SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – I – BIOMECHANICS – SBTA1102

INTRODUCTION

1.1 Biomechanics

Biomechanics is the study of the structure, function and motion of the mechanical aspects of biological systems, at any level from whole organisms to organs, cells and cell organelles, using the methods of mechanics.

Biomechanics is defined as mechanics applied to biology, and mechanics itself is the response of bodies to forces or displacements.

Biomechanics applies mechanical principles to the human body in order to understand the mechanical influences on bone and joint health.

Developments in the field of biomechanics have improved our understanding of normal and pathologic gait, mechanics of neuromuscular control, and mechanics of growth and form. This knowledge has contributed to the development of medical diagnostic and treatment procedures. It has provided the basis for the design and manufacture of medical implants and orthotic devices and has enhanced rehabilitation therapy practices. Biomechanics has also been used to improve human performance in the workplace and in athletic competition.

1.2 History of Biomechanics

Aristotle

Aristotle was fascinated by anatomy and structure of living things. Aristotle might be considered the first biomechanician. He wrote the first book called "De Motu Animalium" - On the Movement of Animals. He saw animals' bodies as mechanical systems and what causes these movements.

Galen

The second century anatomist, Galen, wrote his monumental work, On the Function of the Parts (meaning the parts of the human body) as the world's standard medical text for the next 1,400 years.

Leonardo Da Vinci

He had an understanding of components of force vectors, friction coefficients, and the acceleration of falling objects, and had a glimmering of Newton's 3rd law. By studying anatomy in the context of mechanics, da Vinci also gained some insight into biomechanics. He analyzed muscle forces as acting along lines connecting origins and insertions and studied joint function.

Da Vinci tended to mimic some animal features in his machines. For example, he studied the flight of birds to find means by which humans could fly; and because horses were the principal source of mechanical power in that time, he studied their muscular systems to design machines that would better benefit from the forces applied by this animal.

Galileo

Galileo , the father of mechanics and part time biomechanic made important contributions to biomechanics. He was particularly aware of the mechanical aspects of bone structure and the basic principles of allometry. Galileo Galilei was interested in the strength of bones and suggested that bones are hollow because this affords maximum strength with minimum weight. He noted that animals' bone masses increased disproportionately to their size.

Borelli

Borelli embraced this idea and studied walking, running, jumping, the flight of birds, the swimming of fish, and even the piston action of the heart within a mechanical framework. He could determine the position of the human center of gravity, calculate and measured inspired and expired air volumes, and showed that inspiration is muscle-driven and expiration is due to tissue elasticity. Borelli was the first to understand that the levers of the musculoskeletal system magnify motion rather than force, so that muscles must produce much larger forces than those resisting the motion.

1.3 Applications of Biomechanics

1. Sports Biomechanics - Subfield of biomechanics where the laws of mechanics are applied in order to gain a greater understanding of athletic performance through mathematical modeling, computer simulation and measurement.
2. Locomotion and Gait- Walking pattern analysis. Locomotion of humans and animals.
3. Fluid Biomechanics- the study of the fundamentals of biological fluid flow, has been recognized to be extremely important for the understanding of how changes in the flow behavior within living tissue maybe affect both the fluid and the tissue.
4. Cardiovascular Biomechanics - The Cardiovascular Biomechanics group performs research in the field of computational and experimental biomechanical analysis of the cardiovascular system.
5. Ergonomics - Ergonomics applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance. Ergonomics is the study

of people while they use equipment in specific environments to perform certain tasks. Ergonomics seeks to minimize adverse effects of the environment upon people and thus to enable each person to maximize his or her contribution to a given job.

6. Rehabilitation - Rehabilitation biomechanics is a field of study that addresses the impact of disability and the effectiveness of rehabilitation therapies and interventions on human performance. Engineering and physics principles are applied to evaluate and analyze body movement and manipulation.
7. Plant Biomechanics - Interdisciplinary science describing behavior of plants subjected to forces and displacements at the level of molecules, cells, tissues, organs, whole organisms, and ecosystems.
8. Forensics - Forensic biomechanics is the application of biomechanical engineering science to litigation where biomechanical experts determine whether an accident was the cause of an alleged injury.
9. Implant Designing- Designing of orthotic and prosthetic devices, heart valves, etc
10. Biomechatronics - Biomechatronics is an applied interdisciplinary science that aims to integrate biology, mechanics, and electronics. It also encompasses the fields of robotics and neuroscience. Biomechatronic devices encompass a wide range of applications from the development of prosthetic limbs to engineering solutions concerning respiration, vision, and the cardiovascular system.

1.4 Perspectives of Biomechanics

1. Historical Perspective
2. Technological Perspective - Incorporation of engineering, physics, computer, and mathematical concepts applied to human movement patterns.
3. Philosophical Perspective-Multidisciplinary, Creativity and theorizing.
4. Future Perspectives- continuation of descriptive types of biomechanical analyses, continued modification and improvement of equipment, continued invasion of the discipline by other professions

1.5 Rigid Body Biomechanics

Rigid Body is defined as a particular system of particles which does not deform. The distance between any two given points on a rigid body remains constant in time regardless of external forces exerted on it. A rigid body is usually considered as a continuous distribution of mass. This means they change neither their form nor their volume when forces act on them. It is described by its orientation and location.

Location-Determined by the position of any one point of the body, and the orientation is determined by the relative position of all other points of the body relative to that point.

Deformable-body mechanics - Studies how forces are distributed within a material, and can be focused at many levels (cellular to tissues/organs/ system) to examine how forces stimulate growth or cause damage.

Fluid mechanics - Concerned with the forces in fluids (liquids and gas).

Principle of Transmissibility

The conditions of equilibrium or motion of a rigid body will remain unchanged if a force acting at a given point of the rigid body is replaced by a force of the same amplitude, direction, and line of action, but acting at a different point

Statics – The branch of biomechanics that deals with the study of forces on rigid body which is stationary.

Dynamics - The branch of biomechanics that deals with the study of forces on rigid body when it is in motion.

Kinematics - The branch of biomechanics that deals with the branch of dynamics without considering forces causing motion. It relates the motion variables (displacement, velocity, acceleration) with the time. Some examples of kinematic concepts are displacement, velocity and acceleration.

Kinetics - The branch of biomechanics that considers the forces causing the motion.

1.6 Anatomical Concepts in Biomechanics

1. Anatomical Reference Position- Standing up straight with the body at rest. The feet are slightly separated and arms relaxed and palms facing forward. It is the starting point for describing the body. It helps to talk about different parts of human body.

2. Reference Plane

Three basic reference planes used in anatomy:

Sagittal plane- Divides the body into left and right halves.

Coronal/Frontal plane- Divides the body into back and front halves.

Transverse plane - Divides the body into top and bottom halves.

3. Forms of Motion

Linear Motion- A uniform 1 D motion with all parts in same direction and same speed. Velocity does not continuously change direction.

Rectilinear- Straight Line

Curvilinear- Curved line

Angular Motion - The motion of a body about a fixed point or fixed axis.

Axis of Rotation - Equal to the angle passed over at the point or axis by a line drawn to the body.

4. Plane Movements

Sagittal Plane Movements

Flexion- Movement that decreases the angle between two body parts.

Extension- Movement that increases the angle between two body parts.

Hyperextension- Rotation beyond anatomical position. Excessive movement of a joint in one direction

Frontal Plane Movements

Abduction- Taking the body part away from the central line.

Adduction- Moving the body part towards the central line.

Lateral Flexion-Bending movement of a body part in the lateral direction – side wards. Shoulder,Fingers and hip joints undergo these movements.

Transverse Plane Movements

Rotation- It is twisting motion. Joints which permit rotation include the shoulder and hip. Ex- Ball and socket joints.

Medial rotation - rotational movement towards the midline.(Internal rotation)

Lateral rotation - rotational movement away from the midline.

Supination- Outward rotation of forearm

Pronation- Inward rotation of forearm

Dorsiflexion - Flexion at the ankle, so that the foot points more superiorly.

Plantarflexion -Extension at the ankle, so that the foot points inferiorly.

Circumduction- Conical movement of a limb extending from the joint at which the movement is controlled. A general motion with circular movement

Inversion -Movement of the sole towards the median plane

Eversion- Movement of the sole of the foot away from the median plane.

Elevation - Movement in a superior direction (e.g. shoulder shrug),

Depression -Movement in an inferior direction.

1.7 Fundamentals of Biomechanics

Biomechanics has 9 fundamental principles.

1. Force Motion Principle

Unbalanced forces are acting on our bodies or objects when we either create or modify movement.

Free-body diagram is a simplified model of any system or object drawn with the significant forces acting on the object.

II. Force –Time Principle

It is not only the amount of force that can increase the motion of an object; the amount of time over which force can be applied also affects the resulting motion.

III. Range of Motion

Overall motion used in a movement and can be specified by linear or angular motion of the body segments.

Increasing the range of motion in a movement can be an effective way to increase speed or to gradually slow down from a high speed.

IV. Balance

Person's ability to control their body position relative to some base of support.

Stability and mobility ofbody postures are inversely related

V. Coordination Continuum

How the muscle actions and body segment motions are timed in a human movement.

Two strategies -simultaneous/ sequential can be viewed as a continuum,

VI. Segmental Interaction

Forces acting in a system of linked rigid bodies can be transferred through the links and joints.

VII. Optimal Projection

Optimal range of projection angles for a specific goal.

VIII. Spin

Rotations imparted to projectiles.

Lift force is used to create a curve or to counter gravity, which affects the trajectory and bounce of the ball.

IX. Inertia

Property of all objects to resist changes in their state of motion.

Linear and angular measures of inertia are mass (m) and moment of inertia (I).

1.8 Anthropometric Considerations of Human Body

Anthropometric measurements are those which characterize human body dimensions — size and shape. These measurements are primarily of bone, muscle and adipose tissue (fat). The word combines the Greek root words anthropos (human) and metron (measure).

Typical Anthropometric Measurements

Height, (standing), Height,(sitting), Weight, Waist circumference, Waist to hip ratio, Waist to height ratio, BMI, Pondreal Index, Somatotype, Body Proportions.

Purpose

Anthropometric measurements are useful in many fields. For example, athletes understand that body size and composition are important factors in sports performance. Sports coaches can also use these measurements to monitor an athlete's body to ensure they stay in peak physical shape. Health care professionals rely on body measurements to evaluate a patient's overall health. Anthropometric measurements can also be used when studying groups of people. This broader approach allows researchers to evaluate health trends and concerns in various populations.

Factors

1.Height and Weight

Measure the height using a scale or stadiometer and weight using a weighing scale.

2.Pondreal Index

The Ponderal Index is a measure of body composition using height and weight. It is also known as the Corpulence Index (CI).

PI is calculated from measurements of body mass (M) and height (H). PI = the cube root of body weight divided by height, where body mass is in kilograms and height in meters.

$$PI = 10^3 \, 3\sqrt{\ } W/H$$

3.Somatotype

Somatotype, human body shape and physique type. The term somatotype is used in the system of classification of human physical types.

The system, uses the terms ectomorph, endomorph, or mesomorph to describe the body build of an individual.

Endomorph

Short and Fat - A pear-shaped body, Wide hips and shoulders, A lot of fat on the body, upper arms and thighs

An endomorphic individual typically has short arms and legs and a large amount of mass on their frame. Sports of pure strength, like powerlifting, are perfect for an endomorph. They can gain weight easily and lose condition quickly if training stops.

Sports Benefits

Size benefits sports such as rugby where bulk is useful, provided it can be moved powerfully, Tend to have large lung capacity which can make them suited to sports such as rowing.

Ectomorph

Tall and Thin - Narrow shoulders and hips, A narrow chest and abdomen ,Thin arms and legs, Little muscle and fat

Ectomorphic individuasl are long, slender and thin. Ectomorphs dominate endurance sports and gymnastics. They can archive low levels of body fat which can be detrimental to health.

Sports Benefits

The light frame makes them suited for aerobic activity like gymnastics, Smaller body surface area also enhances their suitability for endurance activity.

Mesomorph

Athletic Build - A wedge-shaped body, Wide broad shoulders, Muscled arms and legs, Narrow Hips, A minimum amount of fat

A mesomorphic individual excels in strength, agility, and speed. Their medium structure and height, along with their tendency to gain muscle and strength easily make them a strong candidate for a top athlete in any sport. They can sustain low body fat levels and find it easy to lose and gain weight.

Sports Benefits

Respond well to cardiovascular and resistance training, All muscle groups can be used to derive positive training adoption

4.Crural index

The ratio of thigh length to leg length. It describes the proportion of the legs. A high crural index is advantageous to long-jumpers since it enables the jumper to apply a force against the ground for a longer time than someone with a low crural index.

Ratio > 1, Lower leg longer than thigh

Ratio < 1, Lower leg shorter than thigh.

5.Body Proportions

Absolute Measures – Height of the body and length of its segments are important.

For equal height persons, different proportions are noticed.

Example:

Person 1 : Long legs & Short trunk

Person 2: Short Legs & Long trunk

Person 3 : Equal Lengths

1.9 Newton’s Laws of motions

Newton’s three laws of motion are the 3 physical laws, these

Newton’s First Law (Law of Inertia)

An object at rest remains at rest, or if in motion, remains in motion at a constant velocity unless acted on by a net external force. laws of motion laid the foundation for classical mechanics. These laws explain the relation between forces and the body on which these forces acted upon

Newton’s 1st law of motion deals with the inertial property of matter. Objects do not move by their own unless someone moves them.

Newton’s Second Law (Law of Momentum or Law of Acceleration)

Newton's second law shows how the forces that create motion (kinetics) are linked to the motion (kinematics).

It is represented as $F = ma$. This is the law of acceleration, which describes motion (acceleration) for any instant in time. It states that the acceleration an object experiences is proportional to the resultant force, is in the same direction, and is inversely proportional to the mass. If the net force were doubled, the acceleration of the object would be twice as large. Similarly, if the mass of the object were doubled, its acceleration would be half as large.

Newton's Third Law

For every action, there is an equal and opposite reaction.

The statement means that in every interaction, there is a pair of forces acting on the two interacting objects. The direction of the force on the first object is opposite to the direction of the force on the second object. Forces always come in pairs - equal and opposite action-reaction force pairs.

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – II – BIOMECHANICS – SBTA1102

MECHANICS OF HARD TISSUES

2.1 Bone

Bone is the primary structural element of the human body. Bones protect the various organs of the body, produce red and white blood cells, store minerals, provide structure and support for the body, and enable mobility.

Bone is unique that it is self repairing. Bone can alter its shape, mechanical behavior and properties to adapt to changes in mechanical demand.

Structure and Composition

Bones are composed of two types of tissue:

1. Compact (cortical) bone: A hard outer layer that is dense, strong, and durable. It makes up around 80 percent of adult bone mass.
2. Cancellous (trabecular or spongy) bone: This consists of a network of trabeculae or rod-like structures. It is lighter, less dense, and more flexible than compact bone.

The compact bone constitutes up to 80% of the bones weight, with spongy bone making up the additional 20%, despite its much larger surface area.

Bones also consists of osteoblasts and osteocytes, responsible for creating bone, osteoclasts or bone resorbing cells ,osteoid, a mix of collagen and other proteins, inorganic mineral salts within the matrix, nerves and blood vessels, bone marrow, cartilage, membranes.

The inorganic component (calcium and phosphate) makes it hard and rigid and the organic component (type 1 collagen) gives the bone flexibility.

The dense fibrous membrane surrounding the bone is called periosteum. It covers the entire bone except for the joints which are covered by cartilage.

The centre of the bone shaft is hollow and known as the Medullary Cavity. This contains both red and yellow bone marrow. Yellow bone marrow is mainly a fatty tissue, while the red bone marrow is where the majority of blood cells are produced.

Types of Bones

Long bone – It has a shaft and 2 ends. It is a weight bearing bones and provides the greatest structure and support

Short bone- It is cube shaped which allows wider range of movement.

Flat- Thin, flat and curved

Irregular- Complicated, unusual shapes

Mechanical Properties of Bone

Structural Properties- Mechanical properties that a structure possesses due to its size & geometry. Structural properties are usually determined by plotting load-deformation relationships of structures made up of like tissues.

Material properties - Mechanical properties that a material or tissue possesses due to the make-up the tissue (the content as well as the arrangement of fibers & cells). Material properties are usually determined by plotting stress-strain relationships of different tissues.

Mechanical parameters depend on the content of organic and inorganic materials. Inorganic materials are responsible for giving the bones elastic properties, are related to the activity of cells which in turn depends on the correct blood supply of the bone tissue.

The forces to which the bone is usually exposed include compression, tension, torsion, bending and shear stress.

1.Elastic behavior (Hookes law)

Law of elasticity states that a material subjected to tensile force would extend in the direction of traction by an amount that is proportional to the load, in other words Stress is directly proportional to the strain.

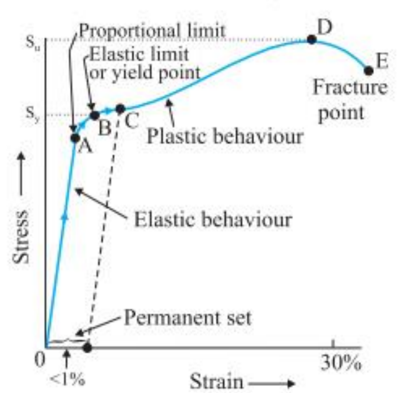


Fig 2.1 Elastic Behaviour

2.Stress and Strain

Stress: The force per unit of cross sectional area. The SI Unit of stress is newton per square meter.

$$\sigma = \frac{F}{A}$$

Strain : It is the ratio of the change in size or shape to the original size or shape. It has no dimensions, it is just a number.

$$\varepsilon = \frac{e}{lo}$$

3.Tension and Compression

A tension is a force that pulls a material apart and compression is a force that squeezes a material together.

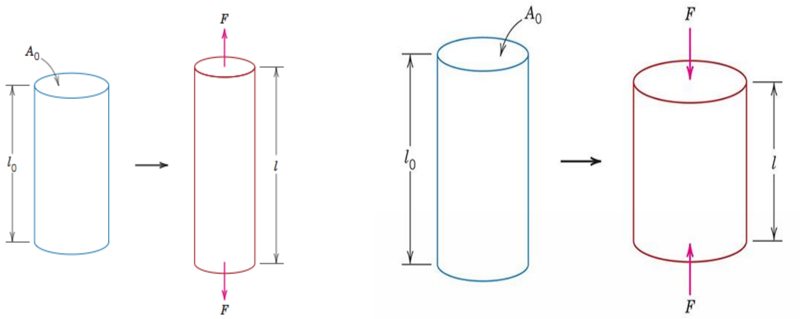


Fig 2.2 Tension and Compression Stress

4.Shear

If instead of applying a force perpendicular to the surface, we apply parallel but opposite forces on the two surfaces we are applying a shear stress.

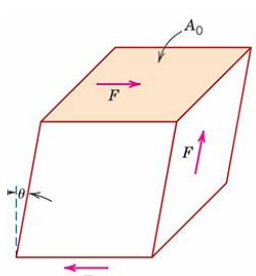


Fig 2.3 Shear stress

5.Torsion

If we hold one end of a cylinder fixed and twist the other end as shown in the figure below, we are applying a torsional (or twisting) stress.

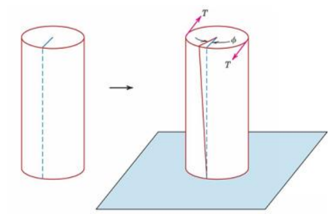


Fig 2.4 Torsion stress

Bulk Properties

Ductility - Characteristic of a material that undergoes considerable plastic deformation under tensile load before rupture

Brittleness- Absence of any plastic deformation prior to failure

Malleability- Characteristic of a material that undergoes considerable plastic deformation under compressive load before rupture

Resilience- Ability of a material to absorb energy when it is deformed elastically, and release that energy upon unloading.

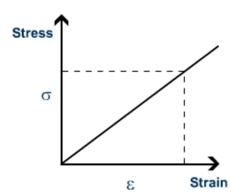
Toughness – property of a material enabling it to endure high-impact or shock loads; ability to absorb energy during plastic deformation

Hardness - Resistance of a material to scratching, wear, or penetration

2.2 Elastic properties of bones

1.Young’s Modulus

The gradient of the straight-line graph is the Young's modulus, E



$$E = \frac{stress}{strain} = \frac{\sigma}{\varepsilon}$$

E is constant and does not change for a given material. It in fact represents 'stiffness' property of the material.

2.Fracture:

Separation of a body into pieces due to stress.

Depending on the ability of material to undergo plastic deformation before the fracture two fracture modes can be defined - ductile or brittle.

Ductile fracture -most metals:

Ductile fracture is a type of fracture characterized by extensive deformation of plastic or "necking." This usually occurs prior to the actual fracture. Crack is stable: resists further extension unless applied stress is increased

Brittle fracture –

Brittle Fracture is the sudden, very rapid cracking of equipment under stress where the material exhibited little or no evidence of ductility or plastic degradation before the fracture occurs.

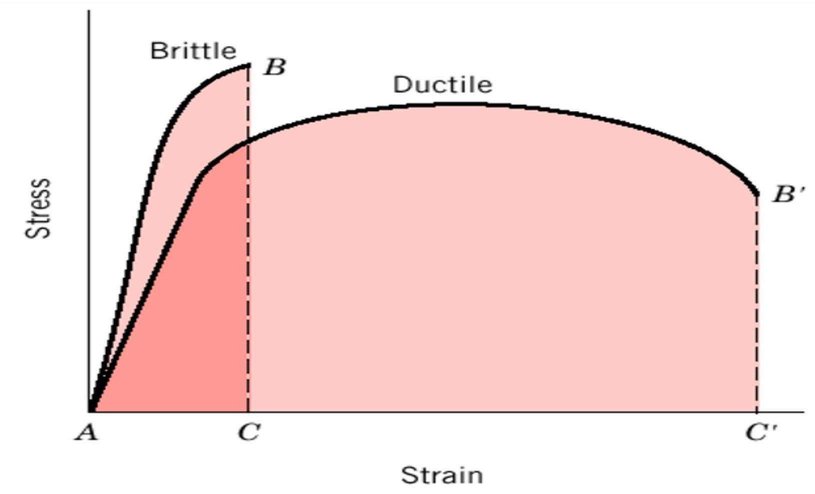


Fig 2.5 Ductile and Brittle Fracture

3.Plastic Deformation:

At some point, the strain is no longer proportional to the applied stress. At this point, bonds with original atom neighbors start to break and reform with a new group of atoms. When this occurs and the stress is relieved, the material will no longer return to its original form, i.e., the deformation is permanent and non recoverable. The material has now moved into the region referred to as plastic deformation. It produces a permanent change in the shape or size of a solid body without fracture, resulting from the application of sustained stress beyond the elastic limit.

2.3 Bone Fracture Mechanics

A fracture, also known as a broken bone, is a condition that changes the contour (shape) of the bone. Fractures often occur when there is a high force or impact put on a bone.

People break bones in sports injuries, car accidents, falls, or from osteoporosis (bone weakening due to aging). Although most fractures are caused by trauma, they can also be pathologic (caused by an underlying disease such as cancer or severe osteoporosis).

(Include Brittle and Ductile Fracture)

Types of fractures

There are many types of fractures:

A fracture can be closed (the skin is not broken) or open, which is also called a compound fracture (the skin is open and the risk of infection significant).

Some fractures are displaced (there is a gap between the two ends of the bone). These often require surgery.

A partial fracture is an incomplete break of a bone.

A complete fracture is a complete break of a bone, causing it to be separated into two or more pieces.

A stress fracture, sometimes called a “hairline fracture,” is like a crack and may be difficult to see with regular X-rays.

Transverse: the break is in a straight line across the bone.

Spiral: the break spirals around the bone.

Oblique: the break is diagonal across the bone.

Compression: the bone is crushed and flattens in appearance.

Comminuted: the bone fragments into several different pieces.

Avulsion: a fragment of bone is pulled off, often by a tendon or ligament.

Impacted: the bones are driven together.

Causes of a fracture

Fractures occur when a force that is stronger than the bone itself is applied to a bone. Fractures can occur from falls, trauma, and a direct blow to a bone. Repetitive forces caused by running can cause a fracture, as well. These running fractures are often called stress fractures; these are small cracks in the bone. Osteoporosis may also cause a fracture in older people.

2.4 Implants for bone fractures

Materials

Metals - Steel based, cobalt based, titanium based

Non metals - Polyethylene, PMMA, Silicones, Ceramics

During Surgery bone fragments are first repositioned into their normal alignment and held together with special implants, such as plates, screws, nails and wires.

a)Intermedullary Nails(IM)

A Rod or nail is inserted through the hollow center of the bone that contains marrow. Screws are inserted at each end of the rod used to keep the fracture from shortening or rotating, It is held in place until the fracture has healed. Rods and screws are also left in the bone after healing is complete. It is used to treat the majority of fractures in the femur (thighbone) and tibia (shinbone).

b) Screws

A simple and common implant device. It is used by themselves to provide fixation or in conjunction with other devices. Screws can be used alone to hold a fracture, as well as with plates, rods, or nails. It comes in different designs based on the type of fracture and how the screw will be used. After the bone heals, screws may be either left in place or removed.

Self Tapping – cuts its own thread as it is screwed

Non Self Tapping – Drill hole and insert

Cortical - Have fine threads all along their shaft, and are designed to anchor in cortical bone.

Cancellous - Have coarser threads, and usually have a smooth, unthreaded portion

Cannulated Screw- Precision placement

C) Wires

Kirschner wires (K-wires) are stiff, straight wires and are commmonly called ‘pins’. They hold the bones in place until they heal. It is drilled through the bone to hold the fragments in place. It is mainly used for supracondylar (elbow) or wrist injuries. They are usually temporary. Once the bones have healed, the K-wires are removed

d) Pins

They are any metal piece that sticks out of the skin after surgery. These metal pieces hold the bones in place while they heal. They need to stick out of your skin to hold the broken bone in place.

e) Plates

Plates are internal splints that hold the broken pieces of bone together. They are attached to the bone with screws. Plates may be left in place after healing is complete, or they may be removed. Compression plates are used for fractures that are stable in compression.

Types of plates

Special oval screw holes.

Locking plates 2.0

(Locking) reconstruction plates

Dynamic compression plates

Universal fracture plates

Sherman's Plate

Egger's plate

f) Spinal Fixation Devices

Two or more vertebrae are anchored to each other through an artificial fixation device. It reduces vertebral mobility and avoids damage to the spinal cord or spinal roots. Usually uses for vertebral fracture, vertebral deformity, or degenerative vertebral disorders

2.5 Lubrication of Joints

The extremely low value of coefficient of friction (COF) found in bone joints (~0.01) is due to the combined effect of the cartilage tissue as well as the synovial fluid present. Cartilage tissue at the ends of bones are soft, slippery and deformable. Synovial fluid contains certain molecules that cause the low COF.

Cartilage is made up of a porous material. It contains 70% by volume water.

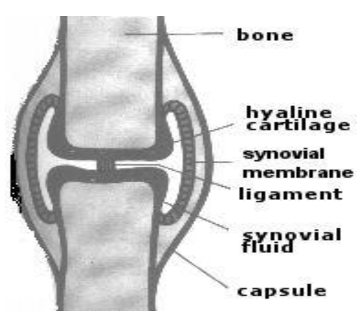


Fig 2.6 Synovial Joint

Synovial Fluid

Syn means like and ovial means egg white. The lubricant is therefore similar to egg white. It is non-newtonian in nature. A synovial joint can be described as a load carrying system consisting of two mating bones with tangential and /or normal motions. The bone ends, which are usually spherical in appearance, are covered with a soft sponge like material, called articular cartilage. The space between these cartilaginous extremities of the bones, known as joint cavity, is filled with a shear- dependent fluid called synovial fluid. The synovial fluid is a clear yellowish dialysate of blood plasma with a concentration of hyaluronic acid molecules.

In a diseased joint, the cartilage surface can become rough and cracked and synovial fluid can lose its non- Newtonian behavior. The pores of a cartilage may increase in size and the hyaluronic acid molecules may be able to pass through them.

Llubrication regimes

Elastohydrodynamic lubrication is a hydrodynamic process in which fluid film pressure causes elastic deformation of the bearing surfaces which in turn modify the pressure in the film region. In other words, the elastic cartilage deforms slightly to maintain an adequate layer of fluid between the opposing joint surfaces. The elastohydrodynamic action can maintain a fluid film under conditions of heavy loading. Due to the deformable nature of cartilage, there is elastohydrodynamic lubrication (EHL).

Squeeze-film lubrication occurs when the bearing surfaces are moving perpendicularly towards each other. Pressure is created in the fluid film by the movement of articular surfaces that are perpendicular to one another. As the opposing surfaces move close together, they squeeze the fluid film out of the area of impending contact. The viscosity of the fluid in the gap between the surfaces produces pressure, which tends to force the lubricant out. The resulting pressure created by the fluid's viscosity keeps the surface separated. This type of lubrication is suitable for high loads maintained for a short duration. Occurs in standing conditions.

Weeping lubrication is a form of fluid lubrication in which the load bearing surfaces are held apart by a film of lubricant that is maintained under pressure. Contractions of muscles around the joint or by compression from weight bearing compression of articular cartilage causes the cartilage to deform and to "weep" fluid which forms a fluid film over the articular surfaces. The concept of weeping lubrication is based on the assumption that cartilage is a weeping bearing. In weeping lubrication, the fluid that is present within the cartilage is squeezed out into the joint space to provide lubrication.

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – III – BIOMECHANICS – SBTA1102

MECHANICS OF SOFT TISSUES

3.1 Soft Tissues/ Biological materials

A primary group of tissue which binds, supports and protects our human body and structures such as organs is soft connective tissue. In contrary to other tissues, it is a wide-ranging biological material in which the cells are separated by extracellular material.

Examples for soft tissues are tendons, ligaments, blood vessels, skins or articular cartilages among many others. Tendons are muscle-to-bone linkages to stabilize the bony skeleton (or to produce motion), while ligaments are bone-to-bone linkages to restrict relative motion. Blood vessels are prominent organs composed of soft tissues which have to distend in response to pulse waves. The skin is the largest single organ (16% of the human adult weight). It supports internal organs and protects our body. Articular cartilages form the surface of body joints (which is a layer of connective tissue with a thickness of 1-5 mm) and distribute loads across joints and minimize contact stresses and friction.

Collagen. Collagen is a protein which is a major constituent of the extracellular matrix of connective tissue. It is the main load carrying element in a wide variety of soft tissues and is very important to human physiology (for example, the collagen content of (human) achilles tendon is about 20 times that of elastin).

Collagen is a macromolecule with length of about 280 nm. Collagen molecules are linked to each other by covalent bonds building collagen fibrils. Depending on the primary function and the requirement of strength of the tissue the diameter of collagen fibrils varies. In the structure of tendons and ligaments, for example, collagen appears as parallel oriented fibers , while many other tissues have an intricate disordered network of collagen fibers embedded in a gelatinous matrix of proteoglycans.

More than 12 types of collagen have been identified . The most common collagen is type I, which can be isolated from any tissue. It is the major constituent in blood vessels.

3.2 Structure and functions and mechanical properties of cartilages, tendons, ligaments

Ligament - Tough fibrous band of connective tissue that serves to support the internal organs and hold bones together in proper articulation at the joints. A ligament is composed of dense fibrous bundles of collagenous fibres and spindleshaped cells known as fibrocytes, with little ground substance (a gel-like component of the various connective tissues). Ligaments may be of two major types: white ligament is rich in collagenous fibres, which are sturdy and inelastic; and yellow ligament is rich in elastic fibres, which are quite tough even though they allow elastic movement.

Tendons are the connective tissues that transmit the mechanical force of muscle contraction to the bones; the tendon is firmly connected to muscle fibres at one end and to components of the bone at its other end. Tendons are remarkably strong, having one of the highest tensile strengths found among soft tissues. Their great strength, which is necessary for withstanding the stresses generated by muscular contraction, is attributed to the hierarchical structure, parallel orientation, and tissue composition of tendon fibres.

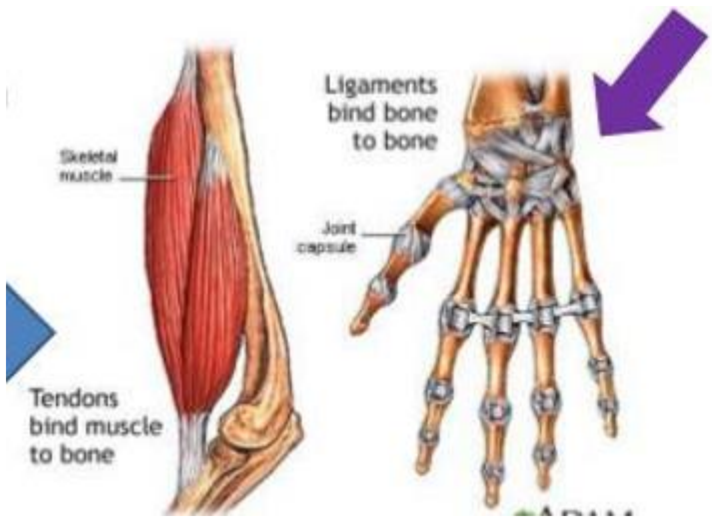


Fig 3.1 Tendons and ligaments

Cartilage is a connective tissue consisting of a dense matrix of collagen fibres and elastic fibres embedded in a rubbery ground substance. The matrix is produced by cells called chondroblasts, which become embedded in the matrix as chondrocytes. The surface of most of the cartilage in the body is surrounded by a membrane of dense irregular connective tissue called perichondrium. Cartilage contains no blood vessels or nerves - except in the perichondrium.

Three types of cartilage:

Elastic cartilage- Yellow in appearance, contains elastic fibres in addition to collagen. Found in external ear, the auditory tube of the middle ear, and the epiglottis.

Fibrocartilage- Tough, very strong tissue found in the intervertebral disks and at the insertions of ligaments and tendons; contains cartilage ground substance and chondrocytes

Hyaline cartilage - smooth and shiny, found in nose, windpipe, and most of the body's joints. Also called articular cartilage

Mechanical Properties

Connective tissues are described as heterogeneous because they are composed of a variety of solid and semisolid components.

Force and Elongation

The force values in the load-deformation curve depend on both the size of the structure and its composition. A larger structure (cross-sectional area) will be able to withstand more force, and a longer structure will elongate further when a force is applied. Thus, if two tissues are composed of the same material, a larger tissue will have greater tensile strength, and a longer tissue will have less stiffness.

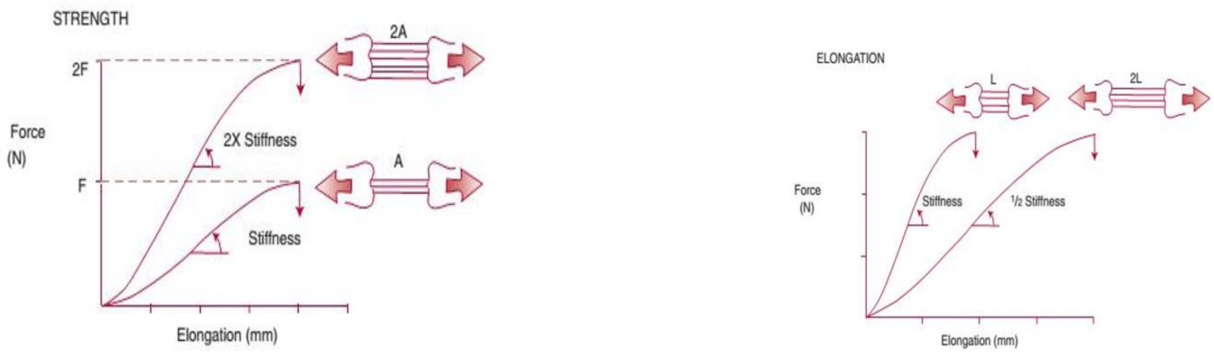


Fig 3.2 Force and Elongation

Stress and Strain

When loads (forces) are applied to a structure or material, an internal resistance to that deformation is produced in the structure or material. The internal reaction to the applied force is called stress. Stress is defined as the force per unit of crosssectional material and can be expressed mathematically in the following formula, where S stress, F applied force, and A area:

S F/A

The relative deformation (change in shape, length, or width) of the structure or material that accompanies the stress is referred to as strain. Strain is the amount of deformation that takes place relative to the original length of the material.

Young's modulus

It is also known as the elastic modulus, is a mechanical property of linear elastic solid materials. It defines the relationship between stress (force per unit area) and strain (proportional deformation) in a material. The modulus of elasticity defines the mechanical behavior of the material and is a measure of the material's stiffness (resistance offered by the material to external loads).

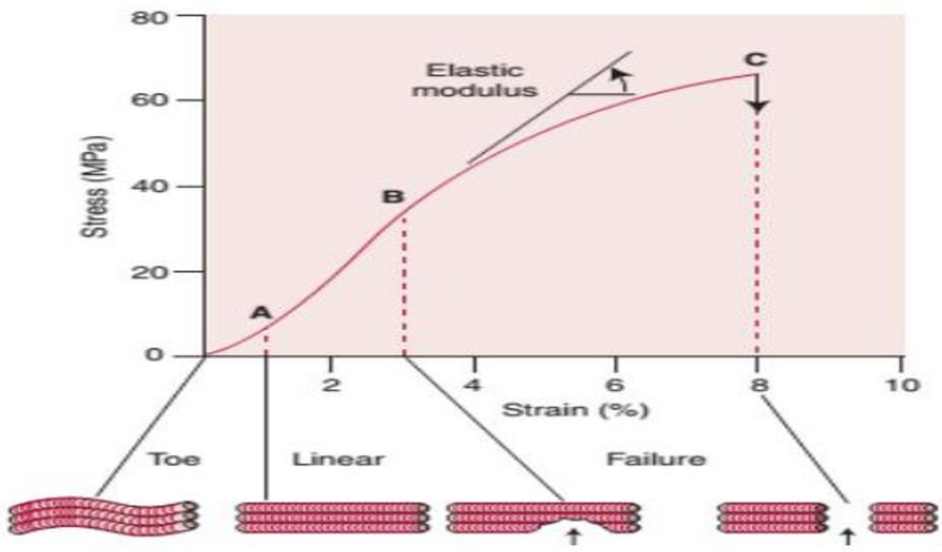


Fig 3.3 Stress strain curve

Toe Region : Uncrimping of crimped tendons

Non linear

2% strain

Linear Region: Fibrils stretch

Linear

Strain less than 4%,returns to original state

Slope gives the Youngs Modulus

Yield & Failure Region: 8-10%- Fibril fractures

Stiffness reduced

3.3 Pseudo elasticity

Pseudoelasticity, or superelasticity, is a reversible elastic response to an applied stress, caused by a phase transformation between the austenitic and martensitic phases of a crystal. It is exhibited in shape-memory alloys.

Pseudoelasticity is from the reversible motion of domain boundaries during the phase transformation, rather than just bond stretching or the introduction of defects in the crystal

lattice. A pseudoelastic material may return to its previous shape (hence, shape memory) after the removal of even relatively high applied strains.
When mechanically loaded, a superelastic alloy deforms reversibly to very high strains (up to 10%) by the creation of a stress-induced phase. When the load is removed, the new phase becomes unstable and the material regains its original shape. Unlike shape-memory alloys, no change in temperature is needed for the alloy to recover its initial shape.

Superelastic devices take advantage of their large, reversible deformation and include antennas, eyeglass frames, and biomedical stents.
Nickel titanium (Nitinol) is an example of an alloy exhibiting superelasticity.

3.4 Viscoelasticity

Elasticity refers to the material’s ability to return to its original state after deformation. Viscosity refers to a material’s resistance to flow. It is a fluid property and depends on the PG and water composition of the tissue. A tissue with high viscosity will exhibit high resistance to deformation. When forces are applied to viscous materials, the tissues exhibit time dependent and rate-dependent properties. Viscosity diminishes as temperature rises and increases as pressure increases. All connective tissues are viscoelastic materials

Three characteristics of VE materials-
Creep
Creep is a slow, progressive deformation of a material under constant stress/load. A Time-dependent deformation under a certain applied load. Generally occurs at high temperature. Rate of deformation is called the creep rate.

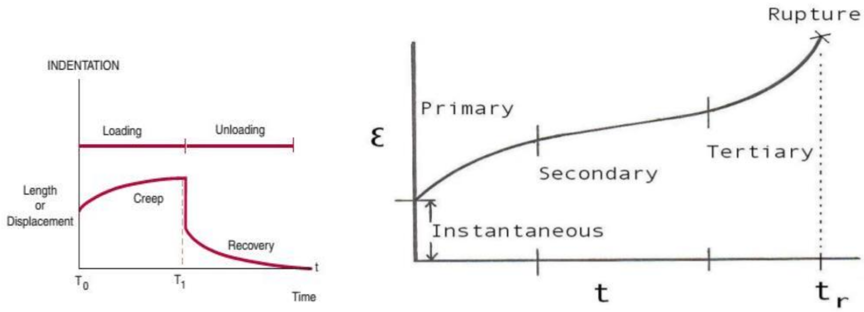


Fig 3.4 Creep curve

Stages of Creep

Primary Creep: starts at a rapid rate and slows with time.

Secondary Creep: has a relatively uniform rate.

Tertiary Creep: has an accelerated creep rate and terminates when the material breaks or ruptures. It is associated with both necking and formation of grain boundary voids.

Stress Relaxation

Indicates stress acting upon a tendon will eventually reduce under a constant deformation. It is studied by applying a constant deformation to the specimen and measuring the stress required to maintain that strain as a function of time. It is due to a re-arrangement of the material on the molecular or micro-scale.

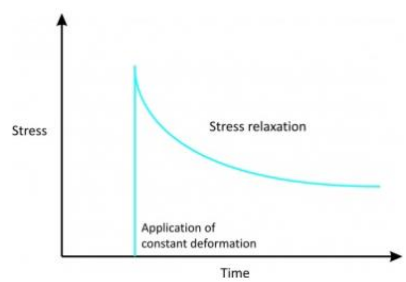


Fig 3.4 Stress relaxation curve

Hysteresis

When the force and length of the tissues are measured as force is applied (loaded) and removed (unloaded), the resulting load-deformation curves do not follow the same path. The energy gained as a result of the lengthening work (force * distance) is not recovered 100% during the exchange from energy to shortening work. Some energy is lost, usually as heat.

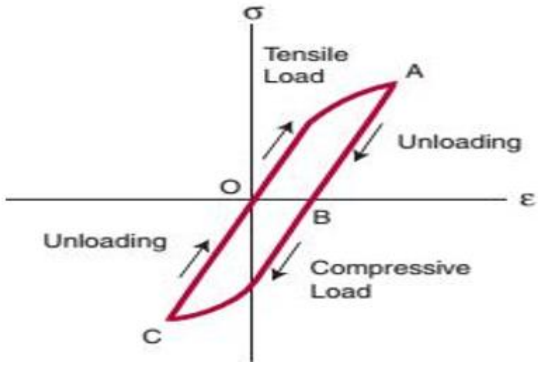


Fig 3.5 Hystresis Curve

3.4.1 Viscoelastic Models

Springs and dashpots constitute the building blocks of model analysis in viscoelasticity. They are connected to one another in various forms are used to construct empirical viscoelastic models. Springs are used to account for the elastic solid behavior and dashpots are used to describe the viscous fluid behavior.

It is assumed that a constantly applied force (stress) produces a constant deformation (strain) in a spring and a constant rate of deformation (strain rate) in a dashpot. The deformation in a spring is completely recoverable upon release of applied forces, whereas the deformation that the dashpot undergoes is permanent.

Three viscoelastic models are based on the arrangement of spring and dashpot.

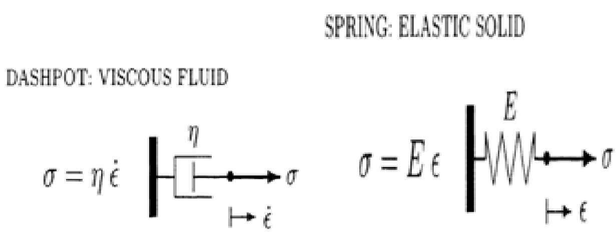


Fig 3.6 Spring and Dashpot Model

a)Kelvin Voight Model

A system consisting of a spring and a dashpot connected in a parallel arrangement. It predicts the creep.

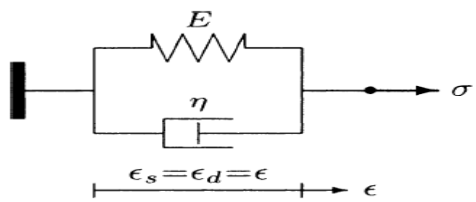


Fig 3.7 Kelvin Voight Model

If s and d denote the spring and dashpot, respectively, then a stress ‘s’ applied to the entire system will produce stresses σ s and σ d in the spring and the dashpot.

Total stress applied to the system will be shared by the spring and the dashpot.

$$\sigma = E\varepsilon + \eta\dot{\varepsilon}.$$

b) Maxwell Model

It is constructed by connecting a spring and a dashpot in a series. It predicts stress decays exponentially with time.

$$\eta\dot{\sigma} + E\sigma = E\eta\dot{\varepsilon}.$$

Fig 3.8 Maxwell Model

c) Standard Linear Model

It is composed of a spring and a Kelvin–Voight solid connected in a series. Three-parameter model used to describe the viscoelastic behavior of a number of biological materials such as the cartilage and the white blood cell membrane. It gives information of both creep and stress relaxation.

$$(E_1 + E_2)\sigma + \eta\dot{\sigma} = (E_1E_2\varepsilon + E_1\eta\dot{\varepsilon}).$$

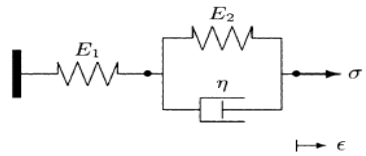


Fig 3.9 Standard linear model

3.5 Structure, function and mechanical properties of skin

Skin is the heaviest single organ. Its thickness varies throughout the body. For eg: Scalp is 1.5mm thick while the back is 4mm thick. Skin is composed of three layers: Epidermis (outer layer), Dermis, and Hypodermis. The outermost layer epidermis acts as a skin barrier. The dermis is the layer of skin beneath the epidermis that consists of connective tissue and cushions the body from stress and strain. The third layer is the mainly made of adipose cell. Skin is considered to be viscoelastic.

Skin has mesodermal cells, pigmentation, such as melanin provided by melanocytes, which absorb some of the potentially dangerous ultraviolet radiation (UV) in sunlight.

The mechanical properties of the skin depends on the nature of collagen and elastin fibres.

Functions - Protection of internal structures – physical barrier to microorganisms and foreign matter, acid PH helps to prevent infection, Sensory perception, Thermoregulation, Excretion, Metabolism, Absorption

Mechanical Properties

The stress-strain behaviour of the skin is typically explained in three phases: When a strain of up to 0.3% is applied, the elastin fibres offer low resistance to the applied strain. The skin exhibits isotropic behaviour and collagen fibres remain tangled and intertwined and do not contribute to the stiffness. Phase 1 offers a linear stress-strain relationship and a low Young's Modulus (0.1-2MPa).

In Phase 2, the collagen fibres offer some resistance to the deformation and the crimped collagen fibres begin to stretch, thus introducing non-linearity into the stress strain relationship.

In the final Phase 3, for applied strain above 0.6%, the crimps begin to disappear and a linear stress-strain relationship can be observed. The collagen fibres break after the application of an ultimate tensile strain of 0.7% .

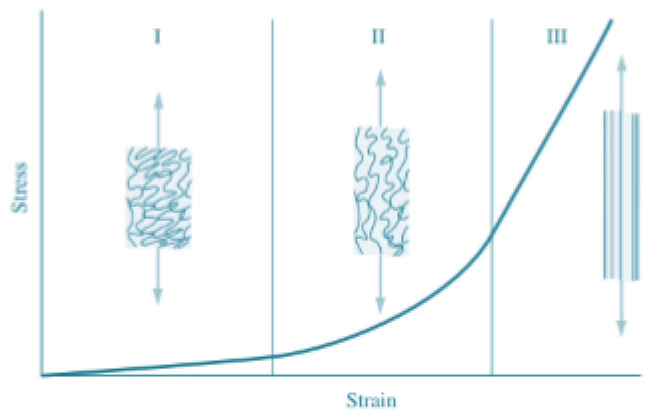


Fig 3.10 Skin stress strain curve

Young's Modulus of the skin is a vital parameter to estimate the characteristics of skin. One of the striking features of a healthy skin is its ability to get back to normal after being pulled. Knowing the Young's Modulus of skin can help in calibrating the elasticity of bio-sensors to measure skin-stretch induced motion artifacts.

Nonlinear stress–strain relationship - The mechanical response of skin tissue is highly non-linear due to the makeup of its microstructural constituents.

Skin also exhibits the relaxation behavior characteristic of viscoelastic materials. When stretched and held to a constant strain level, the stress within the skin material will decay over time.

3.6 Mechanical testing of Soft tissue

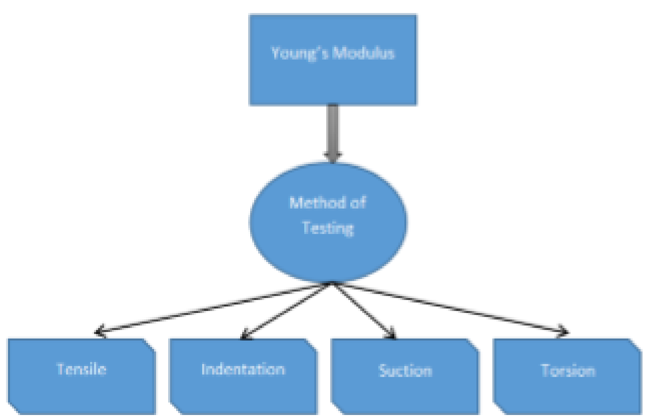


Fig 3.10 Testing methods

The mechanical behaviour of the skin is measured by changing the shape of skin by employing different techniques such as stretching (tensile test), applying normal load on the skin (indentation test), elevating the skin in an aperture (suction test) and rotating the epidermis to different degrees (torsion test).

The mechanical testing of skin can be further classified into in vivo and in vitro tests. In vitro tests provide a simple and easy to model Stress-Strain relationship under controlled conditions. In vitro tests can also be used to calculate the ultimate tensile stress and strain when the skin ruptures. In comparison, in vivo tensile measures are able to include anatomical and physiological effects on skin properties. For example, skin ageing provides a negative impact on skin's ability to perform functions like body temperature regulation and water loss prevention. Longitudinal studies of Young's Modulus values of skin must therefore be done in vivo.

Tensile test

Tensile testing is the most common type of test performed ex vivo under controlled conditions . In tensile tests, the skin is stretched parallel to the plane of the skin. The load can either be uniaxial or biaxial. The maximum and minimum values of the Young's Modulus across the tibial axis were found to be 0.32 and 4 MPa respectively and 0.3 and 20 MPa, respectively. A customised tensile device was used to measure the ultimate stress along with the longitudinal, transverse and shear strain field in an I-shaped tissue sample (taken from an 85-year old male) using Image Correlation Method. The machine had been divided into an upper chamber and a lower chamber to clamp the tissue from both ends. Young's Modulus was calculated for longitudinal, transverse and shear strains.

Indentation test

Indentation is one of the most widely used and accepted means of measurement of skin's bio-mechanical properties in vivo. It employs the use of an indenter which comes in to contact with and applies a perpendicular force on a small area of skin. The indentation method delivers Young's Modulus in the perpendicular direction without any skin pre-stressing Laser or ultrasound sensors are employed to measure the distance of depths on indentation. Spherical and cylindrical indentors are employed for the test. The cylindrical indenter measured a higher average value of Young's Modulus than the spherical indenter at higher indentation depths.

Suction test

The mechanical properties of thin elastic membranes of materials like rubber can be determined using Diaphragm tests, where the membrane is clamped at two ends and inflated in the form of a dome while the pressure of suction is controlled by a pressure controller.

The suction method to investigate anisotropy of skin has evolved to become a common procedure for skin mechanical testing. Generally, it employs the measurement of skin elevation in a circular aperture caused due to vacuum conditions using optical systems like Dermaflex and Cutometer.

Dermaflex is a device with an aperture size of 10 mm, the cup being adhered to the skin to prevent creep. It has been used to measure skin distensibility and to account for mechanical properties of dermis in by measuring elasticities as a percentage of skin retraction after the stretch. The Cutometer is a suction device employing probe apertures between 2-8 mm with the application of negative pressure through a vacuum pump.

Torsion test

Torsion measurements are carried out by applying a constant torque through a guard ring and an intermediary disc and measuring the resultant rotation of skin. As the torque is applied, an immediate elastic deformation occurs followed by the occurrence of creeping viscoelastic deformation which is time dependent. The release of torque leads to immediate recovery followed by a slow recovery process which is usually not completed. In torsion, the elongation is replaced by rotation and hence the measurement of elasticity becomes more complex.

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – IV – BIOMECHANICS – SBTA1102

CARDIOVASCULAR MECHANICS

4.1 Cardiovascular Physiology

Cardiovascular physiology is the study of the cardiovascular system, the physiology of the heart ("cardio") and blood vessels ("vascular").

The main concepts are

a) Cardiac output- The volume of blood being pumped by the heart, per unit time. The cardiac output at rest averages about 5 L/min for normal person.

b) Electrical conduction system of the heart(Electrocardiogram)- The electrical activity of the heart due to depolarization and repolarisation of heart muscles.

c) Regulation of Blood Pressure – Maintaining the systole and diastole.

d) Hemodynamics- Maintaining a mean arterial pressure.

Cardiovascular System- Heart Anatomy

The cardiovascular system consists of the heart, blood vessels, and blood. Its primary function is to transport materials to and from all parts of the body. The heart pressurizes blood and provides the driving force for its circulation through the blood vessels. Blood is propelled away from the heart in the arteries and returns to the heart in the veins.

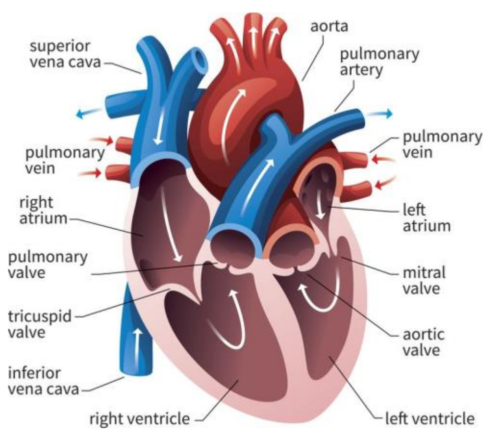


Fig 4.1 Heart

The heart is divided into 4 chambers: 2 on the right hand side and 2 on the left. Each upper chamber is known as an atrium and each lower chamber as a ventricle. The 4 compartments are known as: the right atrium; the right ventricle; the left atrium and the left ventricle. The left atria and left ventricle are separated from the right atria and right ventricle by a wall of muscle called the septum.

The wall of the heart consists of three layers of tissue:

Epicardium — protective layer mostly made of connective tissue.
Myocardium — the muscles of the heart.
Endocardium — lines the inside of the heart and protects the valves and chambers.
These layers are covered in a thin protective coating called the pericardium.

Valves

The heart has four valves that help ensure that blood only flows in one direction:

Aortic valve: between the left ventricle and the aorta.
Mitral valve: between the left atrium and the left ventricle.
Pulmonary valve: between the right ventricle and the pulmonary artery.
Tricuspid valve: between the right atrium and right ventricle.

The heart sound is called "lub-DUB" sound. The "lub" sound is produced by the tricuspid and mitral valves closing, and the "DUB" sound is caused by the closing of the pulmonary and aortic valves.

Process

The right atrium receives non-oxygenated blood from the body's largest veins — superior vena cava and inferior vena cava — and pumps it through the tricuspid valve to the right ventricle.
The right ventricle pumps the blood through the pulmonary valve to the lungs, where it becomes oxygenated.
The left atrium receives oxygenated blood from the lungs and pumps it through the mitral valve to the left ventricle.
The left ventricle pumps oxygen-rich blood through the aortic valve to the aorta and the rest of the body.
The coronary arteries run along the surface of the heart and provide oxygen-rich blood to the heart muscle.

Physiology

Heart muscle is stimulated by nerves and is self-excitable (automaticity). It contracts as a unit

Sinoatrial (SA) node generates impulses about 75 times/minute.

Atrioventricular (AV) node delays the impulse approximately 0.1 second.

The impulse passes from atria to ventricles via the atrioventricular bundle (bundle of His).

AV bundle splits into two pathways in the interventricular septum (bundle branches), the Bundle branches carry the impulse toward the apex of the heart and Purkinje fibers carry the impulse to the heart apex and ventricular walls.

4.2 Heart Valve Dynamics

The heart has four valves that control the direction of blood flow through the heart, permitting forward flow and preventing back flow. On the right side of the heart, the tricuspid and pulmonic valves regulate the flow of blood that is returned from the body to the lungs for oxygenation. The mitral and aortic valves control the flow of oxygenated blood from the left side of the heart to the body. The aortic and pulmonic valves allow blood to be pumped from the ventricles into arteries on the left and right side of the heart, respectively. Similarly, the mitral and tricuspid valves lie between the atria and ventricles of the left and right sides of the heart, respectively. The aortic and pulmonic valves open during systole when the ventricles are contracting, and close during diastole when the ventricles are filling through the open mitral and tricuspid valves.

When closed, the pulmonic and tricuspid valves must withstand a pressure of approximately 30 mmHg. However, the closing pressures on the left side of the heart are much higher. The aortic valve withstands pressures of approximately 100 mmHg, while the mitral valve closes against pressures up to 150 mmHg.

Aortic and Pulmonic Valves

The aortic valve is composed of three semilunar cusps, or leaflets, contained within a connective tissue sleeve. Each of the leaflets is lined with endothelial cells and has a dense collagenous core. They are mainly composed of both collagen and elastin.

The aortic valve diameter was found to be 23.2 ± 3.3 mm, whereas the diameter of the pulmonic valve was measured at 24.3 ± 3.0 mm on autopsy specimens. The aortic root diameter at end systole was 35 ± 4.2 mm and 33.7 ± 4.4 mm at the end of diastole while measuring using echocardiography. The pulmonic leaflets are thinner than aortic leaflets

The aortic valve is anisotropic and viscoelastic. The collagen fibers within each valve cusp are aligned along the circumferential direction. There are also elastin fibers, at a lesser concentration, that are oriented orthogonal to the collagen. It is this fiber structure that accounts for the anisotropic properties of the valve. The purpose of elastin in the aortic valve leaflet is to maintain a specific collagen fiber configuration and return the fibers to that state during cyclic loading. In terms of their viscoelesticity, the valves are more elastic than viscous.

The aortic valve leaflets also undergo bending in the circumferential direction during the cardiac cycle. In diastole when the valve is closed, each leaflet is convex toward the ventricular side. During systole when the valve is open, the curvature changes and each leaflet is concave toward the ventricle. This bending is localized on the valve cusp near the wall of the aorta.

The composition, properties, and dimensions of the aortic valve change with age and in the presence of certain diseases. The valve leaflets become thicker, the lunula become or mesh-like, and in later stages of disease the central portion of the valve may become calcified.

Mitral and Tricuspid Valves

The mitral and tricuspid valves are similar in structure with both valves composed of four primary elements: (1) the valve annulus, (2) the valve leaflets, (3) the papillary muscles, and (4) the chordae tendineae.

The mitral annulus is an elliptical ring composed of dense collagenous tissue surrounded by muscle. It goes through dynamic changes during the cardiac cycle by not only changing in size, but also by moving three-dimensionally. The circumference of the mitral annulus ranges from 8 to 12 cm during diastole.

The mitral valve is a bileaflet valve comprised of an anterior and posterior leaflet. The leaflet tissue is primarily collagen-reinforced endothelium, but also contains striated muscle cells, non-myelinated nerve fibers, and blood vessels.

The mitral leaflet tissue can be divided into both a rough and clear zone. The rough zone is the thicker part of the leaflet and the clear zone is thinner and translucent.

The tricuspid valve has three leaflets: (1) an anterior leaflet, (2) a posterior leaflet with a variable number of scallops, and (3) a septal leaflet. The tricuspid valve is larger and structurally more complicated than the mitral valve and the separation of the valve tissue into distinct leaflets is less pronounced than with the mitral valve.

4.3 Prosthetic Valve Dynamics

Artificial or prosthetic heart valve is a mechanism that mimics the function of a human heart valve. It is used for patients with a heart valvular disease or have a damaged valve.

Types- Mechanical and Biological/Tissue Valves

Mechanical Valves

It is made of titanium or carbon which makes them strong and very durable.

a) Ball and Cage Valve

A ball is housed inside a cage. When the heart contracts and the blood pressure in the chamber of the heart exceeds the pressure on the outside of the chamber, the ball is pushed against the cage and allows blood to flow. When the heart finishes contracting, the pressure inside the chamber drops and the ball moves back against the base of the valve forming a seal.

Advantages

Occluder travel completely out of orifice reducing the possibility of thrombus or pannus growing from the sewing ring to interfere with the Valve Mechanism

Continous changing point of contact of the ball reduces the wear and tear in any one area

Disadvantages

Central flow Obstruction

Collisions with the occluder ball causes damage to blood cells.

Bulky cage design so not suitable for if small LV cavity. or small aortic annulus.

b)Tilting Disc valve

Tilting-disc valves are made of a metal ring covered by an ePTFE (PolyTetraFluro Ethylene) fabric. Metal ring holds, by means of two metal supports, a disc that opens when the heart beats to let blood flow through, then closes again to prevent blood flowing backwards. Disc is usually made of an extremely hard carbon material (pyrolytic carbon), enabling the valve to function for years without wearing out.

Advantages

Low profile, Central blood flow, Decrease turbulence, Thrombotic risk is reduced

Disadvantages

Thrombus and Pannus interfering with the motion of disc, Careful orientation of disc needed during implantation

c)Bileaflet valves

Bileaflet valves are made of two semicircular leaflets that revolve around struts attached to the valve housing. With a larger opening than caged ball or tilting-disc valves, they carry a lower risk of blood clots. They are, however, vulnerable to blood backflow.

Advantages

Carbon leaflets and flange exhibit high strength and excellent biocompatibility, Largest opening angle, Low turbulence, Easier insertion

Tissue valves

Heterografts- Using valves from other animals. Porcine valve of a pig is the most comparable valve to a human.

Pericardial valves: Biological valve tissue can be taken from a cow or horses pericardial sac and be sewed to a metal frame.

Homografts - Actual human valves that are donated. Less risk of infection. No guarantee that the valve will be the correct size for a certain patient

4.4 Mechanical properties of blood vessels – arteries, arterioles, capillaries, veins

There are four types of blood vessels:

Arteries: carry oxygenated blood from the heart to the rest of the body. Arteries are strong and stretchy, which helps push blood through the circulatory system. Their elastic walls help keep blood pressure consistent. Arteries branch into smaller arterioles.

Arterioles : A small branch of an artery leading into capillaries.

Veins: these carry deoxygenated blood back to the heart and increase in size as they get closer to the heart. Veins have thinner walls than arteries.

Capillaries: they connect the smallest arteries to the smallest veins. They have very thin walls, which allow them to exchange compounds with surrounding tissues, such as carbon dioxide, water, oxygen, waste, and nutrients.

The vasculature is a complex architecture of blood vessels that carry blood to and from various organs of the body. The blood vessels may be classified based on their sizes, function and proximity to the heart

Vessel	Aorta	Artery	Arteriole	Capillary	Venule	Vein	Vena cava
Wall Thickness	2mm	1mm	20μm	1μm	2μm	0.5mm	1.5mm
Lumen	25mm	4mm	30μm	8μm	20μm	5mm	30mm

Structural elements of vascular wall

The components of blood vessels

Endothelial Cell (EC)

- Cells lining the inner wall layer of blood vessels
- prevent thrombosis and entry of blood borne bacteria to vascular wall etc.
- regenerate if injured
- mechanical properties are negligible
- Very sensitive to shear stress and so very relevant in biomechanical
- tend to align in the direction of shear stresses

Elastin

- Taut tubular fiber
- Highly elastic; low stiffness (50 N/cm2)
- Bears the load under physiological
- Can stretch up to 60% and remain elastic

Collagen

- Tortuous, thick fiber
- High stiffness
- Responsible for structural integrity of vessel
- Not always wavy, but is wavy in vascular tissues and skin

Smooth Muscle Cell (SMC)

- Involuntary muscle cells
- Responsible for ‘active’ properties of blood vessel wall
- Difficult to measure mechanical properties - E ~ 1 N/cm2

Ground Substance (GS) - Kind of a glue that keeps all components together

Layered microstructure of the vascular wall

The blood vessel wall consists of three layers - the intima, media and adventitia. The thickness of these layers may vary from one kind of vessel to another, however, the exist in all the blood vessels and are made up mostly of various amounts of the above structural components.

a)Intima - Inner most layer - Mostly endothelial cells - Very little collagen (debated)

b) Media - Middle layer - Usually thickest layer - SMCs 33%; GS 6%; Elastin 24%; collagen 37% - Most of collagen and elastin in this layer

c)Adventitia - Outer layer - Mostly collagen - Fibroblasts 9%; GS 11%; elastin 2%; collagen 78%

Mechanical characteristics of vascular wall

Viscoelasticity : The blood vessel wall is viscoelastic. Viscoelasticity is the property of the artery to exhibit both solid and fluid behavior owing to its biphasic microstructure. Solid behavior refers to its ability to exhibit a certain resistance to deformation like an elastic body. Fluid behavior refers to its ability to ‘flow’ due to sustained force. Thus when a constant force is exerted on an artery over an extended period of time, it will first deform like an elastic body, and then continue to deform or ‘flow’ for a finite period.

Anisotropy: The blood vessel wall is significantly anisotropic.

Incompressibility: The blood vessel wall has been shown to be almost incompressible. The incompressibility of the vascular wall does not mean, it cannot be squeezed or extended in one or two directions. It just means that, when the artery is deformed in one direction, an opposite deformation will take place in the other directions in such a way that the volume of the tissue remains a cons; tant.

Residual stress Residual stress is a stress that exists in an uncut tubular artery even when it is under zero pressure. We know these stresses exist because, when a small piece of tubular artery under zero pressure is cut longitudinally, it springs open

4.5 Blood flow

A fluid is any substance that flows or deforms under applied shear stress. Fluid has tendency to flow.

There are Six different types of fluid flow:

Steady and Unsteady

Uniform and Non-Uniform

Laminar and Turbulent

Compressible and In-compressible

Rotational and Irrotational

One, Two, and Three -dimensional Fluid Flow

1.Steady and Unsteady Flow

The steady flow is defined as that type of flow in which the fluid characteristics like velocity, density, pressure, etc at a point do not change with the time.

$$\frac{\partial V}{\partial t} = 0, \frac{\partial p}{\partial t} = 0, \frac{\partial J}{\partial t} = 0$$

The Unsteady flow is defined as that type of flow in which the fluid characteristics like velocity, density, pressure, etc at a point change respected to time.

$$\frac{\partial V}{\partial t} \neq 0, \frac{\partial p}{\partial t} \neq 0, \frac{\partial J}{\partial t} \neq 0$$

2. Uniform and Non-Uniform flow

Uniform fluid flow is defined as the type of flow in which the velocity at any given time does not change with respect to space (i.e length of direction of the flow).

$$(\frac{\partial V}{\partial t})_{t\ is\ a\ constant} = 0$$

Non-uniform fluid flow is defined as the type of flow in which the velocity at any given time changes with respect to space (i.e length of the direction of the flow).

$$(\frac{\partial V}{\partial t})_{t\ is\ a\ constant} \neq 0$$

3. Compressible and In-compressible flow

Compressible fluid flow is defined as the flow in which the density is not constant which means the density of the fluid changes from point to point.

$$\rho \neq \text{constant}$$

Incompressible fluid flow is defined as the flow in which the density is constant which means the density of the fluid does not change from point to point.

$$\rho = \text{constant}$$

4. Rotational and Irrotational flow

Rotational fluid flow is defined as the type of fluid flow in which the fluid particles while flowing along streamline and also rotate about their own axis.

Irrotational fluid flow is defined as the type of fluid flow in which the fluid particles while flowing along streamline and do not rotate about their own axis.

5. Laminar and Turbulent Flow

Laminar fluid flow is defined as the type of flow in which the fluid particles move along well-defined paths or streamline and all the streamlines are straight and parallel. Thus the particles move in laminas or layers gliding smoothly over the adjacent layer. This type of fluid is also called as streamline flow or viscous flow.

Turbulent fluid flow is defined as the type of flow in which the fluid particles move in a zig-zag way, the eddies formation takes place which is responsible for high energy loss.

For vessel flow, The type of flow is determined by a non-dimensional number [(VD) / (ν)] called the Reynolds number.

Where,

D = Diameter of pipe

V = Mean velocity flow in a pipe

ν = Kinematic viscosity of the fluid.

If Reynold Number is less than 2000, the flow is called Laminar flow.

Reynold Number is more than 4000, the flow is called Turbulent flow.

If the Reynold Number is lies between 2000-4000, the flow may be laminar or turbulent.

6. One, Two, and Three -dimensional Fluid Flow

One dimensional flow is that type of flow in which the flow parameter such as velocity is a function of time and one space co-ordinate only, say x.

u=f(x), v=0 and w=0

Where u,v and w are velocity component in x,y and z directions respectively.

Two-dimensional fluid flow is the type of flow in which velocity is a function of time and two rectangular space co-ordinate say x,y.

u= f1(x,y,), v= f2(x,y,) and w= 0.

Three-dimensional fluid flow is the type of flow in which velocity is a function of time and three mutually perpendicular directions. The function of 3 space coordinates (x,y,z).

$u = f1(x,y,z)$, $v = f2(x,y,z)$ and $w = f3(x,y,z)$.

SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – V – BIOMECHANICS – SBTA1102

APPLICATIONS OF BIOMECHANICS

5.1 Mechanics of spinal distraction rods

Spinal fixation devices are used in the thoracic and lumbosacral spine to stabilize the spine, reduce deformities and fractures, and replace abnormal vertebrae. In some cases of lumbar spinal pain, surgical intervention is necessary for the treatment of conditions such as herniated disks, spondylolysis with spondylolisthesis, and degenerative disease with scoliosis. Surgical procedures consist of posterior and anterior (vertebral body) fixation.

Spinal fixation is used in the thoracic and lumbosacral spine to provide stability and restore anatomic alignment in the treatment of fractures, degenerative disease, and infection and tumors and to correct congenital deformities such as scoliosis.

Fixation devices such as plates and rods are attached to the vertebral body or posterior elements by wire, screws, and hooks. Screws and wire can also be used as a primary means of fixation.

Scoliosis is a common indication for spinal instrumentation and fusion. Congenital scoliosis generally results in short, sharply curved segments

The majority of fixation devices used in the thoracic and lumbosacral spine are placed posteriorly. The three primary techniques for attaching instrumentation to the posterior spine are (a) sublaminar and interspinous wires or cables, (b) laminar and pedicle hooks, and (c) pedicle screws.

Rods are commonly used for posterior fixation partly because of their ability to span a long segment. They are attached to the spine with wire, hooks, or screws, and sometimes several of these techniques are combined in the same patient. Wire and occasionally cable are used to attach rods directly to the posterior elements .

Sublaminar wiring is accomplished by passing a wire or pair of wires around the lamina and rod; the ends are usually twisted together. Generally, a smooth rod is used and is attached to the spine at every laminar level. Interspinous wiring involves passing a wire through a hole in the spinous process.

Sublaminar cable or Songer cable is used in place of wire . The cable is more pliable and less brittle than wire. One end of the cable is passed through a premade loop in the other end and is held in place by a metal crimp.

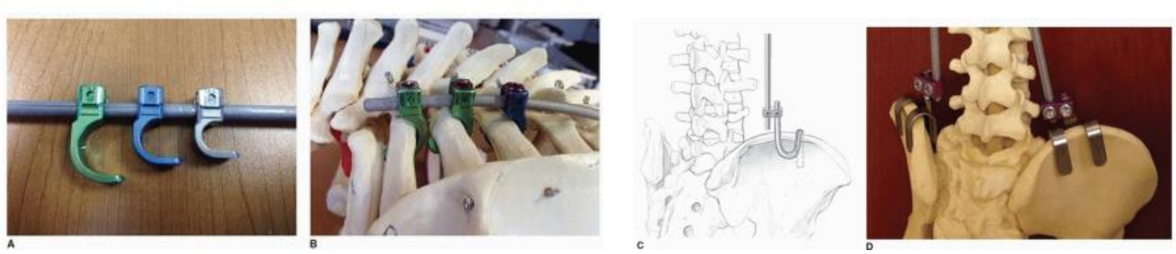
Laminar or sublaminar hooks, used as compression and distraction hooks, are available in a variety of sizes and shapes to accommodate the site of attachment. They function as ‘ ‘hooks’ ‘ as they engage the posterior elements by curving under (upgoing hooks) or over (downgoing hooks) the lamina. The hooks may be sharp or blunt, and some have ridges to help prevent slippage. The body of the hook fits over the rod and is held in place by lock washers, bolts, or set screws.

Pedicle screw fixation or transpedicle screws are angled medially as they pass through the pedicle and into the vertebral body. They have a very shallow cancellous thread pattern to maximize the core diameter and therefore their strength. They are attached to rods or plates posteriorly with clamps, eyebolts, or set screws.

Luque rods are straight or L-shaped smooth rods (6 or 8 mm in diameter), The rods are attached to the lamina at every level with sublaminar wiring, which distributes the corrective force over multiple levels. A 90^0 bend is placed at the end of the rod, and that segment is passed through a hole in the spinous process, preventing rotation and migration of the rod.

The Galveston technique uses long Luque rods attached to the thoracic and lumbar spine with sublaminar wires. The rods continue down the spine and flare out laterally as they enter the iliac bones, providing a stable construct from the thorax to the pelvis.

Harrington distraction rods were originally designed for the treatment of scoliosis. The rods are smooth, with a collar at one end and ratchets at the other end. They usually span at least five vertebrae and transmit a distractive force to the spine at the ends where the laminar hooks are placed. The hook on the ratchet end is held in place with a special washer. Some rods have holes in the collar for wire sutures, which can be used to prevent rotation and migration.



5.2 Control interfaces with application to limb orthotics and prosthetics

Prosthetics involves the use of artificial limbs to enhance the function and lifestyle of persons with limb loss. The prosthesis must be a unique combination of appropriate materials, alignment, design, and construction to match the functional needs of the individual. Lower limb prostheses might address stability in standing and walking, shock absorption, energy storage and return, cosmetic appearance, and even extraordinary functional needs associated with running, jumping, and other athletic activities. Upper limb prostheses might address reaching and grasping, specific occupational challenges such as hammering, painting, or weight lifting, and activities of daily living such as eating, writing, and dressing.

The orthosis acts to control weakened or deformed regions of the body of a physically challenged person. Orthoses may be used on various areas of the body including the upper and lower limbs, cranium, or spine. Common orthotic interventions include spinal orthoses for scoliosis, HALOs used in life-threatening neck injuries, and ankle foot orthoses used in the rehabilitation of children with cerebral palsy.

Control Sites in devices

An investigation of the nervous system, sensory receptive organs and regulatory circuits can offer significant insight into this study and in turn allow us to define our model which will eventually produce analogous simulation of the analyzed functions.

Artificial systems to replace or assist an absent or impaired organ presents particular problems in its automation at the man-machine interface.

A prosthesis that is well adapted to man implies a device which can reproduce physiological actions as closely as possible while including a maximum possibility for control by the individual himself. Such a device must enable the subject to choose the program to be used and to command the starting and stopping of the walking sequence as well as its functioning.

Commands in response to biological signals can be effected in different ways :

1.on-off commands of individual functions

2. graded commands in the stationary or moving position (s) of each degree of freedom

3. a system of codes to signal the choice of an automatic sequence.

Regulation will have to be concerned with a maximum of human sensory perception: visual, tactile, auditory. Where these inputs are non-existent, it will be necessary to artificially generate feed-back information to automatically regulate a function or part of a function. Following this, the information should be relayed to receptive zones so that, at all moments, the individual is aware of his system's functional state.

The artificial system can be commanded through one or several signal inputs. In fact, after integrating the appropriate code system, a single biological signal can suffice to choose and control a function, but in this instance the time to execute such a function would be relatively long. By using several command signals the time to execute a given function would be reduced and several functions could be controlled simultaneously. Nevertheless, an excessive number of biological signals would make control more difficult and would more greatly fatigue the subject.

Different Command Sites

Among the available biological command sites in man, those which represent the best "commandibility" will have to be chosen, i.e. the sites which give rise to precise, rapid and reproducible movements.

Myo-electric signals picked-up by electrodes external to or implanted in the muscle ;

Articular movement especially head or shoulder movement

Occular movement:this involves various transductive methods :

Measurement of the electric field produced by the retina, by electrodes placed on the skin on either side of the eye.

Measurement of eye position by a magnetic method where an induction coil within a contact lens is placed on the cornea.

Transduction of infra-red waves reflected on the iris .

Inspiration and expiration

Jaw or tongue movements, used to activate a series switches, or a control stick;

Voice control using signals originating from glottic transducers, or more sophisticated apparatus which analyses speech itself.

5.4 Automated driver's training programme

The training protocol guidelines that can be used by automated vehicle trainers to optimize overall system use and transportation safety.

It is a driver training program that aims to remove the potential for human error or negligence in recognizing when intervention is required to correct dangerous driving habits. It monitors a fleet driver's behaviors and then automatically assigns the corresponding online interactive training that will help the driver improve

Features:

Training on technical trades such as auto mechanics, welding, painting, electrical, electronics, etc.

Equipped with a Driving track that has all real time driving terrain features such as S, 8, H, up-gradient, parallel, angular track, perpendicular parking, V point etc.

Specialized Aggregate room equipped with Cut section models of various working system of an automobile.

Driving lab facilities to test the physical ability of driver which include the Driving simulator.

Dual Control Vehicle.

Workshop bay-for repair and maintenance of training vehicles.

Benefits:

Enhancing driving skills of drivers.

Creation of pool of trained drivers for auto industry.

Developing right attitude for safe driving and road safety.

Build positive image for company products.

5.5 Sports Mechanics

Sport biomechanics studies the effects of forces and motion on sport performance. Using laws and principles grounded in physics that apply to human movement, athletes and coaches can make sound decisions for developing efficient sport techniques. It refers to the description, detailed analysis and assessment of human movement during sport activities.

In other words, sport biomechanics is the science of explaining how and why the human body moves in the way that it does.

Anatomy and physiology lay the foundation for biomechanics and kinesiology, areas of study about human movement.

The following are some of the areas where biomechanics is applied, to either support the performance of athletes or solve issues in sport or exercise:

The identification of optimal technique for enhancing sports performance , The analysis of body loading to determine the safest method for performing a particular sport or exercise task , The assessment of muscular recruitment and loading,The analysis of sport and exercise equipment e.g., shoes, surfaces and rackets.

Advantages of SBM

Analyze sport movements,

Select the best training exercises,

Reduce or prevent injuries,

Design or choose the sport equipment that best matches athletes' personal needs.

Maximize economy and efficiency of movements.

Principles of BM applied

Forces and Torques

A force is simply a push or pull and it changes the motion of a body segment or the racket. When force rotates a body segment or the racquet, this effect is called a torque or moment of force. Example - Muscles create a torque to rotate the body segments in all tennis strokes. To rotate a segment with more power a player would generally apply more muscle force.

Newton's Laws of Motion

Newton's Three Laws of Motion explain how forces create motion in sport. These laws are usually referred to as the Laws of Inertia, Acceleration, and Reaction.

Law of Inertia - Newton's First Law of inertia states that An object in motion will tend to stay in motion and an object at rest will tend to stay at rest unless acted upon by a force. Example - The body of a player quickly sprinting down the field will tend to want to retain that motion unless muscular forces can overcome this inertia or a skater gliding on ice will continue gliding with the same speed and in the same direction, barring the action of an external force.

Law of Acceleration - Newton's Second Law precisely explains how much motion a force creates. The acceleration (tendency of an object to change speed or direction) an object experiences is proportional to the size of the force and inversely proportional to the object's mass ($F = ma$). Example - When a ball is thrown, kicked, or struck with an implement, it tends to travel in the direction of the line of action of the applied force. Similarly, the greater the amount of force applied, the greater the speed the ball has.

Law of Reaction - The Third Law states that for every action (force) there is an equal and opposite reaction force. This means that forces do not act alone, but occur in equal and opposite pairs between interacting bodies. Example - The force created by the legs "pushing" against the ground results in ground reaction forces in which the ground "pushes back" and allows the player to move across the court .

Momentum

Newton' Second Law is also related to the variable momentum, which is the product of an object's velocity and mass. Momentum is essentially the quantity of motion an object possesses. Momentum can be transferred from one object to another. There are different types of momentum which each have a different impact on the sport.

Linear Momentum

Linear momentum is momentum in a straight line e.g. linear momentum is created as the athlete sprints in a straight line down the 100m straight on the track.

Angular Momentum

Angular momentum is rotational momentum and is created by the rotations of the various body segments e.g. The open stance forehand uses significant angular momentum. The tremendous increase in the use of angular momentum in ground strokes and serves has had a significant impact on the game of tennis.

Centre of Gravity

The Center of Gravity (COG) is an imaginary point around which body weight is evenly distributed. The center of gravity of the human body can change considerably because the segments of the body can move their masses with joint rotations.

The direction of the force of gravity through the body is downward, towards the center of the earth and through the COG. This line of gravity is important to understand and visualise when determining a person's ability to successfully maintain balance.

Balance

Balance is the ability of a player to control their equilibrium or stability. You need to have a good understanding of both static and dynamic balance:

Static Balance

The ability to control the body while the body is stationary. It is the ability to maintain the body in some fixed posture. Static balance is the ability to maintain postural stability and orientation with center of mass over the base of support and body at rest.

Dynamic Balance

The ability to control the body during motion. Dynamic balance is the ability to maintain postural stability and orientation with center of mass over the base of support while the body parts are in motion.

Applications

Running Biomechanics

Running is similar to walking in terms of locomotive activity. In running, there is just one stance phase while in stepping there are two. Shock absorption is also much larger in comparison to walking. This explains why runners have more overload injuries.

Running Requires:

Greater balance, Greater muscle strength, Greater joint range of movement.

Tennis Biomechanics

Tennis biomechanics is a very complex task. Consider hitting a tennis ball. First, the athlete needs to see the ball coming off their opponent's racket. Then, in order, they have to judge the speed, spin, trajectory and, most importantly, the direction of the tennis ball. The player then needs to adjust their body position quickly to move around the ball. As the player prepares to hit the ball the body is in motion, the ball is moving both in a linear and rotation direction if there is spin on the ball, and the racquet is also in motion. The player must coordinate all these movements in approximately a half a second so they strike the ball as close to the center of the racket in order to produce the desired spin, speed and direction for return of the ball. A mistake in any of these movements can create an error.

Cycling Biomechanics

There are 3 points of contact in cycling. Meaning 3 points of the body that make contact with the bike:

Pelvis on the saddle, Hand on the handlebars, Foot on the pedal

Something to be aware of is that these areas can undergo sustained amounts of pressure and compression which can cause numbness, pain and weakness.

Phases of Cycling / Pedaling

There are 2 main phases of the pedal cycle; the power phase and the recovery phase. If you imagine the pedal cycle as a clock face and you start with the pedal at 12 o'clock, this is known as Top Dead Centre (TDC). The pedal is then pushed down from 12 until 6 o'clock, this position is known as Bottom Dead Centre (BDC). The phase between the 2 is known as the Power Phase where all the force is generally generated to propel the bike forward.