints between the condyles of femur (thigh bone) and tibia (leg bone) and one saddle joint between the femur and the patella. The femorotibial has two distinct articulations between the medial and lateral condyles of the femur and the tibia. These articulations are separated by layers of cartilage, called menisci (fibrocartilaginous discs). The lateral and medial menisci prevent bone to bone contact between the articulating surfaces of the femur and the tibia and they also work as shock absorbers. The femoropatellar joint is the articulation between the anterior end of the femoral condyles and the patella which is a floating bone kept in position by the quadriceps tendon and the patellar ligaments. The patella also protects the knee from impact related injuries and enhances the pulling effect of



quadriceps muscles on the tibia through patellar tendon. The stability of the knee joint is provided by (1) ligaments (2) menisci (3) muscles crossing the joint. Flexion and extension are chief movements. These movements take place in the upper compartment of the joint above the menisci. They differ from the ordinary hinge movement in two ways (1) The transverse axis around which these movements take place is not fixed. During extension, the axis moves forward and upwards and in the reverse direction during flexion, (2) These movements are invariably accompanied by rotations. Rotatory movements at the knee are of a small range. Rotations take place around a vertical axis and are permitted in the lower compartment of the joint, below the menisci. Muscles producing movements at the knee joints are:

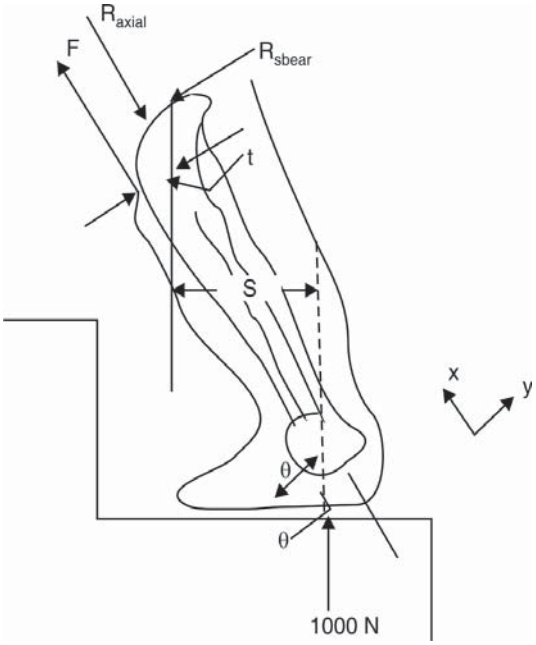
Movement	***Principal Muscles***
1. Flexion	1. Biceps femoris 2. Semitendinosus 3. Semimembranosus
2. Extension	1. Quadricep femoris
3. Medial rotation of fixed leg	1. Popliteus 2. Semimembranosus 3. Semitendinosus
4. Lateral rotation of flexed leg	Biceps femoris

2. The knee is a weak joint because the articular surfaces are not congruent. The tibial condyles are too small and shallow to hold the large and convex femoral condyles in place. The femoropatellar articulation is also quite insecure because of the shallow articular surfaces and the outward articulation between the long axis of the

thigh and of the leg. The stability of the joint is maintained by cruciate and collateral ligaments and muscles crossing the joint. The leg may be abnormally abducted (genu valgum or knock knee) or abnormally adducted (genu varus or bow knee). Common injuries are (1) injury to menisci (2) injury to cruciate ligaments (3) injury to collateral ligaments.

3. Another leg bone on the outerside of tibia is known as fibula. It acts as support to the tibia but does not take any part in the knee joint formation. The front portion of the knee joint is formed by patella which articulates with the lower part of the femur and upper part of the tibia. The patella moves up and down with contraction and relaxation of the thigh muscle while straightening and bending the joint. The movements of the joint are smooth and painless as long as there is no trauma or irregularity in their articular surfaces. Any physical or nutritional trauma may cause degeneration of the articular surfaces or loose body formation. These changes are associated with pain and irregular movements at the joint and further degeneration of the joint.

4. **Case study 1:** To determine muscle force '*F*' acting in patellar tendon, reactions R_{axial} and R_{shear} on the tibial plateau when a man weighing 1000 N is slowly climbing the stairs as shown in the figure. Let θ is angle made by the tibia with horizontal, t = distance between patellar tendon from the patello femoral joint, S = horizontal distance between ground reaction and the patello femoral joint. Assume the weight of the lower leg and any effect of fibula are negligible. We have now a system of coplanar force system and we get three equations of equilibrium *i.e.* $\Sigma Mj = 0$, $\Sigma Px = 0$, $\Sigma P_y = 0$, $\Sigma Mj = 0$, $F \times t - 1000 \times S = 0$



Free Body Diagram of Lower Leg

$$\text{or } F = 1000 \times \frac{S}{t}$$

$\Sigma Px = 0$ (along the long axis of the tibia)

$R_{axial} = 1000 \cos \theta + F$

$\Sigma P_Y = 0$, $R_{shear} = 1000 \sin \theta$

If we take $t = 60$ mm, $s = 200$ mm and $\theta = 60°$, then

$$F = 1000 \times \frac{200}{60} = 3333.3 \text{ N}$$

$$R_{axial} = 1000 \times \frac{1}{2} + 3333.3$$

$$= 3833.3 \text{ N}$$

$$R_{shear} = 1000 \times \frac{\sqrt{3}}{2} = 866 \text{ N}$$

5. **Case study 2:** A man is wearing a heavy boot and doing lower leg flexion and

extension exercise from a sitting position as shown in the figure. We draw the free body diagram of lower leg as well as mechanical model of the leg. *F* is the magnitude of force exerted by the quadriceps muscle on the tibia through the patellar tendon.

R is the reaction on the tibiofemoral joint at point 0. The patellar tendon is attached to the tibia bone at point A. The *CG* of the lower leg is located at point B. The CG of the boot is located at C. The distance of point *AB* and *C* from point O are *a*,*b* and *c* respectively. The tibia makes an angle of α with horizontal and the muscle force makes angle of β with the long axis of the tibia. We resolve the forces along the tibia axis (x-axis) and vertical to the tibia axis (y-axis)

$$F_x = F \cos \beta$$
$$F_y = F \sin \beta$$

$$W_{bx} = W_b \sin \alpha$$
$$W_{by} = W_b \cos \alpha$$
$$W_{lx} = W_l \sin \alpha$$
$$W_{ly} = W_1 \cos \alpha$$

Taking moment about point 'O' which is $\Sigma M_O = 0$

$$F \sin \beta \times a - W_1 \cos \alpha \times W_b \cos \alpha \times c = 0$$

$$\text{or } F = \frac{(b W_l + c W_b) \cos \alpha}{a \sin \beta}$$

Now $\Sigma Px = 0$

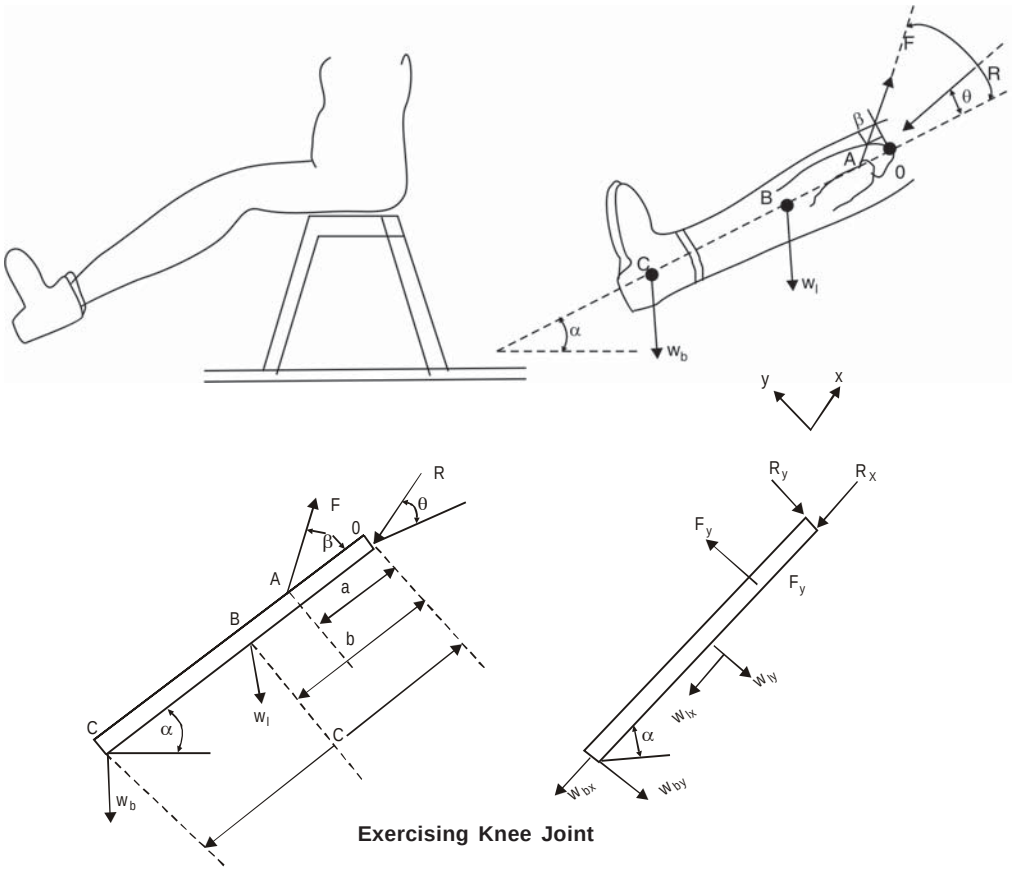
$$R \cos \theta - F \cos \beta + W_b \sin \alpha + W_1 \sin \alpha = 0$$

Now, $\Sigma Py = 0$

$$R \sin \theta = F \sin \beta - (W_b + W_l) \cos \alpha.$$

$$R^2 = [F \cos \alpha - (w_b - w_b) \sin]^2 +$$

$$[F \sin \beta + (W_b + W_b) \cos \alpha]^2$$



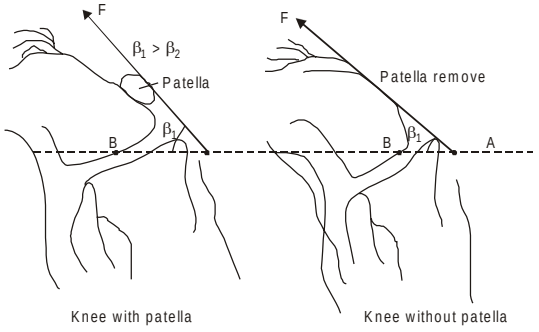
Exercising Knee Joint

$$R^2 = F^2 + (W_b + W_l)^2$$

$$-2F(W_b + W_l)\sin(\alpha + \beta)$$

6. It can be seen that normal component of F (quadricep muscle force = $F \sin \beta$) tries to rotate the tibia about the knee joint while its tangential component (= $F \cos \beta$) along the tibia axis tends to move the tibia towards the tibiofemoral joint. If θ is small, $F \cos \theta$ is more and more muscle force is wasted to compress the knee joint. If θ is large, $F \sin \theta$ is large and a larger portion of the muscle tension is used to rotate the tibia or lower leg about the knee joint.

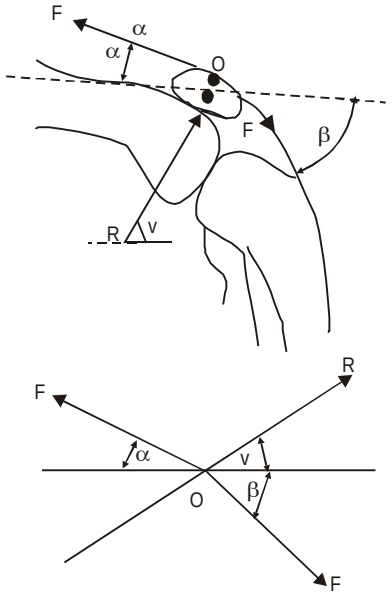
7. It can be seen that the patella bone provides anterior displacement of the quadriceps and patellar tendons thus lengthening the moment arm of the muscular force by increasing the angle β. As shown in the figure, muscular force F make angle β_1 when patella is present and angle β_2 when patella is absent. The moment arm is $AB \sin \beta_1$ with patella > $AB \sin \beta_2$ without patella as $\beta_1 > \beta_2$. Decreasing of moment arm results into the quadriceps muscle to exert more force than normal to rotate the lower leg about the knee joint.



Functions of Patella

8. It can be seen that quadriceps muscle goes over the patella while getting connected to the femur and the tibia. The patella and the muscle form a rope pulley arrangement. The larger is the tension in the muscle, the larger is the compressive force or pressure, the patella exerts on the femoropatella joint.

Now we have three forces F, F and R which are concurrent at point 0 with angles of the forces are α, β and v respectively with the horizontal. We can apply Lami's theorem for finding a solution.



Patella Pressure on patellofemoral Joint

$$\frac{F}{\sin(\beta+\gamma)} = \frac{F}{\sin(180-(\alpha+\gamma)} = \frac{R}{\sin(180-\beta-\alpha}$$

$$\frac{F}{\sin(\beta+\gamma)} = \frac{F}{\sin(\alpha+\gamma)} = \frac{R}{\sin(\beta-\alpha)}$$

or $$R = \frac{F}{\sin(\alpha+\gamma)} \sin(\beta-\alpha)$$

or $$R = \frac{F}{\sin(\beta+\gamma)} \sin(\beta-\alpha)$$

and $\sin((\beta + \gamma) = \sin(\alpha + \gamma)$

or $\sin\beta\cos\gamma + \cos\beta\sin\gamma = \sin\alpha\cos\gamma + \cos\alpha + \sin\gamma$

or $\sin\beta + \cos\beta\tan\gamma = \sin\alpha + \cos\alpha\tan\gamma$

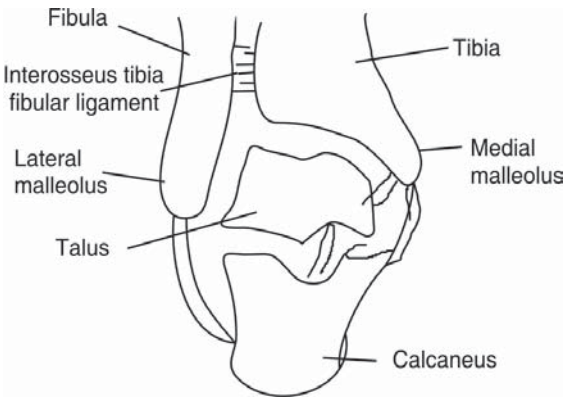
or $\tan\gamma(\cos\beta - \cos\alpha) = \sin\alpha - \sin\beta$

or $$\gamma = \tan^{-1}\frac{\sin\alpha - \sin\beta}{\cos\beta - \cos\alpha}$$

MECHANICS OF THE ANKLE

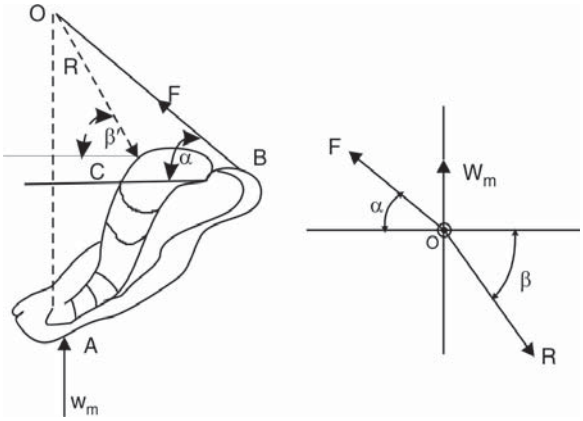
1. The ankle joint consists of a deep socket formed by the lower ends of the tibia and fibula into which is fitted the upper part of the body of the talus. The talus is able to move on a transverse axis in a hinge like manner. The shape of the bone and the strength of the ligaments and the surrounding tendons make this joint strong and stable.

2. The ankle joint complex consists of three joints *i e.* tibiotalar, fibulotalar and tibiofibular. The tibiotalar joint (ankle joint) is a synovial joint of the hinge variety. The articulation is between the spool like convex surface of the trochlea (structure serving as pulley) of the talus and the concave distal end of the tibia. The tibiotalar joint is the articulation between the external malleolus (rounded bony) of the tibula and the medial and lateral surfaces of the trochlea of the talus. The distal tibiofibular joint is the articulation between the internal malleolus of the tibia and the external malleolus of the fibula. The ankle permits flexion and extension in sagittal plane, inversion and eversion, inward and outward rotation, and pronation and supination movements are possible about the foot joints such as the subtalar and transverse joints between the talus and calcaneus.



Ankle Joint

3. **Case study:** Consider a man standing on tiptoe of the foot as shown in the figure. The ground reaction equal to weight of the man is acting vertically unwards at point '*A*' *F* is the magnitude of the force exerted by the archilles tendon and it makes angle α with the horizontal at point B. R is the magnitude of reaction exerted by the tibia on the talus at the ankle joint (point '*C*').



Ankle Joint

It makes an angle β with the horizontal. Now we have three force system and these forces have to be concurrent during equilibrium. We can apply Lami's theorem to find the solution.

$$\frac{F}{\sin(90+\beta)} = \frac{W_m}{\sin(180-\alpha+\beta)} = \frac{R}{\sin(90-\alpha)}$$

$$\frac{F}{\cos\beta} = \frac{W_m}{\sin(\alpha-\beta)} = \frac{R}{\cos\alpha}$$

$$\therefore \quad F = \frac{W_m \cos\beta}{\sin\alpha-\beta}$$

$$\text{and} \quad R = \frac{W_m \cos\alpha}{\sin(\alpha-\beta)}$$

OBJECTIVE TYPE QUESTIONS

Fill up the gaps

1. The hip bone is made of _____ elements
(*a*) two (*b*) three

2. There are _____ hip bones (*a*) two (*b*) three

3. The thigh bone is _____
(*a*) Tibia (*b*) femur

4. Lower limbs and upper limbs have a _____ by which they are attained to axial skeleton (*a*) girdle (*b*) joint

5. Tibia and _____ are leg bones (*a*) femur (*b*) fibula

6. The hip joint is formed by the femoral head fitting well into the deep socket of the _____(*a*) acetabulum (*b*) sacrum

7. The _____ of the leg does not take part in the formation of knee joint (*a*) tibia (*b*) fibula

8. Patella is also known as _____ (*a*) knee cap (*b*) force deflector

9. Patella is a large _____ bone developed in the tendon of quadriceps femoris
(*a*) sesamoid (*b*) irregular

10. Acetabulum has a shape of _____
(*a*) cup (*b*) plane

11. In varus deformity, the femoral neck bends or twists _____ (*a*) inward (*b*) outward

12. In valgus deformity, the femoral neck bends or twists (*a*) inward (*b*) outward

13. The angle of femur neck with vertical is greats than 125° for _____ and less than 125° for _____ (*a*) valgus, varus (*b*) varus, valgus

14. The femoral neck is _____ susceptible to fracture in varus deformity (*a*) more (*b*) less

15. A man with weak hip abductor muscle or painful hip joint usually lean _____ the weaker side (*a*) toward (*b*) away

16. Leaning towards the painful side while walking is called _____ (*a*) abductor gait (*b*) crippled gait

17. The largest joint in the body is _____ (*a*) knee (*b*) hip

18. The most complex joint in the body is _____ *a*) knee (*b*) hip

19. The knee joint is a complex joint formed by the thigh bone, leg bones and _____
(*a*) patella (*b*) talus

20. The ankle joint formed by the tibia and fibula as they form socket into which is fitted upper part of the _____(*a*) calcaneous
(*b*) talus

21. Patella also _____ the moment arm of the muscular force during extension
(*a*) shortens (*b*) lengthens

22. The knock knee is an abnormality of the knee joint when the leg is abnormally -----
(*a*) adducted (*b*) abducted

23. The bow knee is an abnormality of the knee joint if the leg is abnormally ---------
(*a*) adducted (*b*) abducted

24. Cane is held -----side of the painful hip joint to reduce the abductor muscle force
(*a*) same (*b*) opposite

ANSWERS

1. (*b*)	**2.** (*a*)	**3.** (*b*)	**4.** (*a*)	**5.** (*b*)	**6.** (*a*)
7. (*b*)	**8.** (*a*)	**9.** (*a*)	**10.** (*a*)	**11.** (*a*)	**12.** (*b*)
13. (*a*)	**14.** (*a*)	**15.** (*a*)	**16.** (*a*)	**17.** (*a*)	**18.** (*a*)
19. (*a*)	**20.** (*b*)	**21.** (*b*)	**22.** (*b*)	**23.** (*a*)	**24.** (*b*)

THE CARDIOVASCULAR SYSTEM AND BLOOD FLOW

10

Accept God's advice gracefully as long as it doesn't interfere with what you intend to do.

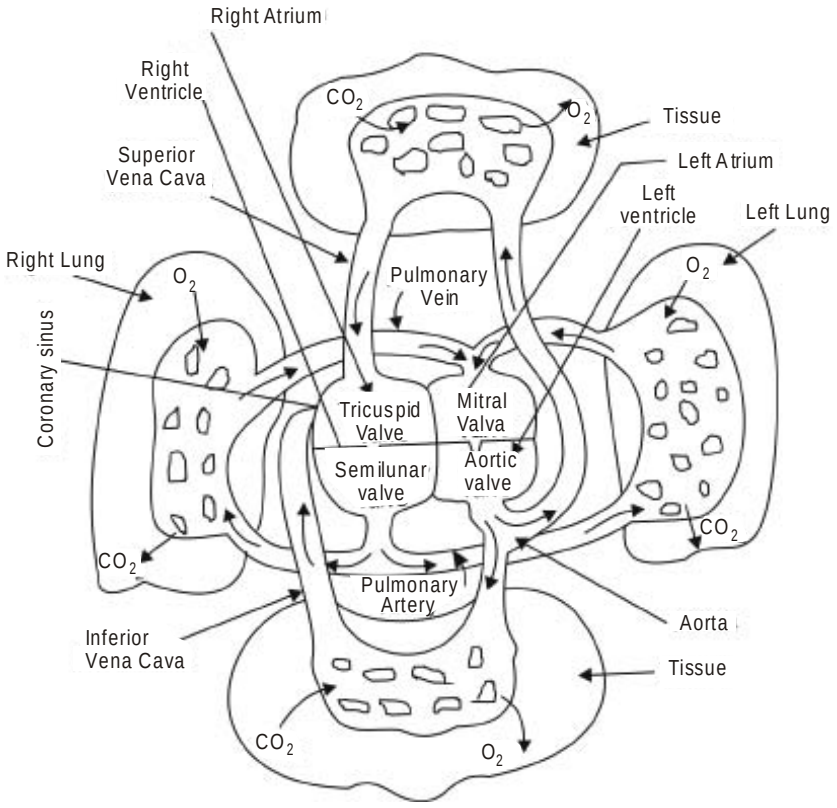
INTRODUCTION

1. The blood has carriers of fuel supply. The blood has ability to transport waste materials to predestined destinations. The blood also contains a mechanism for repairing small system punctures and a method for rejecting foreign elements from the system. Man is able to sustain life because the blood is supplied to all systems of the body. The circulating blood supplies oxygen and nutrients to the cells of the body. The heart is a very important organ in the body which acts as a pump to circulate the blood in the body. The failure of heart is the cause of many deaths. There are many techniques and instruments to measure functioning of heart and to diagnose any of its malfunctioning for treatment so as to avoid its failure. The cardiovascular system consists of heart, distribution system (arteries and arterioles), diffusing system (capillaries in contact with cells) and collecting systems (veins), The cardiovascular system is a closed hydraulic system. Blood pressure, flow and volume are measured by using engineering techniques.

WORKING PRINCIPLE OF CARDIOVASCULAR SYSTEM

1. The cardiovascular system or the blood vascular system is a closed hydraulic system. The blood consists of plasma and corpuscles. The red corpuscles, white corpuscles and thrombocytes are suspended in the plasma. There are about 4.5 to 5.5 million red blood cells per cubic millimeter of blood. There is about 3.5 to 5 litres/min blood circulating in normal adult at rest. The blood circulating system consists of:

(*a*) *Heart:* The circulation of blood is maintained within the blood vessels by the rhythmic pressure in the trunk vessels exerted by the contraction and expansion of the heart. The heart acts as a pump whose elastic muscular walls contract rhythmically to develop pressure to push the blood through the vascular system. The heart contracts



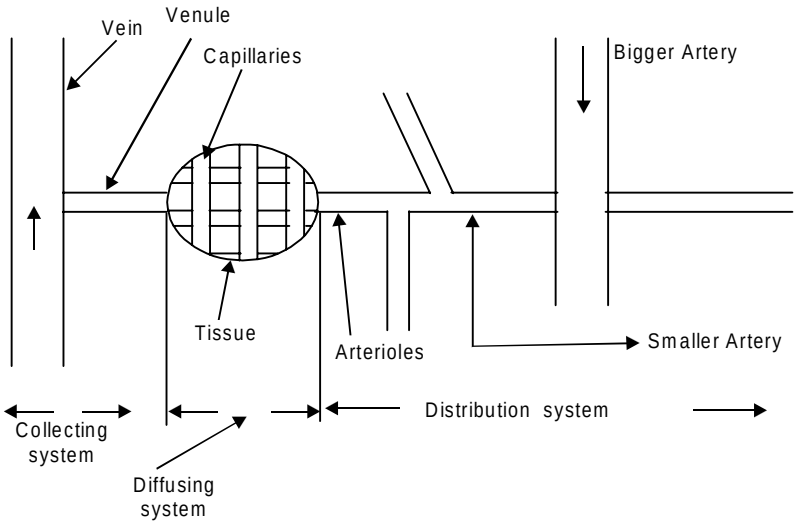
Blood Circulation Systemically

continuously and rhythmically, without rest, about 1,00,000 times per day. The average heart rate is 75 beats per min *i.e.*, each cycle of beat is completed in 0.8 seconds.

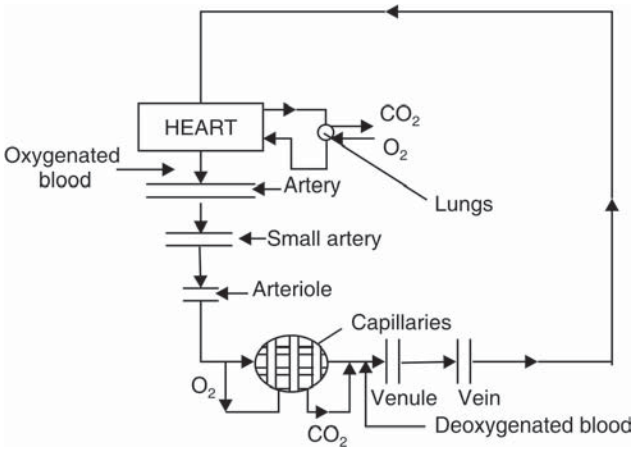
(*b*) *Distribution system:* The blood is supplied to all cells of the body through distribution system which consists of arteries, arterioles and capillaries. Each artery bifurcates to smaller arteries until smaller type (arterioles) is reached. The arterioles feed into the capillaries where oxygen is supplied to the cells and carbon dioxide is removed from the cells. The oxygen depleted blood moves to venules.

(*c*) *Diffusing system:* It consists of fine capillaries which are in contact with the cells of the body. Capillaries take blood from arterioles and transference of oxygen to cells and carbon dioxide to the blood takes place through capillaries. The oxygen depleted blood from capillaries moves to vein. Tissue metabolism is the process by which cells take oxygen from blood and give out carbon dioxide to blood.

(*d*) *Collecting system:* It consists of veins. It collects blood which is depleted of oxygen and which contains waste products of metabolic processes from various organs. The blood is taken back to heart which sends it to lungs for reoxygenation and then the recirculation of oxygenated blood to all systems of the body. The veins differ from arteries in having valves to control the direction of flow towards the heart.



Distribution, Diffusion and Collecting System



Blood Circulation

2. The organs which are supplementing the functioning of cardiovascular system are:

(*a*) *Lungs:* The blood with carbon dioxide and air intake reach lungs which provide a region of interface for the transfer of oxygen to the blood from air and removal of carbon dioxide from the blood to the air.

(*b*) *Kidney/liver and spleen:* These organs help in the removal of waste products and in maintaining the chemical quality of the blood.

THE HEART: WORKING AND STRUCTURE

1. The heart can be considered as a pair of two stage pumps working in series with each stage of the pumps arranged physically in parallel. However the circulating blood passes through from first stage to second

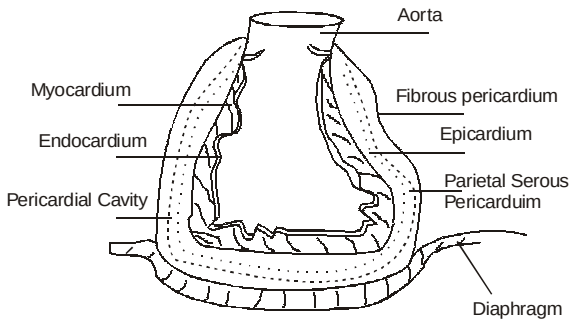
stage. The heart has two halves *viz.* the right heart and the left heart. The right heart is a low pressure pump while the left heart is a high pressure pump. The right heart receives blood from inferior venacava and superior venacava veins and pumps it to the lungs. The blood flow through the lungs is called the pulmonary circulation. The left heart receives blood from the pulmonary vein. The left heart acts as a pressure pump and it pumps the blood for the systemic circulation which has a high circuit resistance with a large pressure gradient between the arteries and veins. The muscle contraction of the left heart is larger and stronger as it is a pressure pump while the right heart is a volume pump with lesser contraction. However, the volume of blood handled by each pump is same as they are working in series. The cardiac muscles form the wall of the heart. The structure is somewhat in between striped and unstriped. The muscles are not in the control of "will". The muscles contract rhythmically and they are immune to fatigue. The muscles receive their own blood supply from the coronary arteries.

2. The deoxygenated blood enters the storage chamber of the right heart which is called the right atrium. The coronary sinus also brings the deoxygenated blood after circulating through the heart by the coronary loop and empties it into the right atrium. When the right atrium is full, the right heart contracts and it forces blood through the tricuspid valve into the right ventricle. Now the right ventricle contracts, the tricuspid valve closes and the pressure in the ventricle forces the semilunar pulmonary valve to open so that the blood can flow through pulmonary artery into the lungs. The blood is oxygenated in the lungs.

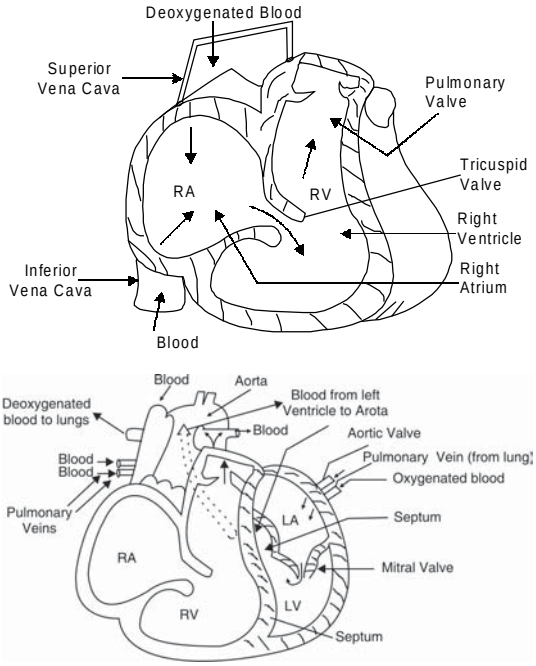
3. The oxygenated blood enters the left atrium from the pulmonary vein. The blood is pumped into the left ventricle through mitral (also called bicuspid) valve by the contraction of the left atrium muscles. When the left ventricular muscles contract, the pressure increases and it closes the mitral valve. The pressure further increases and it forces the aortic valve to open, permitting the blood to rush into the aorta. The outward flowing of the blood from the right and left heart takes place synchronously. The pumping cycle can be divided into two parts viz. systole and diastole. Diastole is the period of dilation when the left and right atrium are filled with blood. Systole is the period of contraction, of the left and right ventricle muscles when the blood is pumped into the aorta and the pulmonary artery. Once the blood has been pumped into the arterial system the muscles relax resulting in a decrease in pressure in both ventricles. The in a outlet valves close and inlet valves open to restart a new cycle of the heart. The volume of blood is about 5 to 6 litres in a man and the heart pumps about 5 litres per min during resting. Hence heart can circulate complete blood in about one min. However, during running or heavy exercise the circulation rate is increased considerably. 120 mm Hg (Mercury) is the average blood pressure during systole which is called "high blood pressure". 80 mm Hg is the average blood pressure during diastole which is called "low blood pressure". A healthy person has 120/80 blood pressure which means systolic pressure = 120 mm Hg (it is gauge pressure, which gives absolute pressure = 120 + 760 mm = 880 mm Hg $\approx \frac{880}{1000} \times 13.6 \times 9.81 =$ 117.4 kpa) and diastolic pressure = 80 mm Hg (It is gauge pressure. The absolute pressure = 80 + 760 = 840 mm of Hg = $\frac{840}{1000} \times 13.6 \times 9.81 = 112.07$ kpa). The rise of the blood pressure or the fall of the blood pressure from the normal blood pressure

indicates malfunctioning of heart or any blockade in the arterial system.

4. **Structure of the heart:** The walls of the heart are composed of a thick layer of cardiac muscle which is called myocardium. Myocardium is covered externally by the epicardium and lined internally by the endocardium. The heart is divided into four chambers by septum. Septum is a thin wall where it divides atrial portion into right and left atrium. Septum is a thick wall where it devides ventricular portion into right and left ventricle. The superior venacava opens into the upper part of the right atrium. The opening does not have any valve. It returns the deoxygenated blood from the upper portion of the body. The larger inferior vena cava opens into the lower part of the right atrium. It has non functioning valve at the opening. The deoxygenated blood from the lower portion of the body enters through it. The coronary sinus brings blood after circulation from the heart and it has an opening between superior and inferior vena cava. The right ventricle is connected with the right atrium through the atrioventricular orifice which is guarded by the tricuspid valve. The tricuspid valve consists of three cusps. The right ventricle is connected to the pulmonary artery through pulmonary orifice which is guarded by the pulmonary valve. The valve consists of three semilunar cusps. The four pulmonary veins, two from each lungs, open into the left atrium. The opening has no valve. The left atrium is connected to the left ventricle through the atrioventricular orifice which is guarded by the mitral valve. The left ventricle is connected to the aorta through the aortic orifice which is guarded by the aortic valve. It consists of three cusps. The walls of the left ventricle are three times thicker than the walls of the right ventricle as to withstand the six times higher pressure in the left ventricle as compared to the right ventricle. As the ventricle has to perform stronger pumping work, its walls are thicker than the walls of the atrium and its surfaces are ridged. The shape of right ventricle is circular while it is crescentic for the left ventricle.



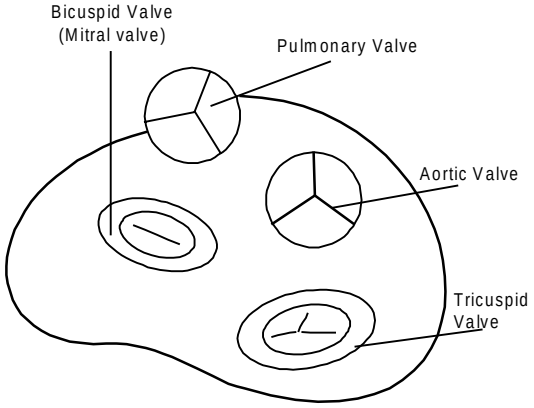
Heart : Walls and Layers



Heart Structure and Blood Flow

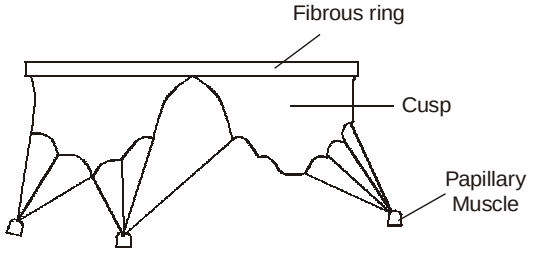
5. **Valves of the heart:** The valves of the heart maintain unidirectional flow of the blood. It also prevent the regurgitation of the blood in the opposite direction. There are four valves in the heart which consist of a pair

of atrioventricular valves and a pair of semilunar valves. The atrioventricular valves are a tricuspid valve having three cusps guarding right atrioventricular orifice and a bicuspid valve (mitral) having two cusps gaurding the left atrioventricular orifice. The semilunar valves are the aortic and pulmonary valves, each having three semilunar cusps as shown in figure.



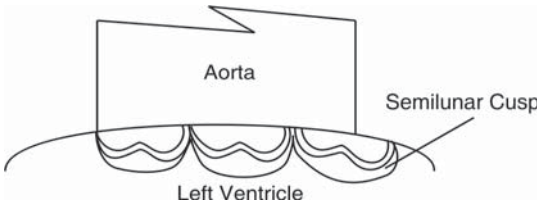
Four Valves of the Heart
(Cut portion and Atria Removed)

Atrioventricular valves are made of a fibrous ring to which the cusps are attached. These are flat and project into the ventricular cavity. The valves are closed during ventricular systole. The tricuspid valve has three cusps.



Atrioventricular Valve

It can admit the tips of three fingers. The bicuspid (Mitral) valve has two cusps. It can admit the tips of two fingers. The bicuspid cusps are smaller and thicker than those of the tricuspid valve. The atrioventricular valve having 3 cusps is shown in figure.

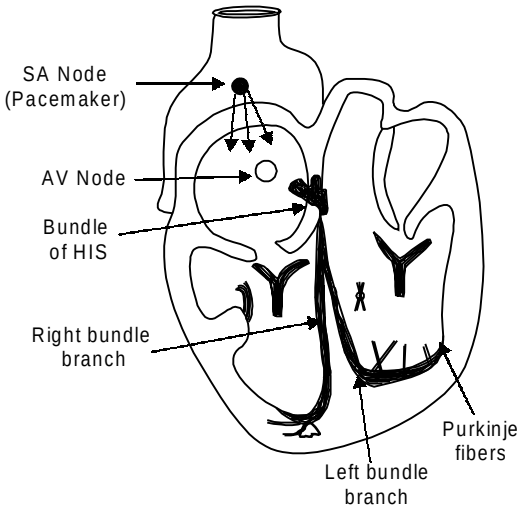


The Aortic Valve

Semilunar valves are the aortic and pulmonary valves. They are called semilunar valves because their cusps are semilunar in shape. Both valves are similar to each other. Each valve has three cusps which are attached to the vessel wall. The cusps form small pockets with their mouth facing away from the ventricles. The valves are closed during ventricular diastole when the cusps expand in the ventricular cavity.

6. **The conducting system of the heart:** The heart contracts rhythmically at about 70 beats per minute in the resting adult. The rhythmic contractile process originates spontaneously in the conducting system and the impulse travel to different regions of the heart so that both atriums contract first and together which is to be followed later by the both ventricles contracting together. The slight delay in the passage of the impulse from the atria to the ventricles permits time for the atria to empty their blood into the ventricles before the contraction of the ventricles. The sinoatrial node (SA) is located superior to the right atrium (full thickness of myocardium) where the excitation of the heart contraction is initiated. Sinoatrial (SA) node is also called pacemaker and it is a special group of excitable cells. Once initiated, the cardiac impulse spreads through the atrial myocardium to reach the atrioventricular (AV) node. The atrioventricular node is situated in the lower part of the atrial septum just above the tricuspid valve. From AV node, the cardiac impulse is conducted to the ventricles by the atrioventricular bundle. The

atrioventricular is the only muscular connection between the myocardium of the atria and the myocardium of the ventricles. The atrioventricular bundle descends to the lowest part of the ventricle septum. At the upper part of the septum, the atrioventricular bundle divides into two branches, one for each ventricle. The right branch moves down on the right-side of the ventricular septum and emerges at the anterior wall of the right ventricle where it joins with the fibers of the purkinje. The left branch of the bundle pierces the septum and passes down on the left side of the septum beneath the endocardium. The left branch further divides into two branches which ultimately join with the fibers of the purkinje of the left ventricles. The conducting system not only generates rhythmical cardiac impulses but also conducts these impulses quickly throughout the myocardium of the heart. It is essential so that the different chambers of the heart can contract in a coordinated and efficient manner. The SA node creates an impulse of electrical excitation that spreads across the right and left atrium. The right atrium receives the early excitation as it is nearer to the SA node. This excitation causes the atria to contract. A short time later, the excitation simulates the AV node. After a brief delay the activated AV node initiates an impulse into the ventricles through the bundle of HIS. The bundle branches take the impulse to the fibers of purkinje in the myocardium. The contraction occurs in the myocardium and the blood is pumped into pulmonary artery and aorta from the right and left ventricles. The heart rate is controlled by the frequency at which the SA node generates impulses. But the nerves of the sympathetic nervous system and the vagus nerve of the parasympathetic nervous system cause the heart rate to quicken or slow down respectively. The effects of the sympathetic and vagus nerves are in opposition to each other but the result is additive if they both occur together in opposite directions. The action of these nerves is called their tone. The nerves affecting the rate of the heart are controlled by the brain. The heart rate increases when a person is anxious, frightened or when a person indulges into overeating or has respiration problems or high blood pressure.

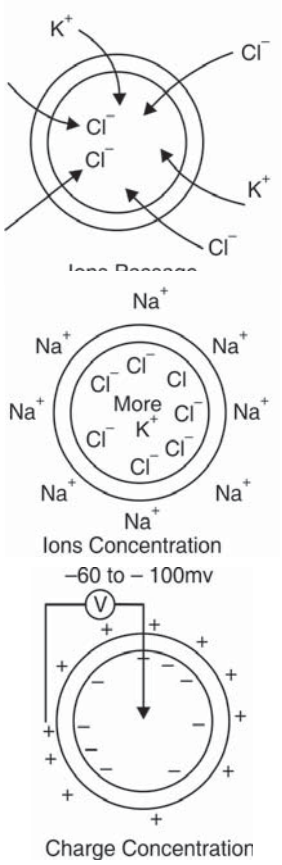


The Heart : Conduction System

RESTING AND ACTION POTENTIAL

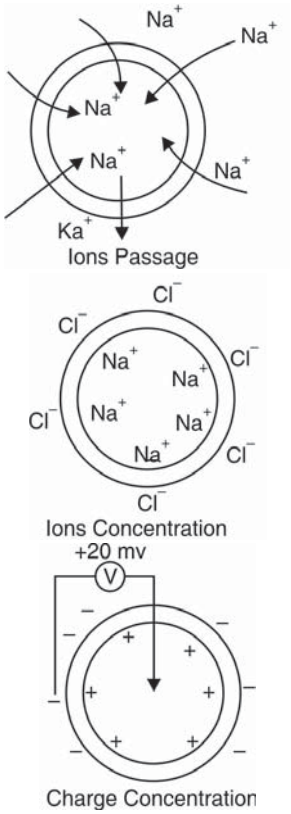
1. Surrounding the cells of the body are body fluids which are ionic and they provide conducting medium for electric potential. The cells of nerve and muscle which are required to generate biopotential, have a semi permeable membrane. The membrane has unique characteristic to permit ions of some substances to pass through it while others are blocked on its surface. The body fluids have prinicpal ions of sodium (Na^+), potassium (K^+) and chloride (Cl^-). The membrane permits potassium and chloride ions to enter inside the cell while it blocks sodium ions. In order to maintain the balance of ions inside and outside the cells, there is higher concentration of sodium ions at outside which is equal to higher concentration of chloride ionsat potassium ions of inside the cell. Though ionic balance from the concentration point of view is achieved but the charge imbalance exists with

positive charge at outside and negative charge at inside. The biopotential is ranging from –60 to –100 mV. It is called the resting potential of the cell and cell in the resting state is called to be polarized. When membrane is excited by any external energy, the characteristics of the membrane change. The membrane now permits more sodium ions to enter into the cell.The movement of positive charged sodium ions constitutes an ionic current flow



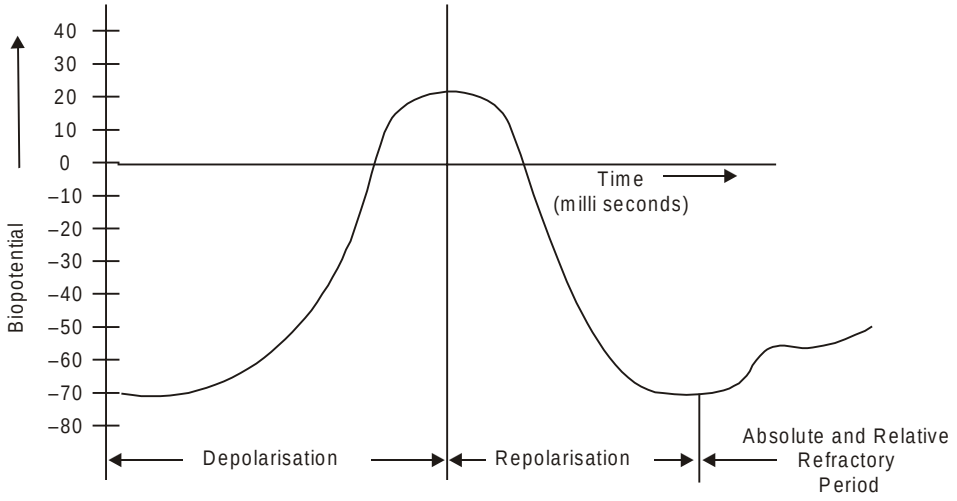
Polarisation of a Cell

which lowers the charge barrier built across the membrane due to positive sodium ions and negative chloride ions. The reduction of the charge barrier accelerates the passage of sodium ions in the cells. The potassium ions which have higher concentration during the resting state inside the cell, start moving out of the cell but their passage is not as rapid as that of sodium ions. The net result is more positive ions inside the cell. This potential is known as action potential. Its value is about +20 mV. The process of a cell gaining an action potential on excitation is known as depolarization. When the rush of sodium ions inside the cell stops, the ionic current does not flow and the membrane again becomes impermeable to chloride and potassium ions. The sodium ions inside the cell are quickly transported to the outside by a process called sodium pumping and cell is again polarized to the resting potential. This process is known as repolarization.



Depolarisation of a Cell

2. The curve showing the potential inside the cell with respect to time during resting potential, depolarization and repolarization, is called wave form of the action of potential. The cycle time varies from the cell to cell.



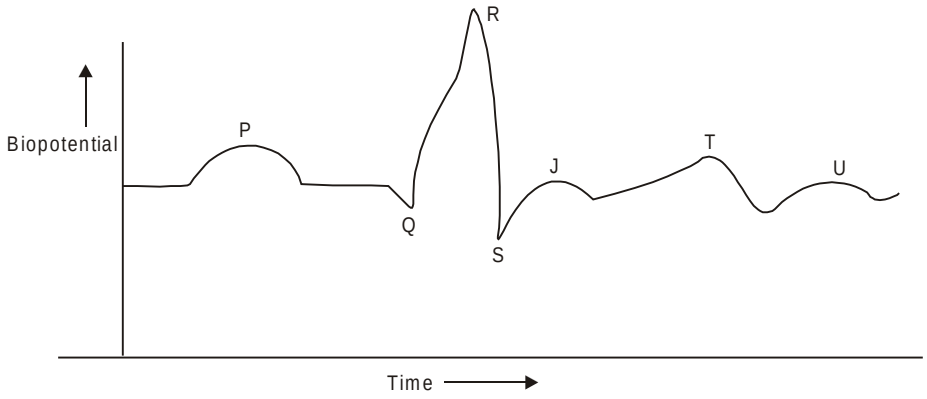
Waveform of the Action

In nerve and muscle cells, repolarization is fast after depolarization and cycle is completed in short time (about 1 milli second). On other hand, the cell of the heart repolarizes very slowly and cycle takes more time (about 150 to 300 millsec). The waveform of action potential does not depend upon the intensity of the stimulus. However the stimulus must be strong enough to activate the cell. After the completion of the cycle, there is a short time during which the cell can not be excited. This period is called the absolute refractory period and it lasts about one millisec. After the absolute refractory period, the cell can be excited by a very strong stimulus during a period of time which is called a relative refractory period. The relative refractory period lasts for much longer time as compared to the absolute refractory period.

3. Each excited cell generates an action potential and current begins to flow. The other cells in the neighbourhood of the excited cell also get excited and the action potential begins to travel which is called the propagation of the action potential. The rate at which it propagates is called propagation rate or conduction rate. The conduction rate depends upon the type of cell and diameter of muscle or nerve. The conduction rate is faster in nerves (about 2 to 140 meter/sec) while it is slow in heart muscle (0.03 to 0.4 meter/sec.)The biopotentials generated by the muscles of the heart give electrocardiogram (ECG) The biopotential generated by the neuronal activity of the brain is called the electro encephalogram (EEG). The biopotential associated with muscle activity constitute electromyogram. (EMG)

THE ELECTROCARDIOGRAM (ECG)

1. The biopotentials generated by the muscles of the heart with time is called the electro cardigram. The action potential starts from a point called the pacemaker or sinoatrial (SA) node which is located near the top of the right atrium. The action wave form propagates in all directions along the surface of both atria. The waveform reaches the junction of the atria and the ventricles. The waveform terminates at a point on this junction which is called the atrioventricular (AV) node. The propagation of excitation is



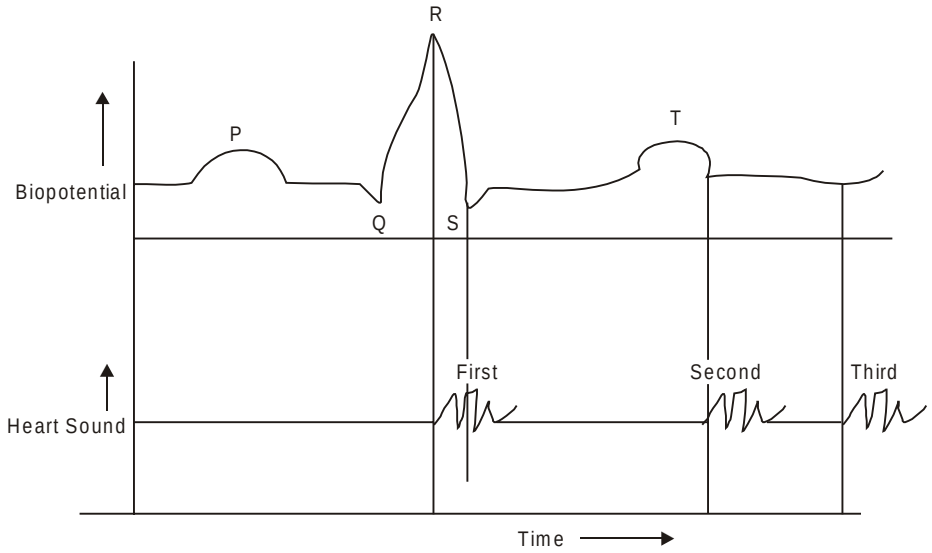
ECG Waveform

delayed at AV node so that the ventricles can be filled up with the blood from the atria. Once the period of delay is over, the excitation is spread to the all parts of the ventricles by the bundle of His. The fibers in the bundle (called Purkinje fibers), branch out into two parts to initiate action potential simultaneously in the myocardium of the ventricles. The action potential moves from the inside to the outside of the ventricular walls. The waveform terminates at the tip of the heart. The depolarization is completed. After 0.2 to 0.4 sec, a wave of repolarization starts in which neighbouring cells play no part but each cell returns to its resting potential independently.

2. If the biopotential is recorded from the surface of the body, the curve is obtained which is called ECG. A typical ECG is as shown in the figures. If prominent features of the curve are given alphabetic designations, we can explain the events related to the action potential propagation with the help of these features. The horizontal portion right of the point P is considered as the baseline or equal potential line. The wave P represents depolarization of the atrial myocardium. The depolarization of ventricles and the repolarization of the atria take place simultaneously which is indicated by QRS part of the curve. The wave T represents the repolarization of the ventricles. The after potential in the ventricles is given by the U wave. The P–Q part of the curve shows the period of the delay caused to excitation wave at the AV node. The ECG helps in the diagnosis of malfunctioning of the heart. Longer cycle time or slow heart is called bradycardia while shorter cycle time or fast heart is called tachycardia. The cycles must be evenly spaced otherwise a patient has arrhythmia. If the duration between P and R is greater than 0.2 second, it suggests the blockage of the AV node. If any feature of the curve is missing, it indicates a heart block. Electrocardiography is the instrument used to record ECG. The cardiac disorder, specially those involving the heart valves can not be diagnosed by the ECG and other techniques like angiography (X-ray photos after injecting contrasting medium into the blood stream) and echocardiography (Ultrasound measurement of the heart) are used.

HEART SOUNDS

1. The beating of the heart and the pumping of the blood is associated with the generation of sounds. The technique of listening to sounds produced by the heart



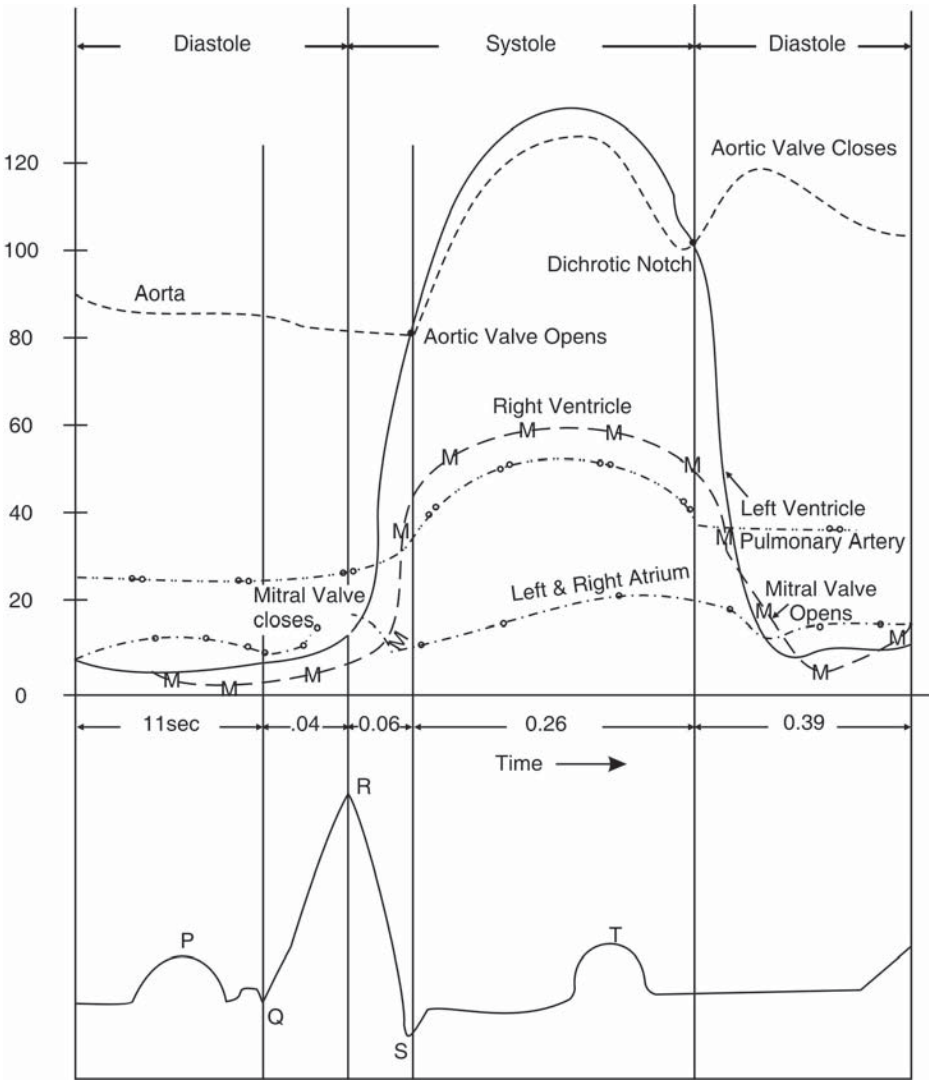
Heart Sound and ECG

and blood vessels is called auscultation. The physicians are trained to diagnose the heart disorders by listening to the sounds. The stethoscope is the device used to listen to the sounds. The "lub-dub" are two distinct sounds that are audible by the help of a stethoscope with each heart beat. The lub is produced when the atrioventricular valves close and prevent any reverse flow of the blood from the ventricles to atria. The lub is also called the first heart sound and it occur at the time of the QRS part of the ECG. The "dub" sound is produced by the closing of the pulmonary and aortic valves. The "dub" is also called the second heart sound and it occurs about the time of the end of the 'T' wave of the ECG. The third sound is sometimes produced after second sound by the rushing of the blood from the atria to the ventricles.

BLOOD PRESSURE

1. The heart has to develops sufficient pressure to circulate blood from heart (1) to lungs and back for oxygenation of the blood (2) to all body systems with the help of the distribution, diffusion and collection system of the blood. The blood pressure has to be sufficient high to overcome the resistance of the arterial vascular pathways. The flow must not stop at any cost and even remotest capillaries must receive sufficient blood which further pass it into the venous system. The other requirement of the blood vascular system is that the system must be capable to dampen out any large pressure variation. Our body is equipped with a monitoring system which can sense and take corrective steps by regulating the cardiovascular operations to maintain proper flow. Therefore in our body, pressure is maintained within a relatively narrow range and the flow is kept within the normal range of the heart.

2. Determining an individual's blood pressure is a standard clinical measurement. Blood pressure values in the various chambers of the heart and in the peripheral vascular system help in diagnosis of functional integrity of the cardiovascular system. First we have to understand the two basic stages of diastole and systole with each heart beat. The pumped blood from heart has the blood pressure which is a function of time (1) in the aorta



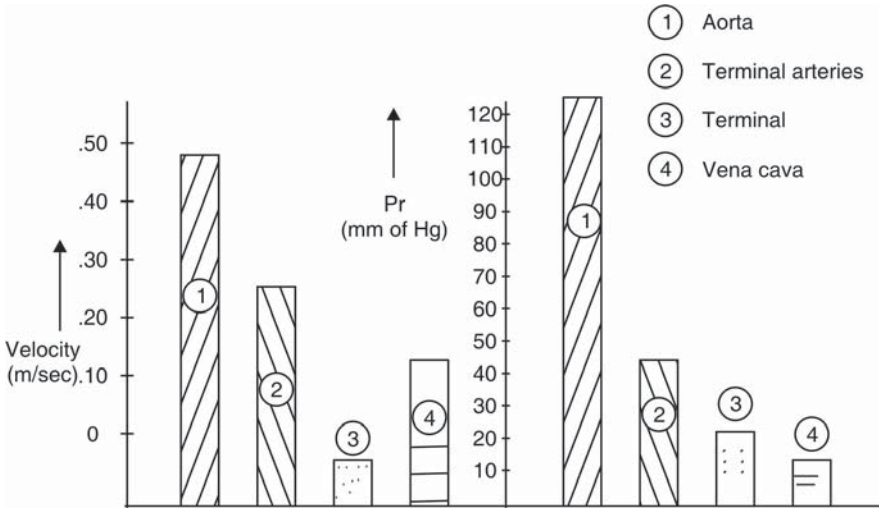
Blood Pressure Variations With Time

(dotted lines) (2) in the left atrium (dot circle lines) (3) in the left ventricle (full lines) (4) pulmonary artery (–00– 00) (4) right ventricle (–m–m–) which are shown in the figure. The events of the heart are also correlated with the features of the ECG in the same figure.

3. During systole, the output of the blood from the left ventricle is high in the beginning and the blood pressure in the aorta increases to the maximum (120 mm Hg). The blood pressure falls as the blood moves further away in the blood vascular system. The systolic period is completed with the closing of the aortic valve to prevent any back flow of the blood from the aorta to the left ventricle. The dichrotic notch (sudden stop in the drop of pressure) indicates the closure of the aortic valve in the figure. Atvial systole lasts for 0.1 sec and ventricle systole lasts for 0.3 sec. The arterial pressure gradually decreases with further flow of the blood into

the distributing and diffusing system. The duration of cardiac cycle is 0.8 sec at the heart rate of 72 beats per min.

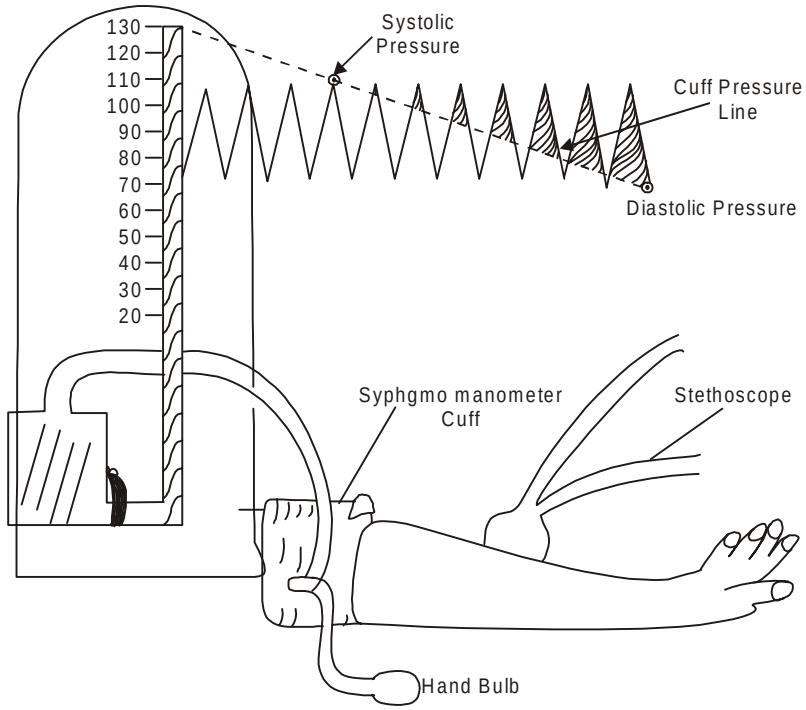
4. The pressure of the pulsating blood changes as it moves through the arteries. The blood gets dampened and reflected by the walls of the arteries. The pressure and volume also get changed when any artery is branched into smaller arteries. In smaller arteries and arterioles, the pressure decreases to 60 to 30 mm Hg and the blood also loses its oscillatory character when the blood flows through the capillaries into the venous system, the pressure drops down to 15 mm Hg. The chief seat of peripheral resistance is arterioles. In venous system, the pressure further decreases to 8 mm Hg in the venules and to 5 mm Hg in the veins . The pressure is as low as 2 mm Hg in the vena cava Normal mean pulmonary artery pressure is 15 mm Hg.



Typical Blood Velocity and Pressure

MEASUREMENT OF BLOOD PRESSURE

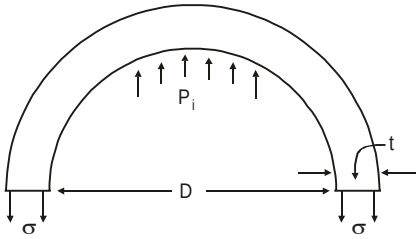
1. The blood pressure is considered a good indicator of the status of the cardiovascular system. The blood pressure is measured by an indirect method using a sphygmomanometer (sphygmos = pulse). In this method, the occlusive cuff is inflated until the pressure exerted by the cuff on the forearm artery is above the systolic pressure. The pressure of the cuff is now slowly lowered. When the systolic pressure becomes higher than the occlusive pressure, the blood in the forearm artery can spurts under the cuff and causes a pulpable pulse in the wrist. Audible sounds generated by the flow of blood and vibration of the vessel under the cuff are heard through a stethoscope. The audible sounds are also called korotkoff sounds. No blood spurts in the artery till the occlusive pressure is higher than systolic pressure. On lowering of the occlusive pressure, the blood starts to spurt as and when occlusive pressure becomes lesser than systolic pressure. The manometer pressure at the first detection of the pulse, indicates the systolic pressure. As the pressure in the cuff is decreased, the audible korotkuff sound decreases and at one point, it suddenly stops. The manometer pressure at the point when sound stops, indicates the diastolic pressure.



Blood Pressure Measurement

2. The indirect method as described above is easy to use and can be automated. However it does not provide continuous recording of pressure variation. It also fails when the blood pressure of a patient is very low. Methods for direct blood measurement provide continuous recording of the blood pressure and they are more accurate than the indirect method. They require however that a blood vessel be punctured in order to introduce the sensor. The pulse pressure is the difference between systolic and diastolic pressure. Mean atrial pressure is diastolic pressure plus one third of pulse pressure.

3. Tension in the wall of blood vessel: A blood vessel can be considered a thin cylinder as thickness of the blood vessel is small as compared to its internal diameter (diameter > 15 × thickness of the wall). If the internal pressure in the blood vessel is P_1, σ = stress developed, D = diameter of vessel, t = thickness of the wall, then for equilibrium.



$$P_1 \times D = 2 \times \sigma \times t$$

or $\sigma = \dfrac{p_i D}{2t} \propto P_1 r$ where r = radius, t = thickness and taken constant.

Hence the stress developed in the blood vessel is proportional to the product of the internal radius and pressure.

4. Example: Let us find the stress in the blood vessels if 1 mm Hg = 130 N/m^2 for (1) an aorta having mean internal pressure 110 mm Hg, t = 1.2 mm and diameter of 2.4 cm (2) a capillary having mean pressure of 20 mm Hg, t = 0.5 μm and diameter of 10 μm (3) the superior vena cava having mean internal pressure of 10 mm Hg, t = 0.15 cm and diameter of 0.03 m.

As found out $\sigma = p_i \times \dfrac{D}{2t}$

Case 1 : $\sigma_{aorta} = \dfrac{110 \times 130 \times .024}{2 \times 0.8012}$

$= 143$ KN/m^2

Case 2 : $\sigma_{capillary} = \dfrac{20 \times 130 \times 10^{-5}}{2 \times 0.5 \times 10}$

Case 3 : $\sigma_{venacava} = \dfrac{10 \times 130 \times 0.03^{-5}}{2\,0.15 \times 10}$

$= 26$ KN/m^2

BLOOD FLOW

1. Blood flow is highest in the pulmonary artery and the aorta as the blood leaves the heart from these two points. The flow at these points is called cardiac output. The cardiac output in a normal adult at rest varies from 3.5 to 5 litres/min. The stroke volume is the amount of the blood that comes out during each heart beat. If heart beat = 80 per min and cardiac output = 4 litres /min, then stroke volume = $\dfrac{4}{80}$ = 0.05 litres/beat. Similarly cardiac index (n) is defined as the cardiac output per min per sq meter body surface area. The typical value of n is 3.3 litres/m^2/ mm. The mean circulation time (≈ 60 sec) can be obtained by dividing cardiac output to the total amount of blood circulation. In the arteries, blood flow is pulsatile. During certain parts of the heart beat cycle, the blood flow can occur in reverse direction. The elasticity of the walls of the blood vessels helps in smoothing out the pulsation and pressure of the blood. The capillaries can enlarge or constrict under the influence of certain drugs or when exposed to low temperatures. The blood flow reduces during vascoconstriction of the capillaries. The blood flow increases during vasodilation of the capillaries. Hence the status of the circulatory system can not be determined by measuring only blood pressure as it varies with the flow resistance of the capillaries. The basic theory of circulatory function is:

(*a*) The blood flow to each tissue of the body is always precisely controlled in relation to the tissue needs.

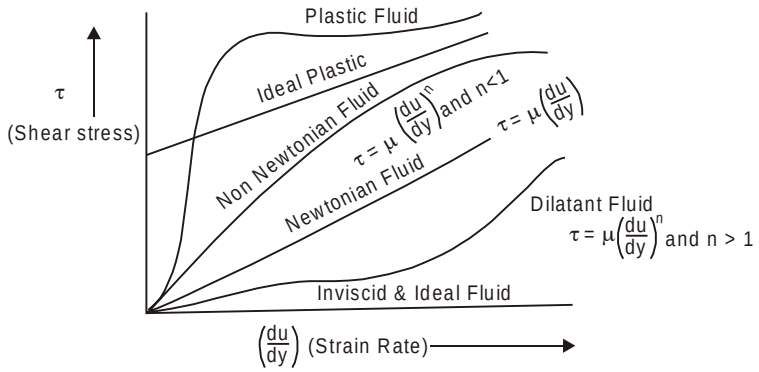
(*b*) The cardiac output is controlled primarily by the local tissue flow.

(*c*) The arterial pressure is independent of local blood flow or cardiac output.

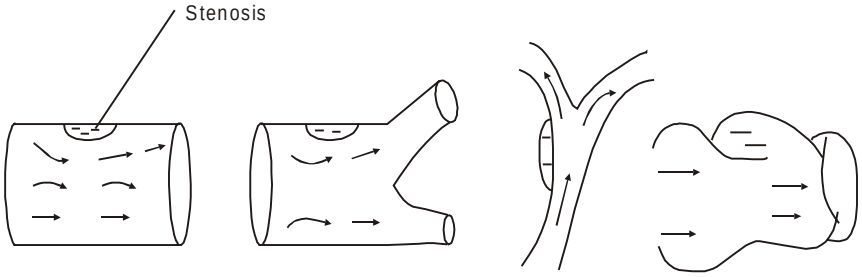
(*d*) Veins besides transporting blood back to heart from the tissues, act as reservoir of blood. The veins can contract and expand as venous walls are thin which permit the veins to hold more blood or less blood depending upon the requirement of various systems.

(*e*) Circulatory shock is caused by decreased cardiac output. It can be due to cardiac abnormalities that decrease the ability of heart to pump blood. It can be also due to the factors that decrease the vanous return flow. The most common cause is trauma to the body as hemorrhage is caused by the trauma.

2. As we have seen in chapter 2, Newtonian fluids obey Newton's viscosity equation and viscosity does not change with the rate of deformation. Non Newtonian fluids do not follow the linear relationship between shear stress and the rate of deformation *i.e.*



Fluid Classifications

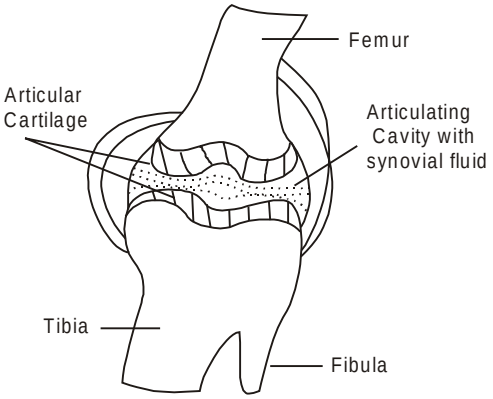


Separation of Blood FLow

$\tau \neq \mu \frac{du}{dy}$. Blood is also a non Newtonian fluid. The Reynold number is the ratio of inertial forces to viscous forces $\text{Re} = \frac{\rho VD}{\mu}$ where ρ = density, V = velocity D = diameter and μ = viscosity. When Reynolds number is large, inertial forces are large as compared to viscous forces and the inertial forces tend to diffuse the fluid particles, causing intense mixing of the fluid, which is characteristic of turbulence. In bloodflow situations, laminar flow continue to occur at Reynolds number as high as 10,000. Hence the blood flow is laminar in the blood vascular system except only in the aorta during a small fraction of each cycle when flow is turbulent. The turbulent blood flow may also arise due to a stenosis or obstruction in the circulatory system. Stenosis may also take place in the valves.

3. **Synovial fluid:** Articulating cavity of synovial joint contains synovial fluid. A knee joint configuration is shown in the figure. Jointing bones have articular cartilage at their ends. Cartilage is collagen rich tissue which has two main properties. Firstly it can maintain shape and secondly it provides bearing surfaces at joints. Cartilage has porous nature. Joint cartilage has a very low coefficient of friction (less than 0.01). The squeezc film effect between cartilage and synovial fluid is considered to give low coefficient of friction. Hence the effective viscosity of the synovial fluid near the articular cartilage is abnormally high. There

is also possibility of increasing concentration of suspended particles (hyaluronic acid molecules) in synovial fluid due to filtration in porous cartilage and its surface topography which provide boosted joint lubrication. The articular surfaces are protected due to the boosted lubrication.



Knee Joint : Synovial Fluid

4. Special characteristics of blood flow are:

(*a*) the Reynolds number of the blood is high (range 10,000) which results into a larger entry length (the length in which 99% of the final velocity profile is achieved). In most cases in the blood vessels the fully developed flow is never reached as the blood vessels start branching before this stage is attained.

(*b*) The blood is flowing through the blood vessels which have different properties. The reason for the different properties is that the blood vessels are formed of different substances such as elastin, collagen and smooth muscles.

(*c*) Unusual large bifurcation or branching of the blood vessels. There are million of blood vessels in the blood circulating system.

(*d*) The blood vessels have to bend into unusual curvature in the blood circulating system which leads to secondary flow in some cases.

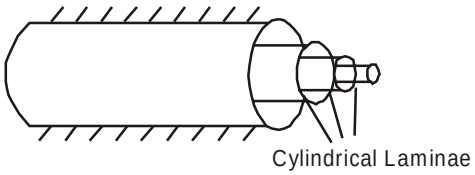
(*e*) The turbulent flow may arise due to a stenosis or obstruction in the circulating system. It may also be due to the defective valves.

(*f*) The blood has unusual pulsating nature which arises from rhythmic action of the heart. The pressure and volume increase during systole which gradually decrease during diastole.

(*g*) The blood has unusual fluid properties. The blood consists of millions of different corpuscles suspended in the plasma. These corpuscles can deform when these are required to pass through the blood vessels having diameter smaller than their own.

(*h*) The blood vessels can contract or enlarge as explained earlier. The veins can enlarge to act as reservoir to store more blood.

5. Hagen-poiseuille flow: The flow of blood in arteries was investigated by the physician Poiseuille. He considered laminar flow through a horizontal round blood vessel as shown in the figure. The flow moves in cylindrical laminae.



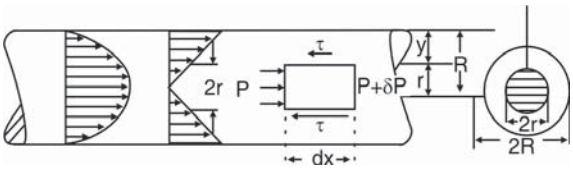
Laminar Flow Through Round Artery

The equilibrium of a cylinder of radius r and length dx is considered with pressure P at right and $P - \delta P$ at left when the blood flow is from right to left. The net pressure force at the ends must be equal to the shear force.

$$P\,\pi r^2 - (P + \delta p)\,\pi r^2 - = \tau\, 2\pi r.dx$$

$$\text{or } \tau = \frac{dp}{dx}\,\frac{r}{2} \qquad ...(i)$$

maximum shear stress $\tau = -\dfrac{dp}{dx}\,\dfrac{R}{2}$ when r = R.



Velocity Profile : Laminar Flow of Blood

The velocity distribution can be obtained by the relationship

$$\tau = \mu \frac{dU}{dy}$$

but $y = R - r$

$\therefore \quad dy = -dr$

Using this, we get $\tau = \mu \dfrac{dU}{dr}$ ...(*ii*)

Putting value from eqn. (*ii*) in eqn. (*i*)

$$\frac{dU}{dr} = \frac{\tau}{2\mu} \frac{dP}{dx} r$$

or $$U = \frac{1}{4\mu} \frac{dP}{dx} r^2 + A \text{ (on integrating)}$$

Condition; $r = R$ then $U = 0$

hence $$A = -\frac{1}{4\mu} \frac{dp}{dx} R^2$$

$$\therefore \quad U = \frac{1}{4\mu} \frac{dp}{dx} (R^2 - r^2)$$

The velocity profile in a fully developed laminar artery flow is a paraboloid of revolution. At the centre line ($r = 0$), the velocity is maximum.

$$U_{max} = \frac{1}{4\mu} \frac{dp}{dx} R^2$$

or $$U = U_{max} \left[1 - \left(\frac{r}{R} \right)^2 \right]$$

Total discharge (Q) through the artery

$$Q = \int dq = \int_0^R 2\pi r dr \, . U_{max} \left(1 - \frac{r^2}{R^2} \right)$$

$$Q = 2\pi U_{max} \frac{R^2}{4} = \frac{\pi}{8\mu} \left(\frac{dP}{dx} \right) R^4$$

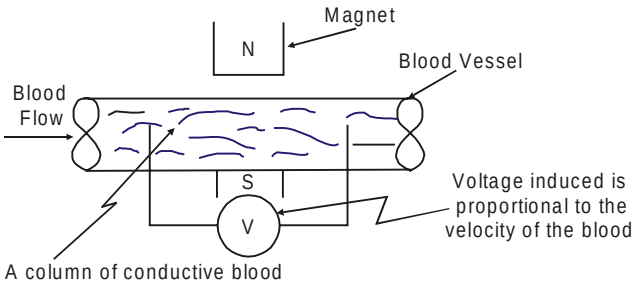
The average velocity (U_{mean}) is given by

$$U_{mean} = \frac{Q}{\pi R^2} = \frac{1}{8\mu} \left(\frac{dP}{dx} \right) R^2 = \frac{U_{max}}{2}$$

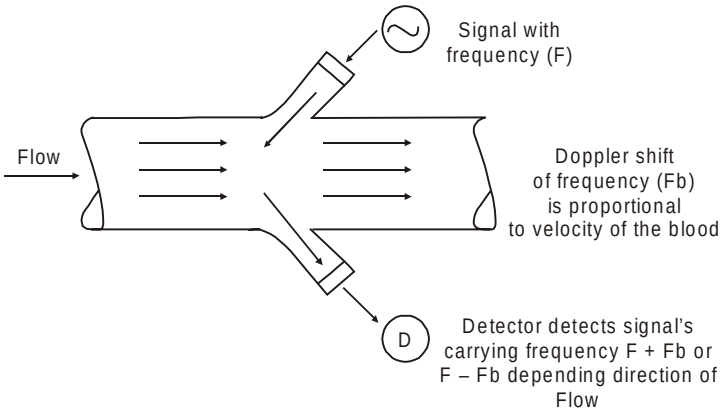
6. The proper functioning of all parts of the body depends on adequate supply of blood to these parts. If the blood supply to any part is reduced by a narrowing of the blood vessel, the function of that part can be severely affected. Incase the blood flow in a certain vessel is completely blocked due to blood clot or thrombosis, the tissues in the area supplied by the blood vessel will die. The brain stroke takes place when the blood vessel of the brain is blocked. The heart attack similarly takes place when there is an obstruction in the coronary arteries that supply blood to the heart muscle. A reduction in the blood flow of the coronary arteries can cause a severe chest pain which is called angina pectoris. A clot in the blood vessels in the lung is called an embolism.

7. Blood flow cannot be measured easily. The blood flow meters are based on the principle of (1) electromagnetic induction (2) ultrasound reflection (3) radiographic principle (4) dye dilution (5) chamber plethysmography. The magnetic and ultrasound blood flow meters actually measure the velocity of the blood stream. A transducer is used that envelope an excised blood vessel to measure the mean velocity of the blood stream. The flow of the blood can be worked out. In an ultrasonic blood flow meter, a beam of ultrasonic energy is used to measure the velocity of flowing blood. A pulsed beam is directed through a blood vessel and transit time is measured. Transit time is shortened if blood flow is in same direction as that of the pulsed beam otherwise transit time is lengthened. In radiographic method, blood is made visible by X-rays by the contrast medium and the movement of the blood can be measured. The dye dilution method measures the blood flow instead of the blood velocity as done

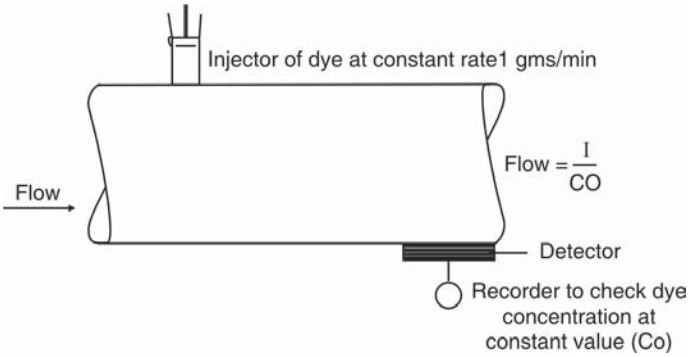
by the earlier described methods. The dye is injected at a constant infusion rate I (gms/min). A detector measures the dye concentration down stream. Concentration increases and finally reaches a constant value Co (gms/litre). The blood flow F (litres/min) = I /Co. In chamber plethysmography the venous occlusion cuff is inflated to stop blood return from the veins of the forearm. Arterial flow causes the increase in volume of the forearm segment which the chamber measures. The flow of the blood is proportional to the change in the volume of the chamber.



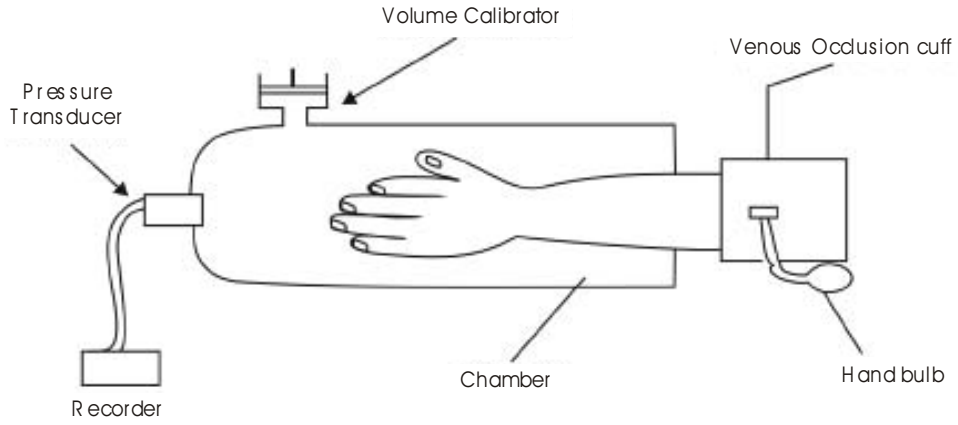
Magnetic Flow Meter



Blood Flow Meter



Dye Dilution Method



8. Solved example: A patient has cardiac output of 4.2 litres/min and heart rate of 84 beats/min and a blood volume of 5 litre. Find out (1) the stroke volume (2) the mean circulation time (3) the mean velocity in the aorta if it has a diameter of 32 mm.

$$\text{The stroke volume} = \frac{\text{Cardiac output/min}}{\text{beats/min}}$$

$$= \frac{4.2 \text{ litres/min}}{84 \text{ beats/min}}$$

$$= 0.05 \text{ litres}$$

$$\text{The circulation time} = \frac{\text{The blood volume}}{\text{cardiac output/min}}$$

$$= \frac{5 \text{ litre}}{4.2 \text{ litres/min}}$$

$$= 1.19 \text{ min}$$

$$\text{Flow} = \text{Area} \times \text{mean velocity} = AV$$

$$\therefore \quad \text{Velocity} = \frac{\text{Flow}}{A} = \frac{4.2 \text{ litres /min}}{Area = \frac{\pi D^2}{4}}$$

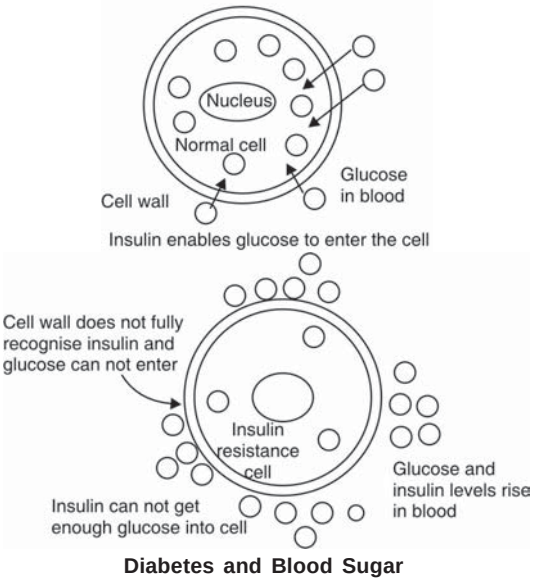
$$= \frac{4.2 \times 10 m^{-3/} \text{ min}}{\pi \times \left(\frac{0.32}{4}\right)^2} \quad \frac{4.2 \times 4 \times 10}{\pi \times (0.032)^2}$$

$$\frac{4.2 \times 4 \times 10^{-3}}{\pi \times 10.24 \times 10^{-4}}$$

$$= 5.22 \text{ m/min}$$

DIABETES AND BLOOD SUGAR

1. Diabetes is a chronic and incurable disease in which excess sugar is present in the blood. Sugar (glucose) is necessary to provide energy to cells of the body. Insulin produced by the pancreatic cells of the body that convert the glucose in the blood into energy. In diabetes, the pancreatic cells produce little or no insulin or the body does not respond properly to the insulin, resulting in glucose levels building up in the blood. The body loses its primary source of energy. Excess blood sugar levels over a period of time harm the eyes, kidneys, heart, nerves and blood circulation to limbs besides starving the cells of the body.



Diabetes and Blood Sugar

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. The blood has carrier of ---------- supply (*a*) fuel (*b*) water

2. The rhythmic pressure is maintained by the contraction and expansion of the ---------- (*a*) artery (*b*) heart

3. The heart beats without rest about 1,00,000 times per ---------- (*a*) day (*b*) week

4. The average heart rate is ---------- beats per min (*a*) 75 (*b*) 150

5. Arteries, arterioles and capillaries form ---------- systems (*a*) diffusing (*b*) distribution

6. The veins form ---------- system
(*a*) dispatching (*b*) collecting

7. The left heart receives blood from the pulmonary ----- (*a*) vein (*b*) artery

8. The ----- heart is larger and stronger as it is a pressure pump (*a*) left (*b*) right

9. The -------- heart is a volume pump
(*a*) left (*b*) right

10. The heart is divided into four chambers by ----- (*a*) epicardium (*b*) septum

11. The inferior and superior vena cava open into ------ atrium (*a*) left (*b*) right

12. The right atrioventicular orifice is guarded by ---------- valve. (*a*) tricuspid (*b*) dicuspid

13. The pulmonary orifice is guarded by pulmonary valve which consists of --------- semilunar cusps (*a*) two (*b*) three

14. The left atrioventricular orifice is guarded by the ---------- valve (*a*) mitral
(*b*) tricuspid

15. SA node is also called --------- (*a*) pulse maker (*b*) pacemaker

16. The propogation of excitation is delayed at AV node so that--------can be filled up with the blood from the -------- (*a*) atria, vena cava (*b*) ventricles, atria

17. The sympathetic nervous system ----- the heart rate (*a*) quickens (*b*) slows down

18. The Vagus nerve of the parasympathetic nervous system ---- the heart rate
(*a*) quicken (*b*) slows down

19. The ---- state of a cell is called polarised
(*a*) resting (*b*) action

20. The process of gaining an action potential on excitation is called -------(*a*) polarisation (*b*) depolarization

21. After sodium pumping the cell is -------- to the resting potential (*a*) depolarized
(*b*) repolarized

22. The dub sound is introduced by the heart by the closing of the valves (*a*) atrio ventricular (*b*) semilunar and aortic

23. The 'lub' sound is produced by the heart by the closing of the ------ valves (*a*) atrio ventricular (*b*) Semilunar and aortic

24. The lub is the -----heart sound (*a*) first
(*b*) second

25. The dub is the -- heart sound (*a*) first
(*b*) second

26. The first heart sound occurs at the time of the -------- part of the ECG (*a*) PQR
(*b*) QRS

27. The second heart sound occurs at the ---------- of the 'T' wave of the ECG (*a*) start (*b*) end

28. The blood pressure is measured by an indirect method using a -----manometer (*a*) cuff
(*b*) sphygmo

29. ------- pressure is the difference between systolic and diastolic pressure (*a*) pulse
(*b*) heart

30. The systolic period is completed with the closing of the -------- valve (*a*) mitral
(*b*) aortic

31. The systolic period starts with the closing of the valve (*a*) mitral (*b*) aortic

32. The action potential is about --------- millivolt (*a*) –70 (*b*) +20

33. The resting potential is about ---------millivolt (*a*) –70 (*b*) +20

34. The walls of the left ventricle is -------times thicker than the walls of the right ventricle (*a*) two (*b*) three

35. The pressure in the left ventricle can be ----------times higher than the right ventricle (*a*) four (*b*) six

36. The walls of --------- are thicker and ridged as composed to the wall of --------

(*a*) ventricle, atrium (*b*) atrium, ventricle

37. The delay line is at ------- node (*a*) SA

(*b*) AV

38. From the AV node the cardiac impulse is conducted to------- (*a*) the bundle of His

(*b*) The purkinje fibre

ANSWERS

1. (*a*)	**2.** (*b*)	**3.** (*a*)	**4.** (*a*)	**5.** (*b*)	**6.** (*b*)	**7.** (*a*)
8. (*a*)	**9.** (*b*)	**10.** (*b*)	**11.** (*b*)	**12.** (*a*)	**13.** (*b*)	**14.** (*a*)
15. (*b*)	**16.** (*b*)	**17.** (*a*)	**18.** (*b*)	**19.** (*a*)	**20.** (*b*)	**21.** (*b*)
22. (*b*)	**23.** (*a*)	**24.** (*a*)	**25.** (*b*)	**26.** (*b*)	**27.** (*b*)	**28.** (*b*)
29. (*a*)	**30.** (*b*)	**31.** (*a*)	**32.** (*b*)	**33.** (*a*)	**34.** (*b*)	**35.** (*b*)
36. (*a*)	**37.** (*b*)	**38.** (*a*)				

THE RESPIRATORY SYSTEM

11

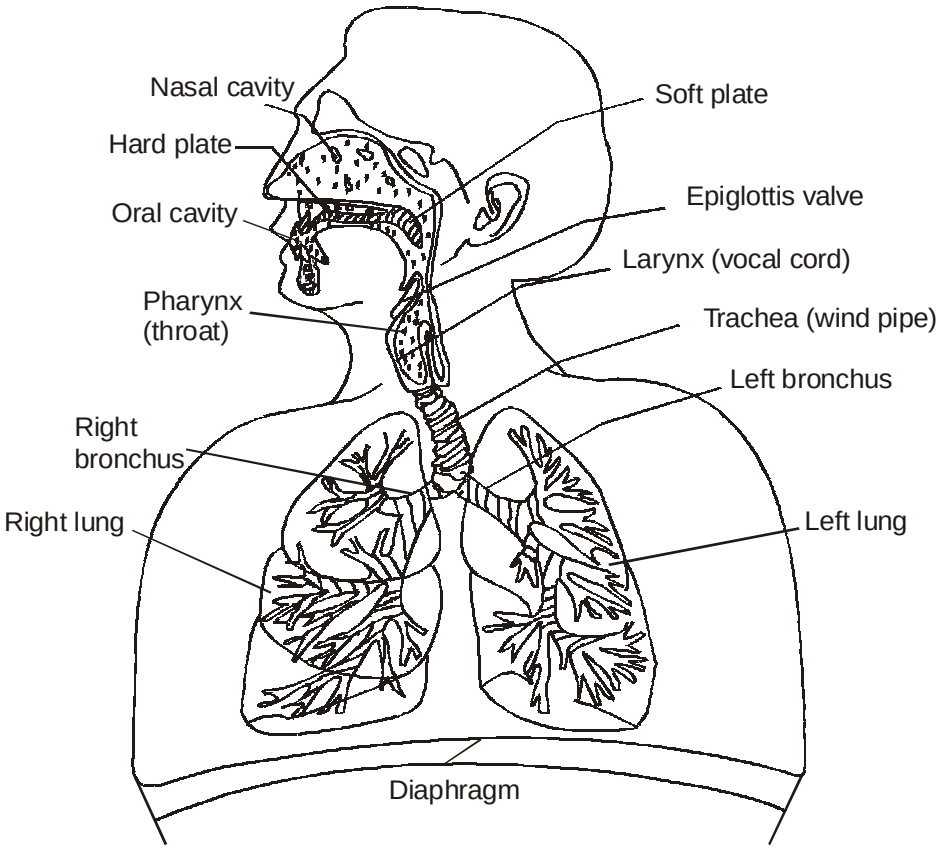
To attain knowledge, add things everyday. To attain wisdom, remove things every day.

INTRODUCTION

1. Respiration consists of two phases viz. inspiration and expiration. Inspiration and expiration are accomplished by the alternate increase and decrease of the capacity of thoracic cavity. The respiration rate is 16 to 20 per minutes in adults. It is faster in children and slower in the aged. During inspiration, air is taken in the lungs and the blood is oxygenated. During expiration, the lungs eliminate carbon dioxide in a controlled manner. Oxygen is required to sustain life as oxygen combines with hydrogen, carbon and other nutrients in order to generate heat and energy. This is called the process of metabolism which is taking place in the cells. Carbon dioxide and waste are produced from the metabolism. The respiration is the entire process of taking in oxygen as a part of air from the atmosphere, transporation of oxygen to the cells and transportion of carbon dioxide from the cells to the atmosphere.

THE RESPIRTORAY TRACT

1. The right and left lungs are elastic bags which are soft and spongy. They are located in a closed cavity which is called thoracic cavity. The right lung has three lobes while the left lung has two lobes. The lungs can shrink to one-third or less in volume. Air enters into the lungs through the air passage formed by the nasal cavities, pharynx, larynx, trachea, bronchi and bronchioles. The trachea (wind pipe) connects the larynx (voice box) to the left and right bronchus. The epiglottis is a valve above the larynx which prevents any liquid or food from entering into the larynx. Each principal bronchus enters into the corresponding lung. Each principal bronchus on entering the lung divides into secondary bronchus which passes to a lobe of the lung. A secondary bronchus gives off tertiary bronchi. Each tertiary (segmental) bronchus goes to a structurally and functionally independent

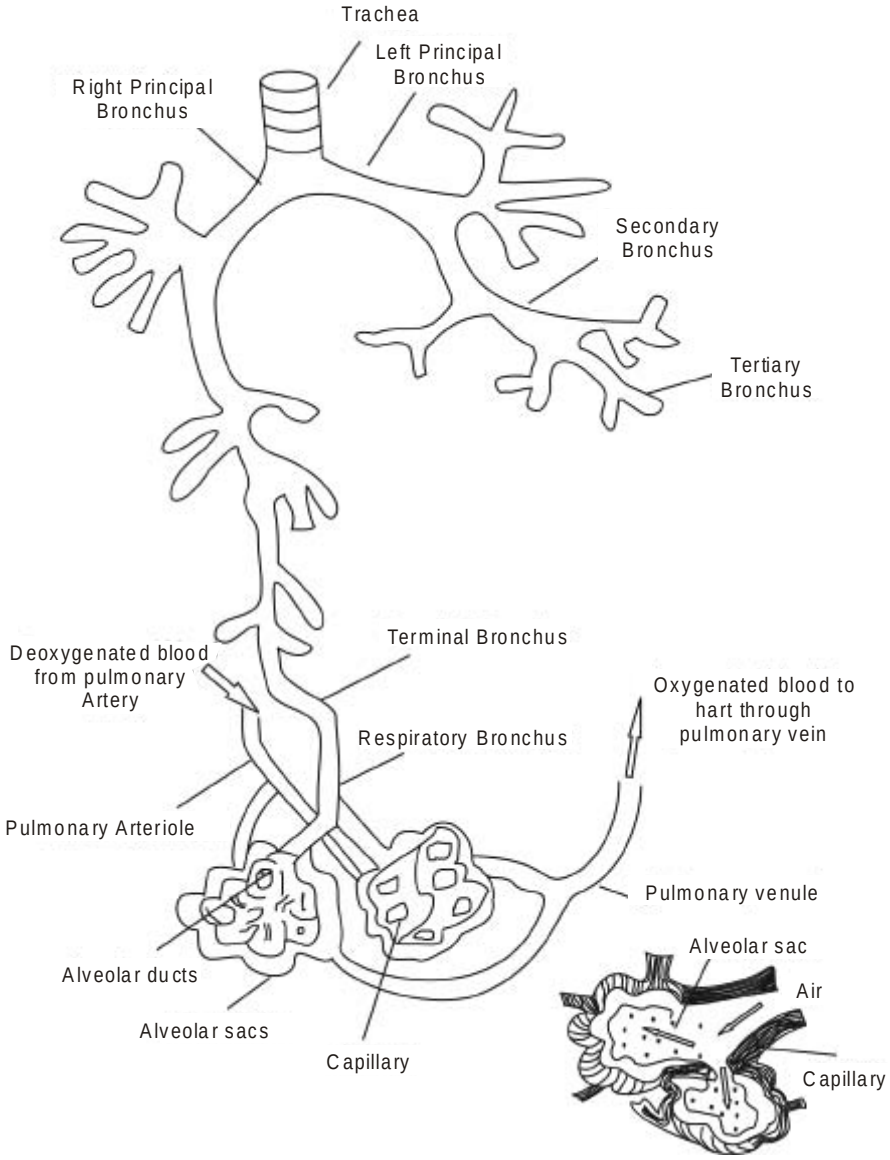


The Respiratory Tract

unit of a lung which is called a broncho pulmonary segment. From here, the air conducting tubes are called bronchioles. Further branching and reduction in size leads to terminal bronchioles and respiratory bronchioles. The respiratory bronchiole is connected to alveolar sacs (small air sacs) which are attached in the wall of the lungs. The alveoli receives deoxygenated blood from pulmonary artery and sand oxygenated blood to heart through pulmonary vein. A respiratory unit is composed of respiratory bronchiole, alveolar ducts and alveolar sacs. The amount of alveolar air replaced by new atmospheric air with each breath is only

$\frac{2}{3}$ rd alveolar air.

Expired air contains 2/3 rd alveolar air and 1/3 rd dead space air (150 ml) *i.e.*, air in nasal passage, pharynx trachea and bronchi.

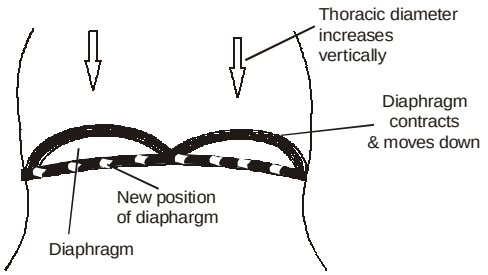


Bronchus, Alveolar and Capillary Network

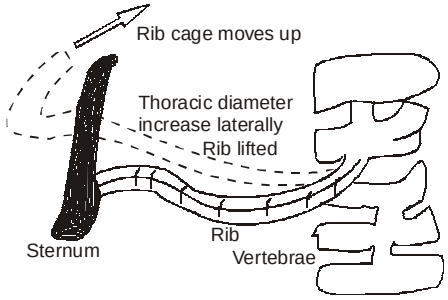
THE MECHANICS OF RESPIRATION

1. The thoracic cavity has a single entrance at the top through the trachea. The capacity of the thoracic cavity can be increased by elongating its dimensions in all direction. This results in air under atmospheric pressure entering into the lungs through the trachea. The size of thoracic cavity increases due to (1) the movement of diaphragm up and down which increases vertical diameter (2) the movement of the rib cage up and down which increases lateral diameter. The diaphragm is a bell shaped muscle located at the bottom of the thoracic cavity. The diaphragm on contraction moves downward and enlarges the thoracic cavity. At the same time muscles lift the rib cage

and sternum. The geometry of the rib cage is such that on its lifting, it increases the thoracic cavity. As thoracic cavity increases in volume, a negative pressure is created in the lungs. The negative pressure is relieved by air rushing into the lungs from the atmosphere. The lungs themselves are passive organs in the inspiration process.



Descent of Diaphragm



Antero Posterior Expansion

The expiration process is also passive and it starts with the release of the diaphragm and rib cage muscles. The volume of thorocic cavity reduces and a positive pressure is developed in the lungs which forces air out of the lungs into atmosphere. During inspiration, the pressure inside the lungs is negative (about–3 mm Hg). During expiration, the pressure inside the lungs is positive (about +3 mm Hg)

2. Deoxygenated blood is brought by the superior and inferior vena cava into the right atrium, from here it moves into the right ventricle. The blood is pumped to the lungs from the right ventricle through pulmonary artery. The blood in the lungs passes through the pulmonary capillaries which are located in the walls of the alveolar sacs. Here oxygen is taken up by the red corpuscles which form oxyhemoglobin. Simultaneously carbon dioxide is liberated from the blood cells which is pushed out to the atmosphere by expiration. The blood pressure in the pulmonary artery is about 20 mm Hg when blood is pumped by the right ventricle and blood pressure is about 4 mm Hg when superior and inferior vena cava brings blood to the right atrium. The interchange of oxygen and carbon dioxide takes place in the capillary surface of the alveoli. The capillary surface is more than 75% surface of the alveoli (80 m^2).

3. The oxygenated blood from the pulmonary capillaries is carried through the pulmonary veins to the left atrium. The blood from the left atrium moves to the left ventricle which pumps the blood into the aorta at high pressure (about 80 to 120 mm Hg) so that the blood can be circulated through all the parts of the body. The blood gives out oxygen at the cells of the tissues. The deoxygenated blood is collected by the venous systems into the superior and inferior vena cava.

4. The flow of the air in the respiratory system is usually laminar. However, during heavy breathing or when there is any obstruction during breathing, the flow of the air can become turbulent. The Reynolds number at which the flow of the air becomes turbulent is as high as 50,000. When Reynolds number is small, viscous forces dominate over inertial forces. If Reynolds number is less than one, inertial forces can be neglected. Low Reynolds number flow is the characteristic of air flows in alveolar passages of diameter less than a few hundred microns.

5. Some of the terminology used for the respiratory measurements are:

(*a*) *Hypoventilation:* Insufficient ventilation to maintain normal partial pressure of carbon dioxide (P_{Co_2})

(*b*) *Hyperventilation:* Abnormally prolonged, rapid or deep breathing which produces the condition of over breathing

(*c*) *Dyspnoia:* Shortness of breath or distress in breathing usually associated with serious disease of lungs.

(*d*) *Hypercapnia:* Excess amount of lung carbon dioxide in the system which results from inadequate ventilation.

(*e*) *Hypoxia:* It is shortage of oxygen due to inadequate ventilation

(*f*) *Compilation work:* The work required to expand the lungs against elastic forces.

(*g*) *Compliance:* The volume increase of lung per unit increase in lung pressure. (the compliance is expressed as litres per cm H_2O. Compliance of the normal lungs is 0.22 litres per 1 cm of H_2O).

(*h*) *Airway resistance:* It is the resistance of the air passage and expressed as cm of H_2O per litre per sec.

THE VOLUME AND CAPACITIES

1. Lung volume and capacities are determined so as to find out the condition of the breathing mechanism. Certain definitions are used to define the parameter related to the breathing mechanism are:

(*a*) *The tidal volume (TV):* It is the volume of gas inspired or expired during each normal respiration cycle. It is the volume between and inspiratory level and expiratory level. The tidal volume is about 500 mL for a normal adult.

(*b*) *Inspiratory Reserve volume (IRV):* It is the extra volume that can be inspired above the tidal volume. The normal value of IRV is about 3000 ml.

(*c*) *Expiratory Reserve Volume (ERV):* It is the extra volume that can be expired by forceful expiration at the end of the tidal volume. The normal value is about 1100 ml.

(*d*) *Residual Volume (RV):* It is the volume of air remaining in the lungs despite forceful expiration. The normal value is about 1200 ml.

(*e*) *Inspiratory capacity (IC):* It is the maximum volume of air that can be inspired after reaching the end expiratory level. IC = TV + IRV. The normal value is about 3500 ml.

(*f*) *Functional residual capacity (FRC) :* If the volume of air remaining in the lungs at the end expiratory level. FRC = RV + ERV or FRC = TLC – IC. FRC can be regarded as the baseline from which other volumes and capacities are specified. The normal value is about 2300 ml.

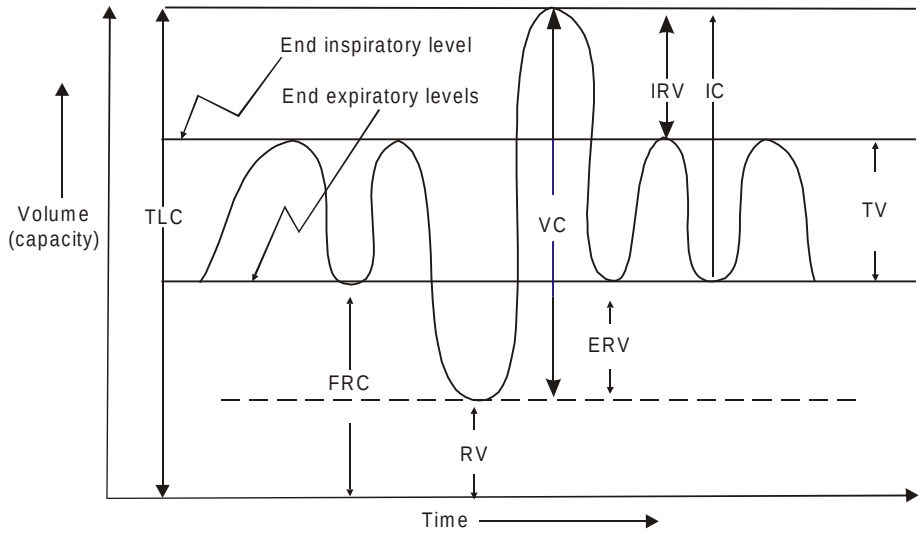
(*g*) *Vital capacity (VC):* It is the maximum volume of gas that can be expelled from the lungs by forceful expiration after a maximum inspiration. It is infact the difference in volume of the maximum inspiration and the residual volume. *VC* = IRV + TV + ERV. The normal value is about 4600 ml.

(*e*) *Total lung capacity (TLC):* It is the amount of gas contained in the lungs at the end of a maximum inspiration. *TLC = TV + IRV + ER + ERV*. The normal value is about 5800 ml.

(*f*) *Respiratory minute volume:* It the amount of air inspired during one minute of rest. It can be obtained by multiplying the tidal volume (TV) by the number of respiratory cycles per minute.

2. Solved Example

(*a*) If a person has *TLC* = 6 litres and the volume of air left in the lungs at the end of maximum expiration is 1.2 litres, then find the vital capacity (*VC*) of the person.



Lung Volumes and Capacities

Here *TLC* = 6 litres

RV = 1.2 litres

We know *VC* = *TLC* – *RV*

= 6 – 1.2 = 4.8 lires

(*b*) A man is doing exercise. The volume of air expired and inspired during each respiratory cycle changes from 0.5 to 3.5 litres. What does this value indicate and what is this value called?

The man inspires and expires the tidal volume during each normal respiration. Hence 0.5 litre indicates the tidal volume. During exercise, he requires maximum volume of air that can be inspired after reaching the end expiratory level. Hence 3.5 litre is the inspiratory capacity. The inspiratory reserve volume = *IC* – *TV* = 3.5 – 0.5 = 3 litre.

(*c*) It is given that 1.2 litre of air remains in the lungs despite forceful expiration. The man can expire 1.1 litre by forceful expiration at the end of the tidal volume. The inspiratory capacity is 3.5 litre. Find FRC, *TLC* and *VC*.

Given : Residual volume (*RV*) = 1.2 litre

Extra reserve volume (*ERV*) = 1.1 litre

Inspiratory capacity (*IC*) = 3.5 litre

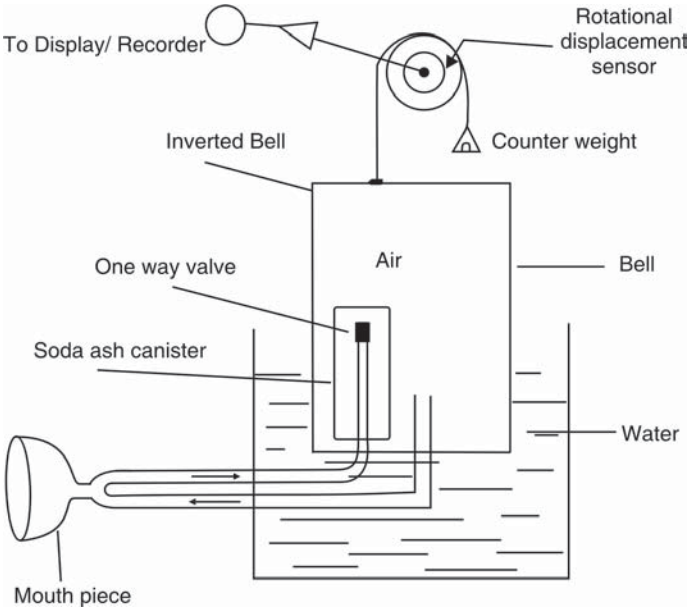
$\therefore$ FRC = *RV* + *ERV* = 1.2 + 1.1 = 2.3 litre

$\therefore$ TLC = *FRC* + *IC* = 2.3 + 3.5 = 5.8 litre

$\therefore$ *VC* = *TLC* – RV = 5.8 – 1.2 = 4.6 litre

THE VOLUME, CAPACITY AND MEASUREMENT

1. The most commonly used instrument for the measurement of respiratory volume is the recording spirometer. All the volumes and capacities of the lungs can be measured except the residual volume, functional residual capacity and total lung capacity. The instrument consists of a movable bell inverted over a chamber of water. The bell contains air above the water line which is to be breathed. To simplify the measurement, the bell is counterbalanced by a weight to ensure air inside the bell remains at atmospheric pressure and the amount of air in the bell is proportional to the height of the bell above the water line. As the patient breaths into the tube connected to the air



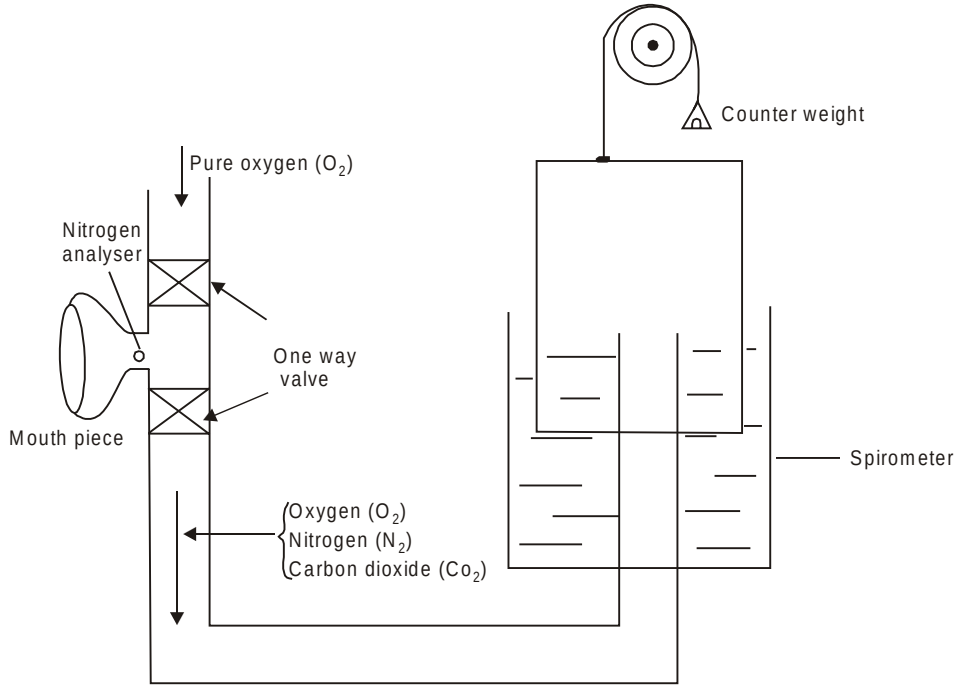
Spirometer

under the bell, the bell moves down with inspiration and moves up with expiration. The height of the bell above the water line can be calibrated to the volume of the air breathed in and out.

2. A gas analyzer is used along with a spirometer to measure the residual volume, FRC and total lung capacity. Following techniques are used:

(*a*) *The closed circuit technique:* It involves rebreathing from a spirometer charged with a known volume and concentration of helium (marker gas). After considerable breathing so that the complete mixing of gas in spirometer and pulmonary gases can be assumed, the residual volume (RV) of the patient can be found out by a gas analyser by finding the volume and concentration of the helium.

(*b*) *The nitrogen wash out technique:* It involves the inspiration of pure oxygen and expiration into an oxygen purged spirometer. After breathing, the gas remaining in the lungs is 78% nitrogen. On breathing of pure oxygen, oxygen will mix with nitrogen in the lungs. On expiration, a certain amount of nitrogen will wash out which can be measured with expired breath. A washout curve can be obtained with each breath from which the residual volume (RV) capacity can be found out.



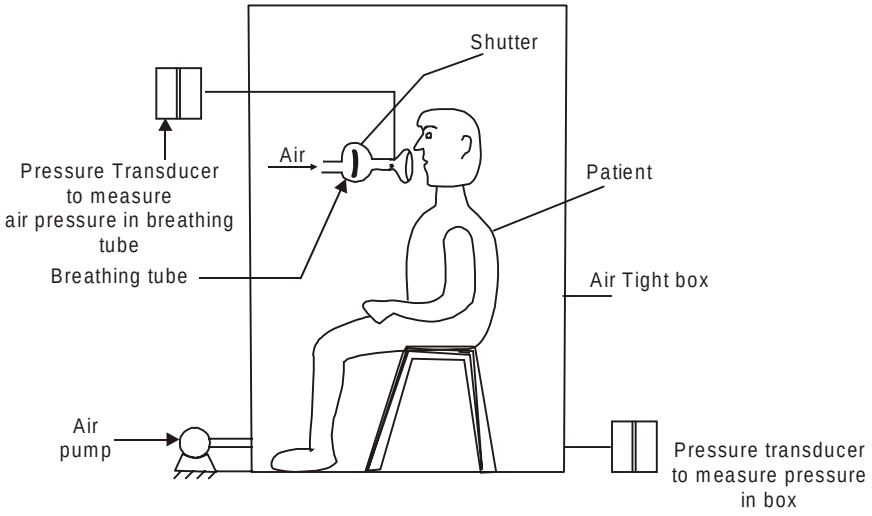
Nitrogen Washed Out Technique

3. The functional residual capacity (FRC) can be measured by using a body plethysmograph. It is an airtight box in which the patient is seated. The patient breaths air from within the airtight box through a tube provided inside the box. The tube has a shutter to close off the tube and an airflow transducer. Pressure transducers measure the pressure inside the box and in the breathing tube on the patient's side of the shutter. Now total air is sum of the air inside the box (V_b) and the air in the patient's lungs (V_P) *i.e.* $V_t = V_b + V_P$. Since the box is airtight and

$dV_t = o$, hence

$dV_b = -dVp$.

We also know that if temperature is constant, then PV = constant is applicable for air in box as per the Boyle's law. Now during expiration, the Vp (Volume of lungs) decreases (dV_P is negative)resulting increase in box volume i.e., Δv_b is positive. Increase in box volume results in the decrease of the pressure in the box (as PV = constant). Similarly during inspiration the volume of lungs increases and the box volume decreases which results into increase in the pressure in the box. Now the shutter in the breathing tube is closed and airflow in the mouth is stopped. The pressure transducer in the tube measures the mouth pressure which is almost equal to alveolar pressure. The changes in mouth pressure correspond to the changes in box volume which correspond to the volume of lungs during expiration and inspiration. If the test is performed at the time of end of expiratory level, the intrathoracic volume must be equal to the FRC.



Body Plenthysmogram

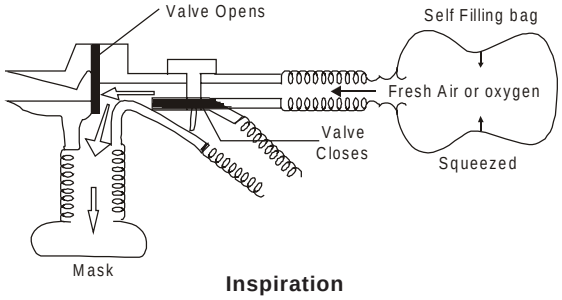
4. **Airway resistance measurements:** Resistance of the air passages is called airway resistance. To determine airway resistance, intra-alveolar pressure and airflow measurements are required. The intra alveolar pressure is measured in cm of H_2O and the flow in litres per sec. The body plethysmograph can be used to measure intra alveolar pressure (P_{ia}) and airflow (f)

   Air resistance is _____

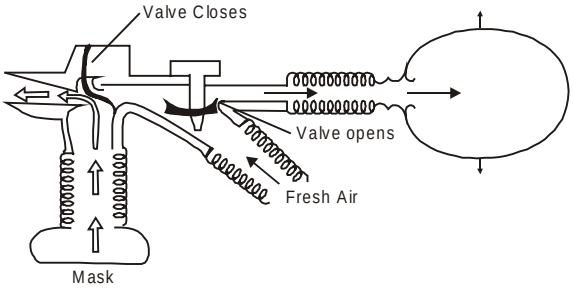
   $R = \frac{P_{ia} - P_{atm}}{f}$ where P_{atm} = atmospheric pressure.

ARTIFICIAL VENTILATION AND VENTILATORS

1. Artificial ventilation is used whenever patient has reduced breathing or respiratory failure. During respiratory failing, we use devices which can supply oxygen and remove carbon dioxide so that normal partial pressure of oxygen (Po_2) and carbon dioxide (Pco_2) can be maintained. The devices for the artificial ventilation consist of a mask breathing valve and self filling bag. The working of the device is as shown in the figure. The breathing valve is designed to permit fresh air or oxygen to the patient and expired air is conducted to the atmosphere. The self filling bag functions as a hand pump. On squeezing, it supplies fresh air or oxygen for inspiration and later fills with fresh air or oxygen by self expanding during expiration.



Inspiration



Expiration Artificial Ventilation

2. **Ventilators:** It is used when artificial ventilation is required for a longer time. The function is to ventilate the lungs of a patient in a manner as close to natural respiration. The ventilators can be negative pressure type in which the flow of air to the lungs is facilitated by generating a negative pressure around the patient's thoracic cage. Other ventilators are positive type in which inspiratory flow is developed by applying positive pressure (Pressure > atmospheric pressure) at the airways. During the expiratory duration, the inspiratory flow delivery system stops the positive pressure at the exhalation system and simultaneously it opens the valve to allow the expired air to the atmosphere. The positive pressure ventilators are preferred over the negative pressure ventilators. Ventilaters used during anaesthesia are small and simpler while those used during intensive care are more complicated and capable of giving accurate control over a wide range of respiratory conditions.

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. Inspiration and expiration are two phases of ---------- (*a*) Hybernation (*b*) Respiration
2. The air is taken in the lungs during --------- (*a*) Inspiration (*b*) Expiration
3. Carbon dioxide is eliminated from the lungs during ----- (*a*) inspiration (*b*) Expiration
4. The lungs are located in the closed cavity which is called -----cavity. (*a*) thoracic (*b*) bronchus
5. The lungs can shrink to --------- in volume (*a*) half (*b*) one third
6. The nasal cavities, pharynx, larynx, trachea, bronchi and bronchioles form----------
   (*a*) air passage (*b*) lungs
7. The wind pipe is called ---------- (*a*) Trachea (*b*) larynx
8. The voice box is called ------ (*a*) trachea (*b*) larynx
9. The thoracic cavity has a single entrance at the top through the------ (*a*) trachea (*b*) larynx
10. The descent of diaphragm increases the thoracic capacity ------(*a*) laterally (*b*) vertically
11. The movement of the ribcage upwards increases the thoracic capacity -------- (*a*) laterally (*b*) vertically.
12. As the thoracic capacity increases ------- pressure is created in the lungs (*a*) positive (*b*) negative
13. During respiration, the lungs are ------ organs (*a*) active (*b*) passive
14. The blood in the lungs passes through the pulmonary ------which are located in the walls of the alveolar sacs (*a*) capillaries (*b*) arterioles
15. The blood passes through the pulmonary capillaries to the pulmonary ---------(*a*) Veins (*b*) venules
16. The flow of the air in the respiratory system is usually ----- (*a*) turbulent (*b*) laminar
17. The blood flow becomes turbulent if Reynolds number is -------- than 50,000. (*a*) higher (*b*) lesser
18. Low Reynolds number flow is the characteristic of the air flow in ---------- passage (*a*) alveolar (*b*) respiratory bronchus
19. The respiratory volume can be measured by ---------- (*a*) volume meter (*b*) spirometer
20. A-------- is used along with spirometer to measure residual volume (*a*) gas analyser (*b*) volume analyser

21. Functional residual capacity can be measured by ---------(*a*) spirometer (*b*) body plethysmograph

22. Artificial ---------- is used whenever patient has reduced breathing (*a*) lungs (*b*) ventilation

ANSWERS

1. (*b*)	**2.** (*a*)	**3.** (*b*)	**4.** (*a*)	**5.** (*b*)	**6.** (*a*)	**7.** (*a*)
8. (*b*)	**9.** (*a*)	**10.** (*b*)	**11.** (*a*)	**12.** (*a*)	**13.** (*b*)	**14.** (*a*)
15. (*b*)	**16.** (*b*)	**17.** (*a*)	**18.** (*a*)	**19.** (*b*)	**20.** (*a*)	**21.** (*b*)
22. (*b*)						

KIDNEY AND BLOOD FLOW

12

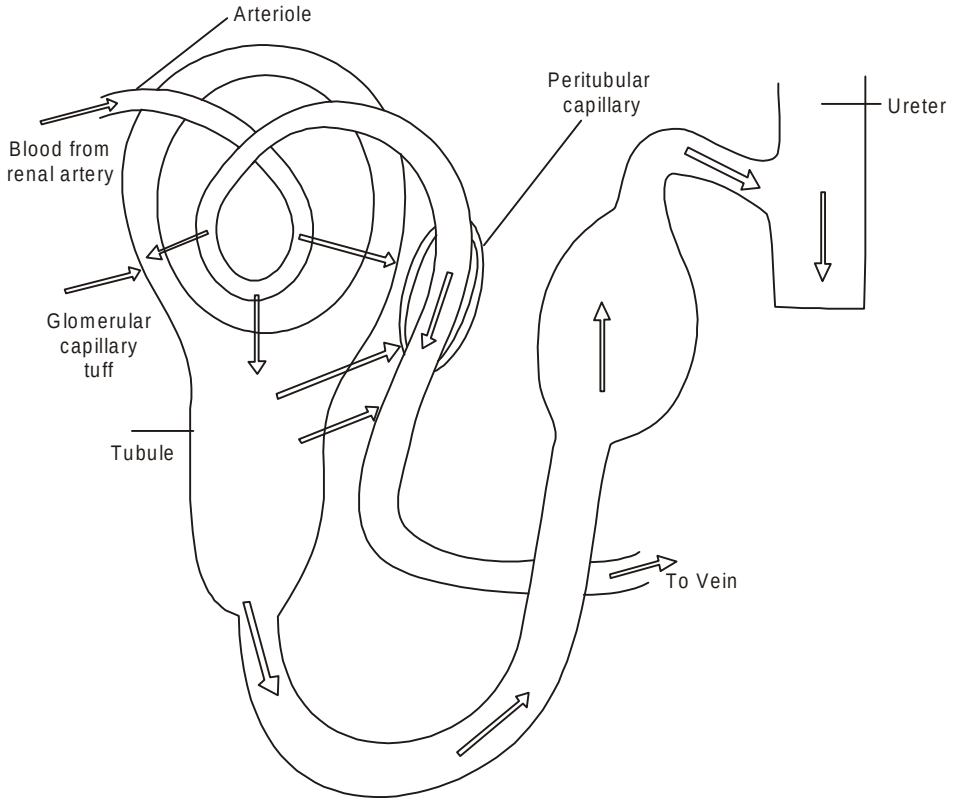
While this door is closing, another door is opeing. It is our job to go find that door.

INTRODUCTION

1. The kidneys are a pair of excretory organs situated on the posterior wall of the abdomen just below the diaphragm, one on each side of the vertebral column. They remove waste products of metabolism, the excess of water and the excess of salts from the bloods. They also maintain pH value. Each kidney is bean shaped. Each kidney is about 11 cm long, 6 cm broad and 3 cm thick. The left kidney is a little lengthier and narrower than the right kidney. The kidney is about 150 gm in normal adult. The kidneys are also called renes from which the deriative renal and nephron have been derived. The red corpuscles of the blood supple oxygen to the tissues of the kidney. In return the kidneys remove waste products from the blood plasma and regulate the composition of blood plasma.

MECHANICS OF KIDNEYS

1. Each kidney consists of one to three million of tiny functional units which are called nephrons. Each nephron consists of a cluster of capillary loop which is called the glomerulus which opens into a collecting tubule. The renal arteries carry blood from the aorta into the glomerular capillary tuft through arterioles. The blood pressure in the glomerulus capillary tuft is about 70 to 90 mm of Hg. The flow of blood is controlled by the arterioles by the amount of contraction. Due to the pressure the waste water and salt in the plasma of the blood pass through the thin walls of the capillaries into the glomerulus, from where they move into the tubule. The glomerulus filtrate a larger quantity of fluid, about 180 litres per day which consists mainly of water and other substance besides the body waste. A large

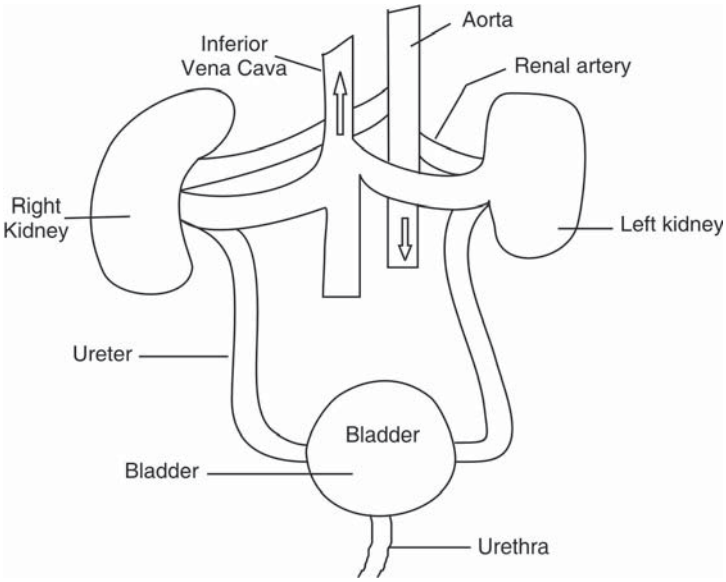


Working of Nephron

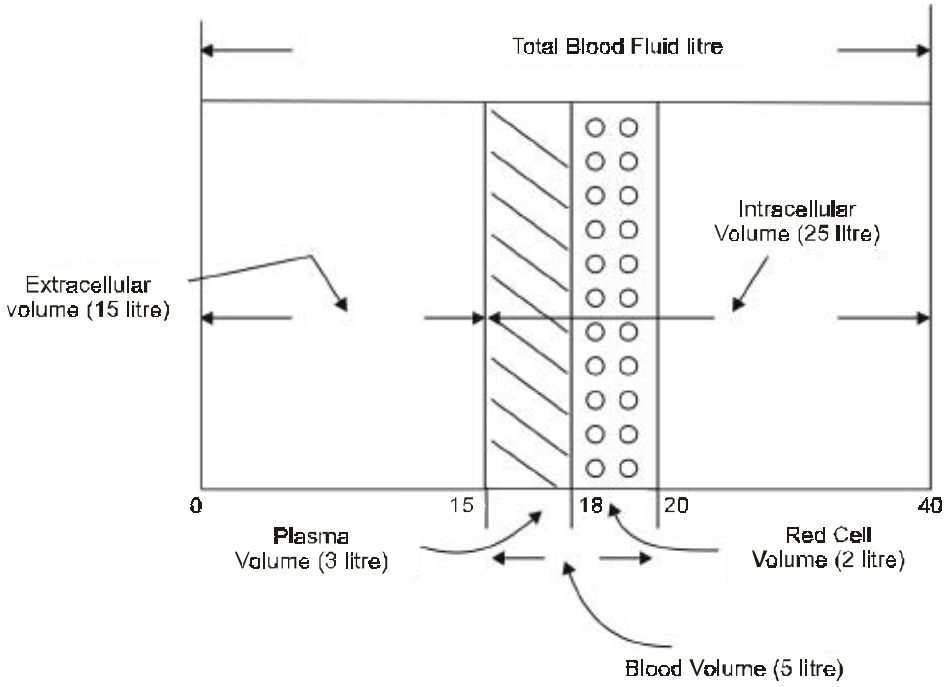
amount of water and other substance are reabsorbed by kidney tubules and waste which is called urine (about 1 to 1.5 litres per day) is passed to bladder through ureter. The total blood flow through the kidneys is about 1200 millilitre per min while extracellular fluid (fluid outside cells) is about 15 litres out of total body fluid of 40 litre which means that intra cellular fluid volume is 25 litres (fluid inside the cells). The blood plasma and extra-cellular fluid are in equilibrium which ensures that the amount of blood equivalent to extra-cellular fluid can pass through the kidneys once every 15 mins. Hence the composition of blood plasma and extra cellular fluid is closely regulated by the kidneys. Special aspects of blood flow through the nephrons–.

(a) The glomerular capillary tuff has high blood pressure which helps in filtering.

(b) Low pressure in the peritubular capillary which permits fluid being absorbed continually into the capillaries.



Blood Flow Through Kidneys



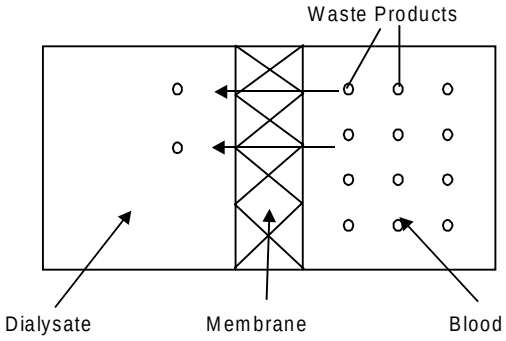
The Respiratory Tract

2. Uremia is urine in blood which is a renal malfunction. In acute renal failure, urine formation stops as kidneys fail to perform excretory or regulatory function on the blood. The renal failure results in changes in the body fluid due to the progressive decrease in the number of functioning nephrons. Due to decrease in number of

functional nephrons, the clearance of urea, creatinine and other metabolic waste products in the plasma of the blood decreases which is called reduction in the glomerular filteration rate (GFR). The kidneys become less effective as regulatory organs. Uremia is the clinical state resulting from renal failure. Uremia affects other organs of the body as certain substances that accumulate in the blood are toxic. The artificial kidney (Dialyzer) is used which is a mechanical device to remove the accumulated waste products in the blood.

THE ARTIFICIAL KIDNEY (DIALYZER)

1. The artificial kidney is a dialyzing unit which operates outside the patient's own body. It receives the blood from the cannulated artery of the patient through a plastic tube. The dialysate consists of electrolyte solutions of desirable composition. The dialysis occurs across a membrane of cellophone. After dialysis, the dialyzed blood is fed to an appropriate vein of the patient through a tube. The dialyzing membrane has small preforation (diameter of about 5×10^{-9} m) and waste products of the blood are able to pass through the membrane into the dialysate fluid because of the existence of a concentration gradient across the membrane. The movement of waste products from the blood to the dialysate results in clearing of the blood and dialysate with waste products is discarded. To speed up the dialysis either a positive pressure is applied to the blood compartment or a negative pressure is created in the dialysate compartment.



Principle of Dialysis

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. Kidneys are a pair of ------- organs (*a*) urinating (*b*) excretory

2. Kidneys remove ------- products from the blood (*a*) waste (*b*) all salts

3. The ---- kidney is a little lengthy and narrower than the -----kidney (*a*) right left (*b*) left, right

4. The kidneys are also called --------(*a*) beans (*b*) renes

5. The kidneys regulate the -------- of the blood plasma (*a*) concentration (*b*) composition

6. Each kidney consists of million of functional units which are called ----------(*a*) neutrons (*b*) nephrons

7. The capillary loop of nephron is called ---------- (*a*) tubule (*b*) glomerulus

8. The glomerulus opens into ---------(*a*) tubule (*b*) ureter

9. The urine is passed to the bladder through ---------- (*a*) tubule (*b*) ureter

10. Uremia is ------in blood which is a renal malfunction (*a*) plasma (*b*) urine

11. Artificial kidney is also called ---------- (*a*) Analyzer (*b*) Dialyzer

12. The dialyzing membrane has small --------- (*a*) charge (*b*) perforation

13. Due to existence of the concentration gradient across the membrane, the waste products are able to pass through the

membrane to --------(*a*) dialysate (*b*) urine

14. To speed up the dialysis either a -------- pressure is applied to the blood compartment or a -------- pressure is created in the dialysate compartment (*a*) positive, negative (*b*) negative, positive

15. The composition of the blood plasma and extra celluar fluid is closely --------by the kidney (*a*) monitored (*b*) regulated

16. The blood pressure in the glomerulus capillary tuff is about ---------- (*a*) 10 mm Hg (*b*) 70 mm Hg

17. The glomerulus filtrate about ---------- fluid per day (*a*) 1.5 litres (*b*) 150 litres

18. A large amount of water and other substance of the filtrate are reabsorbed by kidney ---------- (*a*) tubules (*b*) ureter

19. The kidneys function on the blood---------- to remove waste products and to regulate composition (*a*) corpuscles (*b*) plasma

20. The -------supply oxygen to the tissues of the kidney (*a*) plasma (*b*) red corpuscles

21. The kidneys are located ---------the diaphragm on the posterior wall of the abdomen (*a*) above (*b*) below

ANSWERS

1. (*b*)	**2.** (*a*)	**3.** (*b*)	**4.** (*b*)	**5.** (*b*)	**6.** (*b*)	**7.** (*b*)
8. (*a*)	**9.** (*b*)	**10.** (*b*)	**11.** (*b*)	**12.** (*b*)	**13.** (*a*)	**14.** (*a*)
15. (*b*)	**16.** (*b*)	**17.** (*b*)	**18.** (*a*)	**19.** (*b*)	**20.** (*b*)	**21.** (*b*)

PROSTHESES AND THERAPEUTIC DEVICES 13

When I was sick, I didn't want to die. When I race, I don't want to lose. Dying and losing, it's the same thing.

INTRODUCTION

1. Prosthesis is a fabricated substitute for a missing part of the body as a limb, heart valve, eyes and tooth. Cybernetics is the study of self organizing machines and mechanical brains. The emphasis is to develop prosthetic devices for human enhancement. Prosthetics are hot area of research. Artificial hands and legs give wearers a better quality of life. Degenerative retinal diseases result in the death of the rods and cones (the cells responsible for light detection). The scientists are working on ways to restore functional sight to those who have become blind through disease. The bionic eye system is made of a 3 mm chip implanted into the retina and a pair of virtualr-eality style goggle containing a video camera. The goggles convert the video pictures into an infrared image. Dextra is an artificial hand system which is being developed. It can control up to three fingers by recording the movement of muscles in the remaining part of the arm as a person thinks about moving his hand. Robotic devices are also being developed to help the handicapped and also to enhance the strength of a normal person. The Berkeley lower extremity exokeleton (Bleek) is a device which is being developed. It can calculate how to distribute weight so that wearer feels little or none of it. A soldier who can carry huge loads without getting tired would be more useful on any battle field. A Fireman who needs to climb stairs with heavy equipment or a rescue worker who needs to take supplies into areas where vehicles can not go are other applications of Bleek.

GAIT ANALYSIS

1. Human ambulation or gait is one of the basic need of independent functioning. It is commonly affected by other disease processes or injury. The terminology used to describe gait is :–

(*a*) **Gait Cycle:** It commences when the heel of the reference extremity contacts the ground and ends when the heel of the same extremity contacts ground again. The gait cycle consists of two periods of stance, two periods of swing and two periods of double support.

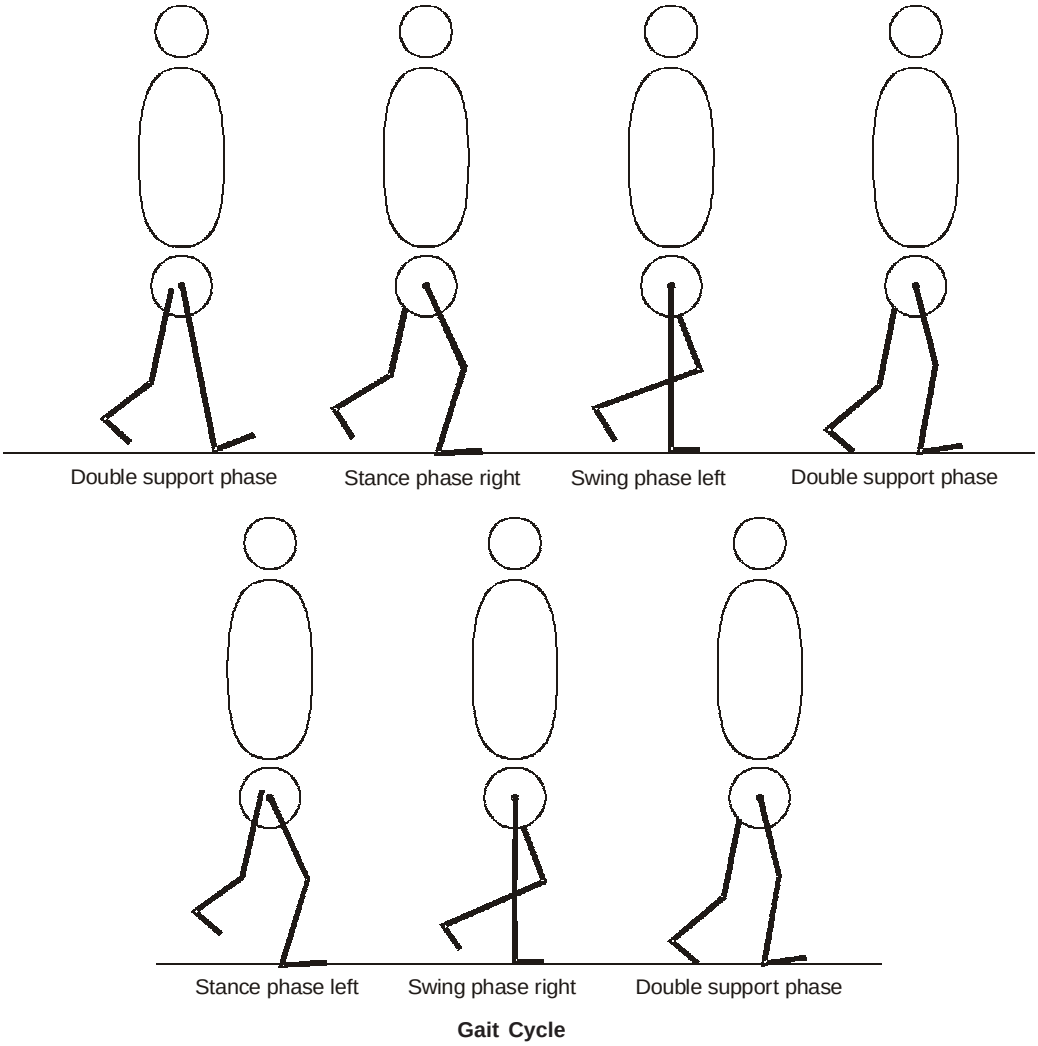
(*b*) **Stance phase:** It is the interval inwhich the foot of the reference extremity is in contact with the ground. For example, when we consider the right lower extremity as reference extremity, the left lower extermity is in swing phase while

the right lower extremity is in stance phase. A single gait cycle contains right and left stance. Stance phase constitutes 60% of the gait cycle.

(*c*) **Swing phase:** It is the interval inwhich the foot of the reference extremity does not contact the ground. Therefore a single gait cycle contains right and left swing phase. The swing phase constitutes 40% of the gait cycle.

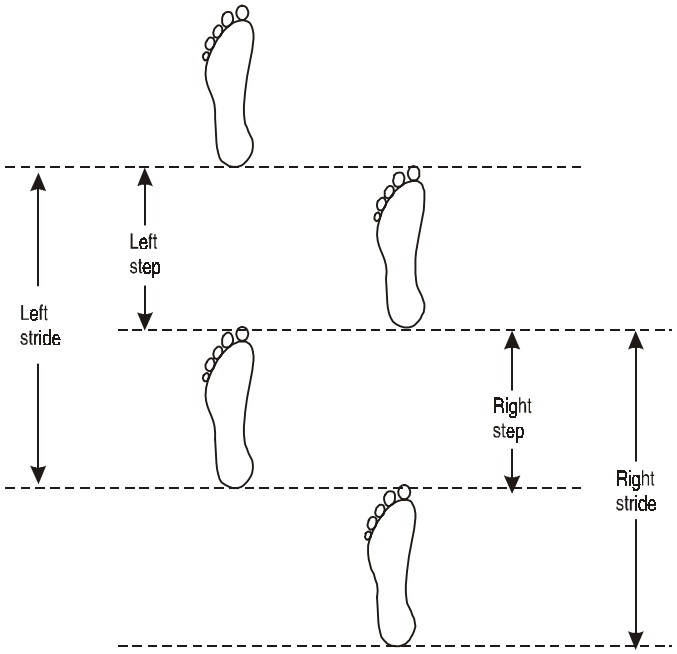
(*d*) **Double support phase:** It is the interval in which body weight is transferred from one foot to the other and both right and left feet are in contact with the ground at the same line. There are two double support phases in a gait cycle.

(*e*) **Stride:** Two steps consisting of a right step and a left step comprises a stride. Step length is the distance from the point of heel strike of one extermity to the point of heel strike of the second extremity. Stride length is the distance from the point of heel strike of one extremity to the point of heel strike of the same extremity.

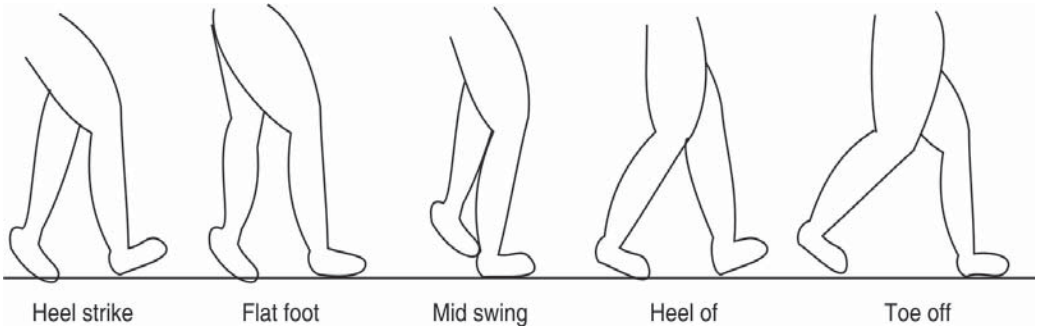


(*f*) **Units:** Each phase of gait has been divided into units. The stance phase has units of (1) heel strike (2) footflat (3) mid stance (4) heel off (5) toe off. Swing phase has units of (1) acceleration (2) midswing (3) deceleration.

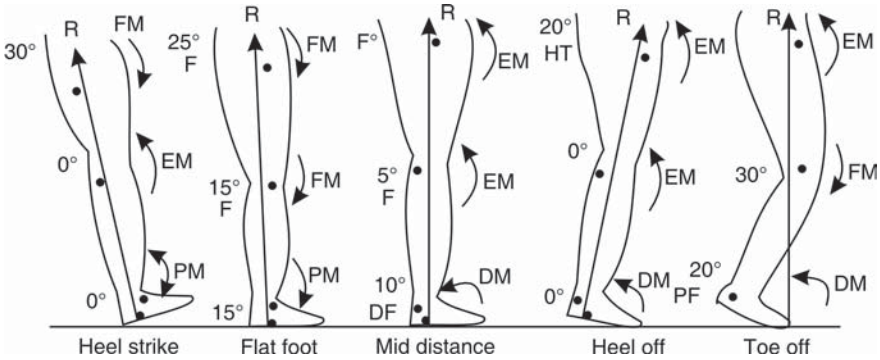
(*g*) **Ground reaction and moments:** The ground reaction vector (R), flexion moment (FM), extension moment (EM), plantar flexion moment (PM) and dorsal flexion moment (DM) have been shown in the figure for various units of stance phase. The ground reaction vector (R) changes from a position anterior (in heel strike) to posterior (in flat foot) which changes the direction of moment at knee from counter clockwise to clockwise. The direction of moment changes in each unit of stance phase.



Step Length and Stride Length



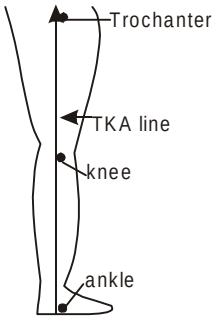
Unit of Stance Phase



Movement During Stance Phase

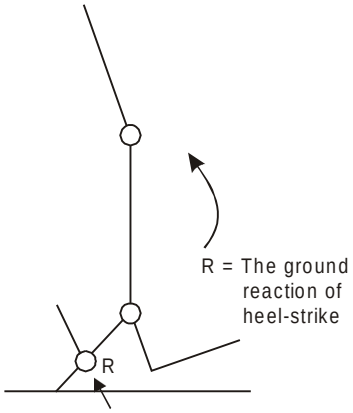
PROSTHESES: CLINICAL REQUIREMENTS

1. **A prosthesis has three major parts :**
   (*a*) The interface which consists of socket, any additional suspension and body operated controls.
   (*b*) The skeleton which replaces the lost limb segment. The skeleton is given a limb–like appearance. It is a system of levers separating the artificial joints.
   (*c*) The artificial joints are required to work as natural joints. They are designed to limit, modify and assist the movements.
2. All movements to the prosthesis are given through interface. The skeleton provides not only a realistic appearance but also incorporates a system of levers by which power/movement is transmitted to the joints. The joints are to perform the control function.
3. **Prostheses for lower limb:** The lower limb bears the body weight. It is required to give support and balance to the body. It has to be strong and capable to provide mobility in the movements during gait cycle as under :
   (*a*) *Midstance:* The body weight during standing erect passes throguh the imaginary line joining centre of ankle, the centre of rotation of the knee and the centre of trochanter (behind hip). This is known as trochanter-knee-ankle or TKA line as shown in figure. The limb can be considered to be made of three levers. The thigh and shin are vertical and foot complex is horizontal. The ankle joint is the junction of the horizontal and vertical levers. If it is controlled, then the natural limitation of extention at knee and hip can be used to stabilise these joints when the body mass is acting on the extensor axis aspects of the joints. A prostheses has mechanical stops to provide this stabilty. We will get greater stability if the joint lies on the extenor side of the weight axis but then the flexion at the begining of the swing phase will be difficult to be initiated.



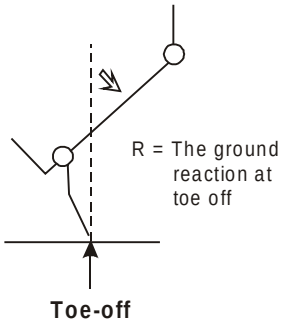
   (*b*) *Heel-Strike:* The stance phase during walking starts with the contact of the heel with the ground. The ground reaction is at the posterior end when the

heel striks the ground. The shin therefore tends to rotate forward causing unwanted knee flexion. This rotation of the shin has to be counteracted by the mechanism of the prostheses.



Heel Strike

(*c*) *Toe off:* A similar reverse action occurs at toe off as the ground reaction is at the anterior end of the horizontal. The shin therefore tends to rotate backward impeding flexion of the knee.



Toe-off

(*c*) *Swing phase:* During this phase, the socket exerts force through the skeleton to the joints which activate their mechanism to propel the prostheses forward.

(*d*) *Alignment Device:* A good prosthesis depends upon a well fitting socket which is properly aligned with the foot and the interposing joint mechanism in both the swing and stance phase. The alignment device must permit (1) tilting of the socket in any direction from the vertical (2) movement of the socket relative to the foot in any horizontal of the joint axis in a horizontal plan direction (3) rotation (4) proper calibration for the adjustment purpose.

4. **Prostheses for Ankle-Foot:** The clinical requirements for the prostheses during the gait cycle are :

   (*a*) *Stance phase:* The prostheses should allow plantar flexion without foot stop at heel contact so that the ground reaction is located anteriorly towards the ankle axis. This alleviates the forward rotation of the shin and stabilises the knee. The stabilisation of knee allows and assists the shin to become vertical when the body passes over the foot. Some doriflexion of the foot is required before the heel rises to prevent excessive knee stability.

   (*b*) *Swing phase:* The prostheses must be light as the ankle foot complex is at the extremity of the limb. It must rise of at toe off with knee flexion to clear the ground. During swing phase, it should dorsiflex.

Single Axle Ankle Joint

Solid-Ankle Cushionded Heel Foot (Sach)

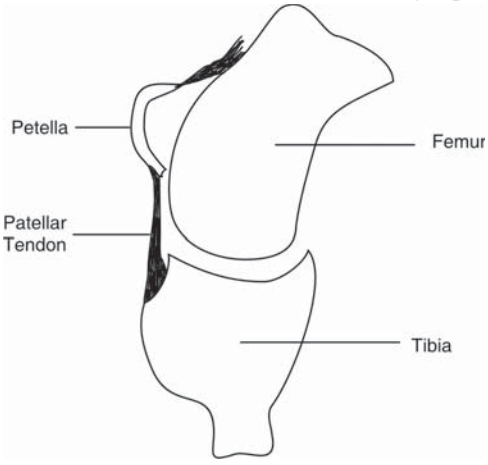
5. **Knee Joints:** Knee joints fall into two gorups: (1) A below knee prosthesis (2) An above knee prosthesis. In a below knee prosthesis, the stump is too long and patient can retain his useful natural knee. In an above knee prosthesis, the amputation is high enough, permitting the artificial knee joint to be incoporated in prosthesis. The clinical requirements of this type of prostheses are:

   (*a*) *Stance phase:* The prosthesis must permit little flexion during full extension while in midstance. It must support the body weight while in flexion. It must extend if required even while supporting the body weight. It should be durable.

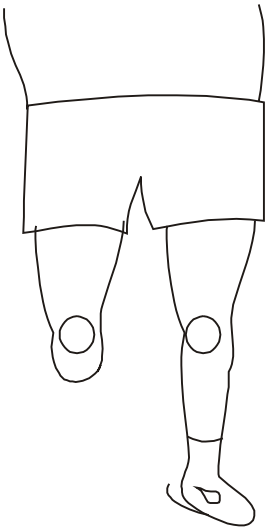
   (*b*) *Swing phase:* The prosthesis can flex at toe off so as to allow the heel to rise freely and clear the ground. However excessive rise due to inertial force is to be prevented. It must develope force to decelerate the shin and foot when it is changing from flexion to full extension.

A BELOW KNEE PROSTHESES

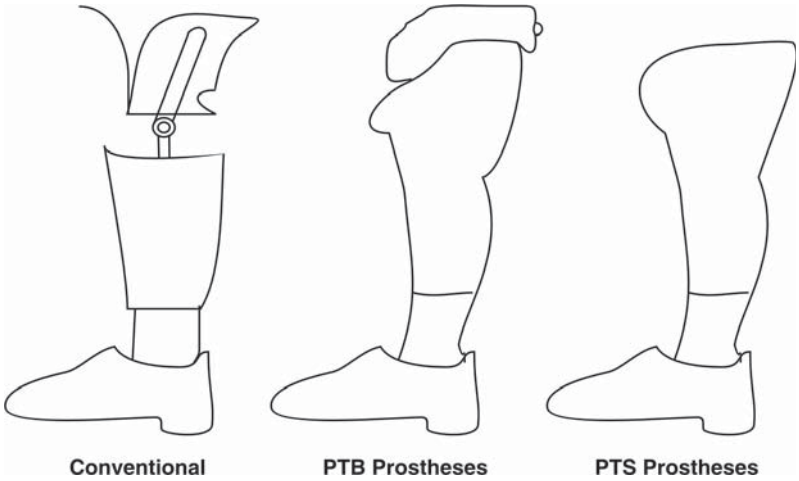
1. Three types of prostheses are available to a below knee amputees viz. (1) conventional (2) patellar tendon bearing. (PTB) and (3) protheses tibiale supra condylienne. Earlier, only conventional type of prostheses was available which has a shank which holds a foot ankle assembly and a socket. The socket cannot provide any supporting force on the anterior aspect. The weight is born by the stump on its medial and lateral aspects and the thigh. A simple hinge joint connects the thigh corset to the socket. With the present trend of an extension of the patellar tendon bearing below knee prostheses commonly known at PTB has been developed, a below knee stump can not be subjected to much pressure at the distal end due to shearing stress developing between soft tissues and the cut end of the bone. After careful consideration of the complete biomechanical problem, the full advantage of weight-bearing capabilities of the patellar tendon is taken in fabrication of this prostheses. A cuff is provided for the suspension. To do away even with the suspension straps and also to increase the weight bearing on the patellar tendon, a prostheses properly known as PTC (Prostheses Tibiale supra condylienne) has been developed. Here the socket is aligned with the knee in flexed position and the suspension is achieved by an extension of the socket so as to completely enclose the patella and the major portion of the femoral condyles.



Patellar Tendon



Below Knee Amputee



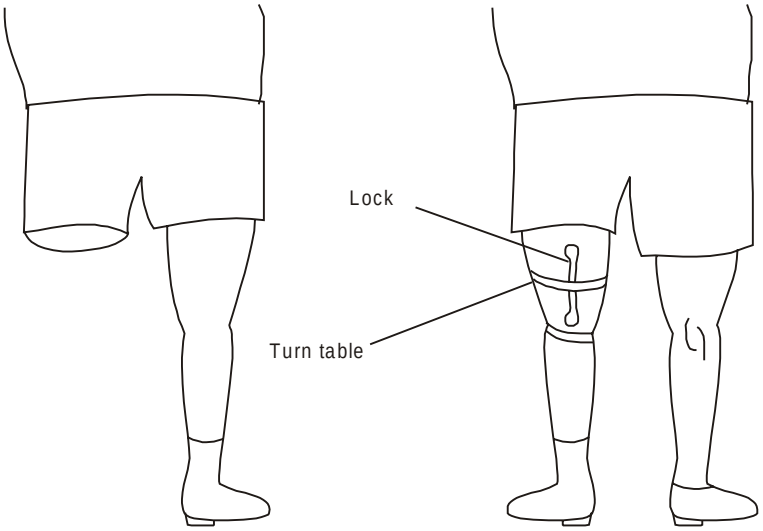
Below Knee Prostheses

2. Earlier nearly all prostheses for below knee amputation had jointed side steels on either side. This is nothing but a simple, uniaxial, elevis mortice-and-tenon or box joint to which a lock is fixed. Since natural knee is not a simple uniaxial joint and there is difference between working of natural and artificial joint, there is a tendency to exaggerate the movement between the stump and the socket which is known as piston action. In below knee amputation, the nautral knee can largely provide the control for both the stance and swing phase.

AN ABOVE KNEE PROSTHESES

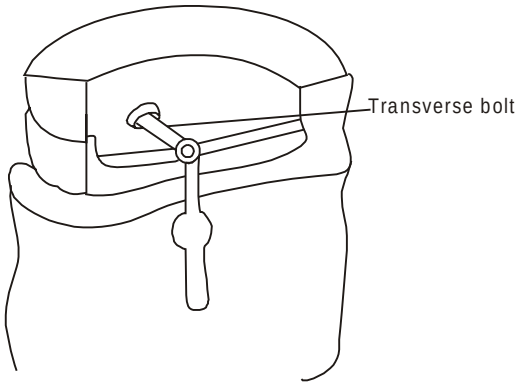
1. For the above knee amputee, the natural control of knee joint is lost. The prostheses must have stance and swing phase controls. It is common to provide simple locks to

prevent flexion or elastic straps over the front of the knee to help accelerate the shin as controls. More complex mechanisms may be more effective but they lead to weight problem and poor reliability. In simple form, the artificial leg for an above knee prostheses incorporates a manual locking type of thigh turntable as shown in the figure. The prostheses does not permit all natural movements like foot inversion and eversion, and turning of the foot or toes upwards. To avoid the stump socket tending to slip over the stump, a torque opposing knee flexion is provided in the artificial leg to increase the stump to stump socket friction.



An Above Knee Prostheses

2. **Uniaxial knee Joint:** It is for the above knee prosthesis. In its simplest form, it is a transvers bolt about which shin rotates on the thigh pioce. Mechanical stops are placed at full extension and upto 120° flexion. Some basic joint mechanisms can be added which modify its actions as under :
   (*a*) Stance phase mechanism: Some in herent stability is incorporated in the prostheses employing the ground reaction force to extend the knee against the extension stop while in errect position.
   (*b*) A simpler lock which engages automatically when standing up.



Uniaxial Knee Joint

(*c*) Stabilising arrangement with friction surface to support the body's weight when knee joint is flexed upto 30°.

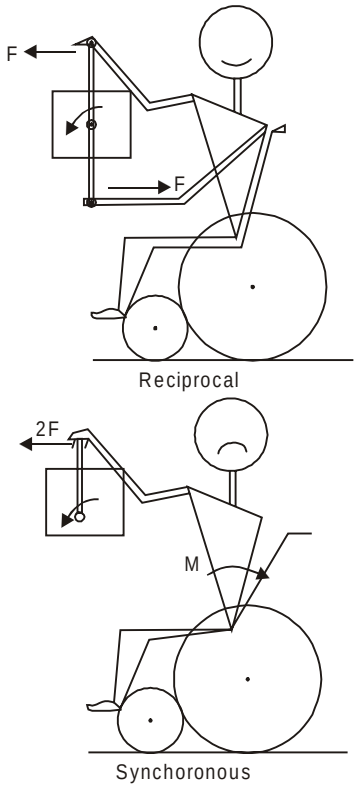
(*d*) Swing phase helping mechanism as knee lock adversely affects the swing phase.

(*e*) Elastic straps over the front knee or knee mechanism with spring inside to assist the shin forward by the recoil after flexion. They act as accelerator for the shin.

(*f*) Variable swing phase controls: We require unimpeded swing in the middle ranges and progressively greater intermittent friction at each end of the swing phase. Both hydraulic and pneumatic controls are available. Both operate the same way with one or two cylinders with piston travels unimpeded until near the end of piston stroke. It then forces air or liquid through an orifice (restricted opening) thus providing damping and resistance. The pneumatic swing controls are lighter.

REHABILITATION OF A PARAPLEGIC

1. Paraplegics have paralysis of both lower extremities and generally the lower trunk. A common garden wheel chair provides them desirable mobility. However they do need regular exercise for the fitness of the body. The assessment of the functional capacity of a paraplegic is important for periodic follow up during medical rehabilitation program. The assessment contributes to establishing the patient's physical fitness. Arm cycloergometry has been found to be very suitable for the wheelchair users with normal upper limbs. An arm exercise with some work load is accompanied by a larger rise in the heart rate, higher blood pressure, increased pulmonary ventilation and oxygen consumption. It is also found that reciprocal propelling is more convenient than synchronous propelling. As shown in the figure, there is a force-couple going to the opposite direction with only axial movement of the trunk in the horizontal plane is the net result in the reciprocal mode while there is a significant bending movement of trunk in the sagittal plane in the synchronous mode.



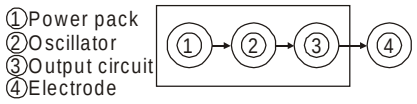
Mode of Propelling

CARDIAC PACEMAKER

1. The arrhythmia means abnormal rhythm of the heart. Rhythmic action of the heart is initiated by regularly recurring electrochemical impulses originating at the natural cardiac pacemaker located at the SA node. Each pacing impulse spread ever the surface of the atria to the AV node. After some delay at the AV node, the impulse is conducted to the ventricles (Refer chapter 10). A normal sinus rhythm (NSR) depends on the proper

functioning of the pacemaker (SA node) and conduction of the impulses. Any change in the NSR is called an arrhythmia. SA node may temporarily or permanently fail due to some diseases and no impulse originates from SA node. The pacing function is taken over by some other cells near AV node. However in that situation the heart is paced at a much lower rate and such condition is called bradycardia or slow heart. In this situation, the heart can not provide sufficient blood to meet the body's demands.

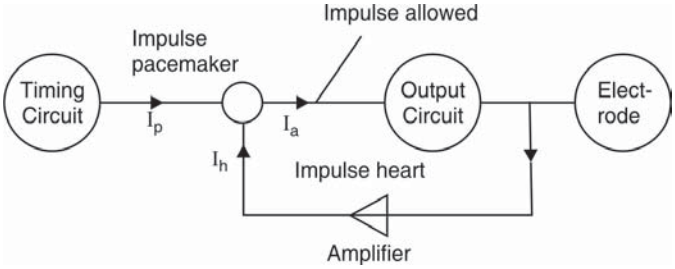
2. A pacemaker system is a device capable of generating pacing impulses like a natural pacemaker and delivering the pacing impulses to the heart. All pacemakers have a pulse generator and electrode. Pacemakers can be (1) asynchronous (fixed rate) (2) demand type synchronous (3) atrial-synchronous (4) rate responsive pacemaker. The asynchronous pacemaker generates impulse at a uniform rate regardless of what is going on in the heart. The oscillator controls the pulse output circuit and impulse is given to the heart through electrode.



ASYNCHRONOUS PACEMAKER

1. Asynchronous pacing is also called competitive pacing as the fixed rate impulse may take place along with the natural pacing impulses of the heart. Hence both impulses compete to control the heart beat. The above problem is overcome in the synchronous pacemaker. The artificial pacemaker does not compete with the natural pacing impulses of the heart. A demand type synchronous pacemaker has a timing circuit, an output circuit electrode and a feedback loop. The timing circuit runs at fixed rate which is lower than the natural pacing rate of the heart. Hence pacemaker remains at stand by mode. The pacemaker takes over when the natural pacing rate of the heart falls below the fixed rate set on the pacemaker. The atrial synchronous is used where the conduction system of the heart fails specially the AV node. The SA node generates impulse which stimulates the atria. The impulse corresponding to atrial contraction (the P wave of the ECG) is detected by the electrode of the artificial pacemaker which triggers with appropriate delay an impulse similar to natural AV node which has failed. Often atrial synchronous pacemaker is combined with the demand pacemaker system so that the combined pacemaker can do the jobs of defective natural pacemaker and defective AV node. The rate responsive pacemaker has a sensor which converts the physiological variables of the patient to electric signals which are fed into the controller circuits. The pacemaker is programmed to control the heart rate as per the electric signal generated by the physiological variables. The controller decides whether artificial pacing is required or the artificial pacing in place of natural pacing. If it is not required, the artificial pacing remains in the non functional state. The pacemakers can also be grouped as internal pacemakers and external pacemakers. Internal pacemakers are permanently implanted in patients who have either failed SA node or have suffered from permanent heart block. The external pace makers have external wearable pulse generator connected to electrode located on the heart. These pacemakers are used if patients have temporary heart irregularities or if patients are undergoing cardiac surgery.

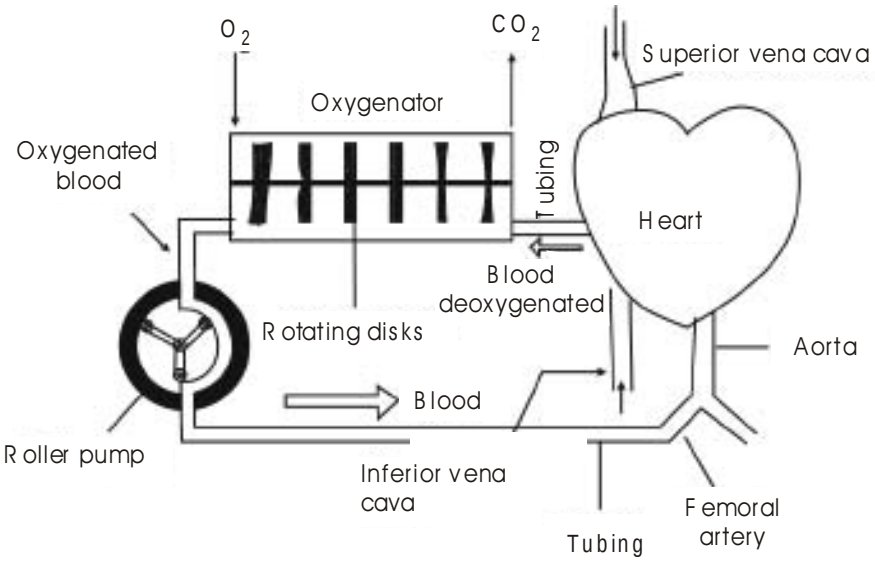
Impulse allowed = I_a
Impulse pacemaker = I_p
Impulse heart = I_h
$I_a = I_h$ when $I_h > I_p$
$= I_p$ when $I_p > I_h$



Demand Type Synchronous Pacemaker

CARDIOVASCULAR PROSTHETIC AND ORTHOTIC DEVICES

1. **Pump oxygenerator.** It is used to perform the hearts pumping action and the lungs oxygeneration function during cardiac surgery. It consists of a pump for maintaining arterial blood pressure and an oxygenerator which can oxygenate blood by removing carbon dioxide. The pump and oxygenerator are connected in series. They are connected either between the right atrium and a femoral artery or between the superior and inferior vena cava. Rollers or multiple fingers pump is used which regularly press the squeezable tubing carrying blood so that necessary arterial pressure and pulsating motion are provided to the blood without any physical contact of the pump and the blood. The oxygenerator can be film type or membrane type. In film type, the rotating disks provide large surface area to the blood exposed to oxygen. In the membrane oxygenator, the blood is made to flow through the tubes made of membrane which is permeable to oxygen and carbon dioxide.



Pump Oxygenerator

2. **Artificial heart.** It is small blood pump of biocompatible material which can replace a deceased heart. The pump is implanted on thoracic cavity and it is operated inside from any electrical or pneumatic device. The artificial heart can be used as a permanent replacement or as a temporary measure until a suitable natural donor heart is planted.
3. **Aortic balloon system.** It is a cardiac assistance device. It is a sausage shaped balloon that can be inserted into aorta through a femoral artery. The balloon is connected to an external apparatus which can inflate or deflate the balloon by supplying carbon dioxide or sucking out carbon dioxide from the balloon. Consider the balloon in the inflated state in the aorta which is permitting some blood to flow past it. As the ventricle contraction starts, suction action is applied to the balloon which causes it to collapse. The ventricle will require now less effort to pump the blood to replace the volume occupied earlier by the balloon. As the aortic valve of the ventricle closes, the balloon is expanded by supplying of carbon dioxide to the balloon. As the balloon expands, it pushes the blood from the aorta to the rest of the body. The balloon performs much of the work which is normally done by the left ventrical.
4. **Defibrillator.** The heart is able to pump blood through precisely synchronized action of the heart muscles. The rapid spread of impulse on the surface of the atria causes atria to contract together and pump blood into the ventricles. After a delay of impulse at AV node, the ventricles are synchronously stimulated to pump blood to the pulmonary and systemic cirulatory systems. If synchronism is lost, then this condition is known as fibrillation. Fibrillation leads to the normal rhythmic contraction of either the atria or the ventricles being replaced by rapid irregular contraction of atria or ventrieles. Atrial fibrillation is the fibrillation of atria while ventricular fibrillation is the fibrillation of the ventricles. Atrial fibrillation leads to inadequate pumping of the blood but ventricular fibrillation more dangerous as this leads to failure of blood pumping and death of the patient. The most successful method of defibrillation is the application of an electric shock to the heart. The electric shock is able to stimulate all muscles of the heart simultaneously. All the cells of the heart muscle enter their refractory period together at the end of the electric shock, after which normal heart action may resume. Generally electric shock of intensity 6 ampere, frequency 60 HZ for duration of 0.25 to 1 sec is applied. Nowadays DC (direct current) defibrillation is used, in which a capacitor is charged to a high DC voltage which is rapidly discharged through electrode across the chest of the patient. There is possibility of accidentally application of the defibrillator output during ventricular repolarization (T wave) which may cause ventricular fibrillation. To avoid this problem, special defibrillator is used which has synchronising circuitry to ensure the output occurs immediately after R wave but before T wave can occur. Such defibrillator is called cardioverter which is a combination of the cardio monitor and the defibrillator.

HEMODIALYSIS

1. Hemodialysis is nothing but an artificial kidney and it is a widely used as a prosthetic device for the patient having acute renal failure. It is a mechanical device to remove the accumulated waste products in the blood (Refer chapter 12).

VENTILATORS

1. Is a therapeutic device which assist a patient in ventilating his lungs. The ventilator is used whenever any patient has reduced breathing

or respiratory failure. The ventilators have been covered in details in chapter 11.

PATIENT MONITORING DISPLAYS

1. In order to periodically check a patient's progress and make vital decisions at times of crisis, the exact reproduction of the ECG, arterial blood pressures and other variables are required. The principal display device for patient monitoring is the cathode ray tube (CRT). The patient monitoring display device can be of two types of CRT displays viz. (1) conventional or bouncing ball (2) non fade display. In conventional or bouncing ball display the method uses oscilloscope with the horizontal sweep driven by a slow sweep generator which makes the electron beam to move from left to right at a predetermined selectable rate. ECG signals are applied to the electron beam to move up or down vertically. As the electronic beam moves up and down at high speed in vertical direction with constant horizontal sweep from trace to trace, the display appears as a continuous wave form which moves from left to right. As the electron beam moves across and forms a pattern on the screen of CRT, the earlier portion of the waveform begins to fade away and ultimately disappears. The ability of trace to remain visible for some duration on the screen of the CRT is called persistance. The duration of persistance depends on the phosphorous coating of the screen. CRTs with persistance of about 1 second are available. As ECG wave form may occur at a rate of 60 events per min, the persistance of 1 sec will allow only one cycle of waveform visible on the screen. In this also, the last portion of waveform will be brighter than the early portion of the waveform. The temporary display of such nature makes diagnosis a difficult task. The problem has been overcome in the nonfade display. In this method the electron beam rapidly scans the entire surface of the CRT screen in a television like raster pattern. The brightness level is kept a very low brightness level so that raster is not visible. A method called Z axis modulation is used so that the beam is brightened only when a brightening signal is applied to the CRT. The brightening signal is generated only when the electron beam is at a location that contains a part of the displayed waveform. The brightening signal produces a dot on the screen. Each time when electron beam scanned the screen, a series of dots are produced on the screen which have ECG pattern. Since dots are produced so close together and the scan is so rapid that the dots appear as a continuous trace. In addition to nonfade display, the ongoing heart rate, systolic and diastolic, blood pressure and the patient's temperature are displayed as numerical readouts.

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. Arrythmia means----------rhythm of the heart (*a*) normal (*b*) abnormal

2. The natural cardiac pacemaker is located at the --------(*a*) AV node (*b*) SA node

3. The impulse of conduction is delayed at -------- (*a*) AV node (*b*) SA node

4. A normal sinus rhythm (NSR) depends on the proper functioning of --------- (*a*) AV node (*b*) SA node

5. If no impulse originates from SA node, the pacing function is taken over by some other cells near -------(*a*) AV node (*b*) septum

6. Bradycardia is a condition in which heart is paced at -----rate (*a*) slower (*b*) faster

7. All pacemakers have a electrode and ------ (*a*) pulse generator (*b*) electric circuit

8. The fixed rate pacemaker is called---- (*a*) synchronous (*b*) asynchronous

9. Asynchronous pacing is also called------- pacing (*a*) harmonious (*b*) competitive

10. The problem of the competitive pacing has been overcome in ---------pacemaker (*a*) synchronous (*b*) asynchronous

11. The timing circuit of the demand type synchronous pacemaker runs at fixed rate which is --------- than the natural pacing rate of the natural heart (*a*) lower (*b*) higher

12. The controller of ------- pacemaker decides whether artificial pacing is required in place of the natural pacing (*a*) synchoronous (*b*) rate responsive

13. The heart's pumping action and the lung's oxygenation function during cardiac surgery is performed by the---------- (*a*) pump oxygenerator (*b*) artificial heart

14. The pump oxygenerator has ----- and ---------- (*a*) roller pump, oxygenerator (*b*) dialyzer, oxygenerator

15. The oxygenerator can be film type or ----- type (*a*) membrane (*b*) screen

16. Artificial heart is a small blood pump of ---------- material which can replace a decreased heart (*a*) strong (*b*) biocompatible

17. Aortic baloon system is a cardiac -------- device (*a*) assistance (*b*) boosting

18. Atria and ventricles are required to -------- simulated one after another (*a*) asynchronously (*b*) synchronously

19. ---------- leads to the normal rhythmic contraction of either atria or the ventricles are replaced by the rapid irregular twitching (*a*) fibrillation (*b*) defibrillation

20. The most common method of defibrillation is the application of ---------- (*a*) an electric shock (*b*) blood infusion

21. A device combining the defibrillator and cardiomonitor is called ---------- (*a*) cardioverter (*b*) cardio defibrillator

22. Hemodialysis is nothing but a --------- (*a*) artificial kidney (*b*) artificial bladder

23. Artificial ventilating the lungs of a patient is done by --------- (*a*) Ventilator (*b*) Respirator

24. The principal display device for patient monitoring is the ---------- (*a*) CRT (*b*) Display tube

ANSWERS

1. (*b*)	**2.** (*b*)	**3.** (*a*)	**4.** (*b*)	**5.** (*a*)	**6.** (*a*)	**7.** (*a*)	**8.** (*b*)
9. (*b*)	**10.** (*a*)	**11.** (*a*)	**12.** (*b*)	**13.** (*a*)	**14.** (*a*)	**15.** (*a*)	**16.** (*b*)
17. (*a*)	**18.** (*b*)	**19.** (*a*)	**20.** (*a*)	**21.** (*a*)	**22.** (*a*)	**23.** (*a*)	**24.** (*a*)

ORTHOSIS

14

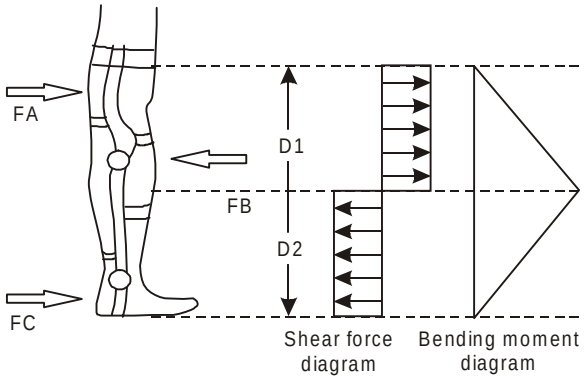
History teaches everything including the future.

INTRODUCATION

1. Orthosis is a greek ward which means 'making straight' or 'correction of maladjustment. Hence orthosis is the science that deals with making & fitting of orthopedic appliances. The desired outcomes of orthosis intervention are achieved by selected application and transmission of forces through the orthosis appliance. The desired outcome of optimal control, corrected stabalization or assistance from orthosis is achieved through variuos design principles. While selecting an orthotic device, the goals of the orthosis are considered. Also the degree of freedom to be atained and the forces required to be achieved from the orthotic device for the desired outcome are considered.
2. While selecting an orthotic device, we have to consider the kinematic characteristics of the defective joint or segment including an analysis of degree of fredom. We have to evaluate before selecting an orthosis for a joint segment, its translation and rotations about various axes. Although we try to correct one or two of the six potential degree of freedom of rotation through the application of orthotic device but an awarenesess of all inherent motions and relative relatiionship between connected segments is essential for maxmising the effectiveness of the orthosis.

THREE FORCE SYSTEM

1. The goals from orthosis can be achieved through selected application of forces developed by the orthotic device. The applied parallel forces are required to be balanced out by using a three points loading system. In the figure, a three force system is applied on the lower limb. The three force system is such that $F_B = F_A + F_e$ and $F_A \times D_1 = F_c \times D_2$. If two posterior pressure pads at A and C in a hip-knee-ankle orthosis are placed at distance D_1 and D_2 from anterior pressure pad B then force in pad 'B' is twice of the equal forces in A & C when $D_1 = D_2$. Both bending moment diagram and shear force diagram are important for designing and achieving the intended goal of the orthosis.



ORTHOSIS FOR GAIT DISABILITY

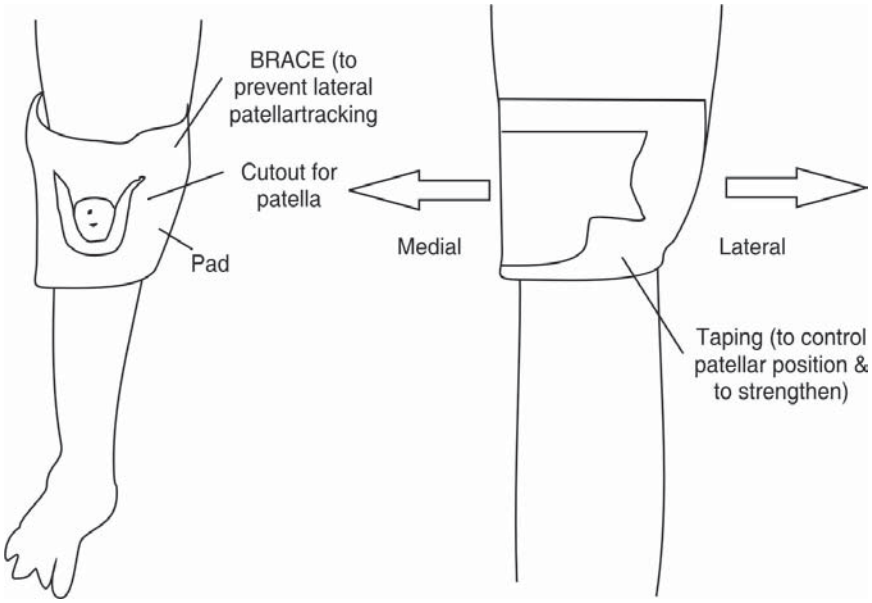
1. A very throughtful orthosis device can be prescribed to a person with neurologic involvenment so that he may access more efficient movement patterns and may reduce residual gait disability. Three basic functional tasks are essential for lower limbs for efficient and successful ambulation. They are (1) weight acceptance (2) one leg stance support (3) swing phase (limb advancement). The above process must happen in smooth manner and the limb must remain stable. It must be able to absorb the impact of superincumbent body weight and stand all moments developed during forward movements of the limb and the body. The function of single limb support involves that the body can carryout forward movement on the weight bearing limb. The limb has to perform this task over a reduced area of support on the ground. The swing advancement involves removal of weight from the limb and its forward progression until next step is initiated. The ground clearance is an essential element of the functional task of the limb during swing limb advancement. The funtional task, gait subphase and critical events for a normal gait cycle are as tabled below :

Function task	**Gait subphase**	**Critical events**
1. Weight acceptance	1. Initial contact	1. Heel first contact
	2. Loading response	2. (*a*) Hip stability
		(*b*) Controlled knee with 15° flexion
		(*c*) 10° Ankle plantar flexion
2. Single limb stance	1. Mid distance	1. Controlled tibial progression
	2. Terminal stance	2. (*a*) 10° dorsiflexion of ankle joint
		(*b*) Heel rise from ground
		(*c*) Trailing limb position
3. Swing phase	1. Preswing	1. 40° knee flexion
	2. Initial swing	2. (*a*) 15° hip flexion
		(*b*) 60° knee flexion
	3. Mid swing	3. (*a*) Hip flexion to 25°
		(*b*) Zero ankle dosiflexion
	4. Terminal swing	4. Knee extention to neutral

2. The goals of orthotic prescriptions are to improve the biomechanics of gait. Primary emphasis is on the more commonly prescribed lower limb braces. The orthosis aims to achieve biomechanical alteration of human movement in upright function. A wide range of ankle-foot orthosis (AFO) designs are used in treating the person with neurologic involvement. Braces are capable of providing some degree of control during stance, swing or both phases of gait. The use of knee braces, taping or foot orthosis can be beneficial treatment during strengthening programme to achieve dynamic control and balance at the patelloferroral joint at knee. Supportive wrapping and bandaging techniques are beneficially used for athletics. Adhesive strapping and protective padding techniques are commonly accepted as orthotic treatment to orthopaedic patients.

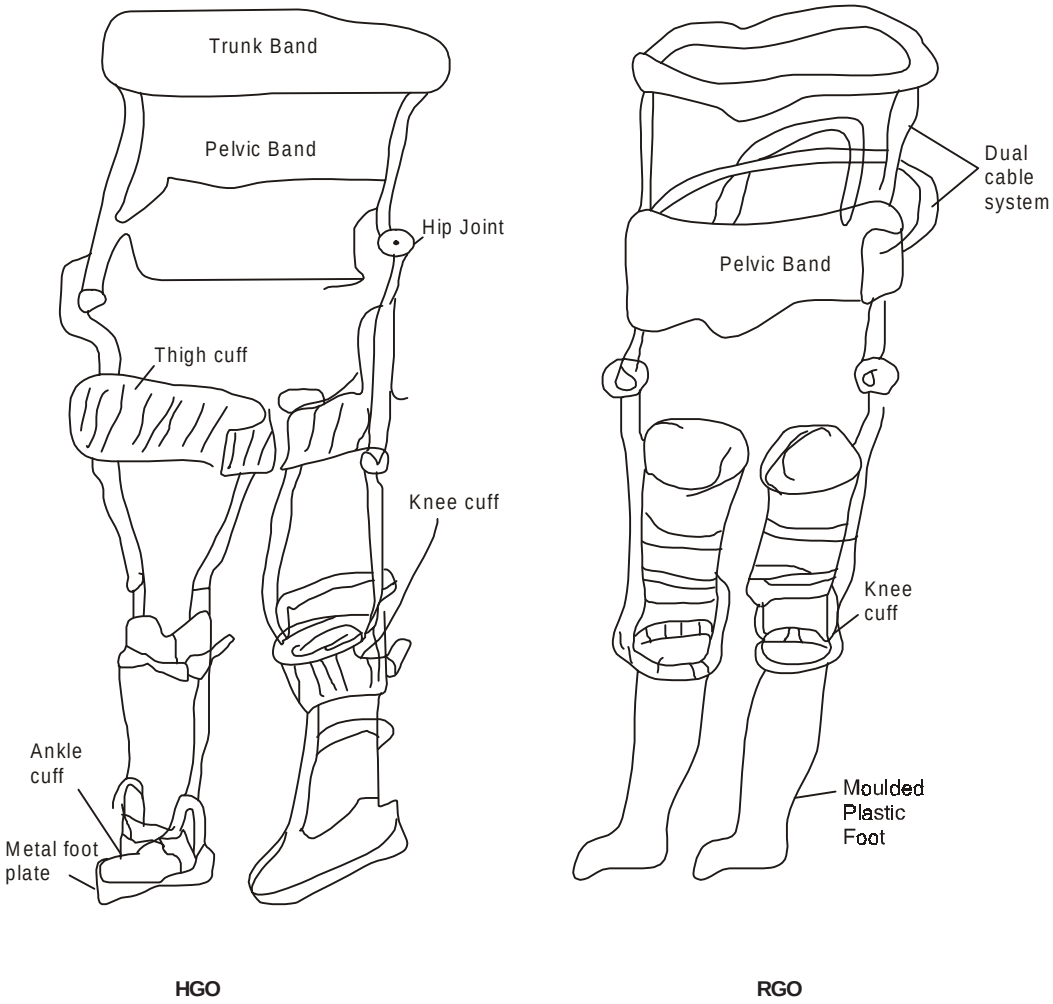
PARAPLEGIC ORTHOTIC WALKING SYSTEM

1. Spinal cord disease or injury causes paraplegia. This results in the loss of physical function like standing and walking. The ability to stand and walk is considered most important in the individuals's potential to return to a normal life style. There has been an increase in the research and development of rehabilitation technology, enabling more paraplegic patients to stand and ambulate. The ability of a person with paraplegia to stand upright imparts several physiological benefits. They include improvement in blood circulation, reduction in spasticity and retardation of osteoporosis. The joint contractures and kidney malfunction are also prevented. The ability to stand and walk also imparts psychological benefits as person



Knee Brace **Knee Taping**

with paraplegia may feel himself a normal person having standing and walking ability. The most commonly used orthotic systems for the paraplegic patients are (1) bilateral KAFO (knee-ankle-foot orthosis) (2) HKAFO (Hip-knee-ankle-foot orthosis). KAFO requires a large energy expenditure for the patients to walk. HKAFO for paraplegic gait allows ambulation at a lower energy cost. Two major designs of HKAFO are hip guidance orthosis (HGO) and reeiprocating gait orthosis (RGO) as shown in the figure. These orthotic systems are similar as the patient is braced from the mid trunk to the feet and the knee and ankles immobilized in a neutral position. These orthosis permit hip flexion and extention but prevent hip adduction. The RGO is designed to be worn inside the patients clothes. The patient requries assistance of roller or reciprocating roller while walking wearing RGO. However HGO is worn outside the patient's clothes and the patient walks with the assistance of crutches.



HGO **RGO**

OBJECTIVE TYPE QUESTIONS

Fill in the gaps.

1. Orthosis means --------- of maladjustment. (*a*) correction (*b*) reduction

2. --------- is a science that deals with making and fitting of orthopaedic appliances.

(*a*) prostheses (*b*) orthosis

3. We try to correct one or two of the -------- potential degree of freedom of motion through the application of orthotic devices. (*a*) four (*b*) six

4. The goals from orthosis can be achieved through selected application of --------- developed by the orthopic device. (*a*) forces (*b*) movements

5. The biomechanics of gait can be improved by ---------. (*a*) orthosis (*b*) prostheses

6. Suppertive wrapping and bandaging techniques are used by ---------

(*a*) orthopaedic patients (*b*) athletics

7. Addesive strapping and protective padding techniquel are used by ---------

(*a*) orthopaedic patient (*b*) athletics.

8. Three basic functional tasks are essential for lower limbs for efficient and successful ---------. (*a*) ambulation (*b*) stance

ANSWERS

1. (*a*) **2.** (*b*) **3.** (*b*) **4.** (*a*) **5.** (*a*) **6.** (*b*) **7.** (*a*) **8.** (*a*)

METALLIC BIOMATERIALS 15

You spend the first two years of your kids' lives teaching them to walk and talk and the next 16 years telling them to sit down and be quiet.

INTRODUCTION

1. Biomaterial is a synthetic material used to replace a part of a living system or to function in intimate contact with living tissues. Therefore biocompatibility is acceptance of an artificial implant by the surrounding tissues and by the body as a whole. The success of implant depends upon–

(*a*) Acceptance of the implant by the surrounding tissues.

(*b*) Implant is nontoxic and non carcinogenic.

(*c*) The material of implant must have high mechanical strength

(*d*) Implant faces varying loads and hence it should have high fatigue life

(*e*) The material should be chemically stable and inert

(*f*) Implant should have sound engineering design

(g) Appropriate molecular weight and molecular weight distribution (weight of implant & its density)

(*h*) Material should be easy to be fabricated and processed for large scale production.

2. Biomaterials can be (1) Polymers (2) Metals (3) Ceramics and (4) Composites. Nylon, silicone rubber, polyster and poly tetra-fuoroethylene are polymers commonly being used as biomaterials. Polymers are resilent and easy to be fabricated but they deform and degrade with time. Titanium & its alloys, Cobalt and Chromium alloys, stainless steel, Gold, Silver and Platinum are common biocompatible metals. Metals are strong, tough and ductile. However, metallic implants are difficult to be produced and they are like to corrode. Aluminium oxide, Calcium phosphates and carbon are common bioconspatible ceramics. Ceramics are inert, strong and highly biocompatible. However ceramics are brittle and they are not resilent. Carbon fibers reinforced polymers and bone cement are biocompatible composite materials. They are tailor made and strong but difficult to be made.

3. The uses of biomaterials are :–

(*a*) Replacement of damaged or diseased parts like hip joint, knee joint & heart valves etc.

(*b*) Assistance in healing as done by sutures, bone plates and intramedullary rod etc.

(*c*) Assistance in functioning as by cardiac pacemaker and intraocular lens etc.

(*d*) Correction of functional abnormality. *Example* : Cardiac pacemaker.

(*e*) Cosmetic correction. *Example*: chin augmentation, augmentation mamo plasty.

(*f*) Assistance in diagnosis: Probes and catheters are made of biomaterials.

(*g*) Assistance in treatment eg. catheters and drains of biomaterial.

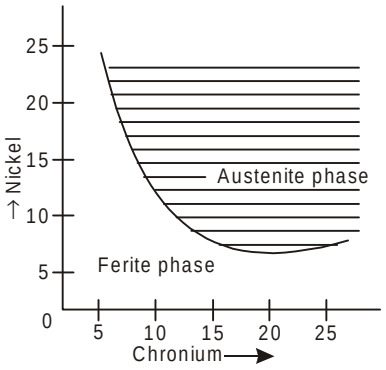
4. As explained above, the success of implant depends upon various factors. Also if '*f*' is failure and '*r*' is reliability, then $r = l - f$. The total reliability of implant having multiple modes of failure (f_1 f_2 ... to f_n) can be given as:

$r = (l - f_1)\ (l - f_2)\ ...\ x\ (l - f_n)$

$= r_1 \times r_2 ...\ x\ r_n$

Most pure metals generate a severe tissue reaction. The reason is that metals have high free energy and they tend to lower their free energy by oxidation/corrosion. This is the reason that vanadium steel can not be used for implants.

5. Stainless steel : The austenite stainless steel such as 316 stainless steel (molybdenum in small percentage) and 316 *L* stainless steel (carbon up to 0.08% only) are most commonly used for implants. These steels are non magnetic and corrosion resistant. The austenite stainless steel is prone to work hardening and it has to be heat treated after cold working. 316 *L* stainless steel has 17 to 20% chromium, 12 to 14% nickel & 2 to 4% molybdenum. The inclusion of molybdenum enhances resistance to pitting corrosion. Nickel stabilizes the austenite (α) phase at room temperature. It also enhances corrosion resistance. The austenite phase stability of steel is influenced by both Nickel & Chromium contents as shown in the figure. The implants of these steels are suitable as temporary implants such as fracture plates, screws and hip nails.



Effects of Ni and Cr on Phase of Steel

6. Co Cr alloys : These are mainly two types of cobalt - chronium alloys viz (1) Castable *Co Cr Mo* alloy (2) Wroughtable by forging *Co Cr Mo* alloy. The castable is used for dentistry and artificial joints. The wrought *Co Cr Mo* alloy is used for making prostheses suitable for heavy loaded joints like hip and knee. The wrought *Co Cr Mo* alloy has good fatigue and ultimate strength and it is used where we require long service life. The cast *Co Cr Mo* alloy (*F* – 75) has mainly 22 to 33% *Cr*, 5 to 7% *Mo*, 2.5% *Ni* and balance *Co* while wrought *Co Cr Mo* alloy (*F* 562) has mainly 19 to 21% *Cr*, 9 to 10.5% *Mo*, 33 to 37% *Ni* and balance *Co*.

7. Titanium and Alloys : Titanium is used for implant as it has low density and good mechanical properties. Titanium (also aluminium) evokes minimum amount of tissue reaction as it forms a tancious oxide layer which resists further diffusion of metal ions to oxygen gas at the interface. While making implant, titanium has to be processed in an inert atmosphere. Titanium is an allotropic material. It can exist as a hexagonal close-packed structure (α phase) upto 82ºC and as a body - centered cubic structure (β phase) above 82ºC. The transformation temperature changes on addition of alloying elements which enables the titanium alloys to have a wide range of properties. The main alloying elements of the alloy are aluminium (5.5 to 6.5%) and vanadium (3.5 to 4.5%).

The titanuim nickel alloys have properties of "shape memory effect (SME)". It means that the material can gain its original shape on heating. Therefore these alloys having SME are used for orthopedic implants, contractile muscles for artificial heart, filter for vena cava, orthodontic dental archwires and intracranial aneurysm clips.

8. **Dental metals :** Dental amalgam is an alloy obtained by mixing silver-tin alloy with mercury. Since mercury is in liquid form, the silver - tin alloy can be mixed in it. The resultant paste is packed into a prepared cavity of tooth. The final composition of dental amalgam contains 45 to 55% mercury, 35 to 45% silver and 15% tin. The amalgam sets in solid form in one day.

9. **Gold :** Gold being base metal has high corrosion resistance but poor mechanical properties. Gold and its alloys are used as dental materials as they have durability, stability and corrosion resistance. Dental fillings of gold can be carried out by two methods viz. casting and maletting. Mechanical properties of gold can be improved by adding not more than 25% copper or 4% of platinum.

10. **Corrosion of metallic implants :** The main reason of metallic corrosion is its oxidation. A metal in pure form stays in metastable equilibrium. Tissue fluid in the human body contains water, dissolved oxygen, chloride and hydroxide ions etc. Hence metallic implants have to face a very corrosive environment. Corrosion is unwanted chemical reaction of metallic implant with environment. The metals tend to lower their energy state by electrochemical reaction with environment. Oxidation and reduction are two electrochemical reactions. Oxidation is a reaction in which electrons are consumed. Oxidation reaction is :–

$$M \rightarrow M^{+n} + ne \quad \ldots(I)$$

Similarly reduction reactions are –

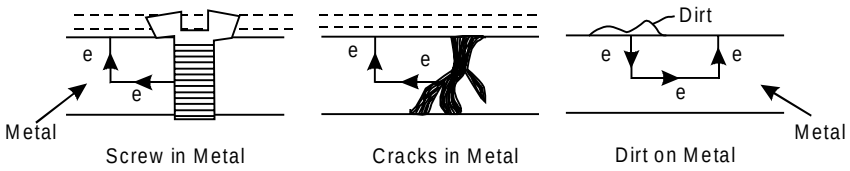
$$M^{+n} + ne \rightarrow M \quad \ldots(II)$$

$$2H_2O + O_2 + 4e \rightarrow 4.0H \quad \ldots(III)$$

$$4H^+ + O_2 + 4e \rightarrow H_2O \quad \ldots(IV)$$

$$2H^+ + 2e \rightarrow H_2 \quad \ldots(V)$$

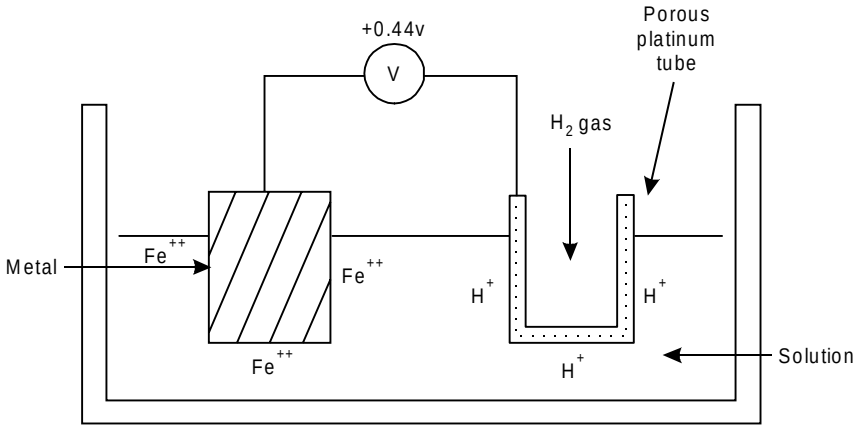
Equation (III) gives corrosion reaction occurring at neutral *PH* solution and metallic implants are generally corroded according to this. It is also seen that variation of oxygen on metal surface leads to corrosion with sites with lower oxygen concentration (cracks, dirt or along screw of implants) become anodes and exposed sites with higher oxygen concentration become cathodes. These anodes and cathodes with body solution connecting them to form electro chemical cells leading to deterioration of metallic implants.The tendency of metals to corrode is given by the standard electrochemical series of Nernst potentials as given below :



Deterioration Due to Oxygen Concentration Gradient

S.N.	*Metal*	*Potential CV*	*Remarks*
1	L_i^+	+ 2.96	Anode
2	K^+	+ 2.92	
3	Ca^{2+}	+ 2.90	
4	Na^+	+ 2.71	
5	Mg^{2+}	+ 2.40	
6	Ti^{2+}	+ 2.00	
7	Al^{2+}	+ 1.70	
8	Zn^{2+}	+ 0.76	
9	Cr^{2+}	+ 0.56	
10	Fe^{2+}	+0.414	
11	Ni^{2+}	+0.23	
12	Sn^{2+}	+0.14	
13	Pb^{2+}	+ 0.12	
14	Fe^{3+}	+0.045	
15	H	0.000	Reference
16	Cu^{2+}	– 0.34	
17	Cu^+	– 0.47	
18	Ag^+	– 0.80	
19	Pt^{2+}	– 0.86	
20	Au^+	– 1.50	Cathode

These protentials are found out in electrochemical measurement in which one electode is metal and other is a hydrogen electrode consisting of porous platinum tube through which hydrogen is passed. The protential of hydrogen electrode is taken as reference *i.e.* Zero potential. Metal having higher protential than hydrogen electrode are known as noble metals while those having lower protential are known as base metals. If two dissimilar metals are present in a solution, then the metal having higher protential will become anode and galvanic corrosion starts which is much rapid than corrosion of a single metal. Hence metallic implant should be made of a single metal without any impurity. Any region of stress will become anode with respect to unstressed region of the same material as stressed region has higher energy level. The corrosion of stressed region starts at the earliest opportunity. Also base metals are less prone to corrosion.



Measurement of Potential Against Standard Hydrogen Electrode

OBJECTIVE TYPE QUESTIONS

Fill in the gap

1. ------- is a synthetic material to replace a part of a living system. (*a*) Biomaterial (*b*) Biometal.

2. The reliability of an implant is ------- if it depends upon two factors having probability of failures as f_1 and f_2. (*a*) $f_1 \times f_2$ (*b*) $(l - f_1)$ $(l - f_2)$

3. The acceptance of an implant by surrounding living tissues is called -------. (*a*)bioacceptance (*b*) biocompatibility

4. Metals have high ------- energy. (*a*) latent (*b*) free

5. Vanadium steel is no longer used for implants as it is pron to -------. (*a*) break (*b*) corrode

6. Titanium has ------- density. (*a*) low (*b*) high

7. Shape memory metals can gain ------- shape on heating. (*a*) original (*b*) small

8. Titanium alloys show --------. (*a*) shape memory effect (*b*) good mechanical properties

9. Dental amalgam is an alloy obtained by mixing ------- with mercury. (*a*) silver-copper alloy (*b*) silver-tin alloy

10. Dental amalgam can set in -------. (*a*) one week (*b*) one day

11. Mechanical properties of Gold can be improved by mixing copper not more than ------ percent. (*a*) 30 (*b*) 25

12. Oxidation is a process in which electrones are -------. (*a*) liberated (*b*) consumed

13. Reduction is process in which electrons are -------. (*a*) liberated (*b*) consumed

14. ------- protential is given by the standard electro chemical series. (*a*) Faraday (*b*) Nernst

15. Hydrogen electrode has ------- protential. (*a*) one (*b*) zero

16. Gold and silver are ------- metals. (*a*) noble (*b*) base

ANSWERS

1. (*a*) **2.** (*b*) **3.** (*b*) **4.** (*b*) **5.** (*b*) **6.** (*a*) **7.** (*a*) **8.** (*a*)
9. (*b*) **10.** (*b*) **11.** (*b*) **12.** (*a*) **13.** (*b*) **14.** (*b*) **15.** (*b*) **16.** (*b*)

POLYMERIC BIOMATERIALS

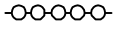
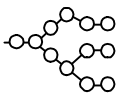
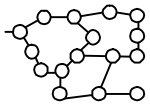
16

Human beings dream of life everlasting. But most of them want it on earth and not in heaven.

INTRODUCTION

1. Polymer as name suggests is many mers (small molecules or repeating units) joining together under suitable condition to form a long chain (a heavy molecule). The process of forming a long chain of a heavy molecule from small molecules is called polymerization. The polymerization can be done by condensation (water is condensed out) or by addition (by rearranging bonds within each monomer). Polymer can be linear, branched or cross linked as shown in table below .

Polymer can be obtained by linking of one type of mers (monomers) or more than two types of mers. Hence copolymers are polymers made form two of more types of mers. The degree of polymerization (DP) is defined as average number of mers (repeating units) per molecule (long chain)*i.e.*, Molecular weight of polymerization = $DP \times$ molecular weight of mers. The possible arrangements of copolymers can be :–

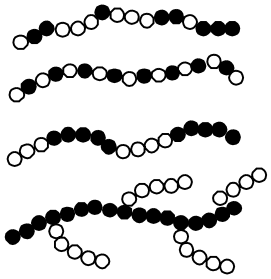
S.N.	Type	Mer or Repeating unit	Linking
1	Linear polymer		
2	Branched polymer		
3	Crossed Linked		

(*a*) Random

(*b*) Alternating

(*c*) Block

(*d*) Graft



2. **Poly dispersity Index (PDI).** The ratio of weight average molecular weight to the number average molecular weight of any polymer is called polydispersity index and is denoted by PDI.

i.e. PDI = $\frac{\overline{M}w}{\overline{M}n}$

where $\overline{M}w$ = Weight average molecular weight

$\overline{M}n$ = Number average molecular weight

$$\overline{M}n = \frac{\sum Ni\,Mi}{\sum Ni} = \frac{N_1M_1 + N_2M_2 + ...}{N_1 + N_2 + ...}$$

where *Ni* = No. of molecules having molecular weight *Mi*

N_1 = Molecules have molecular weight M_1

N_2 = molecules have molecular weight M_2 and so on.

$$\overline{M}w = \frac{\sum Ni\,Mi^2}{\sum Ni\,Mi} = \frac{N_1M_1^2 + N_2M_2^2 + ...}{N_1 + M_1 + N_2M_2}$$

PDI gives an idea about the molecular weight dispersion. Therefore if PDI = 1 *i.e.*, $\overline{M}n = \overline{M}w$, then no dispersion in the system occurs and complete polymerisation has occurred without formation of other products. So in medicinal application, PDI should be unity to avoid any side reactions or side effects due to detachment of byproducts weakly adhered in the polymer.

Example: What is number and weight average molecular weight of polymer? Two monodisperse polymer samples with number average and molecular weight (*a*) 10,000 adn (*b*) 20,000 were weakly adhered in the polymer were mixed. Prepare two samples by taking two parts of (*a*) and one part of (*b*) (2) mixture two was prepared by taking one part of (*a*) and two part of (*b*). Calculate number and weight average molecular weight of mixture 1 and 2. (UPTU 2005-06)

Solution: Number average molecular weight. The arithmatic mean of molecular weight of all the polymeric chains present in the polymeric disperse. It can be given as total mass of polymeric disperse divided by the total number of molecules present. It is denoted by $\overline{M}n$

$$\overline{M}n = \frac{\Sigma N_i M_i}{\Sigma N_i} = \frac{N_1M_1 + N_2M_2 + ...}{N_1 + N_2 + ...}$$

Weight average molecular weight. In this various molecular species are taken proportion to their weights. It is denoted by $\overline{M}w$.

$$\overline{M}w = \frac{\Sigma W_i M_i}{\Sigma W_i} = \frac{W_1M_1 + W_2M_2 + ...}{W_1 + W_2 + ...}$$

But Wi = Ni Mi

$$\text{Hence } \overline{M}\,w = \frac{\Sigma N_i M_i^2}{\Sigma N_i M_i}$$

$$= \frac{N_1M_1^2 + N_2M_2^2 .....}{N_1M_1 + N_2M_2.....}$$

Weight average molecular weight can be determined by viscosity method or ultracentrifuge method. The value of weight average molecular weight is always greater than number average molecular weight.

Given – M_A = 10,000 & M_B = 20,000

Now for mixture (1) having 2A + B, we have $N_1 = 2$, $M_1 = 10{,}000$, $N_2 = 1$ and $M_2 = 20{,}000$

$$\overline{Mn} = \frac{\Sigma N_i M_i}{\Sigma N_i} = \frac{N_1 M_1 + N_2 M_2}{N_1 + N_2}$$

$$= \frac{2\times 10{,}000 + 1\times 20{,}000}{2+1} = \frac{40{,}000}{3}$$

$$= 13{,}333.4$$

$$\overline{Mw} = \frac{\Sigma N_i M_i^2}{\Sigma N_i M_1} = \frac{N_1 M_1^2 + N_2 M_2^2}{N_1 M_1 + N_2 M_2}$$

$$= \frac{2\times(10{,}000)^2 + 1\times(10{,}000)^2}{20{,}000 + 20{,}000}$$

$$= \frac{2\times 10^2 + 4\times 10^2}{40{,}000} = 15{,}000$$

Now for mixture (2) having A + 2B, we have $N_1 = 1$, $M_1 = 10{,}000$, $N_2 = 2$ and $M_2 = 20{,}000$

$$\overline{Mn} = \frac{\Sigma N_i M_i}{\Sigma N_i} = \frac{N_1 M_1 + N_2 M_2}{N_1 + N_2}$$

$$= \frac{1\times 10{,}000 + 2\times 20{,}000}{3}$$

$$= \frac{50{,}000}{3} = 16{,}333.4$$

$$\overline{Mw} = \frac{\Sigma N_i M_i^2}{\Sigma N_i M_i}$$

$$= \frac{N_1 M_1^2 + N_2^2 M_2^2}{N_1 M_1 + N_2 M_2}$$

$$= \frac{1\times(10{,}000)^2 + 2\times(20{,}000)^2}{1\times 10{,}000 + 2\times 20{,}000}$$

$$= \frac{10^8 + 8\times 10^8}{50{,}000}$$

$$= \frac{9\times 10^8}{5\times 10^4} = 1.8 \times 10^4$$

3. During the past few years considerable advances have been made in the development of polymeric materials for use in medicine and surgery particularly for replacements in the cardiovascular system. A number of polymers with proper surface modification which can remain biocompatible for several months are now available. Heart valves, heart-lung devices, catheters, artificial membranes, pacemaker and blood pump are devices which are made from polymeric biomaterials. The successful use of polymeric implants are improved the quality of life of many patients. But the state of art of the production of these polymeric materials for a specific perpose has not been perfected. New polymeric biomaterials are being developed to make good prostheses devices which will enable the patients without limbs to lead a normal life. The commercial polymers can not be used for biomedical applications. They do not have sufficient purity and reproductibility. The polymeric material must meet the need of the surgeons as well as the design problems of the implant. The polymeric material must meet the criteria outside and inside of a physical system. For example chemical inertness and mechanical strength are outside criteria for selection of polymer but the functional characteristics of the polymer with physiological system are inside criteria for the selection or designing the composition of a polymer.

4. Selection of polymeric biomaterial: Certain sets of information that case help in selection of polymeric biomaterial for making of an implant can be grouped into two categories viz (1) General characteristics and (2) Special considerations. The general characteristics which a biomedical polymer must have (1) chemical purity (2) good fabrication methodology (3) adequate mechanical strength (4) no leachable

impurity (5) easy stretchability. The presence of traces of catalyst, residual additive or other impurities in the polymeric implant may trigger thrombosis formation, protein deposition or giant cell growth or any other unfavourable tissue response. Similarly the fabrication history has great significance and biomedical polymer must retain its characteristics even after fabrication. The polymeric material of the implant is reacted upon by physiological environment. The implant must function without being itself demaged and without causing adverse effect on the tissues surrounding it. Hence polymeric biomaterial should not cause – (1) thrombosis (2) any distruction of cellular element of blood (3) cancer (4) toxic and allergic response from tissues (5) adverse effect on immune system (6) depletion of electrolytes (7) fatal effect on enzymes and proteins.

5. Specific considerations mean that a polymeric biocompatible material is designed specifically to meet the functional requirement in the prevalent environment inside the body. To accomplish this, an understanding of the relationship of the structure and properties of the polymer with respect to its interaction with physiological system at molecular level is required. The specific considerations for designing are :

(*a*) *Type of polymers:* certain rigid and elastometric polymers evoke less tissue reaction and thrombosis formation than other.

(*b*) *Molecular weight and Molecular weight distribution:* Most of mechanical properties of a polymer improve with molecular weight upto a limiting value and then remain constant with further increase in molecular weight. Similarly melting point, elasticity and other properties are found to have same trend. However solubility and brittleness shows reverse trend. Therefore, molecular weight of the polymers should be above the limiting value. The properties of the polymers are also affected by the molecular weight distribution of the polymers which should not be broad. Incase of broad distribution, polymer may have two molecular weight chains which may dissociate and leak into the blood stream causing malfunction.

(*c*) *Crystallization and intermolecular forces :* Flexible polymer can be obtained by keeping the chain separated from one another otherwise the polymer will be crystalline and rigid. If crystallisation of the polymer occurs when implanted, stress cracking and stiffening of polymer take place. The highly crystalline polymers like nylon, polyethylene and polypropylene are made flexible with addition of plasticisers. However they can undergo extensive molecular rearrangement under tensile and other stresses and they may again become crystalline. Due to this, they can readily crack or develop pits. These sites also become areas for absorption of protein molecules. The presence of strong intramolecular forces fevours crystallisation of linear polymers which leads to cracks and protien absorption on the surface of the polymer.

(*d*) *Mechanical properties:* An implant or prostheses device has a mechanical function to perform and hence its materical must have enough mechanical properties which depend upon its processing, fabrication, shape, stress and strain relationship and its time dependent changes (creep and deformation). The properties of a polymer like molecular weight and

molecular distribution and crystallinity (crystallinity can be prevented by plasticizers) can be controlled which will ensure a good performance of the polymer.

(*e*) *Surface characteristic:* The surface of a polymer which comes directly into contact with tissues and blood, plays an important role in deciding the biocompatiblity of the polymer. When blood comes in contact with the polymer, there is a rapid absorption of plasma protein on its surface. Subsequent interaction results into the absorption of platelets of the blood which leads to the thrombosis depending upon the nature of the primary layer of proteins. The absorption of proteins from the plasma depends upon the type of surface, hemorheological parameters and types of ionic species present in plasma. The nature of protein absorbed depends upon the physical and chemical nature of the surface of the polymer. Smooth surface of the polymer which is free of pits, cracks and roughness does not absorb proteins. The smoothness of the surface depends upon the micromolecular structure of the polymer and also on its surface treatment.

CERTAIN POLYMERIC BIOMATERIALS

1. **Polyvinyl chloride (PVC):** It is an amorphous and rigid polymer as it has large side group. It has a high melt viscosity which makes its processing difficult. Thermal stabilisers are added to prevent thermal degradation. Plasticizers are added to make it flexible. Lubricants are added to increase melt flow during processing. PVC is used in film form for blood bags, solution bags and surgical packaging. PVC tubing is used in catheters, cannulae dialysis devices and IV administration.
2. **Polyethylene (PE) :** It is available in many grades depending upon density as (1) high density polyethylene (HDPE) (2) low density polyethylene (LDPE) (3) very low density polyethyelene (VLDPE) (4) Linear low density polyethylene (LLDPE) (5) Ultra high molecular weight polyethylene (UHMWPE). HDPE is used for bottles, caps and non woven fabric. LDPE is used for packaging, flexible containers and nonwoven disposeables. LLDPE has excellent puncture resistance and therefore it is used for pouches and bags. Extruded tubes are made of VLDPE. UHMWPE has high density and high mechanical properties. It is used for orthopedic implant such as acetabular cup of tibia in hip joint and patellar surface in knee joint.
3. **Polypropylene (PP):** Thermal and physical properties of polypropylene are similar to polyethylene. Polypropylene has a very high flex life and high resistance to environment stress cracking. It is used for prostheses for finger joint, disposable hypothermic syringes, membrane of blood oxygenator, packaging for devices, containers (solution and drugs), suture, artificial vascular grafts and non woven fabrics etc.
4. **Polystyrene (PS):** High impact polystyrene (HIPS), PS foam and general purpose polystyrene (GPPS) are three grades available. GPPS has good transpancy, ease of fabrication, thermal stability, low density and high modulus. Its ductility, impact strength and resistance to stress cracking can be improved with addition of modifier. It is used for vacuum canisters and filterware. One of the copolymer of polystyrene is acrylonitrile butadicne - styrene (ABS) which has good surface

properties and dimensional stability. It is used for IV sets, blood dialyzers, diagnostic test kits and clamps etc.

5. **Polymethylmeth acrylate (PMMA):** It is amorphous and it has good resistance (in dilute alkalies and inorganic solution), light transparency and excellent optical properties, good weathering properties and good machineability. It is used for blood pumps and reservoirs, IV systems, membranes for blood dialyzer, contact lenses, implantable ocular lenses, dentures and bone cements for prostheses fixation etc.
6. **Polyesters :** Polyethylene terephthalate (PET) is most common polyster which is used for biomedical applications such as vascular graft, sutures and meshes. PET can also be converted by conventional techniques into moulded articles such as lucer filters, check valves and catheter housing.
7. **Polyamids (Nylons):** Nylons are designated by number of carbon atoms in the repeating units. For example Nylon 6 and Nylon 11. The presence of CONH groups provides attraction between chains and improves physical properties such as strength. Certain nylons have specific strength which is five times that of steel and they are most suitable for composites. However nylon is hygroscopic and they lose strength in vivo when implanted.

APPLICATION OF POLYMERS

1. The applications of polymers as biomaterials have been elaborated with each type of polymer. However some other applications are :

S.N.	Polymer	Application
1.	Segmented polyurethane	Artificial heart, heart valves, vascular tubing
2.	Polyalkyle siloxane	Heart valve, hydrocephalus drain link
3.	Segmented copolydimethyle siboxane urethane	Heart valve
4.	Perfluoro butynyl ethyle cellulose	Membrane of oxygenator
5.	Polyalkyle sulfone	Membrane of oxygenator
6.	Hydrogels	As grafted surface for polymers having good mechanical properties
7.	Silicon rubber with silica filler and coated with free silicon	Cosmetic space filler.

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. Polymer is many ------- joining together as a chain. (*a*) mers (*b*) erms

2. Heavy molecule has a ------- chain of repeating unit in a polymer. (*a*) heavy (*b*) long

3. Polymerisation can be done by addition and -------. (*a*) substraction (*b*) condensation

4. ------- are made from two or more types of mers. (*a*) Copolymer (*b*) twin polymer

5. ------- is average number of mers per molecule. (*a*) degree of polymerisation (*b*) degree of saturation

6. The molecular weight of a polymer is 90 and of a mer is 15. The degree of polarisation is -------. (*a*) 12 (*b*) 6

7. Mechanical properties of a polymer improve with molecular weight upto a ------- . (*a*) maxwell value (*b*) limiting value.

8. ------- is added to a polymer to make it flexible. (*a*) Elasticiser (*b*) Plasticizer

9. ------- surface does not absorb protein. (*a*) Rough (*b*) Smooth

10. ------- is used for implantable cellular lens. (*a*) PMMA (*b*) polystyrene

11. LLDPE has excellent ------- resistance. (*a*) flow (*b*) puncture

12. UHMWPE is used for orthopedic implant such as ------- surface of knee joint. (*a*) patellar (*b*) hip

13. Nylons are designated by number of ------- atoms in the repeating unit. (*a*) hydrogen (*b*) carbon

14. ------- are added to increase the melt flow during processing of PVC. (*a*) lubricant (*b*) flow activator

15. ------- are added to prevent thermal degradation of PVC. (*a*) thermal resistant (*b*) thermal stabiliser

16. Nylon has specific strength which is ------- times that of steel. (*a*) two (*b*) five

17. Hydrogels are used as ------- surface for polymers having good mechanical properties. (*a*) grafted (*b*) cleaner of

18. ------- rubber is used for cosmetic implant. (*a*) silicon (*b*) butyl

ANSWERS

1. (*a*) **2.** (*b*) **3.** (*b*) **4.** (*a*) **5.** (*a*) **6.** (*b*) **7.** (*b*) **8.** (*b*)
9. (*b*) **10.** (*a*) **11.** (*b*) **12.** (*a*) **13.** (*b*) **14.** (*a*) **15.** (*b*) **16.** (*b*)
17. (*a*) **18.** (*a*)

BIOCERAMICS 17

Whether you're a man or not comes from your heart, not how much hair you have on your head

INTRODUCTION

1. Ceramics are solids that have inorganic nonmetallic materials as essential components. They are mainly refractory poly crystalline compounds usually inorganic like silicates, metallic oxides, carbides, hydrides, sulfides and selenides. Ceramics have been used in pottery for a very long time. Ceramics are brittle and have low tensile and impact strength. Due to these weak properties, ceramics could not find many applications. However ceramics have high compressive strength, aesthetically pleasing appearance and relative inertness to body fluids which have made ceramics extremely suitable as biocompatible materials to replace various parts of the body particularly bone, heart valve and dental crowns. Ceramics have high specific strength as fibers and they are increasingly used as reinforcing components for composite biomaterial for tensile loading applications such as artificial ligament and tendons. Ceramics have high resistance to plastic deformation and they are nonductile with zero creep. Hence ceramics are very prone to fracture at microcracks where stress concentration takes place. It is very difficult to find accurate tensile strength of ceramic which varies with the presence of microcacks. Due to this, ceramics have low tensile strength in comparison with compressive strength. A flawless ceramic is very strong even in tension. For example, flawless glass fibres are twice stronger than steel in tension. Ceramics are very hard. Alumina (Al_2O_2) and quartz (SiO_2) are ceramics having hardness which is little less than diamond. Ceramics are insulators having low conductivity of electricity and heat. Ceramics are refractoric materials having very high melting points. Bioceramics can be classified as:

(*a*) Relatively inert (nonabsorbable)

(*b*) Semi inert (bio active)

(*c*) Non inert (biodegradable)

RELATIVELY INERT (NONABSORBABLE) BIOCERAMICS

1. As the name suggests, these bioceramics maintain their physical and mechanical properties by resisting corrosion and wear in the hostile environment in the body tissues. They are (1) biofunctional for lifetime (2) biocompatible (3) nontoxic (4) non carcinogenic (5) nonallergic (6) non-

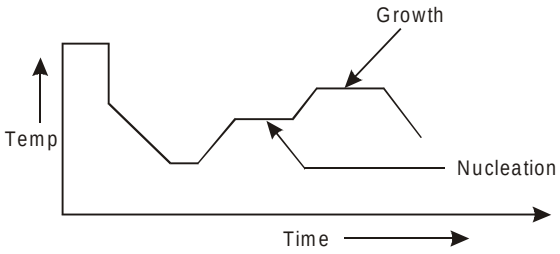
inflammatory. They are generally used for structural support implants such as femoral heads, bone plates and screws etc. They are also used for non structural applications as ventilation tubes, sterlization devices and drug delivery devices. Certain such bioceramics are described in succeeding paras.

2. **Alumina (Al_2O_3):** It is obtained from bauxite and corrundum. Natural alumina is known as sapphire and ruby depending upon colour due to impurities present. The strength of alumina depends upon grain size and porosity. The strength is high for low grain size and low porosity. Alumina is used as biomaterial for orthopedics and dental surgery. As it is hard it is used for watch movements and making emery paper / belt. The properties like low friction and wear, and innertness to the in vivo hostile environment have made alumina an ideal biomaterial for joint replacement. The most popular application of alumina is in total hip prostheses. It has been found that alumina hip prostheses with an UHMWPE (ultra high molecular weight polyethylene) socket is more perfect device than metal prostheses with UHMWPE socket.
3. **Zirconia (ZrO_2):** It is obtained from Zircon ($Zr\ SiO_4$). It has high melting point and chemical stability. It can be used as implant for bone but its properties in these respet are inferior to alumina.It has good compatibility with body tissues and it is also non active to body environment.
4. **Carbons :** Carbon has many allotropic forms like crystalline diamond and graphite, noncrystalline glassy carbon and quasicrystalline pyrolitic carbon. Pyrolitic carbon is generally used for surface coating of implants. The strength of pyrolitic carbon is quite high as compared to graphite and glassy carbon as it has fewer number of flaws and unassociated carbons in the aggregate. Carbon shows excellent compatibility with tissues and blood. Pyrolite carbon coated devices are extensively used for repairing disceased heart valves and blood vessels due to high compatibility. Carbon fibers and textiles are used as reinforcement for composite biomaterials.

SEMI INERT (BIOACTIVE) BIOCERAMICS

1. Bioactive ceramics form strong bonds with surrounding tissues of the body on implantation. Surface reactive bioceramics are (1) bioglasses and ceravital (2) dense and non porous glasses and (3) hydroxy-apatite. The surface reactive bioceramics are used for (1) coating of metal prostheses to increase the bonding of implant with adjacent tissues (2) reconstruction of dental defects (3) as filler to fill the space created by donor bone, bone screw, excised tumors and deceased bone (4) as bone plate and screw (5) prostheses of middle ear ossicles (6) replacing or correcting teeth
2. **Glass ceramics :** They are polycrystalline ceramics. In fine grained structure, they have excellent mechanical and thermal properties. Glass ceramics can be bioglass and cervital glass ceramics depending upon composition. The formation of these ceramics depends upon the nucleation and growth of small crystals and their distribution. 10^{10} to 10^{15} nucles per cm^3 are required to develope a crystal. Certain metallic agents and ceramics are used for nucleation and crystallisation. The nucleation of glass is carried out at temperatures much lower than the melting temperature. The growth takes place at higher temperatures. The composition of cervital is similar to that of bioglass in SiO_2 (40 to 50%) and CaO (20 to 30%) but differs in contents of other components (Na_2O, P_2O_5, MgO & K_2O). Glass ceramics have a very low coefficient of expansion (it can be negative also) and high resistance to surface demage due to controlled grain. Their resistance to

scratching is as high as that of saphire. The glass ceramic has brittleness which gives it a lower mechanical strength. Therefore the glass ceramics can not be used for implant subjected to high loads like joint implants. However they are being used as filler for bone cement, dental restorative composites and surface coating material of implants.



Crystallisation of Glass Ceramic

NON INERT (BIODEGRADABLE) CERAMICS

1. Biodegradable ceramics as name suggests, degrade on implantation in the body. The absorbed ceramic is replaced by endogenous tissues. These ceramics must have controlled in vivo degradation and their degraded products should be easily absorbed by the body without any toxic effects. The rate of degradations varies from ceramic to ceramic. All biodegradable ceramics are variations of calcium phosphate except plaster of paris and biocoral. The most common biodegradable ceramics are – (1) aluminium calcium phosphate (2) plaster of paris (3) coralline (4) hydroxyaptite (5) tricalcium phosphate
2. **Calcium phosphate :** It is commonly used in the form of artificial bone, manufacturing various forms of implansts and as porous coatings on various implants. The mechanical properties of calcium phosphate vary considerably due to variations in structure and manufacturing processes. Infact our natural bones and teeth are made of a crystalline form of calcium phosphate similar to hydroxyaptite. Hence hydroxyaptite has excellent biocompatabilety.
3. **ALCAP ceramics :** Aluminium calcium phosphate (ALCAP) ceramics have unique characteristic that they have a multi-cristallographic structure and the phase of the ceramic can be rapidly resorbed on implantation. ALCAP is prepared from AlO_2 $Ca\ O_2$ and $P_2\ O_5$. ALCAP has insulating dielectric properties but it has no piezoelectric or magnetic properties.
4. **Corals:** They have structural similarity to bone and therefore they are used for bone implants. They provide excellent structure for the ingrowth of bone as their main component calcium carbonate is gradually resortbed by the tissues. Modified corals resemble cancellous bone.
5. **Tricalcium phosphate (TCP) ceramics:** They are used for correction of periodontal defects and augmentation of boney contours. The ceramic can be grounded and sieved to obtain desired size particles for use as bone substitutes and also for making ceramic matrix for drug delivery systems. TCP sets and hardens on addition of water.

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. Ceramics are -------. (*a*) ductile (*b*) brittle
2. Ceramics are mainly refractory poly crystallic compounds usually -------. (*a*) organic (*b*) inorganic
3. ------- have been used in the pottery for a very long time. (*a*) Ceramics (*b*) composites
4. A ------- ceramic is very strong even in tension. (*a*) sintered (*b*) flaw less
5. Flaw less glass fibers are ------- stronger than steel in tension (*a*) four tinos (*b*) twice

6. ------- has hardness which is little less than diamond. (*a*) Alumina (*b*) Zirconia

7. Ceramics are prone to fracture at -------. (*a*) edge (*b*) microcrack

8. Saphire and ruby are natural -------. (*a*) alumina (*b*) Zirconic

9. Carbon has many ------- forms. (*a*) allotropic (*b*) material

10. ------- is an ideal biomaterial for joint replacement. (*a*) alumina (*b*) quartz

11. Carbon shows excellent ------- with tissue and blood. (*a*) adjustment (*b*) compatibility

12. ------- carbon coated devices are extensively used for repairing disceased heart blood vessels.(*a*) fine (*b*) pyrolite

13. The glass ceramics can not be used for implant subjected to -------. (*a*) movement (*b*) heavy loads

14. Bioactive ceramics form strong ------- with surrounding tissues of the body on implantation. (*a*) adhesion (*b*) bonds

15. Biogradable ceramics------- on implantation in the body. (*a*) adjust (*b*) degrade

16. Our natural bone and teeth are made of a crystalline form of -------. (*a*) calcium phosphate (*b*) TCP

ANSWERS

1. (*b*) **2.** (*b*) **3.** (*a*) **4.** (*b*) **5.** (*b*) **6.** (*a*) **7.** (*b*) **8.** (*a*)
9. (*a*) **10.** (*a*) **11.** (*b*) **12.** (*b*) **13.** (*b*) **14.** (*b*) **15.** (*b*) **16.** (*a)*

COMPOSITE BIOMATERIALS 18

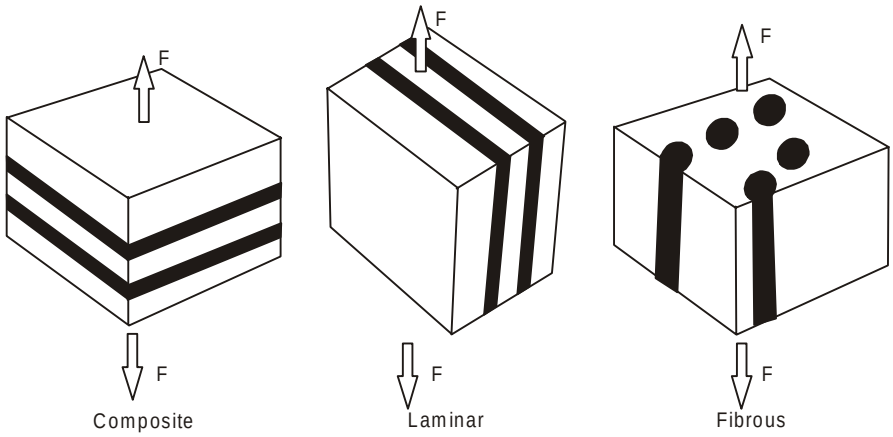
Whether it's the pot that hits the rock or the rock that hits the pot, it's the pot that will break every time.

INTRODUCTION

1. A composite is a non homogeneous material which has two or more distinct constituent materials or phases on a scale larger than the atomic. It is possible to achieve desired properties like flexibility and strength by suitably combining two or more material as distinct phases without forming alloy. The composite materials offer a variety of advantages in comparison with homogeneous materials. Considerable control over material properties can be achieved. There is possibility of making stiff, strong and light weight material or highly resilent and compliant materials. A reinforced plastic is a composite having two distinct constituents/phases of plastic and fibre glass but brass is an alloy (not a composite) as it has no distinct phases of copper and tin. A foam is a composite inwhich one phase is empty space. There are existing many natural composites. Natural composites are bone, cartilage, skin, dentin and wood. Lungs, cancellous bone and wood are also natural foam type composites. A composite material can be biocompatible if the interface between constituents must not be degraded by the hostile environment inside the body. The composites are used for dental filling, orthopedic implant with porous surfaces (UHMWPE) and bone cement (reinforced methyl methacrylate).

STRUCTURE OF COMPOSITE

1. The desired properties can be obtained by suitably modifying the structure of a composite. It is possible to alter the homogeneous structure of a material by using other material soas to get an nonhomogeneous in a larger scale structure. It is also interesting that the properties of a composite depends upon (1) the shape of the inhomogeneities (2) the volume fraction of constituents and (3) the interface among the costituents. One of the constituent can be in shape of fiber, platetlet or lamina. The inclusions can also vary in size and shape (spherical, polyhedral, ellipsoidal or irregular). The inclusions can have random or orderly orientation. The properties of a composite depends upon the structure. For simple structures, it is possible to predict the properties of the composite. Some of simple structures of composites having two constituents are as shown in the figure.



Simple Structures

The force on the composite materials have been indicated. The modulus of elasticity (E) of the composite can be given as : –

$E = E_i V_i + Em\ (1 - Vi)$

where E_i = modulus of elasticity of inclusion

V_i = Volume fraction of inclusion

Em = modulus of electricity of the matrix (main material)

It can be appreciated that by using inclusions of material having high modulus of elasticity it is possible to get a composite material of higher stiffness. The shape of inclusion is important. In isotropic system, inclusion in shape of platelet or flakes are the most effective in creating a stiff composite. The inclusions in shape of fibers are also effective but little less. But spherical inclusions are least effective.

PARTICULATE INCLUSIONS

1. It is very convenient to stiffen or harden a soft material (generally polymers) by the incorporation of particular inclusion. The shape of inclusions plays an important part in deciding the properties as explained already. The stiffness E of a composite is –

$$E = \frac{5(Ei - Em)\mathrm{Vi}}{3 + 2\,Ei / Em} + Em$$

where Ei = modulus of elasticity of inclusion

Em = modulus of elasticity of matrix

Vi = Volume fraction of inclusion

2. The strength of composite depends upon the brittleness and duetility of inclusions and the matrix. The fiberous composites fail when fiber inclusions break or buckle or pullout take place from the matrix. Carbon fibers are generally used in HDPE as reinforcement to get a composite for knee replacement. Carbon fibers can be also used with UHMWPE to get more stronger composite. Carbon fibers are also used to reduce the temperature of implant and in improving mechanical properties like resistance to creep. Metal wires are used with PMMA. They are also used in bone cement to achieve near about equal strength of the bone. Graphite fibers have been used in bone cement. The metal implants are generally found to be much stiffer than bone in total hip replacement which results into the shielding and resorbing of nearby bone. The composite materials are better alternative to metals for implants. They also help in promoting healing.

POROUS COMPOSITE

1. It is desirable to have voids and cellular solids in the matrix which will reduce the stiffness of the composite. Such structures are flexible and they can be seen in seat custions, filters, sandwich panels (insulation), floating devices and coatings to encourage tissue growth. The stiffiness (E) of the composite is :

$E = Es\ (Vs)^2$

Es = modulus of elasticity of solid phase

Vs = Volume fraction of solid phase.

2. Porous composite have a higher ratio of surface area to volume. Hence more area is exposed to hostile environment in the body. Hence they must be more innert to tissues. Porous composite allows tissue growth which is desireable as it allows a relatively permanent jointing of the implant with the surrounding tissues. Porous composites are used for implants in bone and artificial roots of teeth. Porous composites are also used in soft tissue applications as artificial skin, ligaments and blood vessels.

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. A composite is a ------- material. (*a*) homogeneous (*b*) non homogeneous

2. A reinforced plastic is a-------. (*a*) polymer (*b*) composite

3. A composite has ------- distinct constituent materials or phases. (*a*) atleast three (*b*) two or more

4. Foam is a ------- material. (*a*) composite (*b*) polymer

5. Foam has one of its phase as -------. (*a*) empty space (*b*) light material

6. A foam type composite has ------ratio of surface area to volume. (*a*) less (*b*) high

7. The properties of a composite depend up the volume fraction and shape of the ------- (*a*) matrix (*b*) inclusions

8. ------- inclusions are least effective in improving properties of a composite. (*a*) fiberous (*b*) spherical

9. ------- fibers are used with HDPE to get a composite for knee replacement (*a*) metal (*b*) carbon

10. ------- are used with PMMA for bone cement to achieve near about strength of the bone. (*a*) metal wires (*b*) nylon filaments

11. Porous composites have ------- ratio of surface area to volume. (*a*) lower (*b*) higher

12. For implants in bone and artificial roots of the teeth ------- composites are used. (*a*) porous (*b*) particulate

13. The voids and cellular solids in the matrix will ------- the stiffness of the composite. (*a*) increase (*b*) decrease

ANSWERS

1. (*a*) **2.** (*b*) **3.** (*b*) **4.** (*a*) **5.** (*a*) **6.** (*b*) **7.** (*b*)
8. (*b*) **9.** (*b*) **10.** (*a*) **11.** (*b*) **12.** (*a*) **13.** (*b*)

BIOGRADABLE POLYMERIC BIOMATERIALS

19

Endure today's pain today. Do not add it to yesterday's. Nor attempt to shoulder tomorrow's.

INTRODUCTION

1. The biogradable has same meaning as other terms such as absorbable and resorbable. The biogradable polymers are those polymers which can be broken down through hydrolytic mechanism without the help of enzymes. The biogradable polymeric biomaterials have two major advantages which are:

(1) These materials are absorbed by the body leaving no trace at the implant site.

(2) These materials regenerate tissues and their implant is used as temporary scaffold for tissue regeneration.

TYPES

1. All biogradable polymeric biomaterials can be divided into eight groups based on their chemical origin as under:

(*a*) Biogradable linear aliphatic polyesters and their copoymers. This group of biogradable polymers are widely used in surgery. Polyglycolide polylactide, polycaprolactone and polyhydioxy buty rate are linear aliphatic polysters . The copolymers are formed through copolymerisation of the members of this linear aliphatic polysters are also included in this group.

(*b*) Biogradable copolymers obtained from copolymerisation between linear aliphatic polysters and monomers other than linear aliphatic polysters.

(*c*) Polyanhydrides

(*d*) Polymerisation of orthoesters.

(*e*) Polymerisation of ester–ethers.

(*f*) Polysaccharides which are biodegradable such as hyaluronic acid and chitin.

(*g*) Polyaminoacids

(*h*) Inorganic biogradable polymers having nitrogen - phosphorous linkage instead of ester linkage.

APPLICATIONS

1. The widely used biomedical application of biodegrable polymeric biomaterial has been in wound closure. These biomaterials are based either upon the glycolide or the lactide family. Their degradation with time and environment is vary important. These biomaterials are used as surgical meshes for hernia and body wall repair.

2. The next largest biomedial application of biodegradable polymeric biomaterials is in drug control and release in devices. Polyanhydrides and orthoester polymers are these types of biodegradable polymers which are used to prepare a drug depot which would last for a few months.
3. Biodegradable polymeric biomatierials particularly totally resourbable composites have recently been used in the field of orthopedics as PDS pins for the fixation of internal bone fracture.
4. Biodegradable polymeric biomaterials are also used as vascular grafts and stunts, nerve growth conduits, augmentation of defected bone, ligament and tendor prostheses and intramedullary plugs for total hip replacement.
5. Biodegradable polymeric biomaterials have a controlled in vivo degradation. The material must be biodegradable and its degraded products should be easily absorbed by the body without any toxic effects. The rate of degradation of the material should match the demand of the end use to which it will be put. Bioabsorable sutures is one of such application.

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. Biodegrable polymeric biomaterials are absorbed by the body leaving ------- trace at the implant site. (*a*) no (*b*) some
2. Biodegradable polymeric biomaterials encourage the tissues -------. (*a*) destruction (*b*) regeneration
3. The biodegradable polymeric biomaterials are widely used for wound -------. (*a*) closure (*b*) repair
4. The role of degradation of biomaterial should match the demand of the end ------- to which it will be put. (*a*) use (*b*) system
5. The degraded products should be easily absorbed by the body without any ------- effect. (*a*) unhealthy (*b*) toxic
6. The biodegradalic polymeric biomaterial can control drug release and it can be used as a drug -------. (*a*) depot (*b*) storage
7. Biodegradable polymeric biomaterials can be broken down through hydrolytic machanism ------- the help of enzymes. (*a*) with (*b*) without
8. Nowadays, ------- sutures are used in surgery. (*a*) nylon (*b*) biogradable

ANSWERS

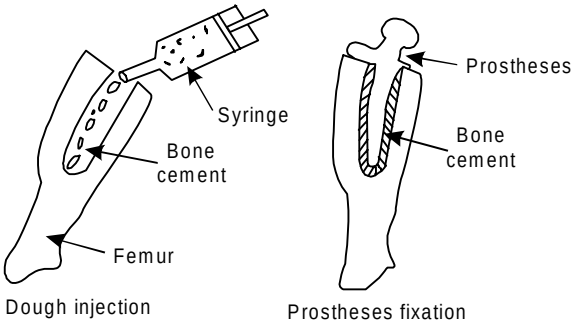
1. (*a*) **2.** (*b*) **3.** (*a*) **4.** (*a*) **5.** (*b*) **6.** (*a*) **7.** (*b*) **8.** (*b*)

ORTHOPEDIC PROSTHESES FIXATION 20

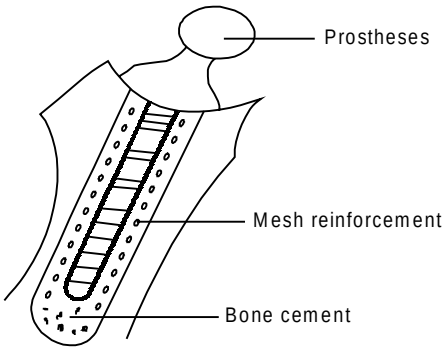
There are two kinds of people–givers and takers. The takers may eat better, but the givers sleep better.

INTRODUCTION

1. The fixation and maintenance of a stable interface between the prostheses and tissues is a most difficult problem of orthopedic joint prostheses implantation. Frequent prostheses fixation problems are related to infection, wear and wear particles, loosening of prostheses and failure of implants. The failure of implants can be (1) mismatch of properties of tissue and biomaterial (2) wrong design of implants (3) improper surgery and fixation (4) post surgical improper care (5) loosening of implant. Prostheses fixation can be mechanical or bone cement fixation.
2. **Mechanical fixation :** Bolts and nuts (to fix femoral components to the femur bone in total hip prostheses) and metal pegs (to fix acetabular coresponent with metal to metal bearing surfaces) are the mechanical methods of fixation of prostheses. This method of fixation and bearing surfaces have many drawbacks like (1) massive tissue reaction (2) harmful release of wear particles during metal to metal friction and (3) stress concentration around the holes resulting into loosening of fixation. The passive mechanical fixation is a better method of fixation in which press fit is used to fix the femoral ceramic stems of a hip joint instead of bolts and nuts. The large size of the stem also helps in distributing the stresses on a large area. The passive fixation also includes the formation of a membrane at the interface of the bone and implant which prevents any relative movement between them or loosening of joint.
3. **Bone cement fixation :** Bone cement is made of PMMA (polymethyl methacrylate) powder and MMA (methyl methacrylate) monomer liquid. When the powder and liquid are mixed, the monomer liquid wets the polymer powder particle surfaces and links them by polymerisation. The mixture has a dough state when it is injected into the prepared intramedurally cavity. The prostheses is then placed over the cement as shown in the figure. The setting time of the bone cement takes 5 to 15 minutes. The properties of cured bone cement are comparable to those of acrylic resins (compressive strength atleast 70 Mpa).



Bone Cement Fixation



Mesh Reinforcement

The use of a mesh reinforcement (a wire coil) around a prostheses in bone cement fixation helps in decreasing the stress on the bone cement.

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. Bolts and nuts are the mechanical methods of fixation of -------. (*a*) prostheses (*b*) bones

2. The press fit used for the fixing of femoral stem of a hip joint is a ------- mechanical fixation. (*a*) passive (*b*) tight fit

3. The bone cement consists of PMMA ------ and MMA -------. (a) powder, liquid (b) liquid, powder

4. The bone cement takes ------- minutes to polymerise and set. (*a*) 30 – 40 (*b*) 5 – 15

5. The wire coil with the bone cement fixation of prostheses helps in the ------- of the stress on the bone cement. (*a*) increase (*b*) decrease

6. The large size of stem in passive mechanical fixation helps in -------the stresses on the larger area. (*a*) localising (*b*) distributing

7. The passive mechanical fixation also induces the formation of a ------- at the interface of the bone and implant. (*a*) membranes (*b*) void

ANSWERS

1. (*a*) **2.** (*a*) **3.** (*a*) **4.** (*b*) **5.** (*b*) **6.** (*b*) **7.** (*a*)

PHYSIOLOGICAL SIGNALS AND TRANSDUCERS

21

One can enjoy life a lot more by saying yes than by saying no.

INTRODUCTION

1. The body produces various physiological signals. The accessibility to these signals is important because (1) they can be internal (blood pressure) (2) they may emanate from the body (infrared radiation) (3) they may be derived from a tissue sample (blood or tissue biopsy). All physiological signals can be grouped into the flowing categories – (1) biopotential (2) pressure (3) flow (4) dimensions (for example : imaging), (5) displacement (such as velocity, force, and acceleration) (6) impedence (7) temperature and (8) chemical concentration and composition.
2. The transducer is a device that converts one form of energy to another. A transducer converts a physiological signal to an electric output. The transducer should respond only to the targeted form of energy present in the physiological signal and it must exclude all other energies. The transducer should interface with the living system in such a way that it should extract minimum of energy and also it should not be invasive.

SOURCES OF PHYSIOLOGICAL SIGNALS

1. Physiological signals are generated by the body during the functioning of various physiological systems. Hence physiological signals hold information which can be extracted from these signals to find out the state of the functioning of these physiological systems. The process of extracting information can be very simple as feeling the pulse to find the state of heart beats and it can be complex which may require analysis of the structure of tissue by a sophisticated machine. Depending on type of energy, the physiological signals can be:
   (*a*) *Bioelectrical signals:* These signals are generated by nerve cells and muscle cells. The source of these signals are cells which undergo change of state from resting potential to action potential under certain conditions. The change of potential in many cells generate an electric field which fluctuates and in this process it is to emit bioelectric signal. ECG and EEG are obtained from the biosignals from heart and brain respectively.

(*b*) *Biomechanical Signals:* These signals are generated by some mechanical function of a physiological system. These signals are related to motion, displacement, pressure and flow of the physiological system. The respiratory physiological system functions with the movement of chest which can be analysed.

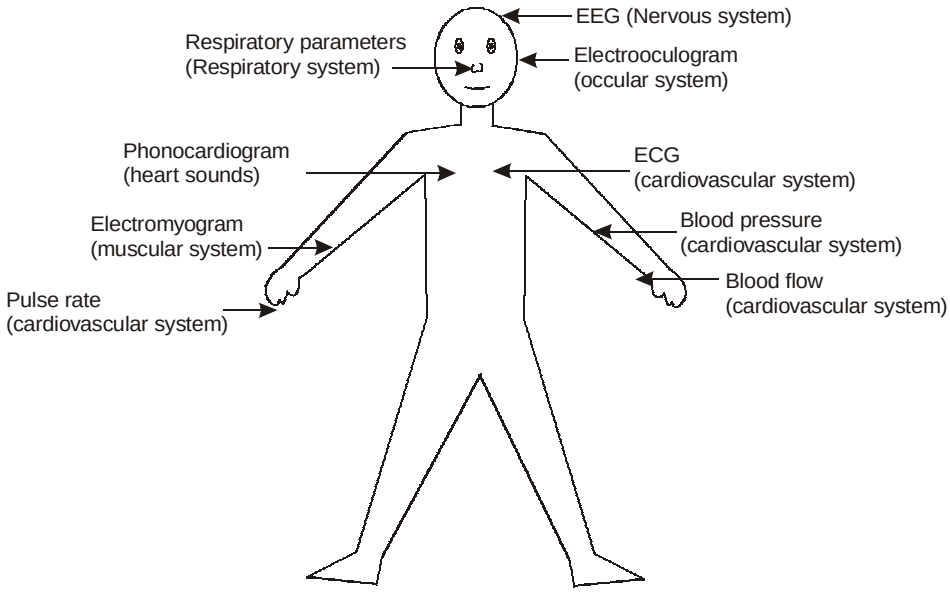
(*c*) *Bioacoustic Signals:* These are created by the physiological systems which are dealing with the flow of blood and air. The flow of the blood in the heart, the opening and closing of chest in respiratory system generate unique accoustic signals.

(*d*) *Biomedical Signals:* Weak magnetic fields are generated by various organs like heart, brain and lungs while functioning. Magneto encephalograph is obtained from the biomagnetic signals from the brain.

(*e*) *Biochemical signals:* The information is obtained by chemical measurements from the living tissues or analysis of the samples obtained from the body. The concentrations of various constituents in the blood and the measurement of partial pressure of oxygen and carbon dioxide in respiration are found out by this method.

(*f*) *Bioimpedence Signals:* The impedence of the skin depends upon the composition of skin, blood distribution and blood volume through the skin. The measurement of impedance helps in finding the state of skin and functioning of various physiological systems. The voltage drop by the tissue impedence is nothing but a bioimpedence signal.

(*g*) *Bio optical Signals:* These signals are produced by the optical variations by the functioning of the physiological system. The blood oxygenation can be measured by measuring transmitted and reflected light from the blood vessel.



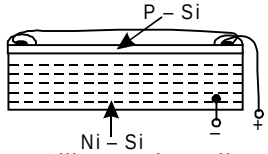
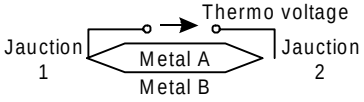
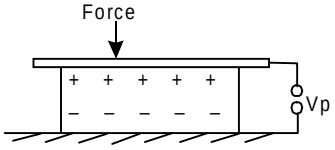
Sources of Physiological Signals

TRANSDUCER

1. Transducer is a device which converts one form of variable or energy into another form of variable or energy. Generally, transducer is required to convert physiological variables into electrical signals which are easier to be processed. The relationship between input and output variable can be linear, logarithmic or square. The transducer can be active or passive depending upon conversion of non electrical variable into electrical signal. The active transducer directly converts input variable into electrical signals while passive transducer modifies either excitation voltages or modulates the carrier signals. The passive transducers are externally powered while active transducers are self generating and requrie no external power.

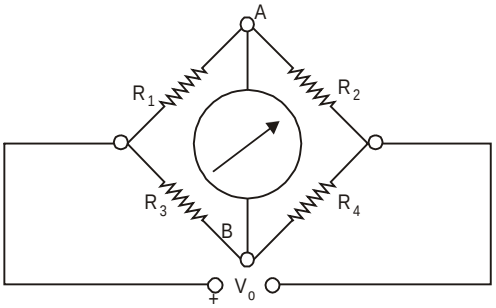
ACTIVE TRANSDUCERS

1. Modern digital computers make the application of these transducers absolutely very essential. Type of transducer, principle of operation and typical applications are tabled as under :–

S.N.	Type	Principle of Operation	Typical Application
1	Moving Coil generator	Motion of Coil in a magnetic field induces a voltage.	Measurement of : (*a*) Velocity (*b*) Vibration
2	Photovoltaic	A voltage is generaten in a semiconductor for junction (solar cell) when simulated by radiant light energy  **Silicon solar cell**	Light variation is measured as current output of cell. Physiological signals modulate light intensity.
3	Thermocouple	When the junction of two dissimilar metals is heated and other is cooled, then an emf is generated across the juctions.  	Measuring of: (*a*) temperature (*b*) heat flow (*c*) radiation
4	Piezoelectric effect	An emf is generated when an external force is applied to a crystalline material like quartz :  	Measurements of (*a*) Sound (*b*) Vibration (*c*) Acceleration (*d*) Pressure variation.

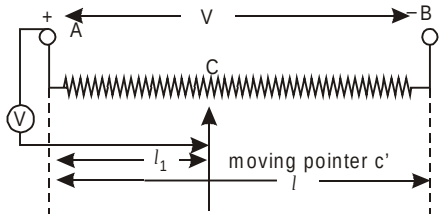
PASSIVE TRANSDUCERS

1. The passive transducer consists of a usually passive circuit element which changes its value as a function of the physical variable developed by physiological signal to be measured. There are only three passive circuit elements that can be used to change voltage at the output of the cercuit according to the physical variable : (1) resistors (2) capacitors and (3) inductors. The passive transducer is part of a cercuit normally an arrangement similar to a wheatstone bridge which is powered by an *ac* or *dc* excitation.
2. Principle of Wheatstone Bridge. The circuit is as shown in the figure. These are four resistances R_1, R_2, R_3 and R_4 connected to *a* DC source (V_0). The voltmeter (V) indicates the difference of potential between junction '*A*' and '*B*'. The value of potential at junction '*A*' = $V_0 - V_0 \frac{R_2}{R_1+R_2}$ and at junction '*B*' = $V_0 - V_0 \frac{R_4}{R_3+R_4}$: It can be seen that if $R_1 = R_2 = R_3 = R_4$ = then potential at junction '*A*' and '*B*' is same $\left(\frac{V_0}{2}\right)$ and voltmeter reading will be zero. Any variation in resistance in any of arm will vary the potential between junction '*A*' and '*B*' which can be read by the voltmeter. In unbonded strain gauge, the arrangement is made such that resistance in arms R_1 and R_4 is reduced by ΔR and resistance in the arms R_2 and R_3 are increased by ΔR which gives potential at junction '*A*' = $V_0 \left(1-\frac{R+\Delta R}{2R}\right)$ and at junction '*B*' = $V_0 \left(1-\frac{R-\Delta R}{2R}\right)$. Hence there is a potential difference equal to $\frac{\Delta R}{R}$ between junction '*A*' and '*B*' where ΔR depends upon the variable input.

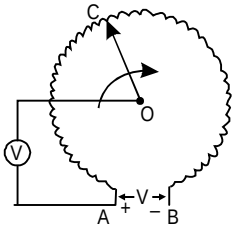


Resistive Passive Transducers

3. **Potentiometer :** An ordinary potentiometer can be used to convert displaement or rotary motion into a change of resistance. In linear displacement potentiometer, the reading of the voltmeter at point '*C*' = *v*/*l* × l_1 which depends upon the position of the pointer '*C*'. Similarly rotational displacement potentiometer, the pointer '*C*' rotates as per the input variable.



Linear Displacement

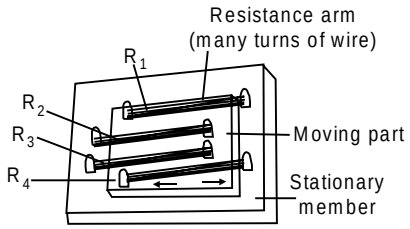


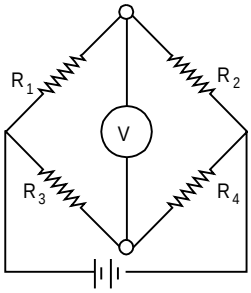
Rotational Displacement

4. **Strain gauge :** The resistance of a resistive element is proportional to length and inversely proportional to area *i.e.*,$R = r\ l/A$ (r = resistivity, l = length and A = area). If a tensile force is applied to extend its length and reduce area, then resistance of the resistive element will increase. Similarly if

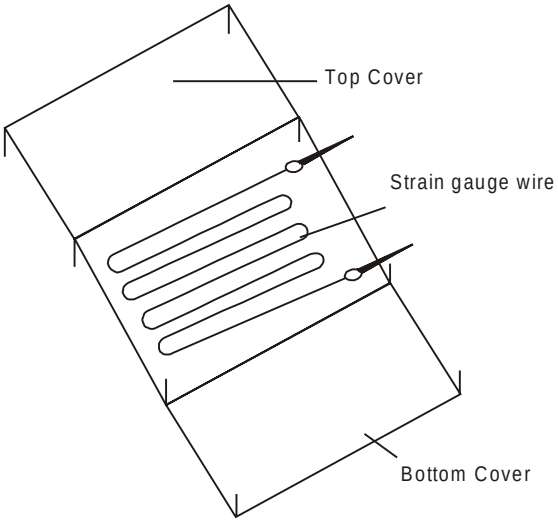
compressive force is applied, its resistance will decreases. We define gauge factor as the ratio of $\frac{\Delta R}{R}$ to $\frac{\Delta L}{L}$ *i.e.,* gauge factor $G = \frac{\Delta R / R}{\Delta L / L}$. The strain gauge can be (1) unbonded and (2) bonded in order to obtain sufficient resistance for each arm (four arms of wheatstone bridge). Several turns of thin wire are used between two posts (refer to figure). Four posts are mounted on stationary part and other four posts are connected to the transducer which can move to right or left with respect to the stationary part. If moving part moves to right, resistive elements R_2 and R_3 are relaxed tension. As explained in the principle of wheatstone, the change of resistance is indicated by the voltmeter which depends upon the linear movement of the transducer. In the bonded strain gauge as shown is the figure, a thin resistance wire is shaped in a zigzag manner and it is cemented between two paper / foil covers.

The compact strain gauge can be easily cemented to the surface of a structure / body and any change in surface dimension is indicated by the change of the resistance of the strain gauge.

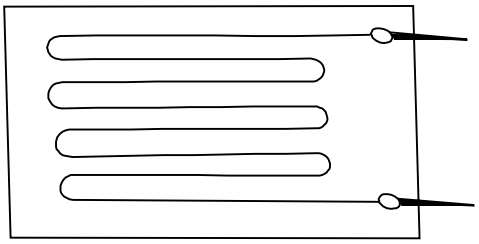




Unbounded Strain Gauge and Connectivity



Parts of Bonded Strain Gauge



Bonded Strain Gauge

5. **Solved Example (strain gauge).** A strain gauge (l = 0.1 meter) is bonded to a surface (Area = 4 cm^2) having modulus of elasticity $E = 200\ G\ N/m^2$. The strain gauge unstrained resistance is 200 *ohm* and gauge factor (G) = 10. When load is applied, the resistance changes by 0.01 *ohm*. Find the stress and load applied.

$$\text{Gauge factor } G = \frac{\Delta R / R}{\Delta L / L}$$

$$\Delta L = \frac{\Delta R}{R} \times \frac{L}{G} = \frac{0.01}{200} \times \frac{0.1}{10}$$

$$= 0.5 \times 10^{-6}\ m$$

$$\varepsilon = \text{strain} = \frac{\Delta L}{L} = \frac{0.5 \times 10^{-6}}{0.1} = 0.5 \times 10^{-5}$$

$$\text{Stress } \sigma = \varepsilon \times E$$

$$= 0.5 \times 10^{-5} \times 200 \times 10^9$$

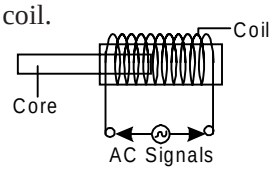
$$= 1 \times 10^6\ N/m^2$$

$$\text{Force} = \sigma \times A$$

$$= 1 \times 10^6 \times 4 \times 10^{-4} = 400\ N$$

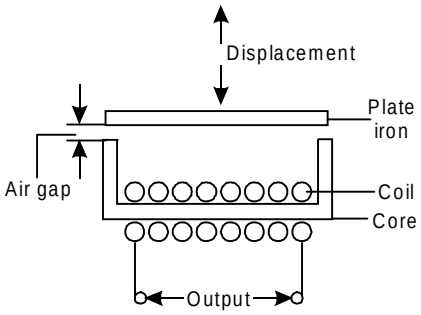
INDUCTIVE PASSIVE TRANSDUCERS

1. **Variable induction :** The property of inductance is varied in the cercuit to change the output voltage in accordance with the input variable. The inductance $L = n^2\ G\mu$ (n = number of turns in coil, G = form factor of coil and μ = permeability of core material inside the coil). Though induction can be varied by any of these three parameters, but generally arrangement is made to change the permeability to achieve variation in induction of the cercuit as per the variable input. In the passive induction transducer, the core is made of a soft magnetic material which changes the induction of the coil when it is moved inside or outside, thereby the output of *ac* signal is changed as per the displacement of the core in the coil.



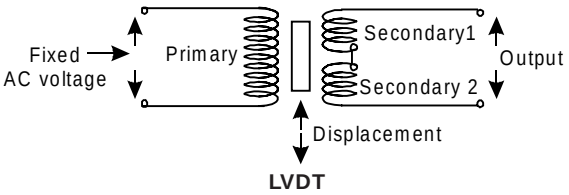
Induction Displacement Transducer

2. **Variable reductance :** In this, core remains stationary inside the coil but the air gap in the magnetic path of the core is varied to change the net permeability, thereby varying the output signal as per the input variable (displacement).



Variable Reductance Transducer

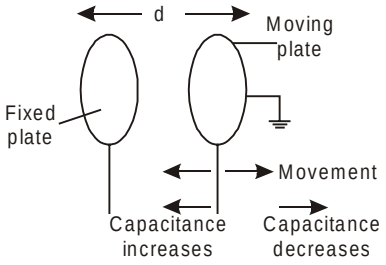
3. **Linear Variable differential transformer (LVDT).** The transducer consists of a transformer with one primary and two secondary windings. The secondary windings are connected as shown in the figure so as that their induced voltages oppose each other. If the core is positioned in central position as shown in the figure, the voltage induced in both secondary windings is equal and opposite, thereby the output voltage is zero. If the core is moved upwards, the voltage in secondary 1 is greater than voltage in secondary 2. Similarly the voltage in secondary 2 will be greater than voltage in secondary 1 if the core moves down. The output voltage will vary as per the movement of the core which is changing as per input variable.

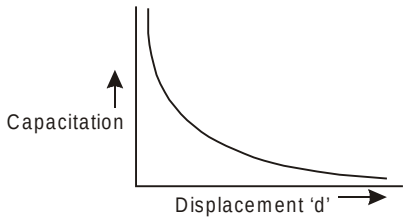


LVDT

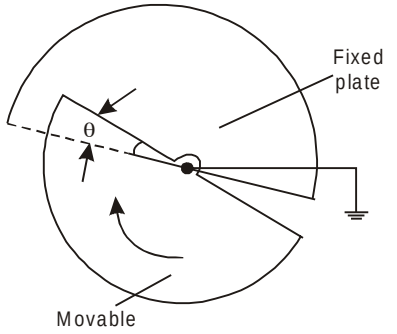
PASSIVE CAPACITANCE TRANSDUCERS

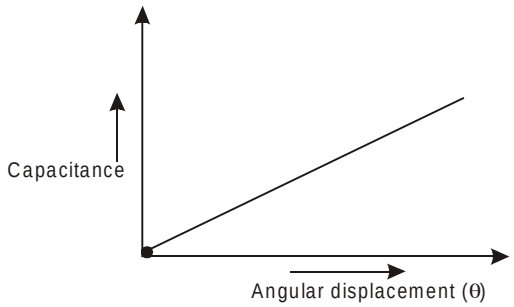
1. **Variable capacitance :** The capacitance (C) of a capacitor having two parallel plates of area 'A' which are separated by a distance 'd' is : $C = E_o E_r \frac{A}{d}$ (E_0 = dielectric constant of free space and E_r = relative dielectric constant). The capacitance can be changed by varying any of the parametes but it is parameter 'd' (separation between plates) which is usually changed in the transducer. In the linear displacement type capacitance transducer, one plate of capacitor is fixed while other plate is movable to change the capacitance as per the input variable. In the angular displacement capacitance transducer, one plate is fixed while other plate rotates to change the capacitance as per the input variable.





Variation of Capacitance with Displacement





Variation of Capacitance with Angular Displacement

TEMPERATURE MEASUREMENT

1. The physiological state of an individual is indicated by his body temperature. It has been seen that a person in shock has reduced blood pressure in circulating system which results into low body temperature. Infection and illness are usually reflected by a high body temperature. Special heated incubators are used for maintaining the body temperature of infants. The temperature of the joint of an arthritic patient is closely linked with the amount of local inflammation. The temperature can be measured by (1) thermocouples (2) thermistor and (3) radiation and fiber optic detectors. The principle of thermocouple has already been explained in para 5 of this chapter.
2. **Thermistors:** It is a shortened word for thermo and resistor which means that they are semi conductors having a high negative temperature coefficient. The resistance of

thermistors decreases as temperature increase while resistance increases as temperature decreases. The resistance of thermistor can be given as

$R_{T1} = R_{T0} e^{\beta\left(\frac{1}{T_1} - \frac{1}{T_0}\right)}$ where R_{T0} are resistance at T_1 and T_0, β = temp coefficient. Thermistors can be formed into disks, beads, rods or any desired shapes. Thermistor probes are available with resistance from a few hundred ohms to several megohms. Most thermistor thermometers use the principle of wheatstone bridge to obtain a voltage output which varies as per input temperature.

3. **Infrared thermometers:** Our skin is perfect emitter of infrared radiation and the energy emitted is proportion to the body temperature. A device sensitive to infrared radiation can measure the emitted energy from a patient without clothing (room temperature 21ºC) and directly indicates the body temperature. Such type of thermometers can detect areas of poor circulation, locate breast cancer or other unknown sources of heat in the body. The thermograph is an infrared thermometer incorporated into a scanner which can be used to scan entire surface of body or some part of body like a television camera. The infrared energy detected in scanning is used to modulate the intensity of a light beam so that to get the image on the photographic film in which the brightness depends on the detected infrared radiation. The image is called a thermogram.

4. **Transduction principle & applications:** Biomedical transducer consists of two parts: (1) sensing element and (2) transduction element. A detector or sensing element is that part of a transducer which responds to a physical phenomenon or its change. A transduction element transforms the output of a sensing element to an electrical output. Hence transduction element acts as a secondary transducer:

5. **Transduction principle :** Several basic physical variables and the transducers available for measurement are listed as under :

S.N.	Physical Variable	Transducer
1	Displacement	(*a*) Variable resistance
		(*b*) Variable inductance
		(*c*) Variable reluctance
		(*d*) LVDT
		(*e*) Variable capacitance
		(*f*) Unbonded strain gauge
2	Velocity	Magnetic Induction
3	Surface strain	strain gauge
4	Force/Pressure	(*a*) Unbonded strain gauge
		(*b*) Piezoelectric
5	Temperature	(*a*) Thermocouple
		(*b*) Thermistor
6	Light/infrared	(*a*) Photovoltaic
		(*b*) Photoresistor
7	Magnetic field	Hall effect

In medical applications, the physiological variable can be transformed into one of the physical variable (as listed in the table) which can be measured very conveniently. This is known as transduction principle.

6. **Force transduction :** A force summing member is used for the conversion of physical variables. The force can be transformed into (1) surface strain (figure '*a*') (2) displacement (figure '*b*') (3) output voltage in LVDT (figure '*c*') (4) photo resistivity (figure '*d*').

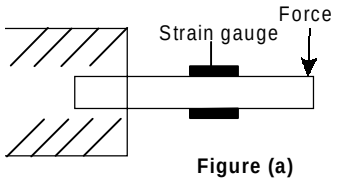


Figure (a)

Transduction with strain gauge

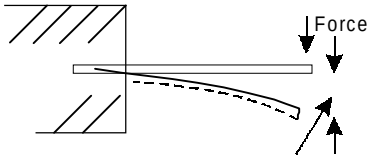


Figure (b)

Transduction in Displacement

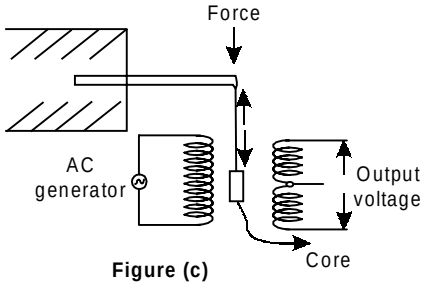


Figure (c)

Transduction in output voltage

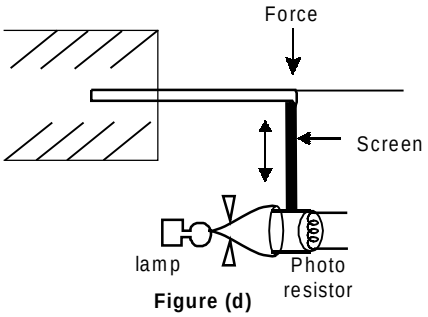


Figure (d)

Transduction in variable resistivity

Force Transducer with Transduction

7. **Transduction for displacement, velocity and acceleration :** The parameters of displacement (D), velocity (V) and acceleration are interlinked as under :

$$V = \frac{\partial D}{\partial t} \text{ where } t = \text{time}$$

$$A = \frac{\partial V}{\partial t} = \frac{\partial}{\partial t}\left(\frac{\partial D}{\partial t}\right) = \frac{\partial^2 D}{\partial t^2}$$

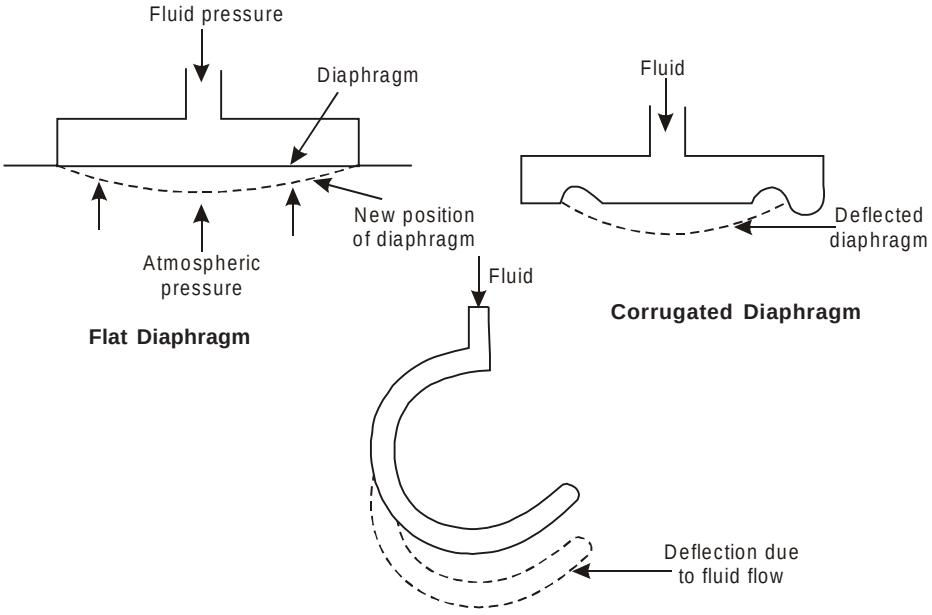
we can also write above relations as under

$$D = \int V \partial t = \iint A \partial^2 t$$

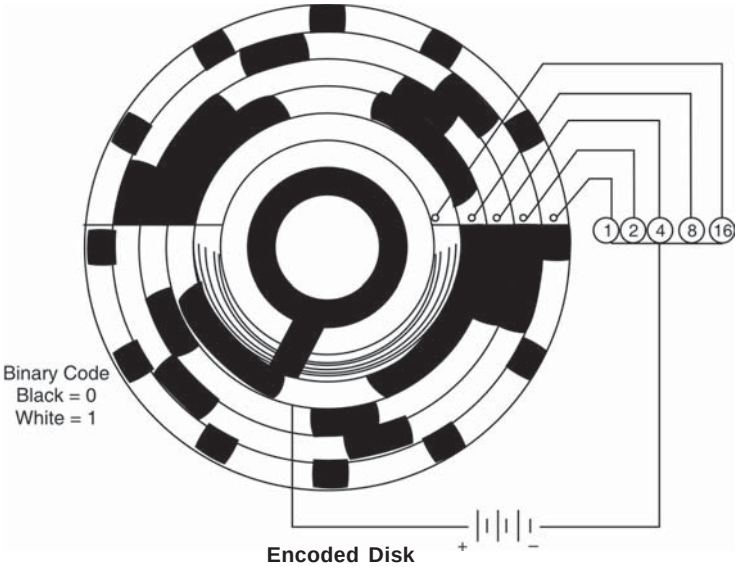
$$V = \int A \partial t$$

If we know one out or three variable, then we can find out other two variables by differentiation or integration. Though velocity and displacement transducers are readily available, but their applications in biomedical are difficult. Therefore displacement and velocity are measured by indirect methods like magnetic or optical methods.

8. **Pressure transduction :** Pressure is measured using diaphragm which gets deformed under pressure. The deformation is measured with the help unbonded strain gauge or LVDT. The output of these devices varies as per input pressure variable. The transducers using flat or corrugated diaphragms are designed to work on the principle of variable capacitance or reluctance. The diaphragms are usually for moderate pressure ranges and bourdon tubes are used for high pressure ranges. The diaphragm type transducers infect measure gauge pressure (the blood pressure at one side of diaphragm which gets deformed against atmospheric pressure). The absolute pressure can be measured if there is a vacuum at one side of the diaphragm.



9. Analog to Digital transduction: Digital data can be easily processed by computers which require that the output of transducers or instruments should be in digital form. If the output of a transducer is not in digital form, a device to convert the output from analog to digital form has to be used. Generally transducers contain encoded disks or rulers with digital pattern which are photographically transformed on them. These patterns can be decoded with the help of a light source and photodiode or photo transistor. The encoded disk rotates and a digital signal indicating its position is obtained in digital form.



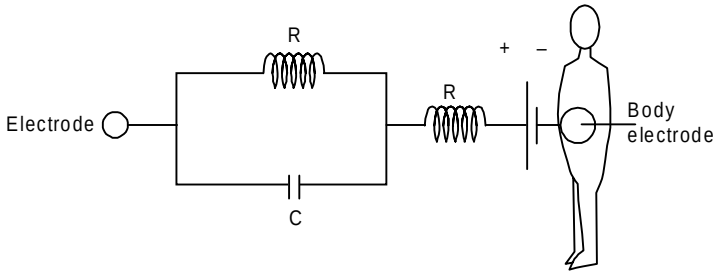
Encoded Disk

10. Biopotential electrodes: The biopotential electrodes can be grouped as under :

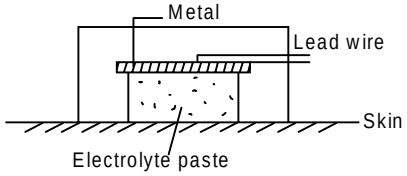
(*a*) *Microelectrodes:* They measure bioelectric potential near or within a single cell. Their tips are sufficiently small to penetrate a single cell to get the potential from the cell.

(*b*) *Body surface electrodes:* These electrodes do not penetrate the skin or cell but they are fixed on the surface of the body to measure the potential. ECG, EEG and EMG are obtained by using these electrodes. The floating electrodes are the latest version of these type of electrodes which eliminate direct contact of metal with skin by use of electrolyte paste or jelly, thereby permitting conductive paste between metal and skin.

(*c*) *Needle electrodes :* These electrodes are designed to penetrate the skin to record EEG potential of a region of the brain or EMG potential of a muscle. They are infact sharp and small subdermal needles to easily penetrate the scalp for EEG. They are required to penetrate up to surface at some depth of the skin which is parallel to brain or muscle.



Biopotential Electrode Interface



Floating Type Body Surface Electrode

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. ------- is a device which converts one form of energy into another. (*a*) Transducer (*b*) biomechanism

2. The ------- transducer directly converts input variable into electrical signal. (*a*) active (*b*) passive

3. The ------- transducers are externally powered. (*a*) active (*b*) passive

4. The ------- transducers are self generating. (*a*) active (*b*) passive

5. The resistance of resistor element is ------- to length and ------- to area. (*a*) proportional,

inversely proportional (*b*) inversely proportional, proportional

6. The wheat stone bridge principle is used in ------- strain gauge to find out input variable. (*a*) mercury (*b*) unbonded

7. In LVDT, the induced voltages of two secondary windings ------- each other. (*a*) add (*b*) oppose

8. ------- are semiconductor having a high negative temperature coefficient (*a*) thermocouples (*b*) thermistors

9. A transducer consists of sensing element and ------- element. (*a*) transduction (*b*) amplifying

10. The ------- element acts as a secondary transducer. (*a*) sensing (*b*) transduction

ANSWERS

1. (*a*) **2.** (*a*) **3.** (*b*) **4.** (*a*) **5.** (*a*) **6.** (*b*) **7.** (*b*)
8. (*b*) **9.** (*a*) **10.** (*b*)

SIGNAL PROCESSING

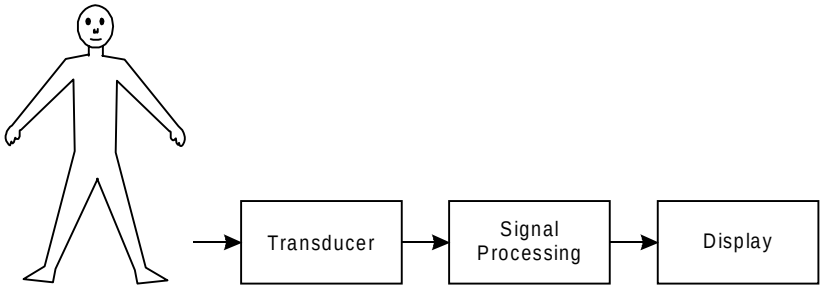
22

If you can find humour in anything, even in poverty, you can survive it.

INTRODUCTION

1. Signal processing (same as signal conditioning) has a rich history and its importance is evident in diverse fields like radar, data communication, nuclear sciences and biomedical engineering. In applications like EEG or systems for speech transmission or speech recognition, we like to extract some characteristic parameters. Alternatively we may like to remove interference such as noise from the signal or to modify the signal to present it in a form which is more easily interpreted by an expert. Also a signal transmitted from input to output stage or over a communication channel is corrupted in a variety of ways like distortion, fading and insertion of background noise. In such cases, processing of the signals is essential.

2. To understand signal processing and its requirement, we take the example of wheat and the process involved in converting the wheat into flour. We have to process the wheat in the first stage and then analyse the flour we get. Depending upon the grade required for the flour, we filter the contents and reprocess the whole thing till the wheat is transformed into flour of the required grade. Signal processing may be seen in a similar manner.



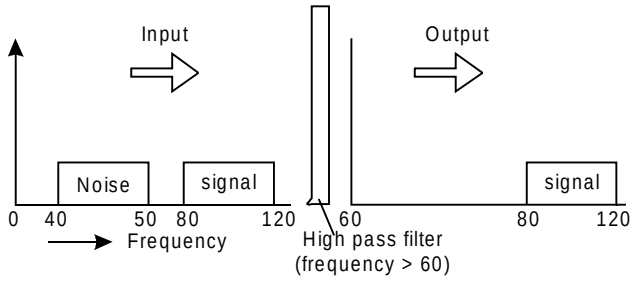
Signal Processing in Instrumentation

SIGNAL PROCESSING IN BIOINSTRUMENTATION

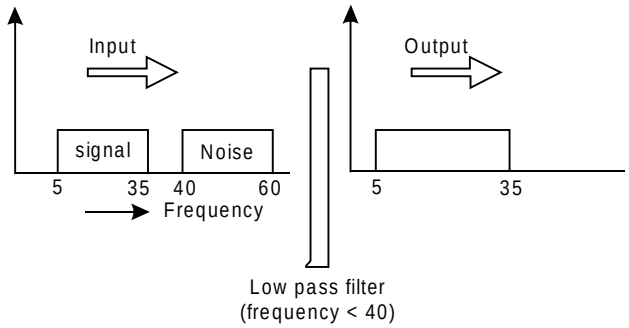
1. The purpose of signal processing is to process the signals from the transducers inorder to prepare them to operate displaying or recording devices suitably. The part of instrumentation system that is provided to amplity, modify or transform the electric output of the transducer is called signal processing system. It also includes any device which is used to combine or relate the outputs of two or more transducers (multiplexing). The input and output of signal processing system are electrical signals but the output signals are generally modified with respect to the input signals.
2. The transducer output is generally not suitable to be coupled to the display unit directly. The signal processing has to be done on the signals generated by the transducers which consists of amplification, filtering averaging, matching of impedance of the transducer to the display unit. Signal filtering is a process to reduce the undesirable signals such as noise. Averaging of repetetive signals is carried out in order to reduce noise if it cannot be done by the method of filtering. Transformation of signal is done to convert the input signals from the time domain to frequency domain which can be further processed or conditioned in a easier way.

METHOD OF SIGNAL PROCESSING

1. **Signal amplification :** The signals generated by the transducers are very weak. Amplifiers are used to increase the level or to boost the amplitude of the signals to match the requirements of the recording or display units. Amplification also increases the resolution and sensitiveness of the instrument. The bioelectric signals often contain components of extremely low frequencies. In order to achieve a faithful reproduction of the signals, the amplification must have excellent frequency response in the subaudio frequency range.
2. **Filtering :** It is a device or circuit which amplifies some of the frequencies present in its input and attenuates or blocks other frequencies which are not required. Filters can be classified as (1) high pass filters (2) low pass filters (3) band pass filter and (4) band stop filters. High pass filters only amplify the frequencies which are above certain value. Low pass filters only amplify the frequencies below a certain value. Band pass filter amplify frequencies which are within a certain band. Band stop filters amplify all frequencies except those in certain band.



High Pass Filter

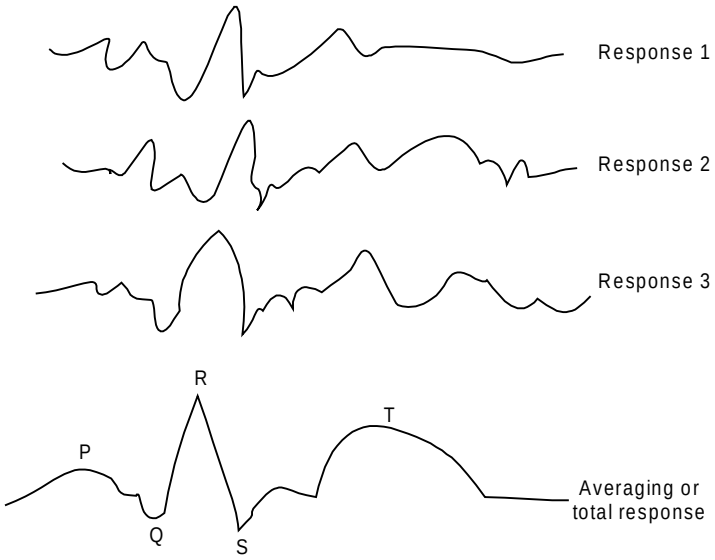


Low Pass Filter

Filters can also be classified as passive or active filters. Passive filters use passive components such as resistor, capacitor and inductors. Active filter use amplification in addition to passive components. The filters can also be classified as analog and digital flitters. An analog filter processes analog inputs and its output is analog. A digital filter processes digital data and generates digital data output. Analog filters are based on mathematics operators and digital filters require no more than addition, multiplication and delay operations. Certain instruments use analog to digital conversion to convert a signal to digital form which can be further filtered by employing high speed digital computing. All measuring and recording instruments pick up some degree of noise signal of 50 *Hz* from power lines and nearby operating machineries. The noise signals of 50 *Hz* can be attenuated by the application of low pass filter which permits frequencies below 50 *Hz* to pass through. Such filters are called 'Notch' filters

3. **Signal averaging :** Filtering is effective method to remove noise signals incase transducer signals and noise signals do not overlap. Noise signals having frequencies higher than 100 *Hz* in ECG signals can be easily blocked by employing a low pass filter cercuit with a cut off frequency value of 100 *Hz*. However if noise signals have frequency range of 50 *Hz* to 100 *Hz*, then use of a low pass filter cercuit with a cut off frequency values of 50 *Hz* will attenuate some components of ECG signals which can not be permitted. Signal averaging is the appropriate technique for such case. It is a digital technique of separating a repetitive signals from noise without introducing signal distortion. The requirements from the signals and noise before employing signal averaging are – (1) The signal waveform has to be repetitive and signal must occur more than once at regular intervals (2) The noise has to be random and non periodic (3) The temporal position of signal wave form can be accurately ascertained. Each new signal waveform or curve is made to align (curve fitting) with previous signal waveform so that repetitive signal are added up. The signal strength is increased a number of times the signal waveforms are added. However noise is random in occurrence and it has mean of zero. ECG signals are corrupted by random noise signals which are broadband. Noise signals can not be removed by filter cercuits without the loss of some part of ECG signals. The technique of signal averaging is employed by first identifying the QRS complex of ECG signals.

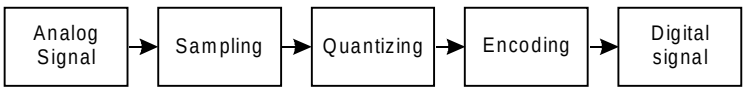
HIGH PASS FILTER



Signal Averaging

Signal averaging of this noisy signal requires a way to time align each of the QRS complexes of the signal responses as shown in the figure. The time at which each stimulus occurs is considered as the reference time and the values for each response are summed upto get the total response at the reference time. By repetitive summing, it is possible to enhance the signal to noise ratio. Signal averaging is commonly used with ECG, EEG and EMG and it is performed on a computer. The technique involves digitizing signal, storing in memory and locating the stimulus.

4. **Digital transformation**: Until recently, signal processing has been commonly carried out using analog equipment. For example, a biopotential amplifier is to receive a weak electrical signal of physiological system and increase its amplitude so that it can be conveniently further processed recorded or displayed. Generally such amplifications are is the form of voltage amplifications as they are suitable for increasing the voltage level of signal. The computers offer tremendous advantages in flexibility and speed. Hence signal processing employing digital computers are being increasingly used now adays. In analog signal amplitude and time are varying continuously over its respective intervals. In a digital signal, amplitude and time take on discrete values. An analog signal can be converted into digital form by following processes – (1) sampling (2) quantising and (3) encoding. In sampling operation, only sample value of analog signal at uniformly spaced discrete instant of time are retained. In quantizing operation, each sample value is approximated to the nearest level in a finite set of discrete level. In the encoding operation, the selected level is represented by a codeword that consists of prescribed number of code elements.



Analog to Digital

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. The transducer output is ------- to be coupled to the display unit. (*a*) suitable (*b*) not suitable

2. High pass filter only amplify the frequencies ------- the certain values. (*a*) below (*b*) above

3. Low pass filters only amplify the frequencies ------- the certain value. (*a*) below (*b*) above

4. Low pass filters attenuating noise signals of 50 *Hz* are called ------- filter. (*a*) notch (*b*) blotch

5. The signals can not be separated from noise bye filtering in case noise and signals have ------- frequencies. (*a*) overlapping (*b*) different

6. The method of ------- signals is used for ECG and EEG. (*a*) filtering (*b*) averaging

7. In averaging, the waveform of the response is made to ------- with the waveform of the previous response. (*a*) oppose (*b*) align

8. Sampling, quantising and encoding are used to convert signal *z* to ------- signal. (*a*) digital, analog (*b*) analog, digital

9. Signals are transformed from -------domain to -------domain. (*a*) time, frequency (*b*) frequency, times

10. ------- filters have components as resistors, capacitors and inductors in the their cercuits. (*a*) active (*b*) passive.

ANSWERS

1. (*b*) **2.** (*b*) **3.** (*a*) **4.** (*a*) **5.** (*a*) **6.** (*b*) **7.** (*b*)
8. (*b*) **9.** (*a*) **10.** (*b*)

DIGITAL IMAGE ACQUISITION AND PROCESSING

23

Learn from the mistakes of others. You can't make them all yourself.

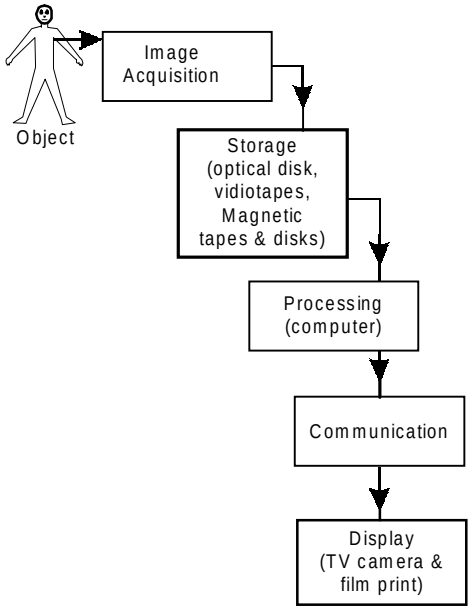
INTRODUCTION

1. The photographic film had been the principal means for acquisition and storage of image for many years. In recent times, computers have become the frontmost devices for a processing, transferring, storing and displaying images. The computers and digital imaging processing techniques have revolutionised the way the medical images are produced and manipulated. Medical data can be acquired by imaging systems like cameras, which can be fed into computers. The computers can perform mathematical operations to produce images having good quality and can highlight aspects of images which are required for diagnosis. The images can also be stored, retrieved or transmitted to remote sites through telephone lines or any other communication means. Radiography, computed radiography, ultrasound, magnetic resonance and other imaging systems can be considered as cameras or vision devices which are considered means that can transfer an image from one surface to another. The camera can be also visualised as a pin hole device through which all elements of the original image must pass through to the final image. An image can be processed without any regard to the type of camera used for transferring the image.

ELEMENTS OF DIGITAL IMAGE PROCESSING SYSTEM

1. The digital image processing system consists of (1) acquisition (2) storage (3) processing (4) communication and (5) display. Two elements are basically required to acquire digital images. The first element is a sensor which produces output signal proportional to the input level of energy to which it is subjected. The input energy can be x-rays, ultrasound, radiation or changing magnetic field etc. The second element is called digitizer, which converts the electrical output of the sensor into digital form. The storage methods of digital images can be classified as (1) short term storage devices like computer memory (2) on line storage with fast recall such as magnetic disks and (3) archival storage for infrequent access like magnetic tapes and optical disks. Processing

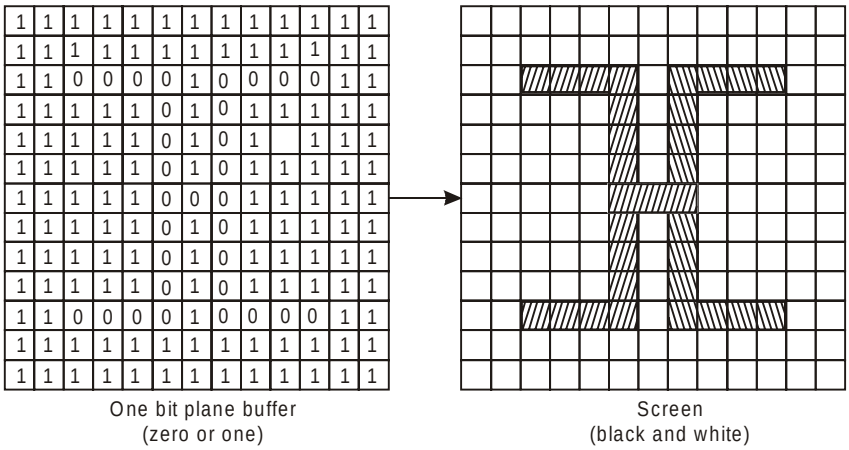
of digital images involves processing of procedures known as algorithms which performs various mathematical operations on the medical data obtained form input digital images. Image processing is characterised by specific solution. The technique varies from application to application depending upon the method of acquisition of the image. However the powerful hardware and basic software to start different image processing systems of the computer remain same. These are supplemented by the specialised software to process the image depending upon the method of acquisition. Communication in digital imaging system involves local communication between image processing system and transmission of medical data from one point to another in remote area. The display devices of the image processing systems are monitors and TV systems.



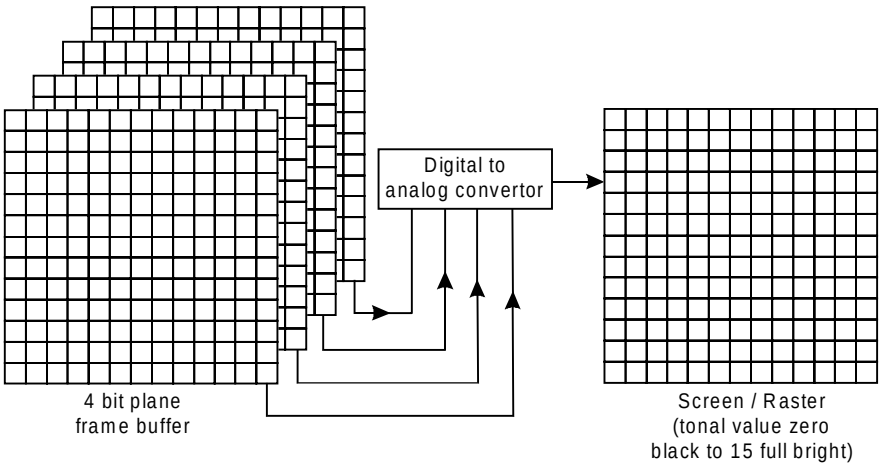
Elements of An Image Processing System

RASTER AND FRAME BUFFER OF A COMPUTER

1. The screen of a computer consists of a large number of minute subdivisions which are called picture elements or pixels. A frame buffer of a computer consists of a large continuous pieces of computer memory. There can be one memory bit for each pixel in the raster. The memory bit can be either in zero (0) or one (1) state. If a particular pixel is activated, the corresponding bit in the frame buffer is changed from zero (0) to one (1). A 320 × 320 raster has 64,000 pixels. Since each pixel has one bit in a single bit plane, therefore 64,000 memory bits are required in a single plane. A single bit plane yields a black and white display. Colour or grey level can be achieved by using additional bit planes. Hence the intensity of each pixel on the raster is decided by the combination of the pixel value in each of bit plane. The pixel value in single bit can be two *i.e.*, zero or one. If there are four bit planes, then there can be $2^4 = 16$ combinations and the resulting binary number is interpreted as an intensity tone between zero and 15 (*i.e.*, $2^4 - 1 = 15$). The raster is an analog device and it requires an electrical voltage. The digital data of frame buffer is converted into an analog voltage through a digital to analog convertor (DAC). In a 4 bit plane, the value between zero (dark) to 15 (full bright) on each pixel can be got by the digital to analog convertor. A colour frame buffer can be implanted with three bit planes one for each primary colour like red, green and blue. Other colours are obtained with their combinations.



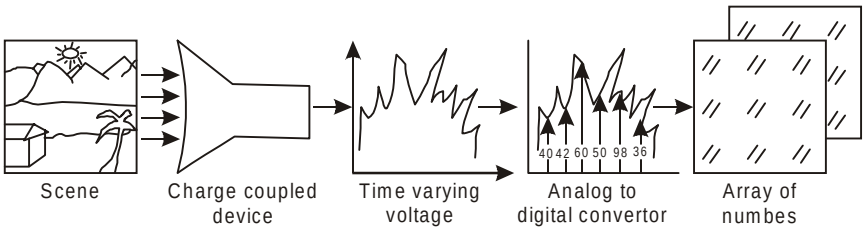
Each Picel of Screen With Tonal Value From Frame Buffer (zero for black and one for white)



4 Bit Plane Buffer

VISION PROCESSING

1. The image on the human eye or on a TV scanner (having light sensitive surface) is two dimensional. The real world which surrounds us is made of three dimensions. The two dimensional (2D) intensity image is generated by the projection of three dimensional (3D) scene. However the 2D image contains information about the brightness of each pixel. The 2D image is scanned by some means to provide a continuous voltage output that is proportional to the light intensity or brightness of the image on the surface. The output voltage $f(x,y)$ is sampled at the discrete number of x and y points of the image (pixel / picture elements) which are converted into numbers. The numbers correspond to the grey levels of intensity corresponding from black (zero brightness) to white (highest brightness)



Transferring of Image to Numbers

intensity. In case of colour images, the intensity value is combination of three separate arrays of numbers *i.e.*, each array gives the intensity value of each of the basic colour viz red, blue and green colour. This is called digitization process and the image is transfered into a 2D image from the light source to the light sensitive surface and later into an array of numbers which are dependent on the local image intensities at the corresponding x and y positions on the light sensitive surface. It can be seen that first step of vision precessing is transformation of light energy to array of numbers which is the language of computers. A vidicon tube or charge coupled device (CCD) are light sensitive transducers which are used for transformation of light energy. The tube is a type of sensor with its surface coated with a photosensitive material. The resistance of the sensor is inversely proportional to the light intensity falling on it. An electric gun emitting electrons is employed to produce a flying spot scanner. The scanning of the sensor is done repidly from left to right and top to bottom. The scanning produces a time varying voltage which is proportional to the image intensity of the scanned spot. The continuously varying output voltage is fed to an analog to digital convertor (ADC). The voltage amplitude of the ADC is periodically sampled and converted to the array of numbers. A typical ADC will produce 36 digital frames consisting of 256 × 256 (or 512 × 512) pixels per seconds.

IMAGE RECONSTRUCTION

1. When 3D objects are projected on 2D sensor surface of the camera, a lot of information, disappears which means such trans -formation is not one to one. Reconstruction of objects of a 3D scene from only one image is difficult as it involves recapturing information of 3D original scene from the captured depictions of 2D image. The aim is to recover a full 3D scene from this 2D image as it is done in computer graphics *i.e.* a 3D representation which is dependent on the coordinate system of the object. The intensity of the image can be synthesised using standard computer graphic techniques from such a representation. The image reconstruction process involves two tasks which are (1) to recover the information lost in 2D projection of the scene and (2) to understand image brightness. The information available in the 2D image is the brightness of the different pixels, which is proportional to the reflection, illumination and orientation of the object with respect to viewer and light source. In computers, the method of image processing uses digital image functions. These are represented by matrices since coordinates are integer numbers. The image functions have range $R = f(x,y)$, $\{1< x < x_m \text{ and } 1< y < y_n\}$ where x_m and y_n are image coordinates. The range of image function value is limited as the lowest value is black and the highest value is white. The image function has also grey level values in between black and white

values. The quality of a digital image improves in direct proportion to the spatial, spectral, radiometric and time resolution. The spatial resolution depends upon the proximity of neighbouring image sampling points in the image plane. The spectral resolution is dependent upon the band width of light friquencies captured by the sensor. On other hand, the radiometric resolution depends on the number of grey levels between black and white values. The time resolution is dependent on the interval between two successive sampling. The image is processed by a computer by carrying out image digitization, sampling and quantization. In image digitization, the image function $f(x, y)$ is sampled into a matrix with 'M' rows and 'N' columns. A continues image function $f(x,y)$ can be sampled using a discrete sampling points in the image plane. The sampled image function $F_s(x, y)$ is the product of the $f(x, y)$ and $S(x, y)$ (sampled function). The Fourier transform of the sampled image is the sum of periodically repeated fourier transform $F(u, v)$ of the image. The transition between the value of image function (brightness) and its equivalent is known as quantization. If 'K' is the number of levels of quentization and 'b' is the number of bits used to express the the brightness of pixels, then $k = 2^b$.

LOOK UP TABLES

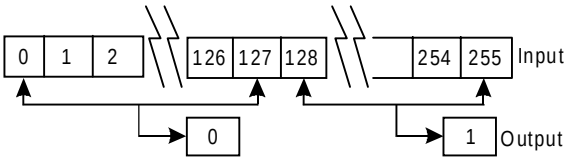
1. Several algorithms of digital image processing are used with technique brown as single image pixel point operations. It performs manipulation on sequential individual pixels rather than large arrays. The general relation utilizing discrete single pixel point process for an entire image array is :

$O(x,y) = M[f(x, y)]$

Where $f(x, y)$ = input image pixel at x and y

$O(x, y)$ = output image pixel at x and y

M = linear mapping function which converts input brightness value to output brightness value. It is time consuming and wasteful of computer resources incase the above type of operation is to be performed on a large image at every pixel. A look up table (LUT) is an alternative technique to map large images. A LUT stores an intensity transformation function which is designed in such a way that its output grey level values are a selected transformation of the corresponding input values. Let us understand how it is done. We take a 8 bit computer which can have input values of 256 grey levels ($2^8 = 256$). Suppose it has a designed LUT which gives an output value of zero for input value between zero and 127 and an output value of one for input values between 128 to 255. Then the entire point process will result in binary output images that have two sets of pixel *i.e.*, zero and one. Similarly LUT can be designed to give other selected outputs for the corresponding input values.

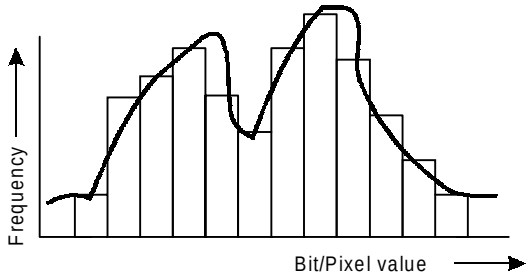


Look up Table

HISTOGRAM

1. Histogram provides a representation of image contrast and brightness characteristics. The brightness histogram $h_f(z)$ of an image is a function which gives the frequency of the brightness value 'z' in the image. The histogram of an image having 'N' grey levels is given by a one dimensional array having 'N' elements. The histogram helps in finding optimal illumination condition for capturing an image grey scale, its transformation as well as proper image segmentation of the

object from the background. It can be appreciated that the change of position of the object does not affect histogram. Manipulation of histogram can correct poor contrast and brightness which can dramatically improve the quality of the image.



Histogram

LEVEL OF IMAGE DATA REPRESENTATION

1. The goal of computer representation is to achieve image understanding with the highest processing level. The image data representation consists of lower and upper processing levels which are applied by technical available procedures by the computer, similar to our natural vision. The representation can be :

(*a*) *First level of representation*. The representation is iconic and it consists of images containing original data about pixel brightness in the form of integer matrices. Certain prepatory operations are performed such as highlighting some aspects of the image and manipulation, like filteration or edge sharpening.

(*b*) *Second level of representation.* In this, the segmentation of images is performed *i.e.*, the parts of the images are joined into groups that seems to belong to the same object.

(*c*) *Third level of representation*. It is geometric representation having prior knowledge about 2D and 3D shape of the object. The quantification of a shape is made on the basis of illumination and motion of the object.

(*d*) *Fourth level of representation.* In this, the representation of data is made on the basis of the relationship models. The information gained from the images may be used by semantic nets and frames *i.e.*, prior knowledge of the relationship among adjacent regions is usually used in processing.

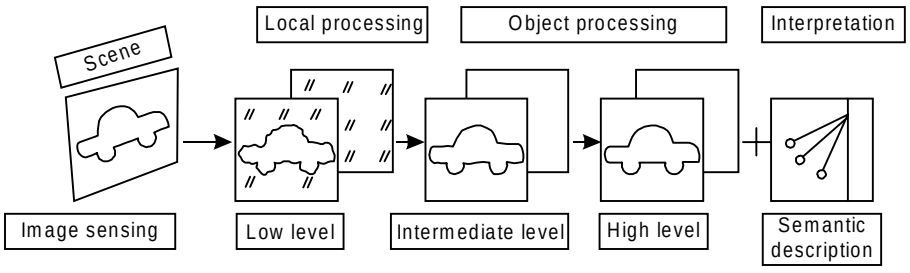


Image Processing Stages

GREY LEVEL THRESHOLDING

1. It is a simplest segmentations process. Many objects or regions are characterised by fixed reflectivity and light absorption by their surfaces. A brightness constant or threshold can be fixed so as to segment or separate the object and its background.

ALGORITHMS

1. Data and an algorithm are two basic related parts of any progrmme. An algorithm is a finite set of instructions if followed can accomplish a particular task. All algorithms must have following criteria :

(*a*) Input — zero or more.

(*b*) Output — atleast one.

(*c*) Definiteness — each instruction must be clear and unambiguous.

(*d*) Finiteness — after a finite number of steps, each instruction must end.

(*e*) Effectiveness — each operation must be definite and feasible. All instructions must be feasible to be carried out. While creating or using algorithm for digital processing, the principle of human image perception must be followed. As an image is to be understood by a human, the information should be expressed using variables which are easier to perceive like contrast, border, contour and shape texture. The sensitivity of human senses varies logarithmically to the brightness of input signal. Hence after an initial logarithmically transformation, the response to stimuli, may be treated as linear. A few examples of algorithms are :

(*a*) *Algorithm for basic thresholding:* Search all pixel of f (i, j) of image *f*. An image element g (i, j) of the segmented image is an object pixel if f (i, j) > T and it is a background pixel otherwise.

(*b*) *Algorithm for computing the brightness histogram* (*i*) Assign zero value to all elements of the array h_f

(*ii*) For all pixel f (x, y) of the image *f*, increase h_f (x, y) by 1.

COMPRESSION

1. We have seen that digital image is sampled and mapped as a grid of dots and picture elements (pixels). Each pixel is given a tonal value (white, black, shade of grey or colour) depending upon brightness which is represented in binary code *i.e.*, zero and one. The binary digits / bits for each pixel are stored in a sequence by a computer. In order to handle large data, data is compressed and reduced by a mathematical representation. The bits are then interpreted and read by computer to produce an analog version for display or printing. The file size of a digital image is very large and it requires very large memory of the computer, thereby taxing the computing and networking capatibilites. Compression is used to reduce the size of image file for storage, processing and transmission. All compressing techniques are based on algorithms which are nothing but mathematical shorthand, abbreviating the long string of binary code of an uncompressed image, thereby creating a compressed image file requiring lesser memory space. Compression can be done by either standard or proprietary techniques. Compression can also be classified as either loss less compression or lossy compression. The loss less compression abbreviates the binary code without discarding any information. Hence on decompression, image is bit for bit identical to the original uncompressed file. The lossy compression uses a method of averaging or discarding the least important on the basis of understanding of visual perception.

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. Two elements for acquiring digital image are sensor and --------. (*a*) digitizer (*b*) processor

2. Short term storage device for image processing is computer's -------. (*a*) CPU (*b*) memory

3. The screen of a computer consists of a large number of minute subdivisions which are called -------. (*a*) pixel (*b*) bits

4. A frame buffer consists of a large continuous pieces of computer --------. (*a*) pixel (*b*) memory

5. The memory bit can be either in zero or ------- state. (*a*) two (*b*) one

6. The pixel value in single bit plane can be -------. (*a*) one (*b*) two

7. A four bit planes can have ------- combinations as output at each pixel. (*a*) 8 (*b*) 16

8. Incase of colour images, ------- bit planes are required. (*a*) 4 (*b*) 3

9. The first step of vision processing is transformation of light energy to array of --------.(*a*) figures (*b*) numbers

10. Data and ------- are two basic related parts of any program. (*a*) a computer (*b*) an algorithm

11. ------- techniques are based on algorithms to reduce the image data file. (*a*) compression (*b*) shortening

12. Compression can be classified as loss less or ------- compression. (*a*) gainless (*b*) lossy

13. The image is processed by a computer by carrying out image digitization, sampling and --------. (*a*) quantization (*b*) manipulation

14. The scanning produces a time varying voltage which is proportation to the image ------- of the scanned spot (*a*) position (*b*) intensity

ANSWERS

1.	(*a*)	**2.**	(*b*)	**3.**	(*a*)	**4.**	(*b*)	**5.**	(*b*)	**6.**	(*b*)	**7.**	(*b*)
8.	(*a*)	**9.**	(*b*)	**10.**	(*b*)	**11.**	(*a*)	**12.**	(*b*)	**13.**	(*a*)	**14.**	(*b*)

RADIOGRAPHY 24

If the wise does not approve your book, it is bad. If a fool applauds it, it is worse.

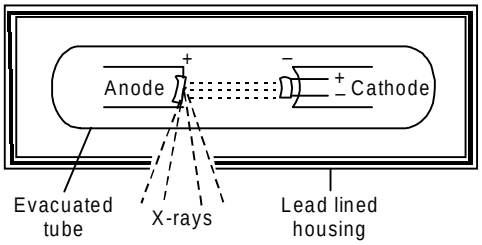
INTRODUCTION

1. Conventional x-ray examination techniques still dominate the field of diagnostic imaging, although most of the images at present being produced are digital. X-rays emanate from a small point source and pass through a portion of the body and onto a detector that records the x-rays that reach the detector as an image which is called radiograph. X-rays radiation is electromagnetic radiation which can ionize the matter through which it passes as it has high energy content. The ionization can cause damage to DNA and cells in human tissues. However it can penetrate the body to allow noninvasive visualization of the internal anatomy of the human body. X-rays also exhibit particle like behavior which are discrete packets of pure energy. These discrete packets are called photons. Inorder to reduce the ill effect of ionization due to x-rays while taking radiography, new x-rays techniques are being developed to minimise the radiation dose. The chief x-rays methods used in the examination are radiography, fluoroscopy, tomography and bronchography.

X–RAYS AND X–RAY TUBE

1. When an electron in an atom transits from outer orbital (higher energy) to inner orbital (lower energy) radiation is emitted. Such a transition of electron can occur, if the atem is in an excited or unstable state and it has a vacancy in the inner electron shell to which the electron can move from the outer electron shell. The emitted radiation can be in the visible, ultraviolet, or x-rays portion of the electromagnetic spectrum. The emitted radiation is called characteristic radiation as its energy content is uniquely characteristic of the atomic species that produced it.
2. There is an another method available to produce x-rays. If an electron beam is accelerated so as to hit a metal target, a shower of radiation is produced by the interaction. If the electron beam is accelerated with enough energy by applying suitable voltage, the radiation produced is x-ray portion of the electromagnetic spectrum.
3. A vacuum tube device as shown in the figure is used to produce x-rays. The tube contains a tungsten filament (the cathode) and a metal

target (the anode) which is also made of tungsten. The filament cathode is heated with electric current. A high voltage is applied between the anode and the cathode. The high voltage facilitates the electrons of the cathode to be drawn off and accelerated towards the anode. The accelerated electrons strike the anode. This results into the production of characteristic x-rays (characteristic of tungsten metal). The x-ray tube is completely enveloped by lead casing on all sides except for a small exit port. The lead casing is used as the lead can absorb most of the emitted x-rays. Hence x-rays can come out of the port only. These x-rays are used for radiography.



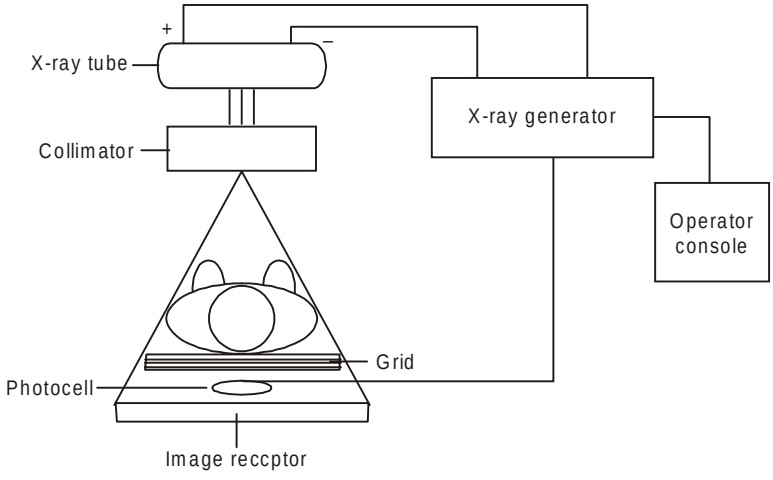
X-Ray Tube

OPERATING PRINCIPLE

1. X-rays are absorbed by the body in relation to specific density and atomic number of various tissues. In irradiating a volume of interest, these absorption differences are recorded on an image receptor.

RADIOGRAPHY SYSTEM

1. A high voltage generator as shown in the figure, supplies the essential power to x-ray tube. A collimator is used at the exit port of the x-ray tube to limit the extent of the x-ray field. The x-ray exposure is kept for precise and finite duration by an electronic time switch. The exposure is also autormatically terminated after a certain amount of radiation has been received by the image receptor with the help of phototiming cercuit. The operator selects all operating parameters like exposure and dose of radiation from the operator's console.



X-Ray Imaging System

2. An image receptor is a device which can detect and record an x-ray image. It is placed below the patient so that x-ray after passing through patient falls on the image receptor. The patient's anatomy modulates the intensity of the x-ray field as it passes through his body. The differential x-ray absorption and transmission by tissues of the body results in an exit radiation beam that varies in intensity in two dimensions. The exit radiation beam reaches a detector which detects and records the two-dimensional intensity distribution. The image receptors used in diagnostic radiology can be :

(*a*) Photographic film, coupled with an intensifying phophor screen.

(*b*) Storage phosphor screen.

(*c*) Direct digital readout device.

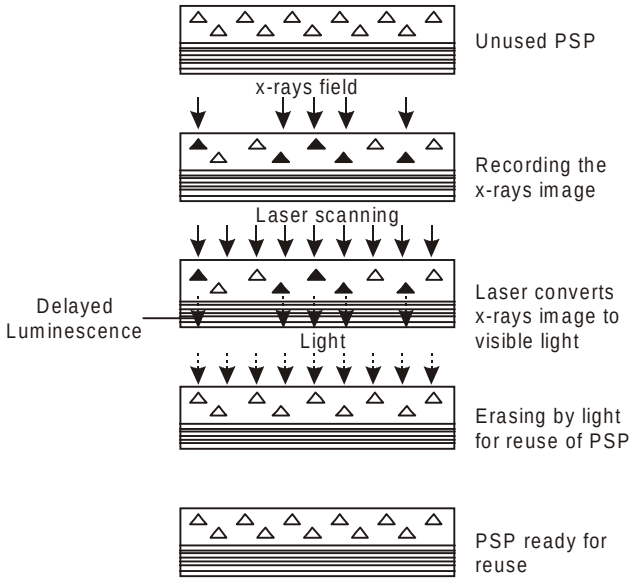
PHOTOGRAPHY OR X–RAY FILM

1. X-rays normally can not be detected directly by the human sense. Hence indirect methods of visualisation have to be used to see the image of the intensity distribution through the body of a patient. Although x-rays have a much shorter wave length than visible light but x-rays can react with photographic emulsions in same way as it happens incase of visible light. The film exposed of x-ray and carrying an image of the x-rays intensity is processed in the developing solution. The sensitivity of the photographic emulsion can be increased by the use of intensifying screens which are similar to the fluoroscopic screens. The screen is kept into close contact with the film surface so that the film is exposed to x-rays and also to the light emitting from the fluorescent screen. X-ray film is packed in light-tight cassettes with or without intensifying screens. The one side of the cassette is made of thin plastic which can be easily penetrated by the x-rays.

2. An intensifying screen (fluorescent screen) consists of polyster with plastic coating and a phosphor layer that absorbs x-rays and in response emits visible light. A radiographic cassette consists of a pair of intensifying screens with a sheet of double emulsion film sandwiched between the screens. The film records the visible light image emitted by the intensifying screens in response to irradiation by x-ray. Two phosphor screens are more efficient in detecting x-ray than a single screen. However sharpness decreases.

STORAGE PHOSPHOR SYSTEM (PSP)OR COMPUTED RADIOGRAPHY

1. Storage phosphor or photostimutable phosphor system is used to obtain radiograph in digital form which are suitable for computer based storage and processing. This method is also commonly known as computed radiography. The method also uses a cassette containing a screen coated with phosphor similar to that used in conventional screen film. However, the phosphor used in the intensitying screens emits visible light immediately upon absorption of x-rays which is called fluorescence. The phophor in PSP systems responds to irradiation with x-rays by storing electrical charges in a pattern matching to the pattern of absorbed x-rays intensities. The pattern is read later by a scanning laser device. Laser causes localized heating of the phosphor which leads to stimulation of the metastable trapped charge. The stimulation of the metastable trapped charge leads to conversion of the trapped charge into visible light, which is called delayed luminescence. The visible light is then converted to electric current by a photo multiplier tube which is digitized and stored as a digital image in a computer.This is called computed radiography.



Storage Phosphor System or PSP

THE DIRECT DIGITAL DETECTOR

1. The direct electronic capture of the radiographic image is the future trend of digital imaging. These will be no need for storage phosphor cassette and subsequent laser readout or digitization of photographic film incase the use of direct digital detector. Concerted efforts are being put up to develop the direct digital detectors. These detectors will convert the radiographic image (the distribution of intensities in two dimensions) into an electrical signal that can be digitized. It is being tried to develop detectors having better spatial resolution and less noise than PSP systems. Such detectors can also be mounted permanently on the x-rays system so as to eliminate cassette handling by any operator.

IMAGE FORMATION

1. X-rays diverge from a point source, travel in straight lines and these can affect a photographic emulsion. A point source of light produces shadow of a object in its path as shown in the figure. Similarly any object in the path of x-rays casts a shadow which can be recorded on the photographic material as an image. The image formed by x-rays differs from the image formed by the light rays. X-rays can pass through substances which are opaque to light rays. Therefore x-rays can project shadows of structures hidden below the surface of the object and record their images also on to a photographic material.

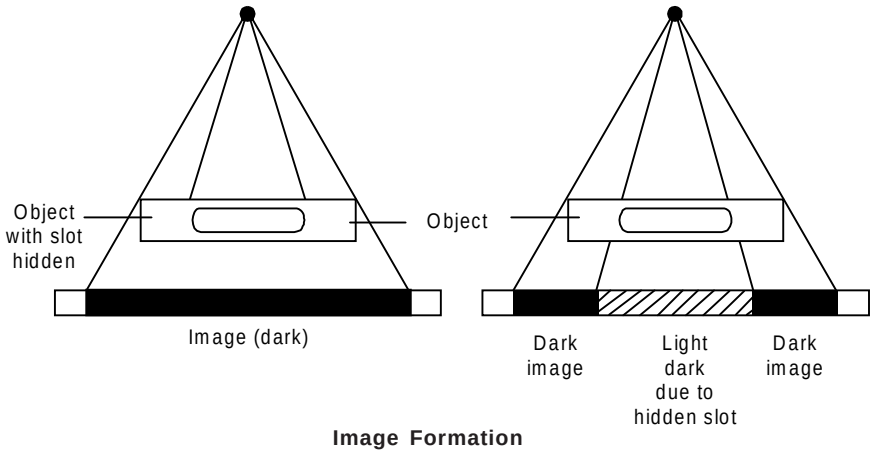
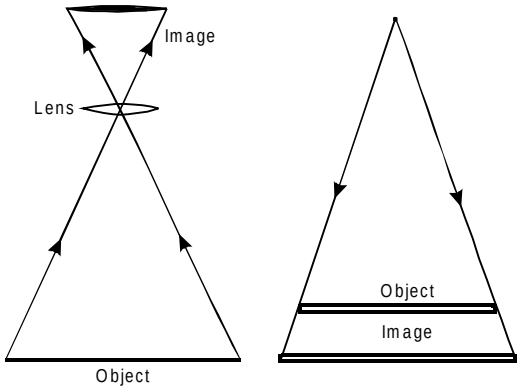


Image Formation

PROJECTION AND VIEW

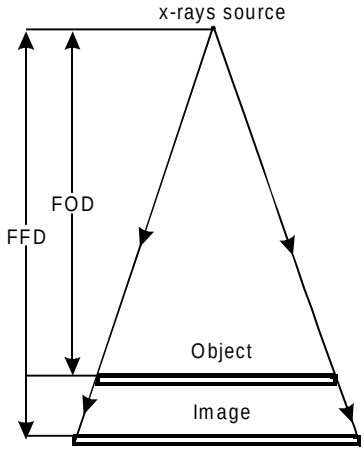
1. It can be seen that x-rays images are formed by projection *i.e.*, images of objects lying in the path of x-rays are projected on to a photographic material. This differs from the way images are formed on the retina of the eye or on the photographic film in a camera when light rays travel from the object to the recording medium to produce an image which is called a view of the object. The radiographic image produced by x-rays is a projection of the object.



View **Projection**

MAGNIFICATION

1. Since the light passes through a lens, the image produced on the retina or on the photographic film is smaller than the object. However in the case of a projected image, a magnified image is formed because the x-rays continue to diverge as they pass from the object to the recording film. The greater is the distance between the object and the film, the greater is the magnification of the image.



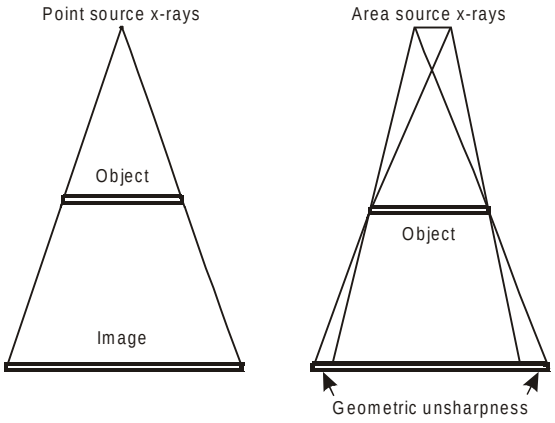
Magnification

$$\text{Magnification} = \frac{\text{Image Size}}{\text{Object Size}}$$

$$= \frac{\text{Focus to film distance (FFD)}}{\text{Focus to object distance (FOD)}}$$

IMAGE SHARPNESS

1. The aim of the radiography is to produce an image as sharp as possible. The factors leading to image unsharpness are :
   (*a*) Geometry
   (*b*) Movement
   (*c*) Absorption
   (*d*) Photographic factor
2. **Geometric unsharpness.** Since x-rays are not originated from a point source but from small area (port of the x-ray tube), this gives rise to geometrical unsharpness to the image as shown in the figure.



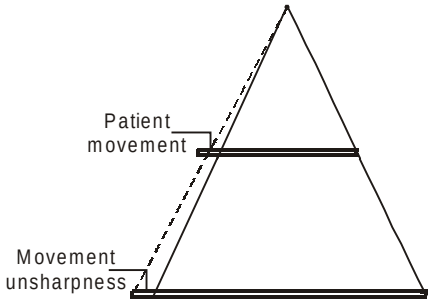
Geometric Unsharpness

The amount of geometrical unsharpness increases with increase in source area (focal spot) and increase in object to film distance.
Geometrical unsharpness

$$= \frac{\text{Object to film Distance}}{\text{Object to focus distance}} \times \text{focal spot size}$$

MOVEMENT UNSHARPNESS

1. This type of unsharpness results due to patient, equipment or film movement during exposure.



Movement Unsharpness

ABSORPTION UNSHARPNESS

1. If we consider a spherical object of uniform density, absorption will be greatest at the centre and least at the periphery. The gradual fall off in absorption towards the edges leads to the image having an ill - defined boundary which is called absorption unsharpness.

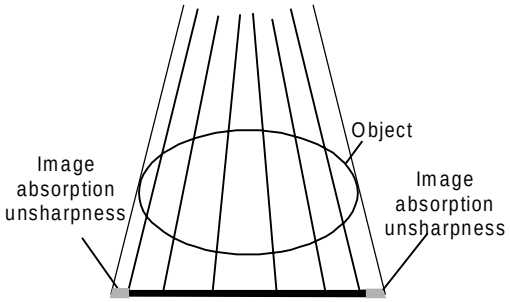
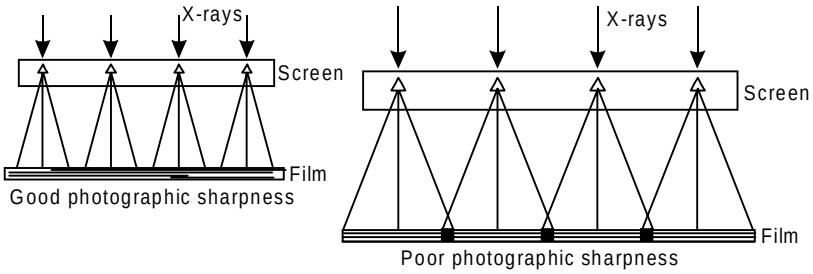


Image Absorption Unsharpness

2. **Photographic unsharpness :** The intensifying screen contains crystals which fluoresce when irradiated by x-rays. The main reason of photographic unsharpness is the spread of light between the crystals and the photographic emulsion. The spread of light will be greater with larger crystals and increased distance between the crystals.



Photographic Unsharpness

QUALITY OF DIAGNOSTIC RADIOGRAPHS

1. High quality of diagnostic radiographs can be achieved by :

(*a*) Scatter control

(*b*) Proper radiographic technique

(*c*) Technical image quality control programme

SCATTER CONTROL

1. In addition to the x-rays that pass straight through the body and contribute to the radiographic image, other scattered x-rays deviating from straight path are absorbed by the image receptor which blur the image, reduce contrast and increase image noise. Scattered x-rays do not contain useful information. Grids are used effectively to control scatter. A grid is a device which is placed directly in front of the image receptor and it consists of a series of closely spaced lead strips. The strips are oriented such a way that x-rays that are scattered from the tissues are absorbed. Only unscattered x-rays can pass through the grid. Hence grid filter blocks out most of the scattered radiation and improves the image quality.

2. Proper Radiographic Technique. Selection of the appropriate parameters of x-rays machine produces an optimally exposed radiograph with acceptable image contrast. The operators should be well trained to know proper radiographic techniques.

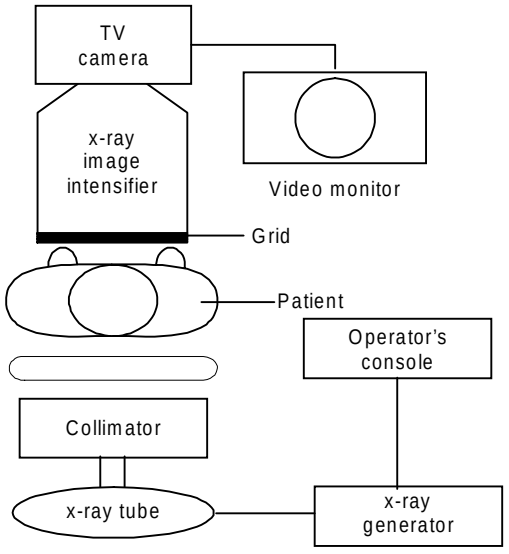
3. Technical quality control program. The aim is to optimise image quality while keeping the radiation exposure to patients and staff to minimum. Technical quality control program includes the monitoring of the performance of radiologists and technicians, patient service times, and other performance measures.

FLUOROSCOPY

1. It is a radiological technique by which the deeper structure of the body can be studied under direct vision on a fluorescent screen. The screen consists of a cardboard which is coated with a thin layer of fluorescent material, like zinc cadmium sulphide. The screen is covered with a thin sheet of lead glass through which the light rays can pass. However x-rays cannot pass through the sheet so that fluroscopic image is protected. When the screen is actuated by x-rays, light is emitted reflecting the pattern of the organs of the body through which the x-rays have passed. The fluoroscopic image can be seen more effectively in darkness when the eyes are fully adopted in darkness. The sharpness and contrast of a fluoroscopic image is generally

inferior to those of a good radiogram. The chief advantage is that the fluoroscopy is a real time radiography. Fluoroscopic system allows continuous viewing of a time varying x-ray image and permits live visual evaluation of dynamic events.

2. Modern fluoroscopy systems use a x-ray image intensifier as shown in the figure. The intensifier converts the x-ray energy to visible light. The intensifier is coupled optically to a television camera. The fluoroscopic image is viewed on a cathode ray tube (CRT) or a video monitor.



Layout of an Intensified Fluoroscopy System

IMAGE INTENSIFIER

1. The faint image of a fluoroscopic screen can be made brighter with the use of an electronic image intensifier. The intensifier tube contains a fluorescent screen which is coated with a special material to act as photocathode. The electronic image generated on the photo cathode is focussed onto a phosphor screen at the end of the tube by the help of an electrostatic lens system. Due to the acceleration of the electrons by the electrostatic lens system (25 kv) and output image is smaller than the primary fluorescent image, but there is a high brightness gain in the output image which makes it possible to observe the image in the normal illuminated room.

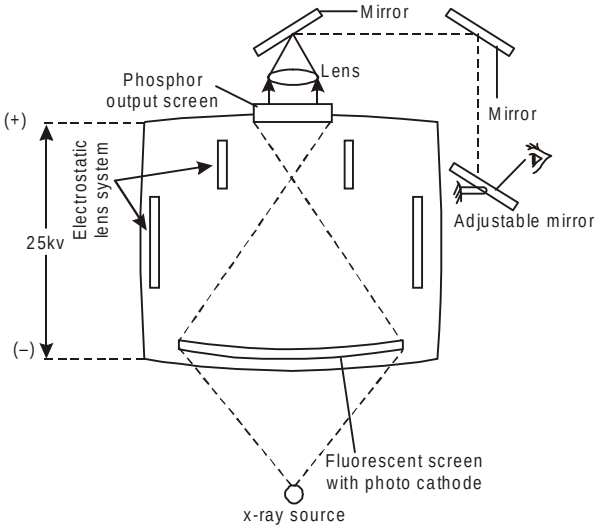


Image Intensifier

IMAGE QUALITY

1. The image quality depends upon following :

(*a*) Contrast. It is the difference in brightness of two neighbouring regions. In grey - scale image where signal differences are represented by varying shades of grey or brightness, high contrast means that two objects of different composition in the image appear very light or very dark. In a lower contrast image, there is less difference in relative brightness.

(*b*) Noise. It is any signal component in an image that does not convey any useful information. The aim is to have a higher signal to noise ratio to reduce the random noise.

(*c*) Spatial Resolution. It is ability of an image to faithfully reproduce small details. It is also called sharpness. Unsharpness (blur) indicates lack of spatial resolution.

LIMITATION OF RADIOGRAPHY

1. The superimposition of 3 dimensional information on a single plane of photographic film which makes diagnosis confusing and difficult.
2. The photographic film usually used for making radiograph has limited dynamic range which permits the organs that have only large variation in x-ray absorption relative to their surrounding parts will have sufficient contrast differences on the film. This helps in distinguishing the organs easily on the radiographs. The bony structures can be clearly identified while it is difficult to discern the shape and composition of soft tissue organs accurately.

MASS MINIATURE RADIOGRAPHY (MMR)

1. Mass miniature radiography is a fluroscopic image which is photographed by a camera. This method is used for quick survey of persons for diseases like tuberculosis.

BRONCHOGRAPHY

1. This is a radiological technique by which the bronchial tree can be visualised with the aid of a radioopaque dyc. The dye used is an loidized oil, called lipoid, (40% dyc iodine in poppy seed oil). It is rarely used today due to the advent of CT scanning.

DIGITAL SUBSTRACTION ANGIOGRAPHY

1. Firstly a pre-injection image (mask) is acquired. The injection of iodinated contrast agent is then performed. After this, the images of specified vessels are acquired. These images are subtracted from pre-injection images (mask) of the vessels. This technique greatly helps in contrast enhancement as the subtraction removes the appearance of stationary anatomy from the resulting images while synthesizing images containing only contrast in the blood vessels. Each image in the sequence reveals a different stage in the filling of vessels with contrast.

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. X-rays that pass through body and reach a detector as an image is called ---------. (*a*) radiograph (*b*) electrograph
2. X-rays can --------- the matter through which they pass. (*a*) not disturb (*b*) ionize
3. The ionization can cause damage to --------- and cells in human tissues. (*a*) BNA (*b*) DNA
4. X-ray techniques are being developed to --------- the radiation dose. (*a*) increase (*b*) minimise
5. An image --------- is a device which can detect and record an x-ray image. (*a*) receptor (*b*) captor
6. X-rays have much --------- wavelength than visible light . (*a*) longer (*b*) shorter
7. A fluorescent screen consists of polyster plastic coated with a ---------layer. (*a*) phosphor (*b*) sulphur
8. Storage phosphor is used to obtain radiograph in --------- form. (*a*) visual (*b*) digital
9. The radiograph produced by x-rays is a --------- of the object. (*a*) projection (*b*) visulisation

10. The ratio of image size to object size is ---------. (*a*) magnification (*b*) clarity factor

11. --------- is used to control the scatter x-rays. (*a*) filter (*b*) grid

12. Fluoroscopy allows continuous viewing of --------- x-ray image. (*a*) time varying (*b*) stable

13. The intensifier converts x-ray energy to ---------. (a) current (b) visible light

ANSWERS

1. (*a*) **2.** (*b*) **3.** (*b*) **4.** (*b*) **5.** (*a*) **6.** (*b*) **7.** (*a*)
8. (*b*) **9.** (*a*) **10.** (*a*) **11.** (*b*) **12.** (*a*) **13.** (*b*)

COMPUTED TOMOGRAPHY 25

Too many people spend money they haven't earned, to buy things they don't want, to impress people they don't like.

INTRODUCTION

1. A conventional radiograph is a 2 - dimensional image formed by the super-imposition of images from successive layers of the body in the path of the x-rays The image of one layer is obscured by the superimposition of the images of above and below layers. Tomography is used to overcome this problem. In this technique the images of selected layers are recorded sharply while images of other layers are unsharp. The technique involves some form of movement of the patient or equipment during the exposure. The movement causes images from the unwanted layers to move relative to the film during exposure resulting into unsharpness. However the movement keeps images from the selected layer are kept stationary relative to the film and these images are recorded sharply. Tomography involves the synchronised movement of any two of three subjects viz x-ray tube, the film and the patient while the third subject remains stationary. Exception is autotomography in which there is movement of the patient only.

2. Computed tomography is the name given to the diagnostic imaging technique in which tissues of the body are digitally reconstructed from attenuated x-rays data obtained from many directions in a particular plane.

PRINCIPLE OF TOMOGRAPHY

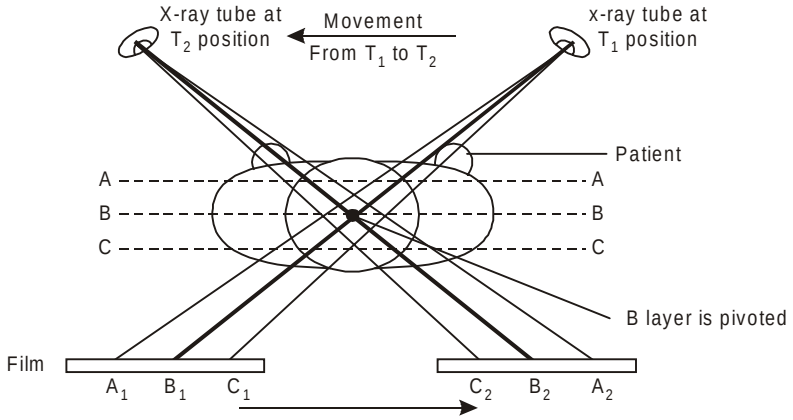
1. A tomographic image can be generated by following methods of coordination of movement during exposure :

(*a*) The patient remains stationary while the x-ray tube and the film (or detector) move in coordination. This is most widely used method.

(*b*) The x-ray tube remains stationary while the film (or detector) with the patient move in coordination.

(*c*) The film (or detector) remains stationary while x-ray tube with the patient move in coordination .

2. When the x-ray tube moves over the patient, the projected images of structures on different levels of the body move with different velocities. The structure which is nearer to x-ray tube will have its image moving faster. Similarly farther the structure is to the x-ray tube, the slower its image will move as the movement of x-ray tube and film is linked through a pivot. Hence the film moves at the same velocity as images of the structures only at the level of the pivot. Only these images are recorded on the same part of the film throughout the movement. Images of structures on all other layers move at a different velocity to that of the film and these images are not recorded on the same part of the film throughout the movement. These images are therefore recorded as blurred. As shown in the figure, the film is pivoted at *B* layer. When x-ray tube moves from T_1 to T_2 position during exposure, the quality of images at different level of layers are :



Priniciple of Tomography

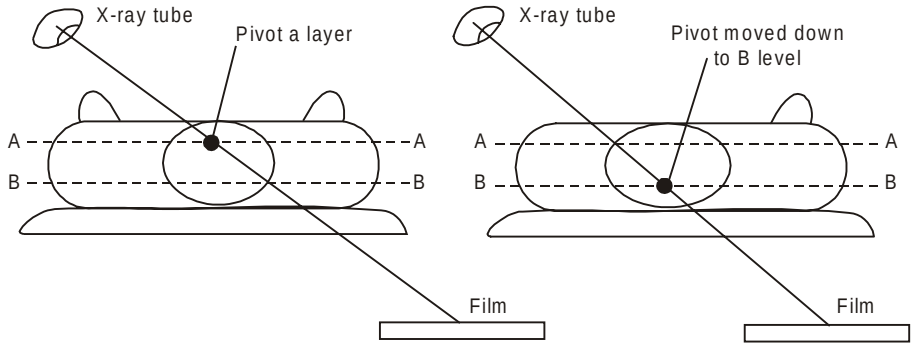
(*a*) Images layer *B* move at the same velocity as the film and images are recorded on the same part of the film throughout the exposure. The images recorded at point B_1 and B_2 are sharp.

(*b*) Images of layer *A* move faster than the film. The images of *A* move from the left of B_1 to the right of B_2 as shown in the figure. Images are not recorded on the same part of the film and images are therefore blurred.

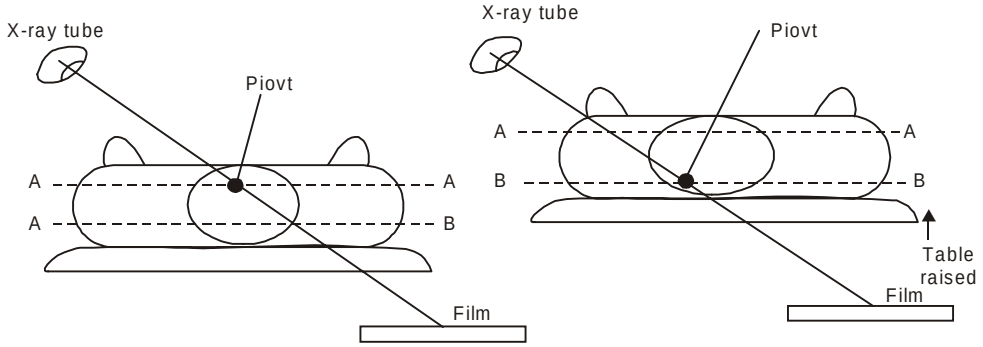
(*c*) Images of layer *C* move slower than the film. Images are therefore blurred.

3. It is possible to record sharp images of structures on one layer of the body which are free from obscuring images from other layers. Throughout the movement, there is no change in the magnification of images on the object plane as this would produce image unsharpness. For constant magnification, focus to pivot distance must remain constant. The layer recorded sharply is called the object plane. It is parallel to the film. Generally the film is parallel to the table to at the level of the plane. If the film lies at angle of the table top during the movement, the layer will be visualised same angle. This technique is called inclined plane tomography.

4. The height of the pivot above the table top can be changed which enables to select any level in the patient for the tomography. The level can be varied by two ways. Either the pivot can be lowered or raised above the table top to the required level in the patient (variable pivot system as shown in the figure) or the pivot is kept in a fixed position and table top is raised or lowered to bring the desired level of tomography to the level of the pivot (fixed pivot system as shown in the figure).

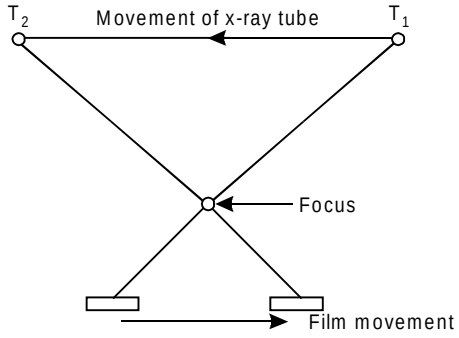


Moving Pivot System



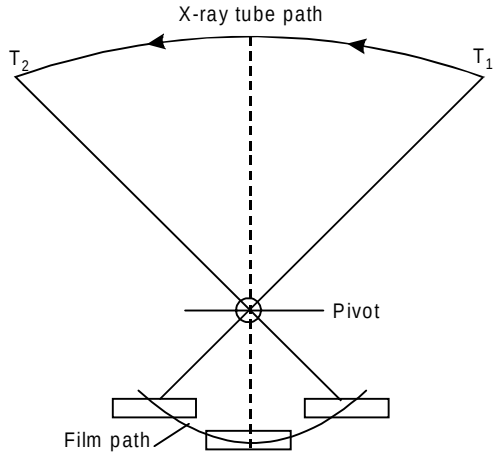
Fixed Pivot System

5. The simplest type of movement of x-ray tube and film is linear and parallel to table top which is also called line to line. The focus to film distance (FFD) changes during the movement. FFD is least at the midpoint of the movement. Linear movement is generally confined to one direction only which is along the long axis of the table. In certain tomography systems, linear movement in other directions parallel to the table is allowed. Linear movements have disadvantage that they produce unsharped images.



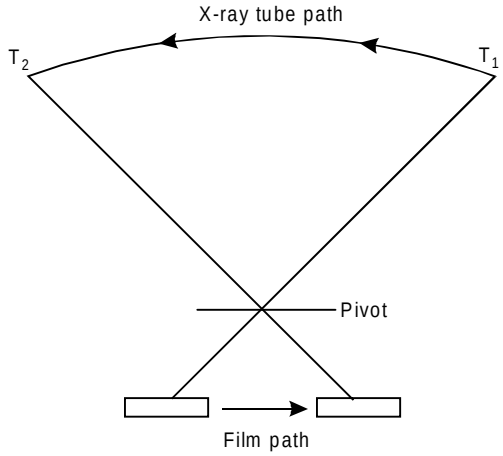
Line to Line

6. Arc to Arc is the movement when x-ray tube and the film move in arcs with the centre of ration at the pivot. Throughout the movement, the tube remains parallel to the tube top *i.e.*, the focus to film distance (FFD) remains constant as shown in the figure.



ARC to ARC

7. In arc to line movement, the x-ray tube moves in arc while the film moves in a line parallel to the table top. During the movement, there is a change in the ratio of focus to film distance to focus to pivot distance. Hence there is continuous change in the magnification of images of the subject layer. This leads to unsharpness of the images.



ARC to Line

RELATIVE DENSITY OF STRUCTURE ON CT

1. Although CT is more sophisticated than plain film radiography but the basic principle is same *i.e.*, dense structures of the body block the passage of x-rays more than soft tissues. Each point on a CT image (a pixel) represents a small volume within the body (a voxel). Dense structures such as bone are displayed as white while less dense structures are displayed as various shades of grey with the least dense structures are displayed as black. Hounsfield unit (named after the inventor of *CT*, Sir Geoffrey Hounsfield) is used to give relative density of a structure on *CT*. *HU* of certain structures are :– air = –1500, fat = –40, water = 0 soft tissue = +80, bone = +400 and metal = +2000. Each pixel on a *CT* image is composed of a shade of grey corresponding to shade or fray corresponding to the average *Hu* of the voxel that it represent. The various shades of grey create contrast in the image. The eye has limitation to appreciate few number of shades of grey. *CT* image has a large number of shades of grey. Hence windows are created to view optimally different structures in the body as per the limitation of the eye.

ELEMENTS OF DIGITAL IMAGING SYSTEM

1. The elements of digital imaging system are :

(*a*) Data acquisition system

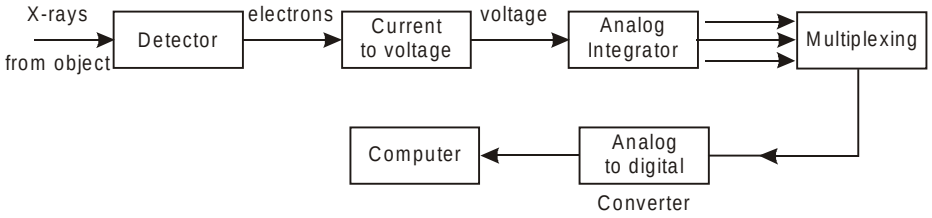
(*b*) Processing unit

(*c*) Communication

(*d*) Display

DATA ACQUISITION SYSTEM

1. Two elements are required to acquire digital images. The first element is detector (sensing device) an electrical signal output which is proportional to the level of x-rays sensed. The second element is called a digitizer which is a device for converting the electrical output of the sensing device into digital form. The detectors for *CT* systems must have high overall efficiency (so as to minimise the patient radiation dose), large dynamic range (the ratio of the smallest and just detectable signal to the largest signal without causing saturation), stable with time and insensitive to temperature variation. Three types of detectors are commonly used in *CT* scanners. They are (1) xenon gas ionization (2) scintillation detector like sodium iodide, bismuth germanate and cesium iodide crystals which convert kinetic energy into flashes of light which can be detected by a photo multiplier. (3) solid state detector (single crystal ($Cd\ WO_4$ and ceramic Cd_2O_2S with photo diodes) which can detect x-ray photons. The output from the detector is variation of electrons (current) as per the intensity of x-rays with the help of current to voltage converter. The multiplexing is a device to take readings from two or more analog integers with a single analog to digital converter. An analog to digital converter is device that accepts a continuous analog voltage signals as input and converts them in to digital output signals. The converters can be (1) voltage to frequency converter with a counter (voltage is converted into pulses and number of pulses is portional to voltage) (2) pulse width convertor (discharged capacitor is charged at fixed rate until it is charged to analog voltage and resulting pulse width is proportional to the analog voltage) (3) up and down integrator converter (the input of analog integrator is alternately switched between the analog voltage to be digiticized and a constant reference voltage and output of analog integrator is used to charge a capacitor at fixed rate as done in pulse width converter.



Data Acquisition

PROCESSING UNIT

1. Computer is used as processing unit. Processing of digital images required procedures which can be expressed in algorithm form. Therefore most image processing functions can be implemented in software of the computer. Some of the principle imaging hardware being added to the computer consists of (1) a digitizer / frame buffer combination for image digitization and temporary storage (2) an arithmetic and logic unit (ALU) processor for performing arithmatic and logic operations at frame rate (3) one or more frame buffers for fast access to image data during processing. Many basic image processing softwares are available which can combine computer softwares of spread sheets and graphics to provide solution to all image processing problems.

2. CT technique generates a two dimensional picture in which each picture element (pixel) value corresponds to the attenuation coefficient of a voxel in the object slice. The information received by the computer from the data acquistion system has to be processed for reconstructing the pictures. The data received by the computer contains following information :–

(*a*) Positional information about scanning frame.

(*b*) The value of absorption or attenuation.

(*c*) Reference information of x-ray output from the reference detector.

(*d*) Calibration information which is available at the end of each traverse.

3. The reconstruction of images from the scanning data is carried out by the computer. The fundamental of the principle is given by the mathematical discovery that a two dimensional function can be determined by the projection of this function from all directions. The scanned data at angles uniformly distributed about the origin can reconstruct the images if data is properly processed or projected. The time required for reconstruction is same as that is required for acquiring the data. Mathematical reconstruction algorithms in software permit reconstruction to start simultaneously as the first projection data is received by the computer. The reconstruction methods are :

(*a*) Interactive methods

(*b*) Analytic methods with the concept of back projection.

(*c*) Analytic methods with the concept of filtered back projection.

ITERATIVE METHOD

1. In this method, an initial guess about the two dimensional pattern of x-ray attenuations is made. The projection data likely to be given by this two dimensional pattern (model predictions) in different directions are then calculated which is compared with the measured data. Discrepancies between the measured data and predicted model data are used in a continuous iterative improvement of the predicted model array.

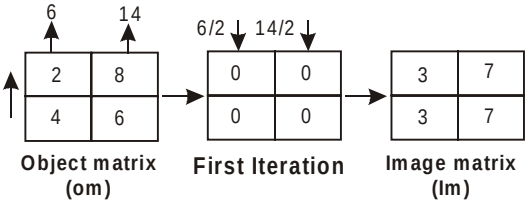
2. Inorder to illustrate the methodology of iterative method to obtain an image of attenuation coefficients from the measured intensity data, we suppose the attenuation coefficients of the first row and second row by a 2 × 2 object matrix as

2	8
4	6

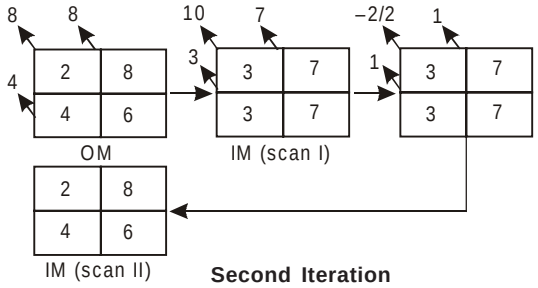
.

Now we carry out scanning in three directions *i.e.*, scan I in vertical direction, scan II in diagonal direction scan III in horizontal direction to find image matrix. Following iterations can be carried out to match image matrix to the object matrix :–

(*a*) Scan I of the object matrix in vertical direction gives the vertical sums of 6 and 14 which is distributed in vertical columns with equal weighing *i.e.*, 6/2 and 14/2 to get an image matrix.

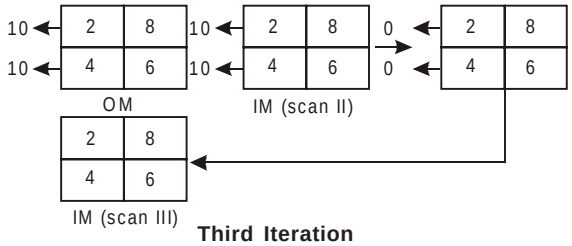


(*b*) Scan II of matrix in diagonal direction of object matrix gives attenuations as 4, 8 and 8 and image matrix after first iteration given 3, 10, & 7. Differences of object and image matrix have values of 1, –2 and 1 which are back projected with equal weighing diagonally as shown in the figure.



Second Iteration

(*c*) Scan III in horizontal direction of object matrix gives attenuations as 10 and 10 while scanning of image matrix after second iteration gives attenuation as

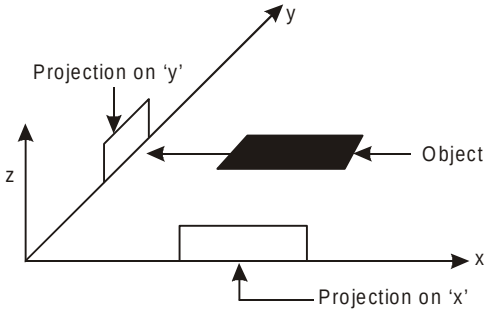


Third Iteration

10 and 10. The object and image matrix now match as difference in values of elements in both matrices is zero. Now we use the final image matrix to generate image with the help of the computer.

BACK PROJECTION

1. In this method, the image is reconstructed directly from the projection data without any need to compare the measured data and the reconstructed model. If projections of an object in the two directions normal to *x* and *y* axes are measured and then this projection data are projected back into the image plane, the area of interaction receives their summed intensities. It can be seen that the back projection distribution is a representation of the imaged object. In actual process, the back projection for all scanned angles is carried out and the total back projected image is made by summing the contribution from all the scan angles. This method generally gives a crude reconstruction of the imaged object



Projection in Normal X and Y Directions

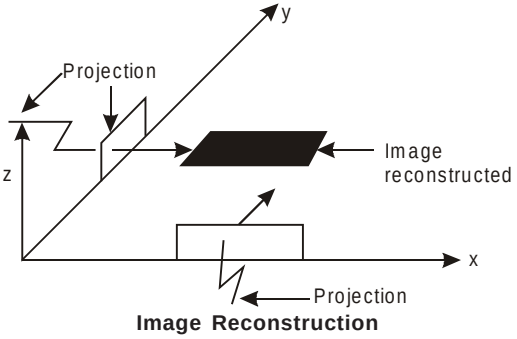


Image Reconstruction

FILTERED BACK PROJECTION

1. It is possible that the image can be reconstructed with the back projection after data has been filtered first. The back projected image is fourier transformed into the frequency domain and filtered with a filter proportional to spatial frequency upto some frequency cutoff. These filtered projectios are used to construct the final back - projected image. The filtering operations can also be carried out in cartesian coordinates by using analytic algorithms which are known as convolution techniques. This is achieved by convolving (filtering) the shadow function with a filter. In principle,

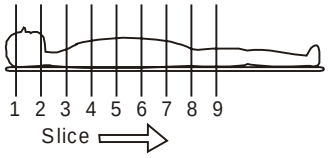
the blurring effect is removed in the convolution process by means of a weighing (suitable processing function) of the scan profiles before back projection. This method has began found to give a good reconstruction of the imaged object.

COMMUNICATION

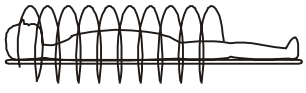
1. Communication in digital image processing is primarily concerned with local communication between image processing systems and remote communication from one place to another which involves transmission of image data.

SPIRAL CT SCANNING

1. Spiral CT scanning was introduced in 1989 which was a dramatic development, helping CT scanning to mature into a true volume imaging modality. In conventional CT scanning, the patient was required to shift after each slice to get a new slice. The rotation of x-ray tube is stopped after each revolution to shift the patient for next slice. The rotation of x-ray tube is therefore intermittent and stoppage of rotation. To frequent speed of scanning, spiral CT scannig was introduced. In spiral CT scanning, there is continuous rotation of x-ray tube and shifting of patient, resulting into much faster scanning rate.



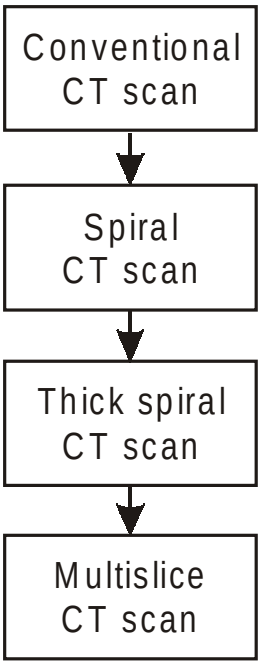
Conventional CT Scan



Spiral CT Scan

MULTI-SLICE COMPUTED TOMOGRAPHY

1. Conventional CT scanners have a single row of detectors whch can acquire a single slice image per rotation. a multislice CT sysetm in contrast uses multiple detector rows (14, 16, 64) which enables it to acquire images of multiple slices per rotation. The speed of gantry is also increased in multisliced CT system resulting in an overall increase in scan speed. These improvements dramatically reduce the scanning time, permitting larger volume to be scanned in a much reduced time. This technique also gives higher resolution and also permitting newer techniques like CT angiography and cardiac CT.



Evolution of Multi-slice CT Scan

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. In computed tomography, the images of selected layers are records ---------. (*a*) sharply (*b*) dimly

2. In computed tomography, some form of ---------- of the patient or equipment is carried out during exposure. (*a*) relative movement (*b*) synchoronised movement

3. In computed tomography, the patient remains stationary while the x-ray tube and film / detector move ---------. (*a*) independly (*b*) incoordination

4. On computed tomography, each pixel of image represents a ---------. (*a*) voxel (*b*) body organ

5. On computed tomography, bone is displayed as ---------. (*a*) white (*b*) black

6. --------- is used to give relative density of a structure on computed tomography. (*a*) Hounsfield (*b*) Hounmerfield unit

7. --------- are used for processing of images on computers. (*a*) CPU (*b*) algorithms

8. A two dimensional function can be determined by the projection of the function from --------- directions. (*a*) three (*b*) all

9. Imaging of brain is difficult by using method of ---------. (*a*) radiography (*b*) tomography

10. Xenon is a --------- detector. (*a*) gas ionization (*b*) x-ray photon

11. --------- detectors convert kinetic energy into flashes of light. (*a*) titillation (*b*) scintillation

12. --------- detectors with photo diodes can detect x-ray photon. (*a*) photiac (*b*) solid state

ANSWERS

1. (*a*)	**2.** (*a*)	**3.** (*b*)	**4.** (*a*)	**5.** (*b*)	**6.** (*a*)
7. (*b*)	**8.** (*b*)	**9.** (*a*)	**10.** (*a*)	**11.** (*b*)	**12.** (*b*)

MAGNETIC RESONANCE IMAGING 26

The grass may be greener on the other side, but it's just as hard to cut.

INTRODUCTION

1. Magnetic resonance imaging (MRI) is quite recent diagnositc imaging that has aroused a wide interest for a number of reasons as under :

(*a*) It employs a strong magnetic field and radio frequency pulses to provide remarkably clear and detailed pictures of internal organs and tissues, thereby eliminating the need of x-ray radiation as in the case of radiography and CT scan.

(*b*) It provides very good distinction between adjacent structures and excellent tissue contrast without injection of potentially toxic contrast agents.

(*c*) In MR 1, bone does not interfere with the signals emitting from the tissues which carry the images of the areas under observation. Previously such areas could not be imaged non invasively such as brain stem and spinal cord.

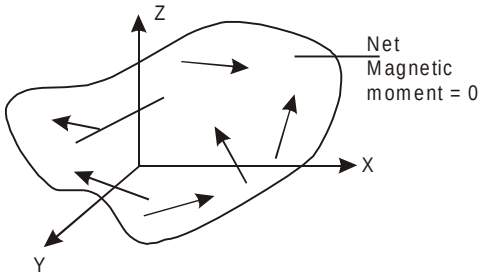
(*d*) MRI can help in detecting diseases of earlier stages that previously could not be done with available methods.

2. MRI is unique imaging method because unlike the usual method of radiography, radioisotopes and CT scanning, it does not rely on radiation. In this, protons of the nuclei of hydrogen atoms are subjected to radio frequency pulses in a strong magnetic field. The protons get thereby "excited" to higher energy level. Protons also get "relaxed" to the lower energy level on the switching off radio frequency pulses. The protons emit radio frequency signals when they move from "excited" to "relaxed" state. These radio signals can be detected by a receiver and a computer can further process the output into an image. In our body tissues, protons of hydrogen are most abundant as hydrogen atoms of water molecules (H of H_2O). Hence MRI image shows difference in the water content and distribution in various body tissues. Each different type of tissues within the same region can be easily distinguished.

PRINCIPLE OF MRI

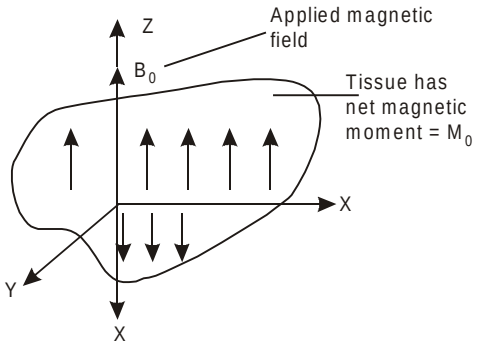
1. Each nucleus of an atom has either proton (one proton in hydrogen) or combination of protons and neutrons. Nucleus having an odd number of combination of protons

and neutrons possesses a nuclear spin (The value varies from $\frac{1}{2}$ to 1) and magnetic moment which has both magnitude and direction. The magnetic moments pertaining to different atoms of a body tissues are randomly aligned and their net magnetic moment is zero as shown in the figure. When



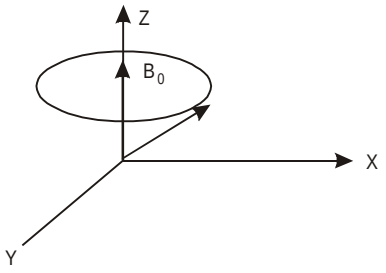
The Method of Encryption

a strong magnetic field is applied, each atom with magnetic moment experiences magnetic torque which tends to align each magnetic moment. Majority of atoms align their magentic moments parallel to magnetic field and rest align anti parallel to the applied field. This results into a net magnetic moment (M_0) created in the body tissue due to the realignment of its atoms as shown in the figure. It is this net magnetic moment accounts for the nuclear magnetic



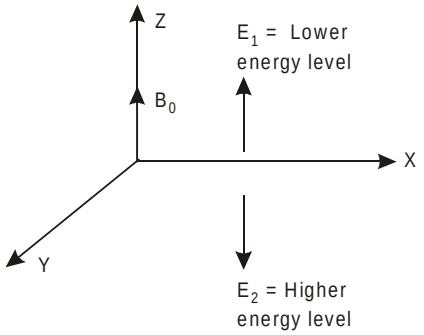
Aligment of Magnetic Moment Due to Magnetic Field

that resonance signals on which the imaging is based. Any nucleus having magnetic moment tends to align with applied magnetic field and in this process it starts processing about the direction of magnetic field as shown in the figure.



Precessing of Nucleus

The processing frequency (W_l) is called Larmer frequency which is related to the strength of the applied magnetic field (B_0) given by $W_l = \gamma B_0$ when γ = constant.



Highest and Lowest Energy Level

The nucleus has highest energy (E_2) when its magnetic moments align anti parallel to the applied magnetic field and lowest energy (E_1) when its magnetic moments align parallel to the applied magnetic field. The excitation energy (E) is required to excite a nucleus from the lower to higher energy level. The excitation energy is given by plank's equation,

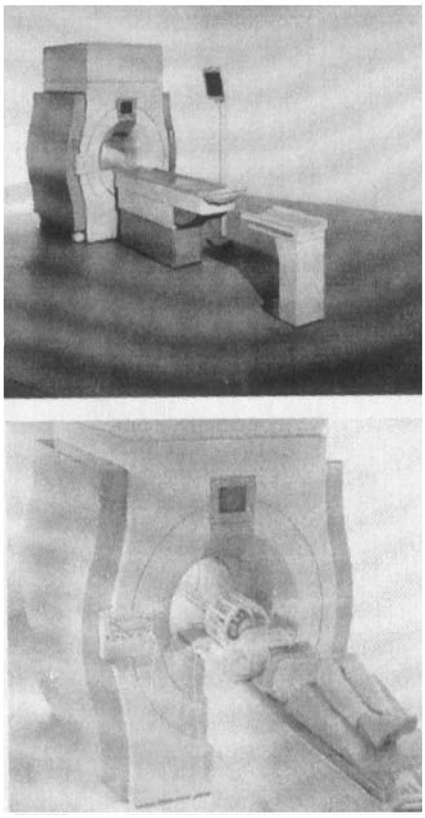
as $E = \frac{h}{2\pi} W_l$ where h = plank's constant. In MRI, the excitation energy is given to nucleus by applying radio frequency pulses.

2. The body tissue has hydrogen protons (nuclei) which absorb energy from the applied RF pulses of suitable frequency. Therefore protons are excited to higher energy level from the lower energy level. When RF pulses are stopped, the absorbed energy of RF frequency is emitted by the nuclei as the electro-magnetic energy of the same frequency similar to the source (transmitter). Hence supplying electomagnetic energy of the appropriate rotational frequency, the protons or nuclei of hydrogen can be excited from a lower energy level (E_1) to higher energy level (E_2). If the energy supply is stopped, the excited protons drop back to lower energy level E_1 (relaxed). In this process, the nuclei emit the energy absorbed during movement from E_1 level to E_2 level. If the RF pulses are repeatedly applied and removed, the nuclei start resonating between E_1 and E_2 energy level. The signals produced during relaxation (move from higher energy to lower energy) is dependent on density of hydrogen, the velocity of flowing fluid through the tissue and the rate at which the excited nucles are relaxed. The relaxation parameters are marked T_1 and T_2. T_1 and T_2 depend on the physical properties of the tissues when exposed to a series of pulses at predetermined time intervals. Different tissues have different T_1 and T_2 properties based on the response of their hydrogen nuclei to radio frequency pulses in the strong magnetic field. These differential properties are made use of by setting equipment parameters (T_R and T_E) inorder to generate images either based on T_1 or T_2 properties of the tissues. Due to this reason, images of the tissues are known as either T_1 or T_2 weighted. T_R stands for the time to repeat RF pulses while T_E is time to receive echo *i.e.,* time internal between application of pulse and listening of the signal.

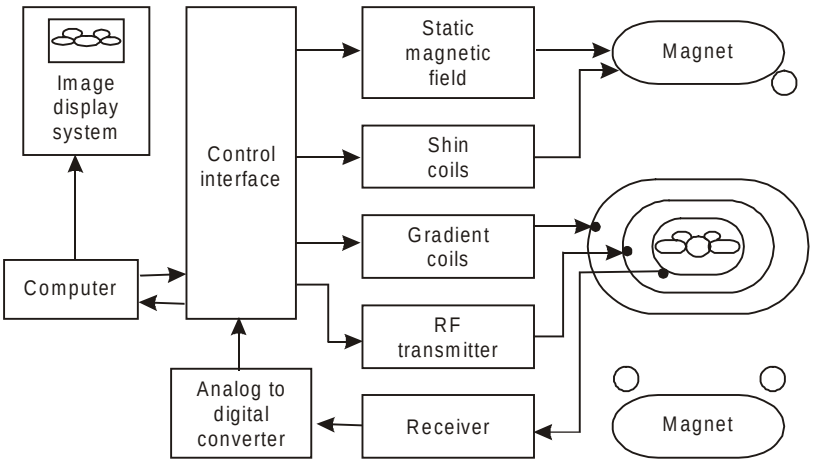
3. Signal intensity pertains to the brightness of signal generated by specific tissue. The tissues that are bright (white) are hyperintense while darker signal tissues are hypointense. The tissues which are in between bright and dark are isointense. The signal intensity of tissue depends upon whether image is T_1 or T_2 weighted. For example, fat is bright on T_1 weighted images and less bright on T_2 weighted images. Similarly water is dark on T_1 weighted images and bright on T_2 weighted images. Similarly gas is dark on T_2 weighted images.

4. Spatial encoding of the MRI signal is accomplished by applying magnetic field gradient across the region of interest. We have seen that magnetic field changes the rotation frequency of nuclei. When RF pulses are applied, the nuclei having same frequency start resonating. By sequentially varying the frequency of RF pulses, nuclei can be selectively excited. There are many techniques by which MRI information can be spatially encoded, acquired and transformed into an image. One of the techniques used is electron technique in which magnetic gradient is rotated to obtain multiple projections which are fed into a computer to generate an image.

5. The components of a MRI system are (1) a magnet (2) gradient coils (3) a transmitter (4) a receiver (5) a computer and (6) shin coils. The layout of the system is as shown in the figure.



The Components of a MRI System



The Components of a MRI System

A strong magnet is provided to produce a highly uniform static magnetic field (1 to 3 Tesla) which is 10,000 to 30,000 times stronger than the earth's magnetic field. The magnet can be permanent or electromagnetic type. The magnet is a large and has cylindrical shape with a large aperture at centre to enclose the sliding table on which a patient can lie down for imaging. The price of the magnet is the main cause of high purchasing and installation cost of MRI system. The gradient coils are provided to create magnetic field gradient in the tissues of the body to be imaged for spatial encoding of the signals. The transmitter operates at radio frequency to generate pulse sequence to resonate the hydrogen protons (nuclei) of the tissues. The receiver is required to detect the MRI signals emitted by nuclei of hydrogen during relaxation. The output of the receiver is linked to the computer. The computer and display system is provided to control the system operation so that images can be processed, stored, reconstructed and displayed, as and when required. Shin coils are placed at suitable places to maintain the homogeneity of the magnetic field.

THE BENEFITS, RISKS AND LIMITATIONS

1. The benefits of MRI are :

(*a*) Image of the brain and other head structure are clearer and more detailed than the images obtained from other imaging methods.

(*b*) Exposure to radiation of a patient during imaging has been completely eliminated.

(*c*) The detection of abnormalities that might be obscured by bone structure in other imaging systems are possible.

(*d*) The contrast material used in MRI is less likely to produce allergic reaction as compared to the iodine based material used in x-ray and CT scan.

(*e*) The diseases at earlier stages can be detected in MRI system. It can detect the functioning of brain and onset of brain stroke at a very earlier stage.

(*f*) MR angiography can provide detailed images of blood vessels in the brain without contrast material.

2. The risks of MRI are :

(*a*) The strong magnetic field can affect any metallic implant in the body of a patient.

(*b*) It is generally avoided in the first 12 weeks of pregnancy incase of pregnant women.

3. The limitations of MRI are :

(*a*) MRI system is costlier than other systems like CT scan.

(*b*) Bone can be better imaged by the conventional x-ray system.

(*c*) CT scan is preferred for patients having severe bleeding or acute trauma.

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. MRI eliminates the exposure to --------- of a patient during imaging. (*a*) shock (*b*) radiation

2. In ---------, bone does not interfere with the signals emitting from the tissues. (*a*) MRI (*b*) CT scan

3. MRI can detect diseases at --------- stages. (*a*) advanced (*b*) early

4. The protons of hydrogen are excited by subjecting to --------- . (*a*) Radiation (*b*) RF pulses

5. The protons emit RF signals when they

move from --------- to --------- state. (*a*) excited, related (*b*) relaxed, excited

6. --------- generates RF pulses. (*a*) receiver (*b*) transmitter

7. RF signals emitted by tissues are detected by ---------. (*a*) receiver (*b*) transmitter

8. The output of the receiver is linked to ---------. (*a*) transmitter (*b*) computer

9. The gradient of magnetic field is produced by --------- coils. (*a*) gradient (*b*) shin

10. The homogeneity of magnetic field is produced by --------- coils. (*a*) gradient (*b*) shin

11. The signal intensity of tissues depends upon whether images are T_1 or T_2 ---------. (*a*) linked (*b*) weighted

12. Spatial enconding of RF signals emitted by the tissues is obtained by magnetic ---------. (*a*) homogeneity (*b*) gradient.

13. MRI system is --------- as compared to CT scan. (*a*) cheaper (*b*) costly

14. The high cost of --------- is the main cause of high purchasing and installation cost of MRI system. (*a*) magnet (*b*) computor

15. The strength of the magnet of a MRI system is about --------- tesla. (*a*) 1 to 3 (*b*) 5 to 7

16. The strength of earth's magnetic field is one gauss and --------- gauss make a tesla. (*a*) 10^4 (*b*) 10^3

ANSWERS

1. (*b*) **2.** (*b*) **3.** (*b*) **4.** (*b*) **5.** (*a*) **6.** (*b*) **7.** (*a*)
8. (*b*) **9.** (*a*) **10.** (*b*) **11.** (*b*) **12.** (*b*) **13.** (*b*) **14.** (*a*)
15. (*a*) **16.** (*a*)

ULTRASOUND IMAGING

27

Everyone thinks of changing the world but no one thinks of changing himself.

INTRODUCTION

1. The application of ultrasound in medical field is based on the sonar principle as used by bats, ships at sea and anglers with fish detectors. It is totally non invasive procedure. Acoustic waves are easily transmitted in water but they are reflected from an interface according to the change in the acoustics impedance. Leaving bones and lungs, all tissues of our body are composed of water which can transmit acoustic waves easily. Ultrasound can be used for obtaining images of internal organs by sending high frequency sound waves into the body. The reflected sound waves (returning echoes) are recorded and processed to reconstruct real time visual images by the computer. The returning sound waves (echoes) reflect the size and shape of the organ and also indicate whether the organ is solid, fluid or something in between. Unlike x-rays, ultrasound requires no exposure to ionization radiation. It is also a real time technique that can produce a picture of blood flow as it is at the very moment of imaging.

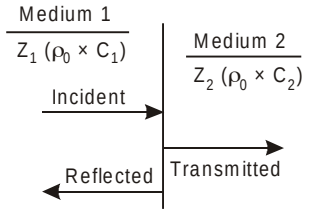
ULTRASOUND WAVE

1. The human can hear sound in the frequency range of 20 hertz to 20,000 hertz. As the name suggests, ultrasound has frequency greater than 20,000 hertz. Diagnostic ultrasound has the range of 1 to 10 megahertz. Ultrasound travels in the form of longitudinal wave *i.e.*, the particles of the medium move in same direction inwhich the wave propagates. The wave transfers energy through the motion of regions of compression and rarefraction within the wave. The propagation of wave depends upon the elastic properties of the medium. If pressure change is ΔP and $\Delta V/V$ is corresponding change in the volume of the medium, than $\Delta P = -\beta \frac{\Delta V}{V}$ where β = modulus of elasticity. The average speed of wave in biological tissues is given by relation $C = \sqrt{\frac{\beta}{\rho_0}}$ where ρ_0 = density of the medium without disturbance. The average speed in tissue is taken as 1540 m/sec.

2. The intensity of a wave is defined as the energy which flows per unit time across a unit area perpendicular to the wave propagation. Intensity (I) = $2\pi^2 \rho_0 cf^2 \zeta_{max}$ for an infinite one dimensional plane wave where f = frequency, ζ_{max} = maximum particle displacement, ρ_0 = density and C = average speed. Therefore intensity depends upon the parameters of impressed ultrasound wave (f and ζ_{max}) and parameters of medium known as specific acoustic impedence z ($z = \rho_0 C$). Biological tissue is not homogeneous acoustically *i.e.,* ρ_0 and C are not constant within the meduim. If we consider a plane longitudinal wave propagations from meduim 1 to medium 2, then the percent of the incident wave energy which is reflected

$= \dfrac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2} \times 100\%$ where Z_1 and Z_2 are acoustic impedence of the medium 1 and 2.

The transmitted energy $= \left(\dfrac{2Z_1Z_2}{Z_1 + Z_2}\right)^2 \times$ 100%. The interface separated by the greatest difference in the speed of sound will provide the greatest reflection as then the value of $z_1 - z_2$ is large. This is the reason why it is difficult to visualise bone. Similarly the acoustic impedance of air and tissue are 42.8 gm/cm^2 and 16×10^2 gm / cm^2 which results into a large value of $z_1 - z_2$ thereby the interface makes the ultrasound energy reflected completely without any penetration. A special jelly is used therefore to minimise reflected energy from the interface of skin and transducer (in air) so that ultrasound can penetrate the body for the imaging of organs. Hence the ability of ultrasound waves to travel through any meduim is restricted by the properties of that medium. These properties include the density and elastic properties which make up the acoustic impedance specific to that meduim. The transmission is also limited by the transducer frequency being used. Higher frequencies have shorter wavelengths ($V = f\lambda$ where v = velocity, f = frequency and λ = wave length) and they can penetrate less than lower frequencies.



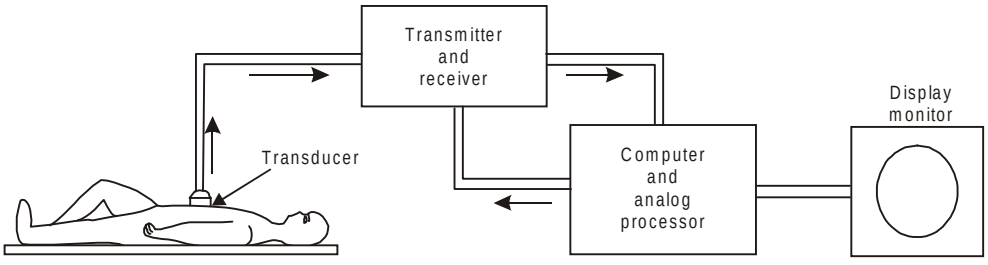
Incident, Transmitted and Reflected Wave

3. The velocity of ultrasound in a medium depends upon modulus of elasticity and density of the medium. The knowledge of velocity in a medium is essential in calculating the depth to which a wave has potential to traverse before it is reflected. The depth of penetration is the product of velocity and time lapsed for the wave to travel from source to interface and back. As the ultrasound beam encounters tissues of different acousitc impedance, velocities are altered such that returning echoes are received by the receiver at different times and echocs have different intensities. The differences in time and intensity have useful information. This information as well as the knowledge about velocity in the tissue are used by the computer to generate the image on the monitor. Transmit power or intensity is manually adjustable in the machine. Ultrasound power is expressed by decible (db).

SCANNING

1. General rules of scanning are :

(1) ultrasound beam should be directed perpendicular to the object of interest for optimal visulisation (2) the transducer must be selected which has the highest frequency allowable for the penetration required (3) a full bladder is required for optimal visualization of the uterus and ovaries (GYN) and (4) scanning of all organs of interest is to be done in two planes which are perpendicular to each other. The scanning modes are : (1) bistable scanning (2) Grey scale imaging (3) A mode (4) B-mode (5) M-mode and (6) real time. Bistable scanning displays images in black and white. Grey scale imaging is commonly used in which an analog to digital scan converter transfers information from the receiver to the computer. Multiple shades of grey enhance tissue characteristics and make the ultrasound image more aesthetic and realistic. Human eye can discern upto 32 shades of grey. Therefore most systems employ 32 shades of grey only. A-mode (amplitude mode) displays the amplitude of individual echoes as a function of distance or time on cathode ray tube. The display is shown alongside the image which is helpful in determining the type of tissue *i.e.*, cystic or solid. B mode (Brightness mode) displays echoes as individual spots on the screen corresponding to the points of origin in the tissue. Differences in amplitudes of returning echoes manifest as different brightness of the dots. Using many pixels (picture elements), these numerous dots can be arranged in such a way as to appear in different shades of grey for good visualisation. A schematics block diagram of a B-mode ultrasound imaging system is as shown in the figure. M-mode (motion mode) is nothing but the application of B-mode to a moving structure varying with time. Real time imaging allows the processing of the grey scale characteristics and the motion of interfaces. The brightness dots move on the monitor screen as the actual interfaces Echocardiogram gives the movement of valves and other structures of the heart which are displayed as a function of time. M-mode technique is used to obtain it. A-mode is used for echoencephalogram which can determine the location of the problem of the brain. B-mode is used for diagnostic scanning of the eye. B-mode is also used for visualizing various organs and stuctures of human body which include breasts, kidneys, ovaries and tubes. It permits examination of foetus as early as the 4-week stage.



Schematic Block Diagram of B-mode Ultrasound

THE ULTRASOUND TRANSDUCER

1. The transducer is a device capable of changing one form of energy into another. In ultrasound, the transducer is both sender and receiver of ultrasound pulses and echoes. The transducer converts electrical impulses into ultrasound waves and vice versa. Generally a piezoelectrical crystal is used to create the ultrasound waves. As the receiver, the transducer has many functions like amplification, compensation, demodulation, compression and rejection. Man-made lead zirconate and lead titanate are also used as transducer. The electricity is applied to the transducer at a specific pulse rate which allows waves to travel and echo back to the receiver. The transducer sends pulse of one microsecond duration with the interval of 999 microseconds before sending next pulse. Hence the ultrasound scan head is in the "listening" mode for the echoes for most of the time. The beam emitted by the transducer has two fields viz. near field and far field. Near field has width from the transducer's face to the focal point beyond which the beam diverges and is called far field. Due to divergence, resolution region is bad in the far field as compared to the near field.

IMAGE RESOLUTION

1. Resolution is the ability of the system to separate and define small and closely separated structure. The resolution can be: (1) lateral and (2) axial. Lateral resolution is the ability of the system to separate and define small structures in the plane perpendicular to the beam axis. Lateral resolution can be optimised by focussing the beam at the area of interest and then slowly increasing the frequency. If the beam width is greater than the separation between two objects then these objects can not be resolved. Axial resolution is the measure of the system to separate and define structures along the axis of the beam. It depends upon the pulse duration. Two neighbouring structures can be resolved by beam if the wavelength of the beam is less than their axial distance between them. However the average ultrasound pulse contains two wave lengths. Therefore higher frequency transducer has to be used to improve the axial resolution. The frequency can not be made much higher to have better resolution as then the penetration of wave falls with increased frequency.

WORKING OF ULTRASOUND

1. The ultrasound image is formed from the useful information contained by the echoes of the ultrasound which are reflected back while traversing and interacting with the tissues of the body. These interaction contributes to image formation and images vary as the tissues vary themselves. It is important to have known values of acoustic impedance (z) and speed of ultrasound in the particular tissue. The acoustic impedance is a function of the elasticity and density of a particular tissue. Materials with high acoustic impedance can transmit sound faster than others. The acoustic impedance of some materials are :

(*a*)	Blood	—	1.6×10^5 gm /cm^2
(*b*)	Bone	—	7.8×10^5 gm /cm^2
(*c*)	Fat	—	1.4×10^5 gm /cm^2
(*d*)	Soft tissue	—	1.6×10^5 gm /cm^2
(*e*)	Air	—	0.004×10^5 gm /cm^2
(*f*)	Water	—	1.5×10^5 gm /cm^2

2. The ultrasound beam is attenuated while traversing through the tissues. The beam may be partly scattered, reflected, refracted or absorbed. The amount of intensity removed from the beam per unit depth is expressed as the attenuation coefficient $dB = 10 \log_{10} \left(\frac{I_2}{I_1} \right)$ which is a logarithmic expression of the ratio of intensity of the returning echoes to the intensity of the original sound beam. As frequency increases, the attenuation coefficient also increases. The beam is generally attenuated one dB per mhz and per cm of tissue traversed. When the beam reaches perpendicular to the tissue interface within the body, the energy is reflected back towards the transducer cum receiver. The amount of energy reflected is proportional to the difference in acoustic impedance between the structures forming the tissue interface. These echoes are manipulated for the reconstruction of the diagnostic image.
3. Another reason of the loss of beam energy is absorption by the way of heat. In order to visualise internal structure, some form of compensation has to be employed. The difference in the intensity and amplitude of returning ehocs are compensated by the methods known as time gain compensation and depth gain compensation. On application of these compensation, equal amplitudes of echoes are displayed for the tissues having same impedances irrespective of the depth traversed or time elapsed between pulse transmission and listening of echo.

ULTRASOUND MACHINE

1. A bed side ultransound machine is about the size of a small cupboard as shown in the figure. It consists of a computer with a display unit, circuitory and a hand held transducer. The transducer has the shape of a microphone. It is meant to send out the ultrasound beam and to receive the reflected sound waves.The reflected sound waves are fed to a computer which with the help of algorithms, process them to create the images.

DOPPLER ULTRASOUND

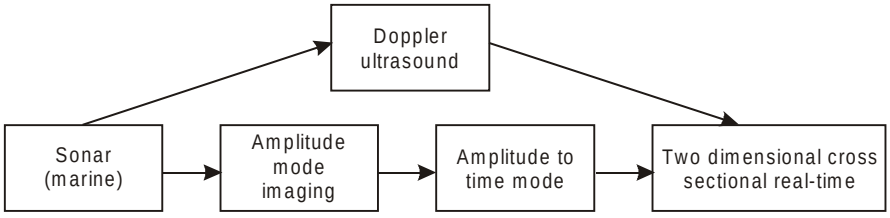
1. Doppler ultrasound is based on the principle that sound reflected by a moving target like blood has a different frequency from the incident sound wave. The difference in frequencies is known as Doppler shift which is proportional to the velocity of the target. Doppler shift is the useful information with the echoes which helps in the detection of flowing blood. It also enables to quantify the velocity of the blood. It is possible to give colour coding to the doppler information and superimpose it on a real time B-mode image facility which can help in identification of blood vessels or blood vessels having abnormal flow. This technique can also be used to diagnose coronary stenosis.

ADVANTAGES OF ULTRASOUND

1. Ultrasound is relatively inexpensive and non invasive. It does not expose patients to ionizing radiation and hence it is safe. It is preferrd for children and pregnant women. The machine is also comparatively inexpensive.

DISADVANTAGES OF ULTRASOUND

1. Ultrasound imaging system is highly operator dependent. It cannot be used for full body survey. It can not image air containing organs or bones. The resolution of the ultrasound image is inversely related to the depth of penetration. The quality of image decreases in the case of obese patients.



Evolution of Ultrasound System

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. The application of ultrasound is based on the --------- principle. (*a*) Sonar (*b*) ultra

2. Acoustic waves are easily --------- in water. (*a*) replaced (*b*) transmitted

3. Ultrasound has frequency --------- than 20,000 hertz. (*a*) greater (*b*) lesser

4. Ultrasound wave travels in the form of ---------- wave. (*a*) transverse (*b*) longitudinal

5. The average speed in tissues of ultrasound is taken as --------- (*a*) 1400 m/s (*b*) 1540 m/s

6. Incident wave at the interface is partly transmitted and partly ---------. (*a*) absorbed (*b*) reflected

7. The intensity of echoes depends upon the characteristic of meduim known as ---------. (*a*) specific density (*b*) specific impedance

8. Specific impedances depends upon density and --------- in the meduim. (*a*) speed (*b*) pressure

9. If meduim 1 and 2 have impedance of z_1 and z_2 respectively, then percent reflected beam depends upon ---------. (*a*) $z_1 + z_2$ (*b*) $z_1 - z_2$

10. Penetration of ultrasound wave in the tissue increases with --------- of frequency. (*a*) increase (*b*) decrease

11. A-mode is --------- mode. (*a*) amplification (*b*) amplitude

12. B-mode is --------- mode. (*a*) brightness (*b*) biotissue

13. M-mode is --------- mode. (*a*) mobile (*b*) motion

14. Piezoelectic transducer can convert electric energy into --------- energy and vice versa. (*a*) ultrasound (*b*) heat

15. When incident sound wave is reflected from moving target, its frequency is changed which is known as --------- shift. (*a*) hobbler (*b*) doppler

16. Ultrasound is a --------- imaging system. (*a*) invasive (*b*) non invasive

17. The quality of image --------- the case of obese patients. (*a*) increases (*b*) decreases

18. Gel is applied between skin and transducer to --------- impedance. (*a*) lower (*b*) increase

19. The change of impedance at bone interface is --------- and ultrasound wave is completely ---------. (*a*) small, transmitted (*b*) large, reflected

ANSWERS

1. (*a*)	**2.** (*b*)	**3.** (*a*)	**4.** (*b*)	**5.** (*b*)	**6.** (*b*)	**7.** (*b*)
8. (*a*)	**9.** (*b*)	**10.** (*a*)	**11.** (*b*)	**12.** (*a*)	**13.** (*b*)	**14.** (*a*)
15. (*b*)	**16.** (*b*)	**17.** (*b*)	**18.** (*a*)	**19.** (*b*)		

RADIOISOTOPES AND RADIOTHERAPY 28

There is no greatness where there is no simplicity, goodness and truth

INTRODUCTION

1. When a combination of neutrons and protons which does not exist in nature, is produced artificially, then the atom is unstable. Such atom is called a radioisotope. The nucleus of radioisotope tries to become stable by emitting alpha and /or beta particle, which may be accompanied by gamma rays (photons radiation). This process is called radioactive decay. The photons radiation emitted by radioisotopes can be easily imaged by gamma cameras. Suitable radioisotopes as labelled tracers can participate in the metabolism or other body functions and therefore are carried or concentrated in target organ. Image quality depends on the tracer concentration in the target area and on the emission dynamics of the radioisotope used. Hence radioisotopes are invaluable tool in the field of medical diagnosis and radiotherapy.

TYPES OF RADIOACTIVE DECAY

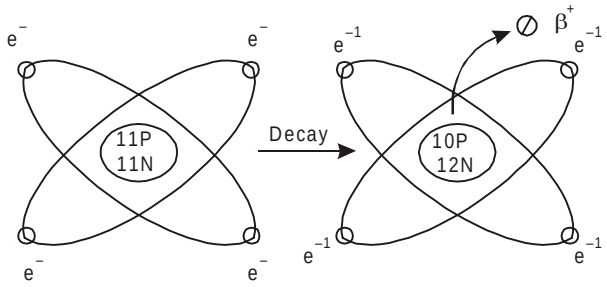
1. Radioisotops can be decayed by: (1) beta decay (2) gamma decay (3) alpha particle emission and (4) decay by electron capture. Beta decay takes place by emission of beta particles from radioisotope. Beta particles have a charge and mass equal to those of high speed electrons. Beta particle can be positrions (β^+) or negatrons (β^-) as shown in the figure. The equation of formation of beta particle can be :–

(*a*) Neutron $\rightarrow$ proton + β^- (negatron)

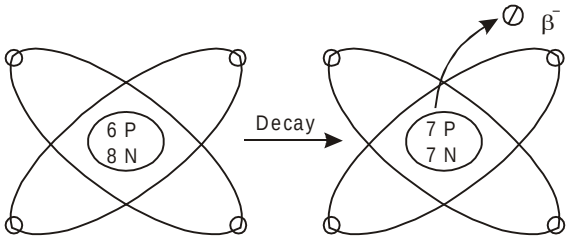
Example : $^{14}_{6}C \rightarrow {}^{14}_{7}N + \beta^-$

(*b*) Proton $\rightarrow$ neutron + β^+ (positron)

Example : $^{22}_{11}Na \rightarrow {}^{22}_{10}Na + \beta^+$



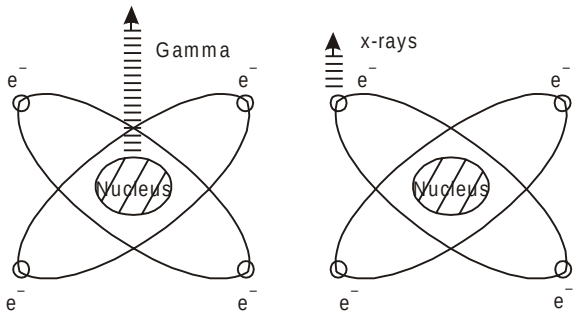
Positron Decay (β^+)



Imgatron Decay (β^-)

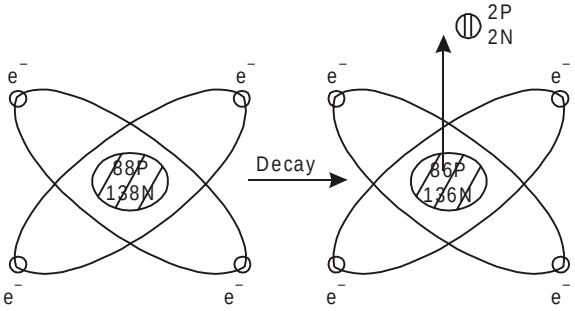
2. Gamma emission involves electromagnetic radiation similar to x-rays but it has a shorter wavelength as shown in figure. Gamma radiation takes place with transformation of nucleus of a radioisotope with emission of alpha or beta particles. The equation of gamma radiation (x) is:

$$131\ I_{61} \rightarrow 131 \times C_{64} + 3\beta^{-1} + \gamma$$



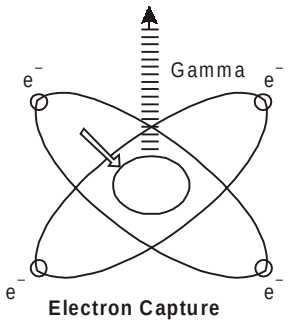
X-Rays and Gamma Radiation

3. Alpha particle consists of helium nucleus with two neutrons and two protons. Radioisotopes having higher atomic weight generally decay by emitting alpha particle which is known as alpha particle emission. Emission of an alpha particle results in decrease of atomic number by two units and atomic mass by four units. The equation of alpha emission is: $226Ra_{88} \rightarrow 222\ Rn_{86} + 4He_2^{++}$



Alpha Particle Radiation

4. The number of protons in a nucleus can also be reduced by the process of electron capture. This is called decay by electron capture. In this radioactive decay, one of the inner orbital electron is attracted into the nucleus where it combines with the proton in nucleus to form a neutron *i.e.*, $e^- + p^+ = n$. Combining results in the loss of one proton and gain of one neutron in the nucleus. Though there is no emission of any particle but x-rays are emitted due to electron moving from inner orbit to nucleus. Iron having atomic number 55 usually decays by this mode.



Electron Capture

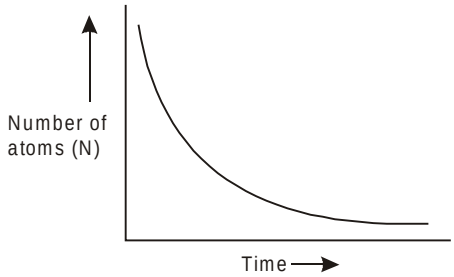
INTERACTION OF NUCLEAR RADIATION WITH MATTER

1. Radioistopes are used as tracers which emit α particle, β-particles or γ-rays. Since these radiations have different physical characteristics, the manner inwhich these interact with other matters also differ. Gamma rays are high energy photons having neither charge nor mass. The penetrating power of gamma rays is much greater than that of alpha or beta particles. However ionizing power of gamma rays is less. Gamma rays can produce: (1) photo-ionization (2) compton effect and (3) pair production. In photoionization, γ-rays interact with orbital electron which is ejected as negatron with energy equal to gamma rays. The negatron interact with other atoms to ionize them. Gamma rays having more energy can be scattered by electron after absorbing energy for ejection. This results into ejection of a negatron and a new photon of lowered energy which moves in altered direction after scattering. In pair production, gamma rays interact with an electron and a positron of nucleus resulting into emission of negatron and of positron. Alpha particle is a helium nucleus having two protons and two

neutrons. Alpha particles interact with matter in two ways. In one case, alpha particles impart energy to orbital electrons of the atom of the matter but without any ejection. Excited electrons emit excess energy as photons. In second case, alpha particles cause ionization of matter by ejection of orbital electrons and leaving behind positive charged atoms. Alpha emitting isotopes are not commonly used as tracer in imaging as these isotopes have higher atomic number. Beta particles (positrons and negatrons) are very small. They have high velocity resulting higher penetrating power. Beta particles dissipate their energy largely by ionisation or excitation of the atoms with which they interact.

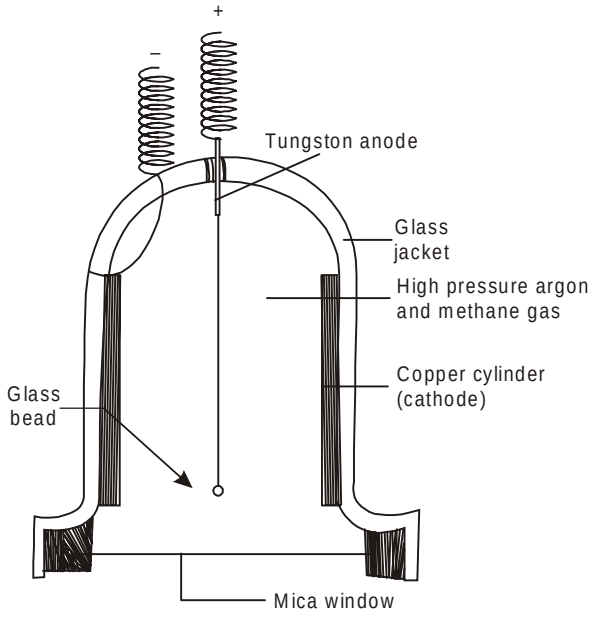
RADIOACTIVE DECAY

1. The number of atoms in a radioisotope that disintegrate during a given time interval decreases exponentially with time as shown in the figure. If λ = decay constant, N_o = number of atoms present originally, N = number of atoms present after time t then $N = N_o e^{-\lambda t}$. The time for the half the number of atoms to disintegrate is given by $t_{1/2} = 0.693/\lambda$



MEASUREMENT OF RADIOACTIVITY

1. The measurement of radioactivity is determination of the rate of emission of alpha, beta and gamma rays from the radioisotope. These radiations are also known as ionizing radiations as they are capable of causing ionization directly or indirectly. The methods commonly used for detection and measuring radioacitivity are based on the ionization of the gases like in Geiger-Mullier counter and proportional counter, or on the excitation of solids or solution as in scintiallation counter or on induction of specific chemical reaction in certain emulsion as in auto-radiography. In the Geiger-Mullier counter, alpha and beta particles enter in the counter tube through mica window having gases under pressure with anode and cathode as shown in figure with potential difference of 800 - 2500 volts. The alpha and beta particles ionize molecules of the gases which move towards appropriate electrode under the voltage gradient. The process produced a continuous flow of ions which produces discharge pulses of 10 volt amplitude with duration of 50 to 100 microseconds. These pulses are counted which is a measurement of radioactivity. In proportional counters, the gradient voltage is kept lower than Geiger-Mullier counter and it requires a preamplifier to avoid reducing the pulse size. Scintillator counter uses a chemical to convert radiation energy into light. When an ionizing particle is absorbed in the scintillator, some of the energy acquired by the scintillator is emitted as a pulse of visible light or near ultraviolet radiation. The light falls on a photomultiplier tube resulting in pulse of electrons which is counted to measure radioactivity.



Geiger-Mullier Counter

RADIOTHERAPY

1. Surgery, radiotherapy and /or chemotherapy are used for the treatment of cancer. It must be ensured in radiotherapy that the radiation dose delivered to a patient should be optimally focused to produce a maximum effect in the volume of cancerous tissue and a minimal effect in the neighbouring healthy tissues. Radiotherapy is carefully planned, simulated, executed and verified. Treatment planning is carried by modelling to match the absorption characteristics of the radiation within the anatomy of the patient. Radiation data is obtained from dosimetry and patient anatomy is acquired from CT scanners. Algorithms are used with these data and patient's anatomy in a computer for modelling. To obtain an optimum treatment plan, the cancerous cells are irradiated from several directions and for certain duration for two weeks or so. The outcome obtained from this radiotherapy is a good indicator of further requirements of radiotherapy for the patient.

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. Radioisotope has -------- nucleus. (*a*) unstable (*b*) stable

2. Photon radiation can be easily imaged by --------- camera. (*a*) Alpha (*b*) Gamma

3. Alpha particle consists of --------- nucleus with two neutrons and two protons. (*a*) helium (*b*) hydrogen

4. Gamma radiation is --------- radiation similar to x-rays. (*a*) light (*b*) electomagnetic

5. Beta particle has charge and mass equal to that of high speed ----------. (*a*) proton (*b*) electron

6. The --------- is time during which half number of atoms disintegrates. (*a*) half time (*b*) half life

7. Radioisotopes are used as ---------. (*a*) tracer (*b*) medicine

8. Radiotherapy is used for the treatment of ---------. (*a*) cancers (*b*) malfunctioning

9. The radiation dose delivered to a patient should be --------- focused on cancerous tissues. (*a*) optimally (*b*) maximumally

10. --------- uses chemical to convert radiation energy into light when an ionizing particle is absorbed. (*a*) Geiger-mullier (*b*) scintillator

ANSWERS

1. (*a*) **2.** (*b*) **3.** (*a*) **4.** (*b*) **5.** (*b*) **6.** (*b*) **7.** (*a*)

8. (*a*) **9.** (*a*) **10.** (*b*)

NUCLEAR MEDICINE 29

All violence consists of some people forcing others under the threat of violence or death to do what they do not want to do.

INTRODUCTION

1. Nuclear medicine comprises of diagnostic examinations that helps in obtaining images of body anatomy and function. The images are obtained by detecting energy emitted from radioactive substance injected in the patient by either intravenously or by mouth. The radiation emitted from the patient is similar to that emerging during radiography or CT-scanning. Nuclear medicine images can assist in diagnosing diseases, tumors, infection and other disorders in organ functioning. CT scan, ultrasound and magnetic resonance provides anatomic or structural information, where as the primary purpose of nuclear imaging is to provide functional data.

EQUIPMENT FOR NUCLEAR MEDICINE

1. Equipment consists of a spacialised nuclear imaging camera and a computer. Gamma camera is used which is enclosed in a metallic housing designed to facilitate imaging of specific parts of the body. The camera is mounted on a metal arm that hangs over the examination table.

OPERATING PRINCIPLE OF NUCLEAR MEDICINE

1. Gamma camera images the gamma (photon) radiation emitted by radioactive compounds. A small dose of radioactive compound is given to patient usually intravenously but sometimes orally so that radioactive material can be localised in specified body organ system. The radioactive compound known as tracer, eventually accumulates in the organ and emits gamma rays. The gamma camera detects the gamma rays, emitted from the body of the patient and works with the computer to produce images which help in measurement and functioning of organs and tissues. Image quality depends on the tracer concentration in the target area and on the emission dynamics of the isotope used. The imaging detector of the camera is made of a sodium iodide crystal where gamma radiation gets absorbed and causes scintillations (tiny flash of light). These are amplified with photo multiplier and the number of scintillations is counted electronically. Spatial localization of the emitting source is achieved with a collimator. The sum of thousands of scintillations creates an image that represents the distribution of radioactivity within an organ or system.

2. The type of tracer to be administered depends on which type of scan is to be performed. Imaging can be done either immediately or after several days. The tracer that is used is determined by what part of the body is under study. It is because some tracers collect in specific organs better than others. Depending on the type of scan, it may take several minutes to several days for the tracer to travel through the body and accumulate in the organ under study.

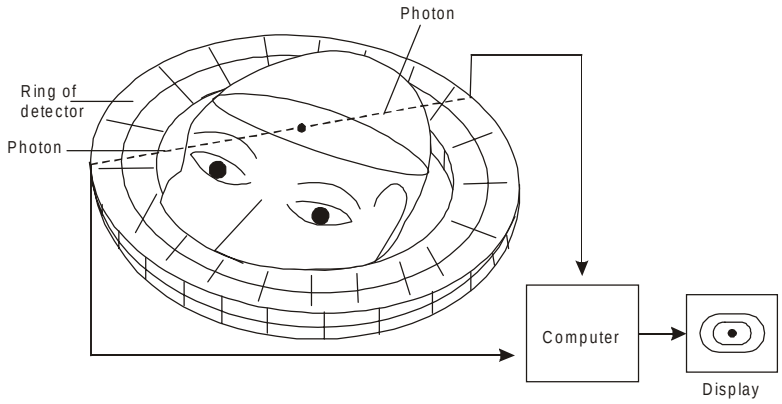
SINGLE PHOTON EMISSION TOMOGRAPHY

1. The computed tomography principles are also being used in nuclear medicine which is then called single photon emission tomography (SPECT). Single photon emission computed tomography is based on a rotating gamma camera. Whereas in CT scan, the image is formed processing x-rays coming out from the body after absorption in the tissues, in SPECT the image is reconstructed using the counted number of emitted photons from the concentration of tracer in the tissues. Like CT scanning, SPECT also uses rotating gamma camera.

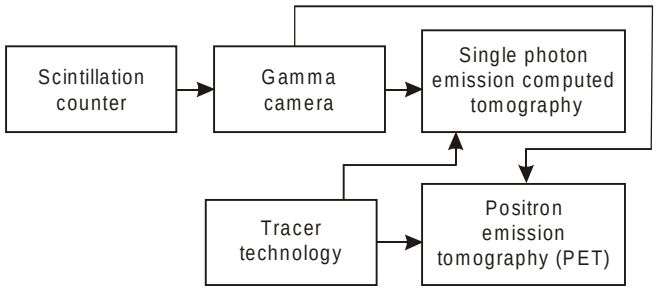
POSITRON-EMISSION TOMOGRAPHY

1. Positron-emission tomography is a from of nuclear medicine that uses cyclotron during the annihilation of the positron-electron pair. Tracers with short life can be produced by cyclotron and computer technology has widely improved. Both have helped in the development of PET.

PET measures the difference in travel times of the two quantas. This can be used to give the location of tracer where annihilations taking place. PET is an analytical technique that provides a way of making in vivo measurements of anatomical distribution and rates of specific biochemical reactions specially in the brain. The use of PET to obtain images requires the integration of three components viz (1) radioisotope /tracer (2) PET device and (3) tracer kinetic mathematical models. The positron emitters mostly used are carbon-11, oxygen-15 and nitrogen-13 which have half life in range of 2 min to 20 min. These tracers are tagged to various metabolically active compounds such as glucose or naturally occurring compounds such as carbon monoxide to image the brain, heart and tumors. The tracers are administered to the patients usually by injection but sometimes by inhalation. Since cyclotron is required to produce positron emitters or tracers, PET has a very high cost.



Positron-emission Tomography



Nuclear Medicine Imaging

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. Nuclear medicine image acquired from the radiation --------- from the body. (*a*) emitted (*b*) absorbed

2. In nuclear medicine radioisotope is --------- in the organ. (*a*) accumulated (*b*) absorbed

3. The primary purpose of nuclear medicine is to provide --------- data. (*a*) structural (*b*) functional

4. --------- camera is used in nuclear medicine. (*a*) positron (*b*) gamma

5. SPET is based on a --------- gamma camera. (*a*) rotating (*b*) linearly moving

6. PET requires --------- and hence it is costly. (*a*) camera (*b*) cyclotron

7. Electron and positron pair produces a pair of --------- travelling at 180° apart. (*a*) photon (*b*) neutron

8. Radioisotopes for PET are artificially produced with ----------. (*a*) generator (*b*) cyclotron

ANSWERS

1. (*a*) **2.** (*a*) **3.** (*b*) **4.** (*b*) **5.** (*a*) **6.** (*b*) **7.** (*a*) **8.** (*b*)

HEALTH CARE INFORMATION AND COMMUNICATION

30

When our memories outweigh our dreams, we have grown old.

INTRODUCTION

1. Health data as collected from operating health care systems, institutions or any other mean are inadequate for planning. Data need to be transformed into information by adjusting and summarising thom on basis of some parameters which can be age, sex or area etc. This information can be transformed into intelligence by processing with experience and perception on social and political values. Health data which is not modified into health intelligence has no value. A health information system is a system to facilitate the collection, processing, analysis and transmission of health information which can help in organising and operating health services and also which can be made useful for research and training of health service personnels.

USES OF HEALTH INFORMATION

1. The uses of health information are :

(*a*) to ascertain the health status of the population which can help in quantitfying their health problems. On basis of these, medical and healthcare needs can be worked out.

(*b*) to ascertain the health status which can be local, national or international

(*c*) to ascertain the effectiveness of the health services

(*e*) to ascertain the degree of satisfaction of the beneficiaries from the health services

(*f*) to initiate research incase of outbreak of new disease or health problem.

SOURCES OF HEALTH INFORMATION

1. The sources of health information are :

(*a*) **Census :** It is carried out in most countries at regular interval of 10 years. Population census provides basic data such as population by age and sex etc.

(*b*) **Registration of death and birth :** It is mandatory in our country for people to register the event of birth and death. Whereas census is an intermittent counting of population, the registration of death and birth keeps a continuous check on total population.

(*c*) **Notification of Diseases :** The incidence and spread of certain specified

diseases are notifiable. List of notifiable diseases vary from country to country. The primary purpose of notification is to effect prevention and to control the outbreak of contagious diseases. However notification provides variable information about fluctuation in disease frequency and warning about likely spread of a disease from other countries.

(*d*) **Hospital Records :** Data such as bed occupany rates, duration of stay, cost-effectiveness of treatment policies is useful in monitoring the use of hospital facilities. A lot of useful information about health care activities and utilization is available from hospital records. The computerization of medical records have enabled health care to be more effectively carried out, planned and evaluated.

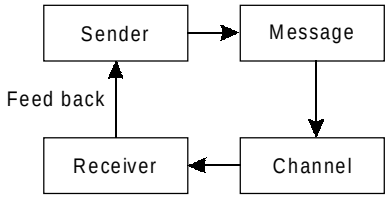
(*e*) **Sample Registration System :** It is initiated to upgrade the death and birth rates. It is a major source of health information.

(*f*) **Morbidity Registers :** They are valuable source of information about duration of illness, fatality and survival cases. They provide information about chronic disease in different parts and natural course of disease.

(*g*) **Health Manpower Statistics:** Information on health manpower is the number of doctors, dentists, veterinarians, pharmacists, medical technicians and nurses working in health care system. Their records are maintained by medical councils which is source of health information.

COMMUNICATION PROCESS

1. Communication is the basis of human interaction. The components of communication are : (1) sender (2) receiver (3) message (4) channel and (5) feed back. The sender is the originator of the message. All communications must have a single person or group of persons as receiver. A message is the information which the sender wants to transmit to the receiver. It may be in the form of words, pictures or signs. The channel is the media of communication between the sender and receiver. It can be face-to-face communication, mass communication (TV, radio and newspapers) and folk media (nautanki, Harikatha and Burrakatha). Feedback is the flow of information from the receiver to the sender. Infact it is reaction of the receiver to the message.



Components of Communication

TYPES OF COMMUNICATION

1. The communication can be (1) one-way (2) two-way (3) verbal (4) non verbal (5) formal and informal (6) visual and (6) telecommunication and internet. One way communication known as didactive method inwhich the flow of information takes place in "one-way" from the sender to the receiver. Two-way communication known as ocrative method inwhich both the sender and the receiver participate. Non verbal communication includes communication through body movements, postures, gestures and facial expression. Formal communication follows line of authority and informal communication uses informal network like gossip circles. The usual forms of communication includes charts, graphs, maps, tables and posters etc. Radio, TV and

internet are mass communication media while telephone and telegraph are point to point telecommunication.

BARRIERS OF COMMUNICATION

1. The barriers of health education between the educator and general public can be: (1) physiological (2) psychological (3) environmental and (4) cultural. Physiological barriers can be difficulties in hearing or understanding expression. Psychological barriers can be created by emotional disturbances and level of intelligence. Environmental barriers are produced by noise, invisibility and congestion. Cultural barriers are due to illiteracy, lower level of knowledge and understanding, beliefs and religion etc. The barriers have to be identified and removed to maintain a good communication.

HEALTH COMMUNICATION

1. The health communication is nothing but health education. It is outward and downward communication of knowledge. Health communication is the foundation of a preventive health care system. The health communication has to perform the functions of :– (1) information (2) education (3) motivation (4) persuasion (5) counselling (6) raising morals (7) health development and (8) organisation. The primary function of health communication is to impart information to people about health problems and ways to maintain and improve their health. Education is to educate the public about prevention oriented approach to health and problems. Most of major health problems and premature deaths can be prevented through proper education. The purpose of health communication is to motivate the public to translate health information into their personal behaviour and into their life style for the betterment of their health. Persuasion is the art of winning friends and influencing people. Health communication can influence the public to improve their life style for better health. Counselling is a process that can help people to understand better and deal effectively with their problems. It can improve and reinforce motivation to change behaviour. Counselling is an important part of treatment, disease prevention and health promotion. It helps people to avoid illness and to improve their lives through their own efforts. Health communication can help to raise morale of the health team to work together persistently. Judicial use of communication media can contribute to health development. Communication is the life and blood of an orgaisation. Communication can move horizontally and vetically. Communication can maintain intra and inter sectorial coordination.

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. Data which is transformed suitably is ---------. (*a*) intelligence (*b*) information

2. Information can be transformed into --------- by processing with experience and perception. (*a*) intelligence (*b*) plan

3. --------- are carried out in most countries in regular interval of 10 years. (*a*) sample registration system (*b*) census

4. It is --------- in our country for people to register the event of birth and death. (*a*) mandatory (*b*) social obligation

5. The incidence and spread of certain diseases are ---------. (*a*) notifiable (*b*) communicated

6. Sender, receiver, message, channel and feedback are --------- of the communication. (*a*) components (*b*) elements

7. One-way of communication is known as --------- method. (*a*) dedicative (*b*) socrative

8. Two-way communication is known as --------- method. (*a*) didactive (*b*) socrative

9. Health communication is nothing but health ---------. (*a*) education (*b*) broadcast

10. TV, radio and newspaper are --------- communication. (*a*) face to face (*b*) mass.

ANSWERS

1. (*b*) **2.** (*a*) **3.** (*b*) **4.** (*a*) **5.** (*a*) **6.** (*a*) **7.** (*a*)

8. (*b*) **9.** (*a*) **10.** (*b*)

BIOTELEMETRY 31

If the same man deceives you twice, then may be you deserve it.

INTRODUCTION

1. Some times, it become essential to monitor physiological events from a distant place. Some of such situations are:

(*a*) Monitoring of astronauts during flight.

(*b*) Monitoring of patients in ambulance while transit to hospital.

(*c*) Monitoring of patients while obtaining their exercise electrocardiogram.

(*d*) Monitoring of patients who are permitted to stay away from the hospital.

(*e*) Monitoring of animals in their natural habitat.

(*f*) Transmission of ECG or other medical information through telephone links.

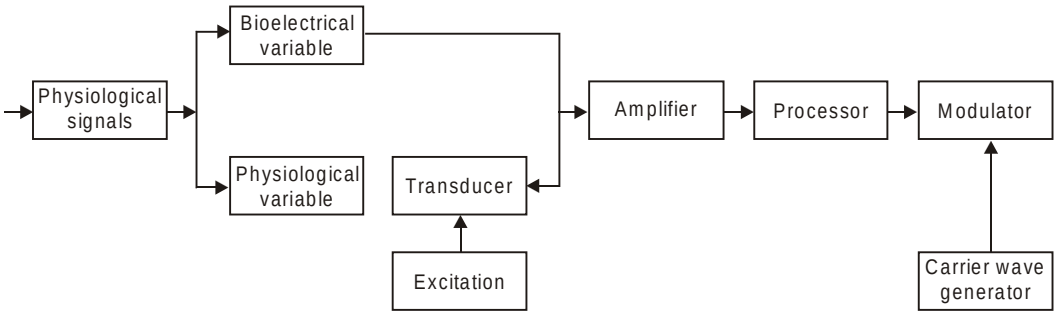
(*g*) Isolating the patients from electricity operated measuring equipment such as ECG equipment inorder to prevent any accidental shock to them.

2. Biotelemetry is a method of measuring biological paramenters from a distance. It is infact modification of existing methods of measuring physiological variables to a method of transmission of resulting data. The transmission of data from the point of generation to the point of reception can be done in various ways. The stethoscope is the simplest device which uses this principle of biotelemetry. The device amplifies acoustically the heartbeats and transmits their sound to the ears of a doctor through a hollow tube system. Certain applications of biotelemetry use telephone lines for transmission. However biotelemetry mainly uses radio transmission by suitably modifying the biological data. Earlier times, the telemetry could be applied to measure (1) temperature by rectal or oral thermistor (2) electrocardiograms by surface electrodes (3) indirect blood pressure by contact microphone and cuff (4) respiration by impedance pneumograph. However it is possible now to apply biolemetry to almost all measurements such as (1) bioelectrical variables eg. ECG, EMG and EEG and (2) physiological variables that require transducers eg blood pressure, blood flow and temperatures. The signal is obtained directly in electrical form in bioelectrical measurements require external excitation for the conversion of physiological variables into variations of resistance, induction or capacitance. The variations can be calibrated

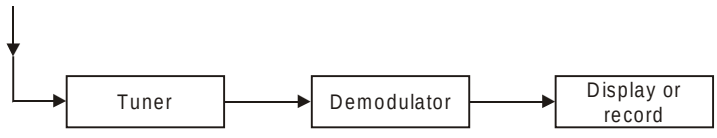
to display pressure, flow and temperature. In biotelemetry, the measurements as analog signals (voltage or current) in suitable form are transmitted which are received and decoded as actual measurements at the receiving end. ECG telemetry is the transmission of ECG, form site of an emergency to a hospital where a doctor can interpret, the ECG and instruct suitable treatment for the patient. Patients with heart problem can wear ECG telemetry unit on the job which relays ECG data to the hospital for checking. ECG telemetry unit is also used for monitoring when an athlete runs a race to improve his performance. Telemetry is also used for transmission of EEG. It is generally used for mentally disturbed children. The child wears specially designed the met known as football helmet or superman's element which has built in electrodes so that his EEG a can be motored for any traumatic difficulty during play. Biotelemetry is also used for electromyogram (EMG) for studies of muscle damage or partial paralysis problem. Biotelemetry is commonly used in blood pressure, blood flow and heart rate research on unanesthetized animals.

BIOTELEMETRY SYSTEM

1. A biotelemetry system consists of transmitter and receiver. The functional blocks of a transmitter is as shown in the figure. Physiological signals are obtained by suitable transducer which are amplified and subjected to modulate the carrier waves for transmission. The receiver receives the transmission and demodulates to separates to separate the signal from the carrier waves to display or record the signal as shown in the block diagram.



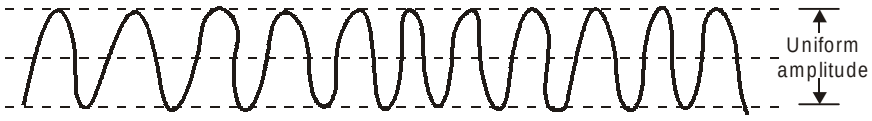
Biotelemetry Transmitter



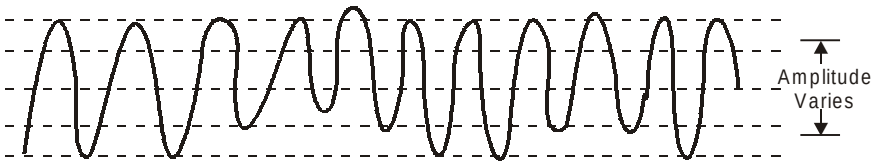
Biotelemetry Receiver

METHODS OF MODULATION

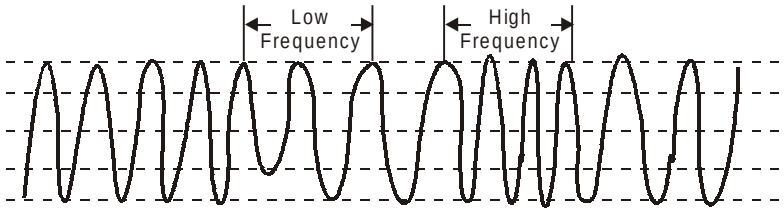
1. The modulation of carrier waves can be carried out either by amplitude modulation or by frequency modulation. In amplitude modulation, the amplitude of the carrier waves is caused to vary with the information signals being transmitted. In frequency modulation, the frequency of carrier wave is caused to very with the information signals being transmitted. Amplitude modulated transmission is susceptible to modulated transmission is less susceptible to electrical interference. The amplitudes and frequency modulation are as shown in the figure.



Carrier Waves



Amplitude Modulation



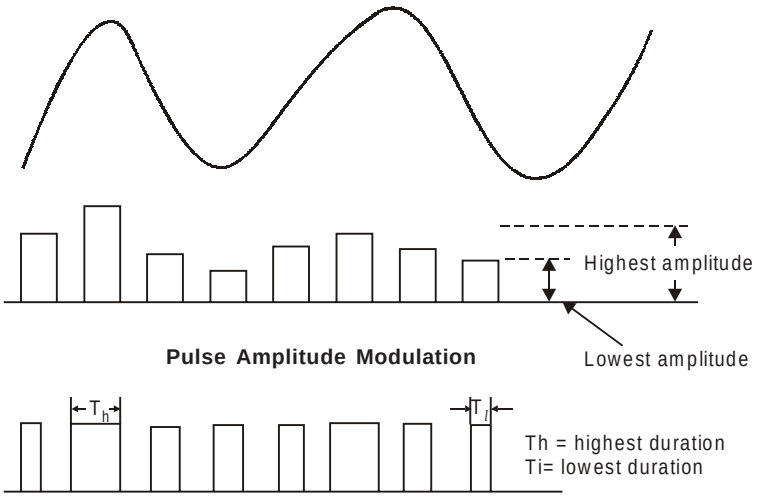
Frequency Modulation

2. In case transmission carrier is in the form of pulses instead of sine waves, the technique of modulation is known as pulse modulation. If amplitude of the pulses is used to convey the transmitted information, the method is called pulse amplitude modulation (PAM). If the width of pulses is varied to convey transmitted information, the method is known as pulse width modulation (PWM).

MULTIPLEXING

1. When many physiological signals are to be transmitted simultaneously, the method of frequency multiplexing is used. In this method, low frequency carrier waves (subcarrier) in audio freqency range are used. The subcarriers are modulated by the physiological signals which further modulate

the RG carrier of the transmitter. Each physiological signal is placed on a subcarrier of a different frequency and all subcarriers Frequency multiplexing is more efficient and less expensive as compared to the method of employing separate transmitter for each physiological signal. At receiving end, transmission is received and demodulated to recover each of the separate subcarriers which are individually demodulated to retrieve original physiological signals.



Pulse Amplitude Modulation

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. _____ is a method of measuring biological parametes from a distance.
   (*a*) Biomeasurement (*b*) Biotelemetry
2. _____ is a device which acoutically amplify the heart beats. (*a*) Stethoscope (*b*) Acoutiscope.
3. Patients with heart problem can wear _____ telemetry unit.
4. _____ helmet is used for mentally disturbed children to monitor their EEG.
   (*a*) Cricket (*b*) Football
5. _____ biotelemetry is used for studies of muscle damage or partial paralysis problem. (*a*) ECT (*b*) EMG
6. In _____ modulation, the amplitude of carrier is varied with information signal.
   (*a*) frequency (*b*) amplitude
7. In _____ modulation, the frequency of carrier is varied with information signal.
   (*a*) frequency (*b*) amplitude
8. If amplitude of the pulses is used to convey the transmitted information, the method is known as _____ . (*a*) PAM (*b*) PWM
9. If width of the pulses is used to convey the transmitted information, the method is known as _____ . (*a*) PAM (*b*) PWM
10. When many physiological signal are transmitted simultaneously, the method of _____ is used. (*a*) signal multiplexing (*b*) frequency multiplexing.

ANSWERS

1. (*b*) **2.** (*a*) **3.** (*b*) **4.** (*b*) **5.** (*b*) **6.** (*b*) **7.** (*a*)
8. (*a*) **9.** (*b*) **10.** (*b*)

APPLICATION OF COMPUTER IN MEDICINE

32

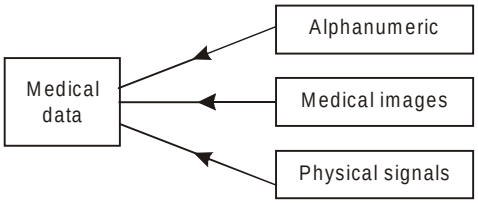
One of the first condition of happiness is that the link between Man and Nature shall not be broken.

INTRODUCTION

1. There are numerous applications of the digital computer in medicine and its related fields. The ability of the computers to store very large quantities of data and to have it readily available for further processing makes them extremely useful in medicine. Computers can also be used in conjunction with biomedical instruments so as to make possible digital control of all functions of the instruments. Since computer has large data storage capacity, it is possible to optimize the measurement conditions of instruments. The incorporation of computer into instruments enables the instruments to have a certain amount of intelligence or decision making capability. The most powerful asset of the computer is its enormous speed of operation. This is possible as the computer can store all the necessary instructions and data in its memory. Data is processed by central processing unit (CPU) of the computer.

CHARACTERISTICS OF MEDICAL DATA

1. In hospital, there are three types of data which are required to be acquired, manipulated and archived. Data can be (1) alphanumeric (2) medical images and (3) physical signals. Alphanumeric data consists of the patient's name, his address, his identification number, the results of his laboratory tests and his medical history. Alphanumeric data are generally managed and organised into a database. The database system is designed to store large data which can be retrieved conveniently and efficiently to provide the information required. Medical images are data obtained from CT scan, magnetic resonance imaging and ultrasound. Image data are generally archived on film. Latest trend is to use picture archiving and communication system (PACS) generally.



Types of Medical Data

In this system, the data of images is stored in digiticized form on optical disks. The data of images is distributed on demand over a high speed local area network (LAN). Images can be reconstructed graphically with very high resolution at different wards of the hospital with the help of the data. Physiological signals are the electocardiogram (ECG), the electroencephologram (EEG), and blood pressure tracings. These are physiological signals which are monitored during surgery and such data is to be processed in real time. If the instrument gives abnormal readings of the physiological signals, the computer system must know immediately and display these readings with warning while analysing the continuous data of physiological signals.

APPLICATION OF COMPUTER IN MEDICINE

1. The applications of computer are :

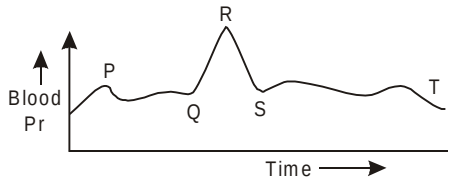
(*a*) *Data Acquisition :* The data output from the instruments is in analog form. The sampling and digitizing as well as identification and formatting of data from the instruments are carried out by computer. The computer can be programmed to reject unacceptable readings.

(*b*) *Storage and Retrieval :* The computer has ability to store large quantity of data which can be retrieved very quickly. During day to day working, large amount of data are accumulated in a hospital from many sources like doctor's reports, laboratory tests and admission and discharge entries. There is also non patient data like accounting records, inventory of medicine, record of hospital staff and inventory of all types. It is impossible to store and retrieve quickly such information without the help of a computer.

(*c*) *Data reduction and transformation:* Physiological signals are useless in raw form. The data has to be subjected to reduction and transformation by the usage of algorithms in computer to obtain meaningful information. The computer can carry out by data reduction and data transformation which is used in CT scanning for the reconstruction of image.

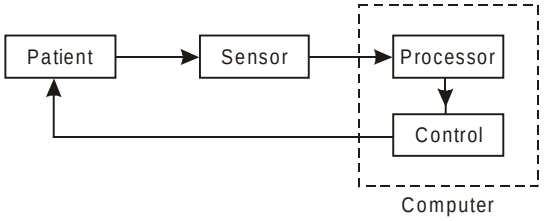
(*d*) *Mathematical operations:* In medicine many important variables are calculated by other variables which are accessible to instruments. For example, many respiratory parameters can be calculated from simple breathing tests. However we can program the computer to work with the measuring instrument to give directly the desired variables instead of the variables that are accessible by carrying out simultaneous mathematical operations.

(*e*) *Pattern recognition:* In order to convert physiological data (in analog form) into meaningful form of useful parameters (in digital form) important features of a physiological waveform or image are to be firstly identified. Computer can make pattern recognition by identifying unique features. For example computer can be programmed to search data of ECG signals to identify each of the important peaks. The downward slope which is most negative between *R* and *S* waves of the QRS complex can be easily identified as shown in the figure.



Pattern Recognition

(*f*) *Initiate control :* Computer can initiate control over other devices as per the programming. The input data can be compared and controlled by providing feedback to source of the data by the computer as shown in figure.



(*g*) *Accuracy :* Computer can be used to control the accuracy of a device within the upper and lower limits as programmed.

(*h*) *Averaging :* Computer can easily average continuous data over a certain time duration. This technique is used to remove the noise signals from the physiological signals as it is done in ECG.

(*j*) *Calibration :* Many devices have to be zeroed and recaliberated after certain time intervals. Computer is used with a such devices to perform the calibration autormatically.

(*k*) *Table lookup :* Table look up and interpolation can be performed with computer. This procedure can be used for the determination of parameters which are dependent on more than one variable.

(*l*) *Formatting, printing and display :* Computer process data in digital form which can be formatted. The raw data can be converted into physical data which can be printed. Hence no further transcribing or processing is required. Computer can present the data in the most meaningful form. Data can be presented in the form of graphs, charts and tables.

APPLICATION OF COMPUTER IN HOSPITAL

1. We have seen the applications of computer in medicine on broad basis. Now we see what are the specific applications of the computer in a hospital which are :

(*a*) *Centralised data of outpatient :* The data of an outpatient from abinitio to his admission and discharge including his laboratory tests are fed through the computers to the central data processing system of the hospital which help in storage, quick retrieval of any information about the patient at any time and white billing him. It helps in the coordination of various departments of the hospital in carrying out the treatment of the patient which also reduces the waiting time for the patient when his treatment involves various departments.

(*b*) *Monitoring of Patients' treatment :* Every hospital has intensive care unit and critical care unit where continuous monitoring of ECG waveform, blood

pressure, heart beat temperature and respiratory rate of every critical sick patient has to be maintained through the computer and the computer gives alarm whenever there is any abnormality in the physiological signals of any patient.

(*c*) *Assistance in diagnosis :* The computer gives clear information on the basis of the physiological signals of the patient which can be easily interpreted by the physicians for the diagnosis of the sickness.

(*d*) *Imaging :* Computers are used in digital radiography, computed tomography, magnetic resonance, nuclear medicine and position emission tomography to reconstruct images (by non invasive methods) of the internal organs of the patients.

(*e*) *Automation of clinical laboratory* : The blood, urine and other specimen can be tested quickly with the help of computer. It is possible with the help of computer to carry out the laboratory test and also to feed the test results directly into database system of the hospital which can be accessed to by any doctor or department.

(*f*) *Inter department communication :* Local area network or client/server environment helps in any hospital to communicate between one department to another department through computer for better coordination.

(*g*) *Biotelemetry:* The are many instances in which it is necessary to monitor physiological events from a distance. Biotelemetry is the measurement of biological parameters over a distance. It is used for special out patients who are discharged from the hospital but they require monitoring from the hospital. The monitoring function is performed by either through radio telemetry or through landline telemetry. The radio telemetry uses a small radio transmitter attached to the patient that can pick up the ECG and other physiological signals which are transmitted to a receiver at a central monitoring system of the hospital. The landline telemetry uses a modem and computer to transmit the physiological signals through telephone lines to the hospital.

Fill in the gaps

1. --------- can be used for digital control of all functions of the instrument. (*a*) computer (*b*) circuit

2. Computer has --------- storage capacity. (*a*) small (*b*) large

3. Incorporation of computer into instruments provides certain amount of ---------. (*a*) reliability (*b*) intelligence

4. Data is processed by --------- of the computer. (*a*) memory (*b*) CPU

5. In hospital, there are --------- types of data to be handled. (*a*) two (*b*) three

6. In PACS, the data of images is stored on ---------. (*a*) film (*b*) optical disks

7. Physiological signals are --------- in raw form. (*a*) useful (*b*) useless

8. The computer can make pattern ---------. (*a*) recognition (*b*) reconstruction

9. --------- uses a small radio transmitter attached to the patient. (*a*) radio telemetry (*b*) land line telemetry

10. It is possible to monitor physiological events from a distance by ---------. (*a*) biocommunication (*b*) biotelemetry

ANSWERS

1. (*a*) **2.** (*b*) **3.** (*b*) **4.** (*b*) **5.** (*b*) **6.** (*b*) **7.** (*b*)

8. (*a*) **9.** (*a*) **10.** (*b*)

TELEMEDICINE 33

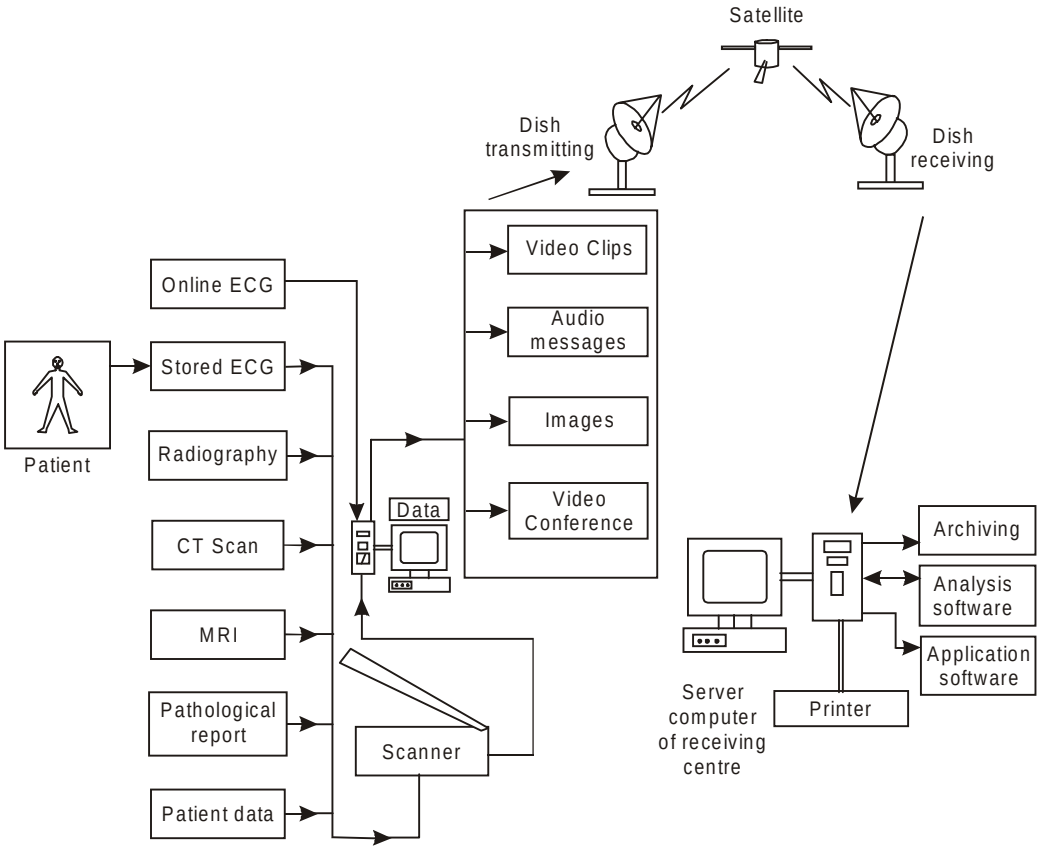
We enjoy the moment better by taking it one step at a time

INTRODUCTION

1. Telemedicine as name suggests, is the application of computer technology and telecommunication to provide health care from one place to another. Telemedicine uses information technology to provide timely treatment to those in need by telecommunication of the necessary expertize, diagnosis and information among distant located parties. Physicians, laboratories and patients can be distant located parties. Telecommunication enables all parties to interact as they are at one place, resulting in improved patient care and management, cost effectiveness and better utilisation of expertise. Telemedicine includes hardware, software, medical equipment and communication link.

TELEMEDICINE APPLICATION

1. Telemedicine can be applied to all medical specialities but its main applications are commonly found in pathology, cardiology, radiology and medical education. Telepathology is used to obtain an expert opinion on biopsy reports and microscopic photos of pathology slides. Teleradiology is used for telecommunication of radiology images like radiographs, CT scan, MRI and nuclear medicine from one place to another for expert interpretation and consultation. The problem faced in teleradilogy is the vast data associated with each image and lack of standardization of data for transmission. Telecardiology relates to telecommunication of ECG, echo cardiography and colour dopler of patient to experts for advice. Teleconsultation is used by the hospital or a patient to consult specialist docters. Tele education can be used for providing medical education to junior doctors working at smaller towns who are professionally isolated from teaching hospitals. The block diagram of a typical telemedicine system is as shown in figure.



Telemedicine System

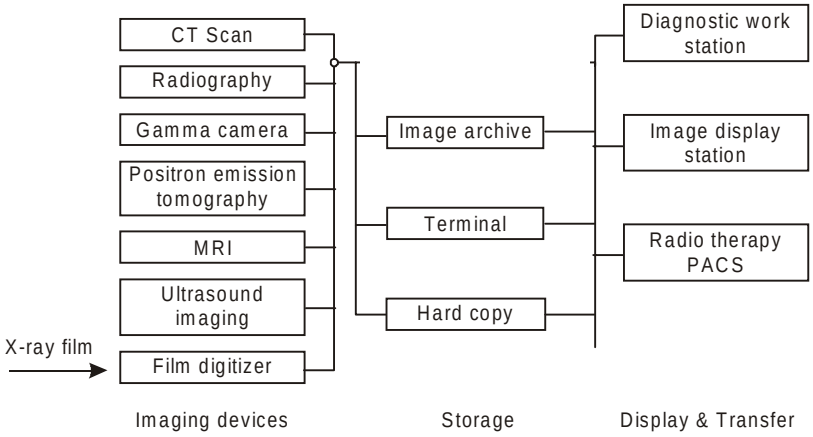
2. Telemedicine concepts can be :

(*a*) *Store and Forward :* In this, information is compiled and stored. The stored information can be in the form of video images and clips or laboratory reports. The information in the digital form is stored and forwarded to the experts for interpretation and advice. The experts can access the same whenever possible and they can transmit back their advice.

(*b*) *Real time :* In this, real time exchange of information takes place between two medical professionals or two centres. The real time exchange of information may be in the form of video conference or it may take place simultaneously with the examination and imaging of the patient.

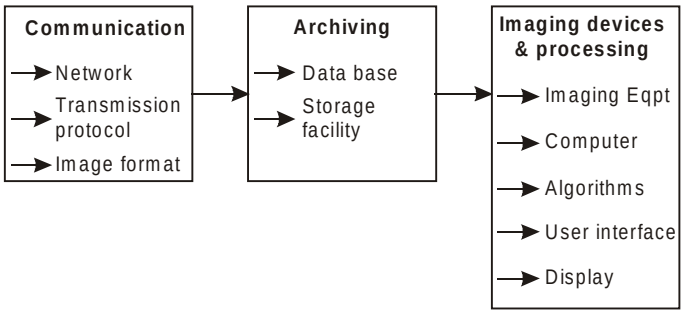
PICTURE ARCHIVING AND COMMUNICATION SYSTEM

1. Integration of medical imaging devices and image processing facilities has firstly evolved picture archiving and communication system (PACS). Advancement in information technology has helped in transmission of medical images to one place to another and PACS has been suitably modified as shown in the figure. The imaging devices transmit the acquired



Picture Archiving and Communication System

images through the network using a standardized transmission protocol. The images have to be compressed to reduce the data as well as their time for transmission. Inorder to avoid accidental erasing, digital images are stored on a meduim capable of storing a large number of images in a read only memory as data base system to facilitate fast retrieval. Images can be viewed at any "image display station" or "diagnostic work station". If required, algorithms can be applied to the 'image data' to enhance certain features or to interprete the clinical information of the images. It is also possible to attach reports and comments to the images. A large number of methods are available for the transmission of images. Inside the hospital, local area network (LAN) is a good solution. However this has to done by compression of data through algorithms. This transfer requires compression and decompression algorithms as well as error detection and correction devices in the system. The transmission of images to remote places has another problem. There is complete lack of internationally accepted standard to code the images for transmission and also complete lack of a communication protocol for such coded images. The most appropriate communication protocol is likely to be "open systems interconnection" (OSI) being developed by ISO. The American collage of Radiology (ACR) with the national electrical manufacturers Association (NOMA) have also prepared a standard for image format and for communication protocol for transmission of medical images.



Needs of Picture Archiving and Communication System

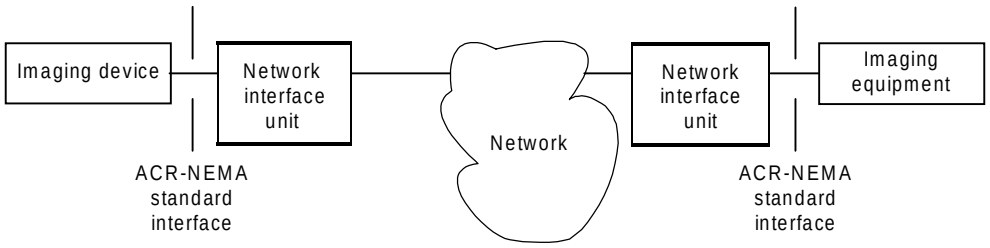
The communication of medical images requires (1) an agreement on the format of representation of the digital image data (2) a communication protocol and (3) either LAN within the hospital or any other mean of communication to distant locations. The ACR-NEMA image format contains following information :

(*a*) identification data of the patient

(*b*) data of the examination and imaging device used

(*c*) image representation data

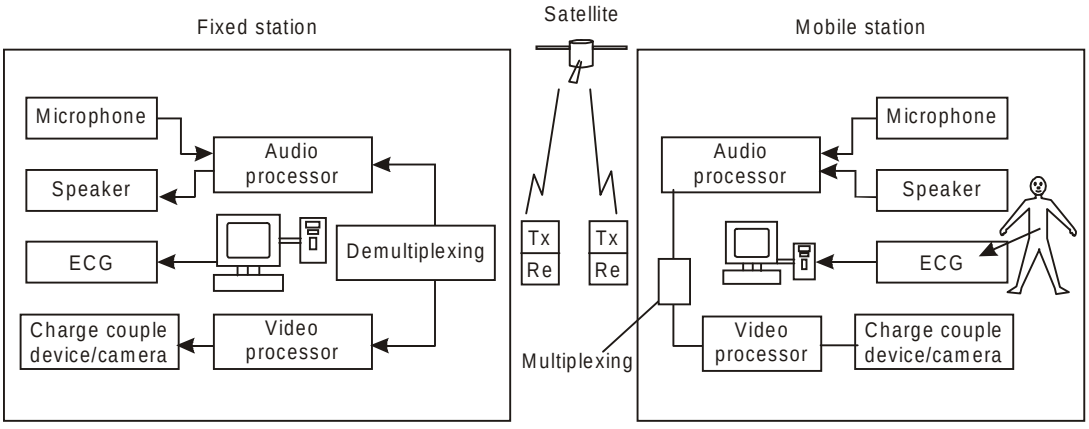
(*d*) image pixel data



ARC-nema Standard Interface

TELEMEDICINE BY MOBILE COMMUNICATION

1. Mobile telemedicine is now possible using mobile communication and satellite communication as shown in the figure. In moving vehicle which has all necessary equipment, works as a mobile station. It obtains colour images, audio signal and physiological signals such as ECG and blood pressure etc. from the patient at the place of sickness which is far away from the health care centre. These are transmitted to the health care centre by the help of mobile communication. Multiplexing and demultiplexing is used to reduce the time for transmissions. The instruction for the suitable treatment is sent to the mobile station from the specialists at the fixed station.



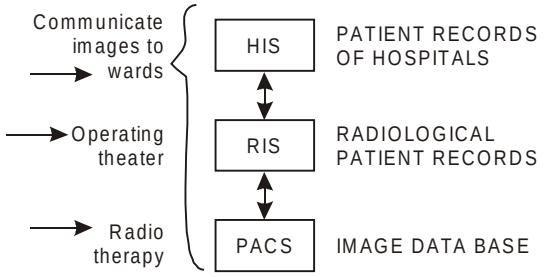
Telemedicine by Mobile Communication

TELEMEDICINE AND INTERNET

1. The world wide web (www) is an internet resource. It has information producing sites which can be accessed by the general public. It is possible to use the world wide web for imparting teleeduction and for other applications of telemedicine. However it is beneficial to have a dedicated link as it offers security to the data and reliability to communication due to fewer users using the link.

MEDICAL INFORMATION SYSTEM

1. Medical information systems (MIS) are being created on a department basis which as radiological information system (RIS) or on a hospital basis such as hospital information system (HIS). These information systems are created to contain and communicate patient data to any authorised user. It is of utmost importance that PACS should be integrated to RIS and HIS for effective utilization of all patient data.



Integrated HIS, RIS and PACS System

MEDICAL CODING AND CLASSIFICATION

1. Medical coding and classification systems are expected to become increasingly important in the health care sector. They are integral part of the electronic health information systems. The coding and classification systems will be used to improve the quality and effectiveness of medical services. Activities connected to the different coding and classification systems are very important attempts at standardization which are taking place in different countries within the discipline of medical information. These activities must secure a proper professional and economic support. It is also of vital importance that national health authorities should participate in these activities so as to establish formal cooperation with professional bodies.

OBJECTIVE TYPE QUESTIONS

Fill in the gaps

1. --------- is to produce health care from one place to another. (*a*) telecommunication (*b*) telemedicine
2. --------- is used for telecommunication of images. (*a*) teleradiology (*b*) telepathology
3. --------- relates to telecommunication of ECG. (*a*) telepathology (*b*) telecardiology
4. --------- is used to obtain an expert opinion on biopsy reports. (*a*) telepathology (*b*) teleconsultation
5. --------- is integration of medical imaging devices and image processing facilities. (*a*) PACS (*b*) MIPS
6. Images have to be --------- to reduce the data for transmission. (*a*) modified (*b*) compressed
7. --------- has a fixed station and a mobile station. (*a*) mobile telemedicine (*b*) telemedicine
8. Inside the hospital, --------- is a good solution for transmission of images. (*a*) WAN (*b*) LAN

9. The --------- is an internet resource. (*a*) international wide web (*b*) world wide web

10. The most likely communication protocol is --------- for transmission of images. (*a*) OSI (*b*) COI

ANSWERS

1. (*b*) **2.** (*a*) **3.** (*b*) **4.** (*a*) **5.** (*a*) **6.** (*b*) **7.** (*a*)

8. (*b*) **9.** (*b*) **10.** (*a*)

DATABASE DESIGN TOPOLOGIES AND NETWORK SECURITY

34

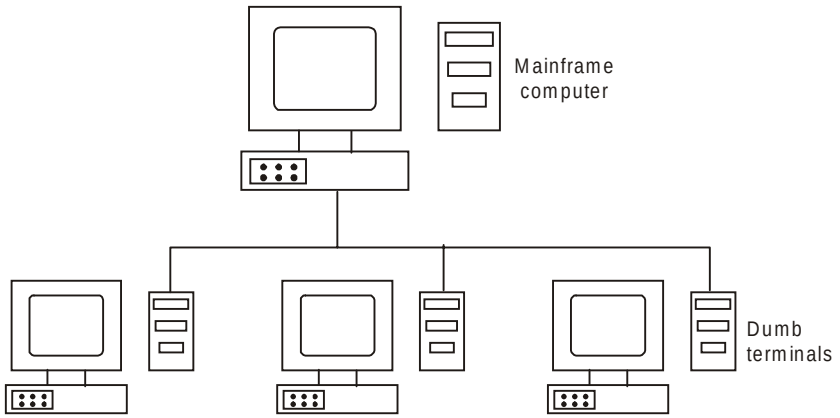
Sulking about your mistakes only leads to future ones.

INTRODUCTION

1. The collection of data usually called database contains information relevant to an enterprise. The primary goal of a data base management system (DBMS) is to provide a way to store and retrieve database information that is both convenient and efficient. Database systems are designed to manage large quantities of information. Management of data involves both defining structure for storage of information and providing mechanisms for the manipulation of information. In addition, the database system must ensure the safety of information stored despite system crashes or attempts for unauthrorised access. Criteria is used to retrieve information from the database. The way the data is stored in the database determines how easy it is to search for information based on multiple criteria. Database is designed such that data should also be easy to be added and removed from the database.

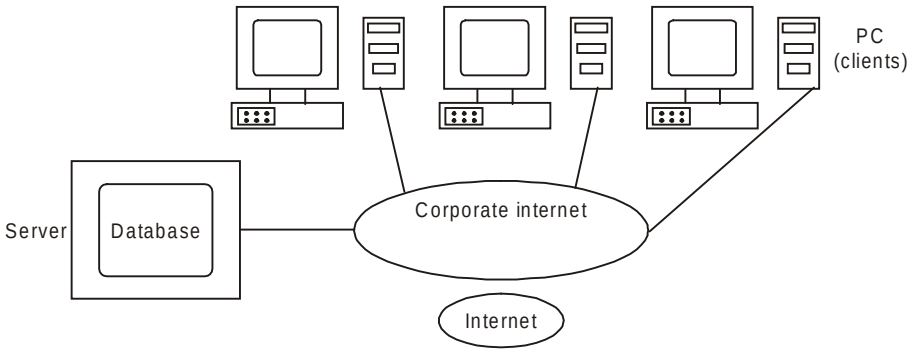
DATABASE ENVIRONMENTS

1. Various possible environments exist for a database which can be (1) the mainframe environment (2) the client/server environment and (3) the internet computing environment. The mainframe environment consists of a powerful mainframe computer and multiple dumb terminals which are networked in the mainframe computer. The dumb terminals depend on the mainframe computer to perform all processing. Client server environment consists of a main computer, called a server and many personal computers that are networked to the server. The database resides on the server. Each user who wants access to the database on the server should have his own personal computer.

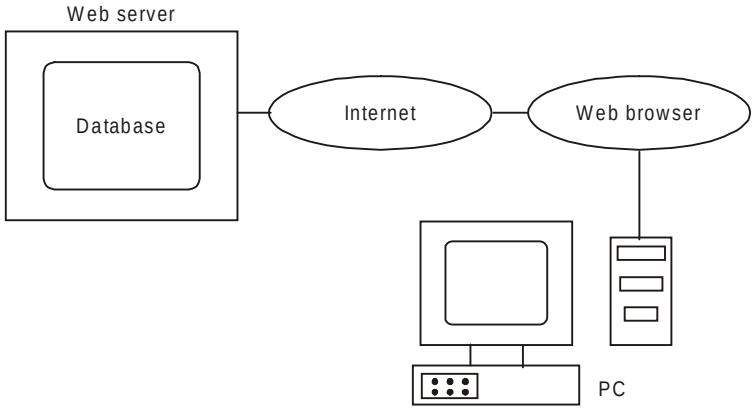


The Mainframe Environment

Internet environment is similar to client/ server computing. A user must have an internet connection and a supported web browser installed on the PC. The web browser connects the PC to the web server.



Client/Server Enviroment



Internet Computing Environment

ASPECTS OF DATABASE DESIGN

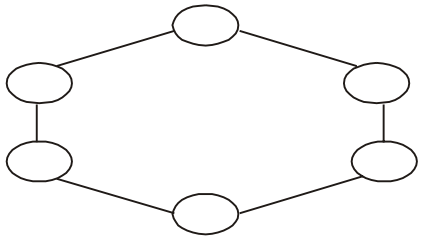
1. **Database Redundancy :** In database design, database redundancy has to be removed. Redundancy means repetition of records or duplicate records existing in the database. Therefore the duplicate records must be removed during the design of database using normalization of database.
2. **Consistency :** It means that the data base must remain consistent before the start of transaction and even after the completion of the transaction during the use of the database.
3. **Integrity :** It means the data base must be accurate. Integrity of database is accuracy.
4. **Anomalies :** There are three types of anamolies during the design of database which are :
   (*a*) Insertion anamolies. They are developed due to wrong insertion of data.
   (*b*) Updation or modification of database anamolies. They are developed while updating or modifying the database.
   (*c*) Deletion anamolies. They are developed during deletion of some data.

NORMALISING OF DATABASE

1. The anamolies are removed by using the concept of normalization of the database. The normalising is used to remove both the inconsistency and redundacy of the database while designing database. Normalising of data base is carried out step by step by using normal forms which can be (1) first normal form (2) second normal form (3) third normal form (4) boyee code normal form (BCNF) (5) fourth normal form (6) sixth normal form and (7) project join normal form (PJNE) and dynamic key normal form (DKNF). While carrying out first normal form, it is ensured that in the domain of each relation, only one value is associated to each attribute and the relation must be in tabular form. Second normal form normalising can be carried after data has been normalised in the first normal form and one prime attribute key is selected from the set of such a attributes of relation in such a way that other non prime attributes are fully functional dependent on the prime attributes key. After normalising for second normal form, normalising for third normal form is carried out. In this, it is established how other attributes are partially dependent on the prime attributes key. Similarly other normal forms are applied to normalise the database.

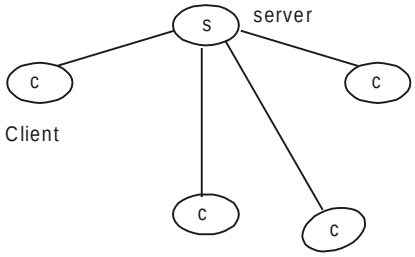
CLIENT/SERVER TOPOLOGIES

1. A single centralised server cannot handle large number of clients. Hence a common solution is to use the cluster of machines arranged in some topology. There are various topologies of client /server database which are :– (1) Ring topology (2) centralised topology (3) hierarchical topology and (4) centralised plus ring topology. In ring topology, a number of machines are connected to one another in the shape of closed loop so that each machine is connected directly to two other machines, one on either side of it. The machines arranged such in a ring, act as a distributed server. The ring topology is easy to be established but any break in a link between any two machines



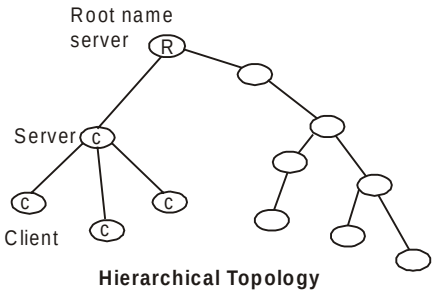
Ring Topology

causes a total breakdown. Centralised topology is the most commonly used form of the topology. The topology has typical client/server pattern used by the databases, web servers and other simple distributed systems. All information and function are centralized into one server with many clients connected directly to the server to send and receive information. Hierarchical topology has long history of usage in the field of internet. The best known hierarchical system on the internet is the "domain



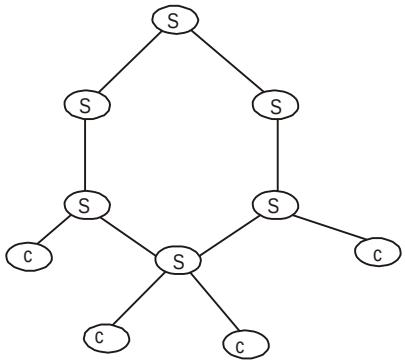
Centralized Topology

name service" where authority flows from the 'root name server' to the server for the resistered clients. In centrilized plus ring



Hierarchical Topology

topology, the server itself is a ring but the system as a whole including clients is a hybrid. The servers are connected in a ring and other machines are connected to ring. This topology has simplicity of a centralised system with the robusress of a ring.



Centralized Plus Ring Topology

NETWORK SECURITY

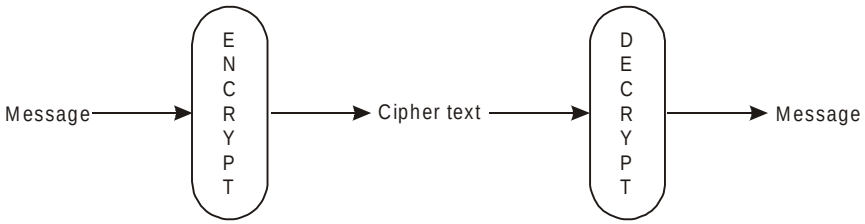
1. Any system attached to a network is exposed to a wide range of security threats. An unconnected system has high security but it has no access. Hence network access and security risk are two opposing requirements. A computer network is interconnection of a large number of computers to increase their access to data while security is designed to control access. Network security has to be designed in such a way that there is a balance between open access and security. Security can be maintained by: (1) secrecy (2) authentication (3) non-repudiation (4) integrity control and (5) privacy. Cryptography has become one of the main tool for privacy, trust, access control, electronic payments, corporate security and other fields. Cryptography is a method of hiding information which is intelligible to only those we intend to understand it. The art of devising ciphers to hide the information is cryptography and the art of breaking ciphers is called crypt analysis. The information or message is firstly encrypted so as to convert it to the cipher text. There are many kinds of ciphers to encrypt the messages. The cipher text is transferred through network to the intended reader who can decrypt the

ciplier text to the intelligible message as shown in the figure. Two fundamental principles are followed in cryptography :

(*a*) All encrypted messages must contain some redundancy.

(*b*) Some measures must be ensured to prevent active intruders to play back the old messages.

2. Patient files on a computer can be accessed by anyone with sufficient know-how. The integration of medical information system through network makes it even more difficult to secure the files against unauthorised access. Passwords and ciphering are used to secure the data.



The Method of Encryption

OBJECTIVE TYPE QUESTIONS

Fill in the gaps.

1. --------- system are designed to manage large quantities of information. (*a*) database (*b*) informative

2. The mainframe environment has a powerful main frame computer and multiple --------- terminals. (*a*) intelligent (*b*) dumb

3. In client / server environment, the database resides on the -------- (*a*) client (*b*) server

4. Internet environment is similar to --------- computing. (*a*) client /server (*b*) mainframe

5. --------- is the repetition of records. (*a*) conistency (*b*) redundancy

6. --------- of database is accuracy. (*a*) integrity (*b*) consistency

7. --------- anomalies are developed due to wrong insertion. (*a*) filling (*b*) insertion

8. The anamolies are removed from the database by using the concept of ---------. (*a*) normalising (*b*) filtering

9. A balance has to be maintanced between open access and ---------. (*a*) security (*b*) restricted access

10. --------- are used to encrypt the message. (*a*) ciphers (*b*) encryptor

11. The art of breaking ciphers is called ---------. (*a*) cryptography (*b*) crypt analysis

12. In medicine, --------- and ciphering are used to secure the data. (*a*) authentication (*b*) password

ANSWERS

1. (*a*) **2.** (*b*) **3.** (*b*) **4.** (*a*) **5.** (*b*) **6.** (*a*) **7.** (*b*)
8. (*a*) **9.** (*a*) **10.** (*a*) **11.** (*b*) **12.** (*b*)

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INDEX

S

T

U

V

W

X

Z