BIOMECHACS

By:

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Acknowledgments

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Contents

جامعة /أكاديمية : المعاهد الفنية الصحية التابعة لوزارة الصحة والسكان
قسم : فنى العظام

توصيف مقرر دراسى

Course Specifications

1- بيانات المقرر		
الرمز الكودى :	اسم المقرر : الميكانيكا الحيوية Biomechanics	الفرقة /المستوى : الثانية
التخصص :	عدد الوحدات الدراسية : نظرى 2	عملى 2

2- هدف المقرر: 2- Overall Aim of Course:	**The purpose of this course is to identify the explanation of the terminology and principles of biomechanics. Also the course covers the theoretical knowledge and practical skill relevant to various joints biomechanics.**
3- المستهدف من تدريس المقرر :	3- Intended learning outcomes of the course (ILOs):
ا. المعلومات والمفاهيم : Knowledge and Understanding:	Upon successful completion of this course the students will be able to: 1- Demonstrate understanding of knowledge and awareness of the issues of biomechanics 2- Recognize principles of mechanisms of fractures and tissue injuries 3- Recognize forces and movements of different joints in relation to their anatomical bases.
ب- المهارات الذهنية : II) Intellectual Skills:	1. Analyze the forces various joints for different static and dynamic activities. 2. Identify relationships between structure and function in different human tissues and the importance of these relationships.
ج- المهارات المهنية	1. Apply principles of biomechanics for

understanding the performance of various musculoskeletal structures 2. Use comprehends knowledge in biomechanics to overcome diverse problems and issues in exercise and movement as well as prevention of tissue injury	الخاصة بالمقرر: III. Professional Skills:
Upon successful completion of this course the students will be able to: ***1.*** Use sources of medical information and communication technology independently. **2**. Communicate effectively with colleagues, staff members and helping personnel. ***3.*** Work in interdisciplinary team according to rules and principles for assessment and within time-planned programs	د- المهارات العامة : IV) General and Transferable Skills:
1-Introduction and basic definitions. **2-** Forces and loads on musculoskeletal system. **3-** Mechanisms and patterns of fractures. 4-Biotribology. 5- Biomechanics of different biomaterials. 6- Biomechanics of shoulder joint. 7-Biomechanics of elbow joint. 8-Biomechanics of wrist joint. 9-Biomechanics of hip joint and total hip replacement. 10-Biomechanics of knee joint. 11-Biomechanics of ankle joint. 12-Biomechanics of spine.	4- محتوى المقرر: 4- Course content

1. Lectures. **2. Group discussions.** **3. Practical sessions.**	5- أساليب التعليم والتعلم 5- Teaching and Learning Methods:
If it is a must to accept disable students they should have certain characters as they will deal with flames and wax carvers and knives. As examples they should;	6- أساليب التعليم والتعلم للطلاب ذوى القدرات المحدودة Teaching and learning

1- Able to move their hands well. 2- Be mentally graded well. 3- See properly. For these students regular Teaching and learning methods could be used.	methods for students with limited abilities
7- Student Assessment:	7- تقويم الطلاب :
a. Class work: 1. Quizzes 2. Midterm theoretical 3. Practical exam **b.** Final exam: Theoretical and practical	أ- الأساليب المستخدمة **a- Assessment methods:**
a. Class work: 1. Quizzes: Quiz I (4th week) Quiz II (11th week) 2. Midterm theoretical (7th week) b. Final exam Practical exam (13th week) written theoretical exam (15th week)	ب- التوقيت **b- Assessment schedule:**
Quizzes (15%), 15 mark Midterm theoretical (15%), 15 marks Final Practical exam (20%), 20 marks Final written theoretical exam (50%), 50 marks. Total percentage 100%	ج- توزيع الدرجات **C-Weight Of Assessments**
8- List of References:	8- قائمة الكتب الدراسية والمراجع :
Lecture and practical notes for biomechanics for orthopedic technicians	أ- مذكرات a- **Course notes:**

1-Knudson, D 2007, Fundamentals of Biomechanics, 2nd edn, Springer: New York, NY, USA. **2-Nigg, B.M., & Herzog, W 2006, Biomechanics of the Musculo-skeletal System, 3rd edn, John Wiley & Sons: Chichester, West Sussex, England.**	ب- كتب ملزمة b- **Essential books (text books)**
Hall S 2013, *Basic Biomechanics*, 7th edn, McGraw-Hill, New York.	ج- كتب مقترحة c- **Recommended**

	books
https://www.journals.elsevier.com/clinical-biomechanics www.pubmed.com	د- دوريات علمية أو نشرات ...... الخ d- **Periodicals, web sites, ,,,,,**

Course Description

This course will focus on orthopedic rehabilitation principles and techniques and approaches to manage common musculoskeletal disorders. This involves identifying, understanding and the clinical manifestations and management plan of disorders affecting various joints. Students will earn about various physical modalities as well as basic principles of orthotics and prothesis. They will also gain practical experience by applying the knowledge gained during the academic year to better understand their audience and create more effective health messages and programming.

Core Knowledge

By the end of this course, students should be able to:

- Demonstrate understanding of knowledge and awareness of the issues of biomechanics

- Recognize principles of mechanisms of fractures and tissue injuries

- Recognize forces and movements of different joints in relation to their anatomical bases.

Core Skills

By the end of this course, students should be able to:

- Analyze the forces various joints for different static and dynamic activities.

- Identify relationships between structure and function in different human tissues and the importance of these relationships.
- Apply principles of biomechanics for understanding the performance of various musculoskeletal structures
- Use comprehends knowledge in biomechanics to overcome diverse problems and issues in exercise and movement as well as prevention of tissue injury

Week	Theory	Practice
1st week	Introduction and basic definitions	Mechanical testing of musculoskeletal tissues: tendons
2nd week	Forces and loads on musculoskeletal system	Mechanical testing of musculoskeletal tissues: muscles
3rd week	Mechanisms and patterns of fractures	Mechanical testing of musculoskeletal tissues: bones
4th week	biotribology	Mechanical testing of musculoskeletal tissues: joints 1st quiz (theoretical and practical)
5th week	Biomechanics of different biomaterials	Mechanical testing of biomaterials
6th week	Biomechanics of shoulder joint	Applied Biomechanics of shoulder joint
7th week	Biomechanics of elbow joint	Applied Biomechanics of elbow joint Midterm (theoretical)
8th week	Biomechanics of wrist joint	Applied Biomechanics of wrist joint
9th week	Biomechanics of hip joint and total hip replacement	Applied Biomechanics of hip joint
10th week	Biomechanics of knee joint	Applied Biomechanics of knee joint
11th week	Biomechanics of the ankle joint	Applied Biomechanics of ankle joint 2nd quiz (theoretical and practical
12th week	Biomechanics of the spine	Applied Biomechanics of spine

Chapter 1
Introduction and basic definitions

Objectives:

- Identify the difference kinetics and kinematics.
- Define the most common axes and planes of motion.
- Identify the Newton's laws of motion.

Kinesiology: is the science that is concerned with motion study. Biomechanics is one of the main elements that contribute in kinesiology and concerned with evaluation of the mechanical characteristics of biological systems. The term biomechanics comes from the Greek word (**Bio)** which means **life** and the word **(Mechanics)** which is the branch of physics that study the influence of forces performance on a body. The aim of orthopedic biomechanics study is to improve performance of human movement and to prevent and treat injury of musculoskeletal system.

What is the difference between kinetics and kinematics?

Kinetics: study of forces which initiate or resist the motion. Forces may be internal or external.

Kinematics: focuses on type of movement **(not the force).**

What is the difference between axis and plane?

Axis: is the line around which the motion occurs.

Plane: is the surface that lies at right angles to axis and in which the motion occurs.

What are types of axis?

There are 3 types of axes:

1- **Sagittal axis:** it runs in the anterior-posterior direction, parallel to sagittal suture of the skull. Movement around this axis occurs in frontal plane.

2- **Transverse axis:** it lies at right angle to sagittal axis, parallel to coronal suture of the skull. Movement around this axis occurs in sagittal plane.

3- **Vertical axis:** it lies parallel to the line of gravity. Movement around this axis occurs in horizontal plane.

What are types of planes?

There are 3 types of planes:

1- **Sagittal plane:** it is anterior-posterior vertical plane that divide the body into right and left haves. Movement at this plane occurs around transverse axis.

Example**:** Nodding of the head.

2- **Horizontal plane:** this plane divide the body into upper and lower haves and movement occurs parallel to the ground. Movement at this plane occurs around vertical axis.

Example: Nose movement with head rotation.

3- Frontal (coronal) plane: this plane divide the body anterior and posterior haves. Movement at this plane occurs around sagittal axis.

Example: bringing the ear to the shoulder.

What are types of motion?

There are 4 types of motion:

1- **Translatory motion:** it is movement in straight line.
2- **Rotatory motion:** it is movement in a curved pathway around fixed axis.
3- **Curvilinear motion:** it is a combination of translator and rotatory motion.

4- **General plane motion:** the object is free to move.

Newton's laws of motion

First law of Newton (law of inertia):

" a resultant force must act on an object to change its state of motion".
" a body can only speed up or slow down if an external force acts on the body".

Second law of Newton (law of acceleration):

It explains the relationship between cause (force) and effect (motion).

" a resultant force leads to a change in momentum of an object"

" the size of the acceleration is directly proportional to the size of the unbalanced force".

"The size of the acceleration is inversely proportional to the mass of the body".

Third law of Newton (the law of action–reaction):

" for every force, there is an equal and opposite force".

" the magnitude of the force on each body is equal in magnitude to the force on the other body".
"The direction of the force on each body is opposite to the direction of the force on the other body".

Chapter 2

Forces and loads on musculoskeletal system.

Objectives:

- Identify the different types of forces.
- Identify the different types of levers in the musculoskeletal system.

There are 2 types of forces that act on an object:

1- Internal force: provided by a source inside the body and it does not affect motion of the object.

Example: muscle contraction.

2- External force: provided by a source outside the body and affects motion of the object.

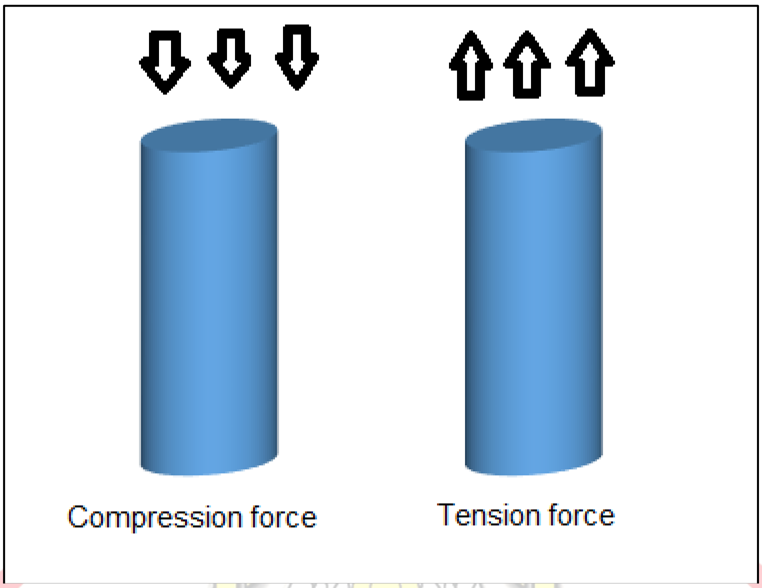
Example: Gravity is force that attract objects and bodies to the earth.

What is the difference between compression and tension forces?

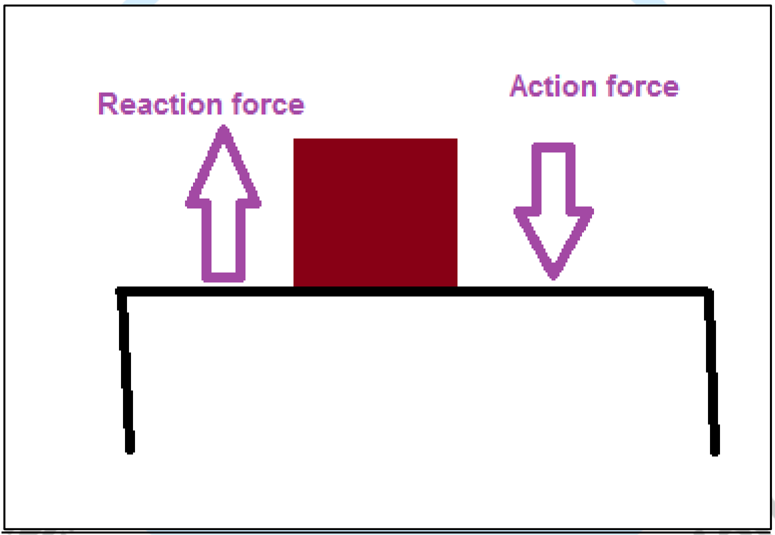
Compression force: direction of the force towards the center and it tends to squeeze the object.

Tension force: direction of the force is away from the center and it tends to pull the object.

Both forces produce structure stress.



Reaction force: it is the force that work in the opposite direction.



What is the difference between stress and strain?

Stress: intensity of force acting on surface of an object.

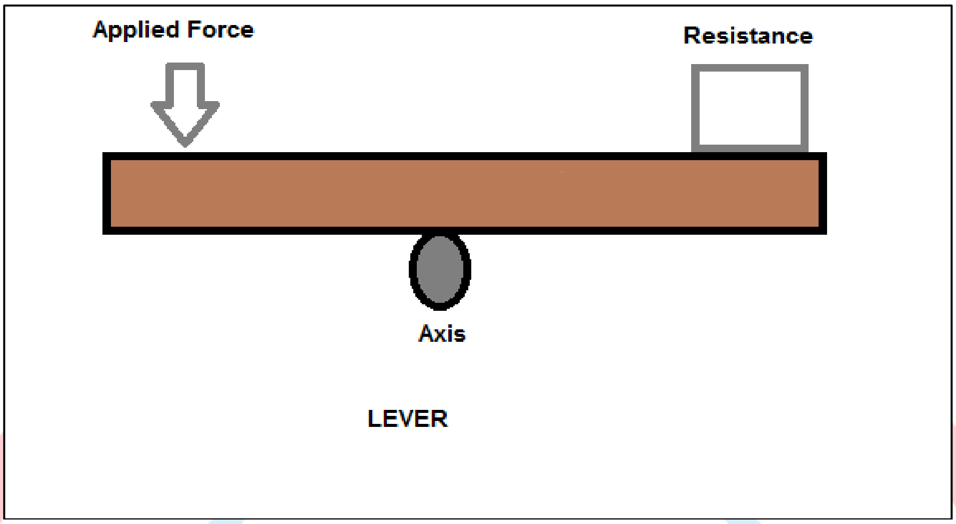
Strain: is an object deformation due to stress.

Levers in musculoskeletal system

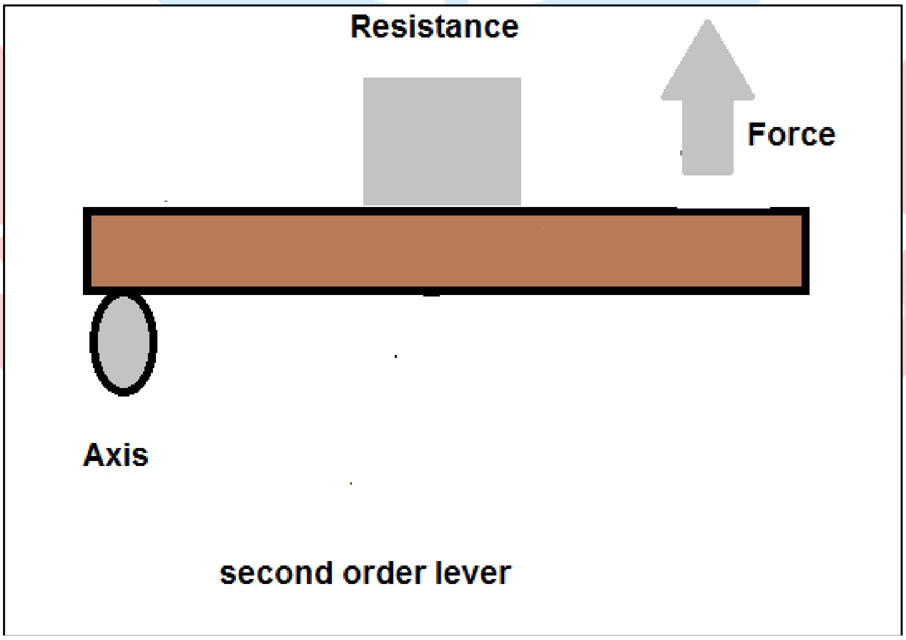
Lever: a machine that consists of a rigid bar that rotate around an axis and it has 2 forces that work on it (applied force and resistance force).

Types of levers:

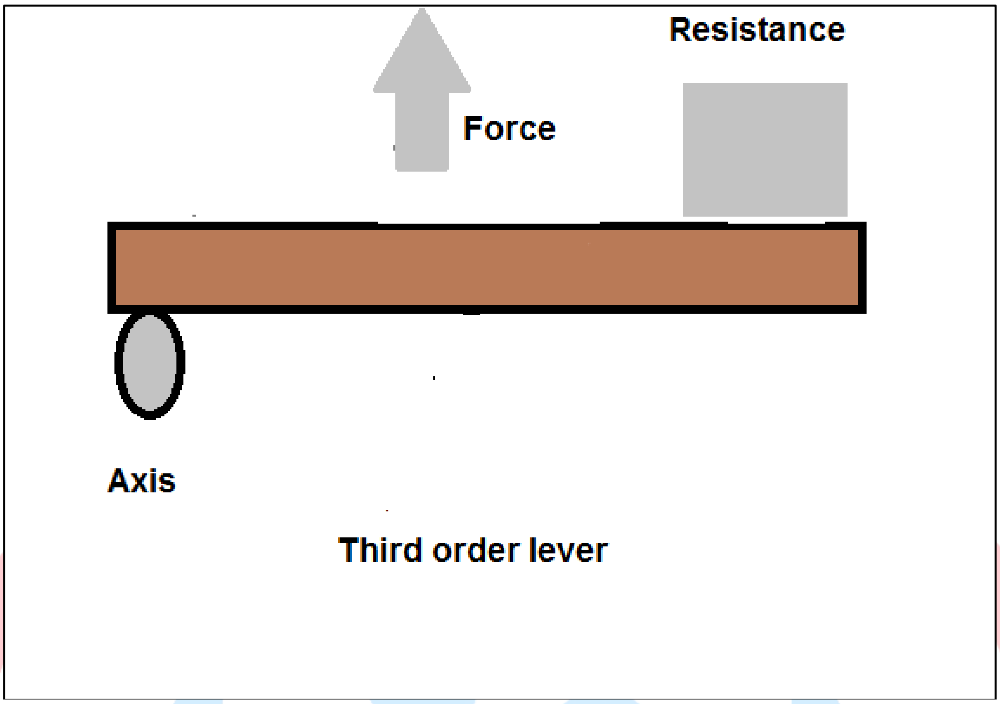
1- First class of levers: in which the axis lies between the applied force and the resistance.



2- Second class of levers: in which the resistance lies between the applied force and the axis.



1- Third class of levers: in which the applied force lies between the resistance and the axis.

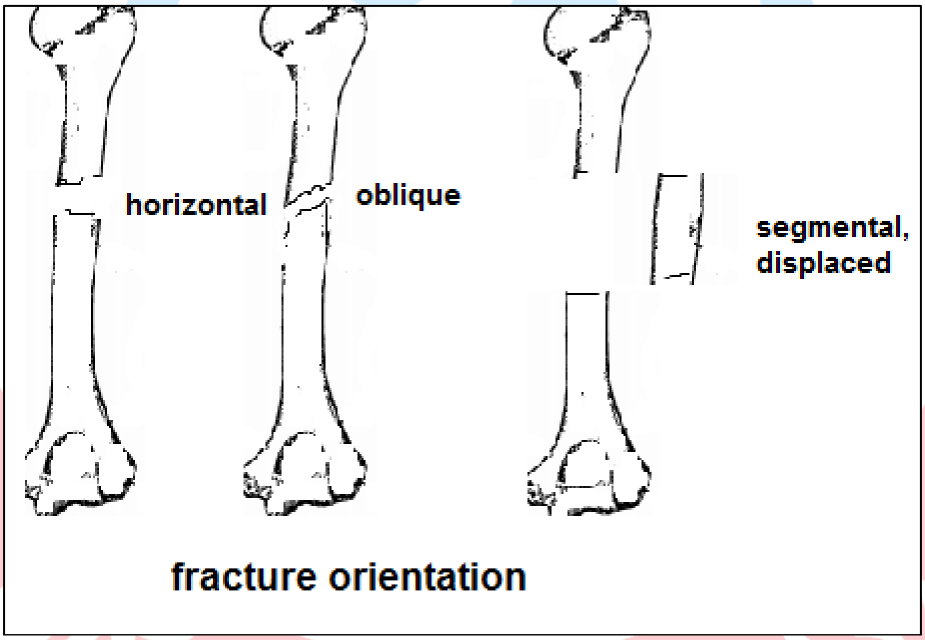


Chapter 3

Mechanisms and patterns of fractures

Objectives:

- Identify the different types of fractures.
- Define the most common fracture mechanisms.
- Identify the different loads and pattern of fractures in adults and children.



Fracture is a break of bone continuity. And it can be described by many methods:

1- The bone ends position: as displaced or non-displaced.

2- Fracture location: e.g intra-articular fracture, intracapsular fracture or metaphyseal fracture.

3- Fracture orientation: linear, horizontal, spiral, oblique and avulsion fractures.

4- The number of bone fragments: as non-comminuted (2 bone fragments) or comminuted (more than 2 bone fragments).

5- Break completeness: as complete or non-complete (involves only one side).

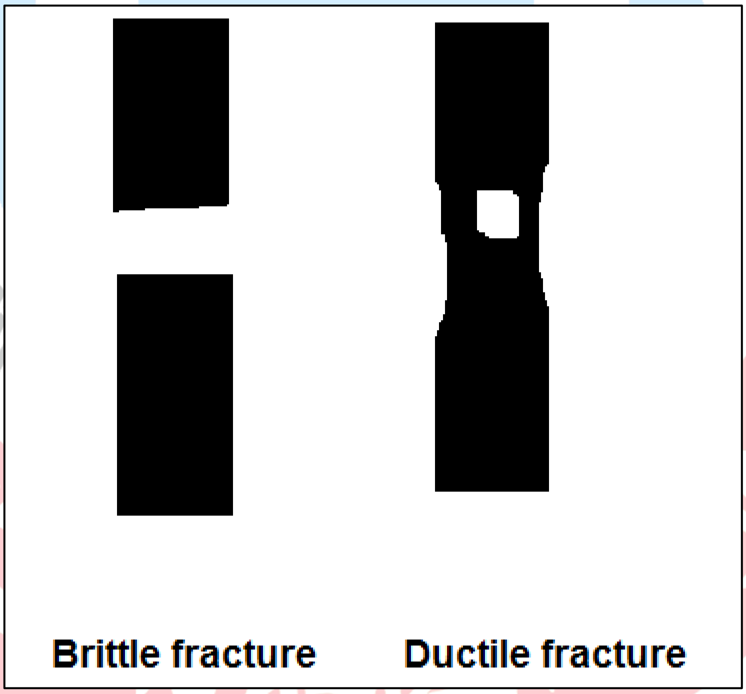
6- Impaction and angulation.

7- If the bone ends penetrate skin or not: as simple or compound fracture.

From mechanical point of view, there are 2 modes of fracture:

1- Brittle fracture: break is initiated in the surface of model and has high liability of propagation in perpendicular direction to the applied stress (unstable) and leaves flat fracture surface. Example: cortical bone fracture.

2- Ductile fracture: where break is initiated in the substance of the model and has low liability of propagation (stable). Example: metal fracture. It is the preferred method in engineering application.



<u>Mechanisms of fracture:</u>

Cortical bone resists compression, intermediate in tension and weak to shear forces

There are 4 main fracture mechanisms:

1-Direct blow: when the load exceeds the tensile strength of bone. It can be high energy (may leads to comminuted fracture) or low energy (can leads to non-displaced fracture.

2-Penetration.

3-Indirect loading: bending, traction, torsion or combination.

4-Repetitive loading (fatigue or stress fracture): when there is prolonged repetitive loading below the tensile strength of bone. It is the most common cause of prosthetic devices failure

Loads and patterns of bone fracture:

Loads on the bone produces fracture in the weakest plane.

1- Tensile load: horizontal fracture perpendicular to loading plane.
2- Compressive load: oblique fracture at 45 degrees of loading plane.
3- Bending load: it produces tensile stress at one cortical point and compression force at the opposite cortical point leading to transverse fracture or butterfly seg
4- Torsional load: it produces shear forces parallel and perpendicular planes tspiral fracture to the longitudinal axis of bone and tensile and compression forces at 45 degrees producing spiral fracture.

In children, the bones are immature and have different mechanical properties as they have thick periosteum that makes a shield around immature bones that contribute in fracture stability and immature bone is weaker and more ductile than mature bone. If the growth plate is involved in fracture, this may affect the growth of long bones.

Compression loads: buckle fracture, usually at metaphysis

Bending loads: greenstick fracture where fracture occurs only at one side of the bony cortex.

Chapter 4
Biotribology

Objectives:

- Define the terminology of tribology.
- Identify the different aspects of tribology: friction, wear and lubrication.

Tribology is the science that study interacting surfaces in relative motion. Biotribology is tribology of the biological systems and it has 3 main aspects:

1- Friction: increased friction force leads to increase wears of the moving surfaces.

2- Wear: is gradual damage of solid surface.

3- Lubrication: decreases wear of the moving surfaces and its efficacy depends on thickness of the lubricant.

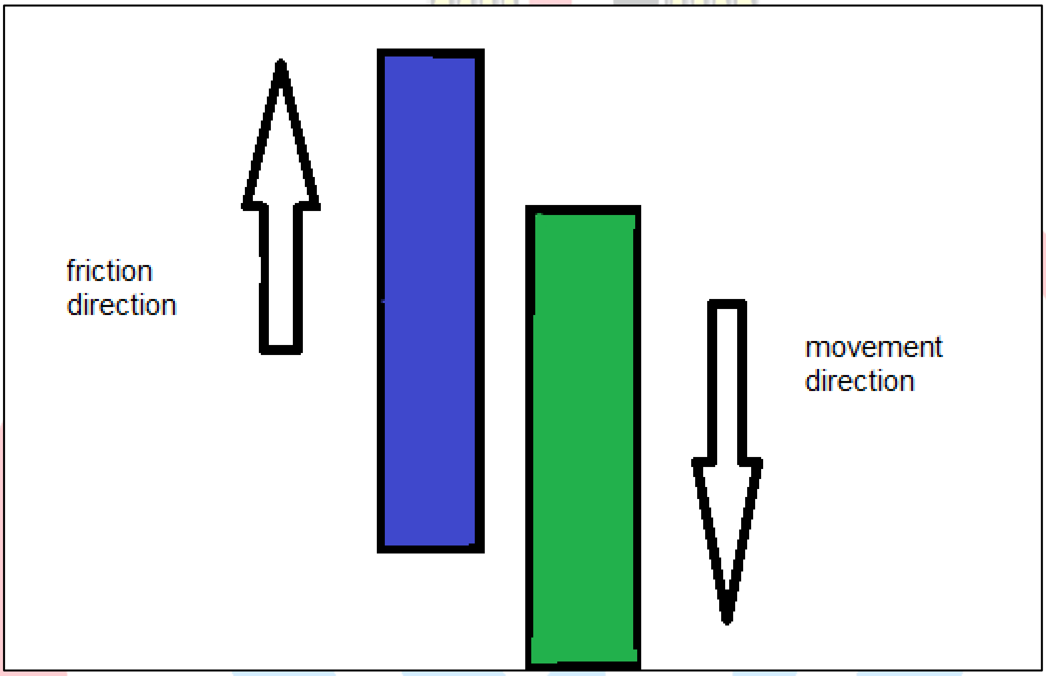
The most important function of the musculoskeletal system is the ability of movement which is mainly occurs via synovial joints. The aspects of tribology helps to understand the function of synovial joints, as well as the pathophysiology of joint diseases. Also, principles of tribology improve designation of artificial joints.

Friction of the synovial joints

It is the relative movement resistance between the 2 in contact moving surfaces. It occurs due to absence of absolute smoothness of the solid surfaces at microscopic level. friction occurs also between different layers of fluid. Friction direction is opposite to the movement direction. There are 2 types of friction of solid surfaces:

1- Static friction: it is the resistance to initiate movement between surfaces.

2- Dynamic friction: it is the resistance to maintain movement between surfaces



Healthy synovial joints have low friction and subsequently minimum wear because the articular cartilage is smooth and the presence of synovial fluid while artificial joints have higher friction and subsequently increased wear.

Wear of the synovial joints

Wear is gradual progressive removal of substance from contact surfaces due to relative motion between them. Wear can be measured by many ways e.g. depth and volume. Wear can occur by many mechanisms as mechanical, chemical mechanism or combination of both.

Wear of the synovial joint leads to joint failure and development of osteoarthritis. A number of protective mechanisms can be used in order to decrease wear of the articular cartilage such as decrease body weight, osteotomy of the knee to shift weight load from compartment to another compartment and osteotomy of the femoral head to improve the contact of the articular surfaces.

Many factors are known to affect artificial joints wear, including design, materials and patients factors

Lubrication of the synovial joints

Three modes of lubrication can occur when lubricant lies between the contact surfaces:

1- Boundary lubrication: fluid film is the same thickness of roughness of the contact surfaces.

2- Fluid film lubrication: fluid film completely separates the contact surfaces

3- Mixed lubrication: fluid film is the slightly thicker than the roughness of the contact surfaces.

Synovial joints are excellent example of tribological system as the opposed articular cartilages and the lubricant is the synovial fluid. The articular cartilage has biphasic properties: solid phase related to collagen and proteoglycans component and fluid phase related to its water content both play an important role in joint lubrication.

Also, many constituents in the synovial fluid such as lubricin and hyaluronic acid plays an important role in synovial joint lubrication.

Chapter 5

Biomechanics of different biomaterials

Objectives:

- Define the terminology of biomaterial.
- Identify the different mechanical properties of different biomaterials.

Biomaterial: it is natural or engineered substance that forms a biological tissue or a mechanical device that replaces or improves a natural function of an organ and can be tolerated by the human body. .

Mechanical properties of biomaterials: It can be divided into:

1- Static properties: strength, stiffness, hardness and ductility.

2- Viscoelastic properties: stress relaxation and fatigue.

Orthopedic biomaterial should be:

- Mechanically suitable.
- Inert.
- High resistance to corrosion.
- Suitable cost

Bone as a biomaterial

Bone is a specialized connective tissue that is formed of cells (osteocytes, osteoblast and osteoclast), extracellular matrix (collagen type I and proteoglycans) and high mineral content. The mineral salts give stiffness to the collagen network. Bones are resistant to fatigue due to its laminated structure.

Bone is composed of 2 types of tissues:

1- Cortical bone: dense (porous from 5% to 30%) and constitute the peripheral walls of bone. It resembles hard plastic.

2- Cancellous bone: less dense (porous 90%) and constitute the central portion of bone.

   Bone is in persistent turn over (remodeling) process by the action of osteoblast osteoclast so bone can change its configuration with change in load .

   Mechanical properties of bone:

- Bone is stiff due its mineral content and has variable strength (like ceramic) as it has more strength to compression and less strength to shear and tension.

- Bone is viscoelastic due its collagen content because of its molecular arrangement.

Metals

Metals have a simple structure as composed of closely packed atoms in a repeating pattern. They atoms are connected by metallic bonds they forms adjacent crystals that can differ in shape and size.

Mechanical properties of metals:

- Metals are denser than other materials and almost all metals (except mercury) are solid so they are stiff and strong. However, pure metals needs more strength and toughness to be used in practical use. So they are transformed to alloys.

- Metals mechanical properties change in high temperature and this enables moulding and shaping of metal for fabrication. This process is called Annealing.

Alloys

Metals are mixed to form alloys in order to increase stiffness, toughness and strength.the most commonly used alloys in orthopedics are:

1- Stainless steel: used in temporary instruments such as plates and nails as it is cheap and has good corrosion resistance.

2- Titanium and titanium alloys: most appropriate for joint replacement as it is very strong and it is half the cobalt–chrome stiffness and has the ability to osteointegeate with bone.

3- Cobalt–chrome: it is much stiff than cortical bone, so not suitable for the stem of the prosthesis but can be used in the articular surfaces of the joint replacement prosthesis as it resist wear.

Ceramics

Ceramics are a large family of non-metallic materials produced by heating, the bonds in ceramics are ionic or covalent bonds. Its structure may be may be crystalline, partially crystalline or amorphous.

Mechanical properties of ceramics:

- Less tense than metals,
- Ionic and covalent bonds have relative higher stiffness and strength as compared to metallic bonds. So ceramics are stronger, stiffer and harder than metals with great resistance to wear. Ceramics are highly brittle and doesn't deform before break.

Polymers

Polymers are large molecules produced by repeating monomers. Copolymers are molecules that are formed by more than one type of polymers. Molecules are bound together by covalent bonds and/or intermolecular attractions between molecules in adjacent chains.

Polymers can be classified as:

1- Natural : DNA, Protein, rubber and silk
2- Synthetic: plastics.

Mechanical properties of polymers:

It depends on many factors:

1- Length: the longer the chain, the stronger the polymer.
2- Cross-linking.
3- Branching.

Polymers have less density, strength and stiffness as compared with metals and ceramics but they have resistance to corrosion and low coefficient for friction.

Examples:

1- Ultra-high molecular weight polyethylene.
2- Polymethylmethacrylate bone cement.

Finally, composites consist of two or more base biomaterials that remain separate after they are combined together.

Chapter 6
Biomechanics of shoulder joint

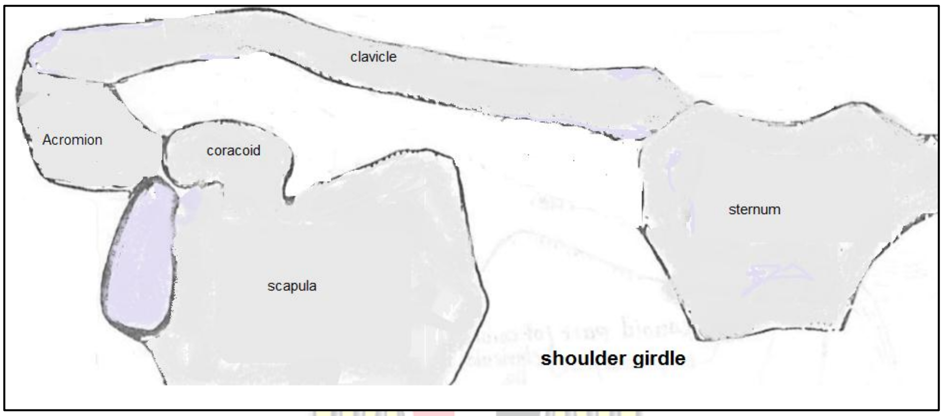
Objectives:

- Identify the functional anatomy and movements of shoulder joint.
- Define the most common factors that maintain stability of the shoulder joint.

Shoulder complex is made of 4 bones: the clavicle, the scapula, the sternum and the humerus. These bones contribute in many articulations: the glenohumeral joint between the head of the humerus and the glenoid cavity, the acromioclavicular joint between the lateral end of the clavicle and the acromion of the scapula. The third articulation is between the medial end of the clavicle and the sternum. Shoulder girdle refer to the clavicle, scapula and the sternum.

The glenohumeral joint

It is a ball and socket variety with 3 axes of movement .The glenohumeral joint has a relative low stability in order to increase mobility. One of the most important factors to increase mobility is the relative big size of the spherical humeral head in relation to the shallow glenoid cavity (about twice its size). There is retroversion of the head of the humerus of 20° to 30° in comparison with the distal humerus. This gives some resistance to anterior shoulder dislocation. The scapula has a 30 degrees anterior angulation to the coronal plane and the glenoid has 5 degrees retroversion in relation to the plane of the scapula.



Stability of shoulder joint

It depends on many factors:

1- The labrum: it is a rim of fibrocartilage that deepen the glenoid cavity to double of its depth. With loss of the labrum, there is increased translation between the articulating surfaces and there is increased risk of shoulder dislocation.

2- Glenohumeral capsule: however the capsule is lax, it provides some stability as it tighten with different movement also it provides negative pressure. Diseases of the capsule affect mobility as in frozen shoulder that limit mobility especially external rotation. Also, effusion or capsule defect decrease stability.

3- Ligaments: 3 ligaments (superior, middle and inferior glenohumeral ligaments) prevent humeral head translation in different directions.

4- Rotator cuff muscles which are responsible on stability during movement.

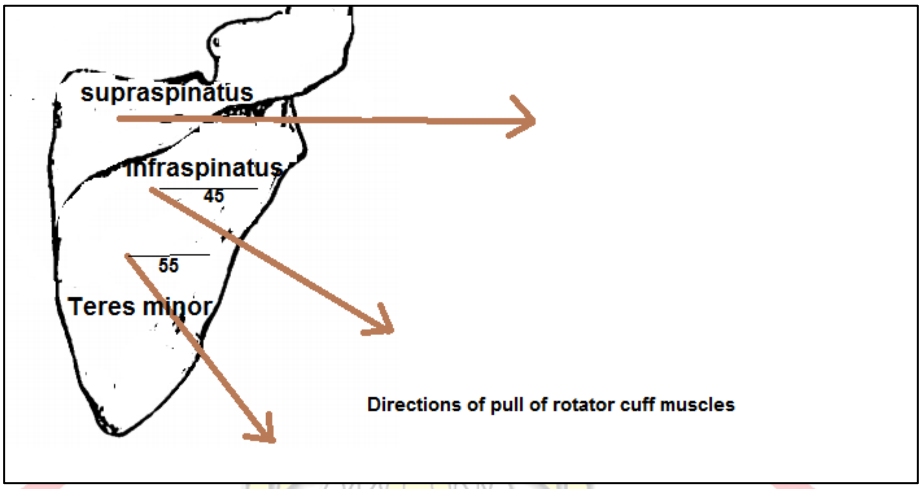
The rotator cuff muscles include:

1- Supraspinaus: pulls on horizontal direction

2- Infraspinatus: pulls 45 degrees from horizontal direction.

3- Teres minor: pulls 55 degrees from horizontal direction.

4- Subscapularis: pulls 45 degrees from horizontal direction.



The movements allowed in shoulder joints are:

1- Flexion (180 degrees): occurs in sagittal plane and carried out by deltoid, biceps.
2- Extension (60 degrees): occurs in sagittal plane and carried out by triceps, deltoid.
3- Abduction (180 degrees): occurs in coronal plane and carried out by supraspinatus, deltoid. The deltoid works with supraspinatus to produce abduction and flexion the shoulder. The force of deltoid is pulls the humeral head upwards and the force of pull of supraspinatus is directed medially. The coupling of the 2 forces rotates the humeral head and pulls it medially against the glenoid cavity.
4- Adduction: occurs in coronal plane and carried out by teres major, subscapularis
5- External rotation (90 degrees): occurs in horizontal plane and carried out by infraspinatus , teres minor
6- Internal rotation (90 degrees): occurs in horizontal plane and carried out by teres major and subscapularis

Scapulohumeral Rhythm

It is coordinated movements of the glenohumeral joint and scapulothoracic articulation during arm elevation. It is about 2 (glenohumeral) to 1 (scapulothoracic).

Reaction force (RF):

It is determined by the positions of the shoulder and elbow. It is difficult to calculate because there is a large number of muscles that act on the shoulder. RF of the shoulder is highest while the shoulder in abduction.

Shoulder abduction with extended elbow: the deltoid contracts to maintain a 90 degree of abduction. The RF is about ½ the body weight.

Shoulder abduction with flexed elbow: the center of the weight of the arm is closed to the body so less force is produced by the abductor muscles. The RF is about 1/4 the body weight.

Chapter 7
Biomechanics of the elbow

Objectives:

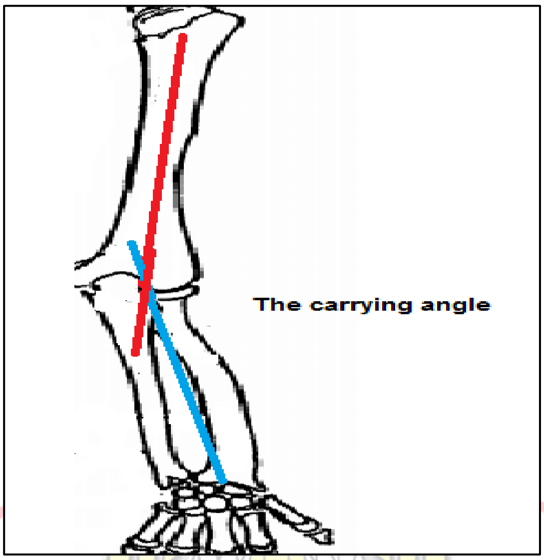
- Identify the functional anatomy and movements of elbow joint.
- Define the most common factors that maintain stability of the elbow joint.

Elbow joint is the articulation between 3 bones: the lower end of the humerus, the radius and the ulna. The humero-ulnar articulation is a stable hinge joint while the humero-radial articulation is a ball and socket joint with lesser stability. It is the axis of the lever system of the forearm.

The distal end of the humerus is divided functionally into medial and lateral parts that are angulated forward about 40 degrees from the shaft of the humerus.

The carrying angle

It is the angle between the longitudinal axis of the humerus and longitudinal axis of the ulna in extended elbow it is about 15 degrees and it is slightly greater in females than in males and it decreases with flexion of the elbow.



Stability of elbow joint

Stabilizers of the elbow can be classified into:

- Primary stabilizers: its loss leads to instability.
- Secondary stabilizers: its loss doesn't lead to instability but if associated with loss of primary stabilizers it causes more worsening of instability.

Factors that maintain stability:

1- Bony (primary stabilizer): the main factor that maintain stability of the elbow is the congruency of the articular surfaces of the humero-ulnar joint

2- Ligaments (primary stabilizer): medial and lateral collateral ligaments. The medial collateral ligament provides restraint to the valgus stress while lateral collateral ligament provides restraint to varus stress.

3- Joint capsule: it resists translation in various directions.

4- The interosseous membrane between radius and ulna prevents longitudinal instability (secondary stabilizer).

5- The tendons of common flexor and extensor tendons (secondary stabilizer).

6- The muscles that act across the elbow joint (biceps, triceps and brachialis muscles) provide compressive forces that maintain joint stability.

The movements allowed in elbow joint are:

1-Flexion: occurs in sagittal plane and carried out by brachialis, biceps, Brachioradialis.

2-Extension: occurs in sagittal plane and carried out by triceps, Anconeus.

Reaction force (RF):

- RF in flexion: the elbow is at 90 degrees of flexion and held at the side of the body

  The main muscle that maintain this position is brachialis muscle

  It equals one and half times the weight of the supported forearm.

- RF in extension: the elbow is at 90 degrees of flexion and forearm held above the head

  The main muscle that maintain this position is triceps muscle

  It equals about 5 times the weight of the supported forearm.

- This means that the elbow reaction force at extension is greater than its value in flexion and this can be explained by the fact that the triceps lever arm is about 30 mm and this shorter than the brachialis lever arm which is about 50 mm.

Chapter 8

Biomechanics of Wrist Joint

Objectives:

- Identify the functional anatomy and movements of wrist joint.
- Define the most common factors that maintain stability of the wrist joint.

Wrist joint makes a connection between the forearm and the hand. It is complex ellipsoid joint between the lower end of radius and the carpal bones. The distal end of radius is concave with 11 degrees palmar tilt. The head of ulna is separated from carpal bones with the triangular fibrocartilage

Carpal bones arearranged into 2 rows:

The proximal row: scaphoid, lunate, triquetrum , pisiform.

The distal row: trapezium, trapezoid, capitate, hamate.

The wrist joint have a set of transverse and longitudinal arches because of its bone morphology:

- Two transverse arches, at the level of carpal bone and the capitate is its keystone and the more mobile distal transverse arch at the level of metacarpal heads and the third metacarpal is its key stone.

- One longitudinal arch formed by the bones of the five digital rays beginning at proximal transverse arch and second and third metacarpal bones make its central pillar.

Stability of Wrist Joint

I) Bony: complex interlocking shapes of carpal bones and it has multifaceted articulation that enables both the movement and stability. Both scaphoid and lunate bones are wedge shaped in sagittal plane with palmar aspects wider than their dorsal aspects and so it has tendency for extension. This tendency is counteracted by the attachment of trapezium and trapezoid to the dorsal aspect to scaphoid giving more stability.

II) Ligaments :A set of extrinsic and intrinsic ligaments

Extrinsic ligaments: ligaments that cross radiocarpal, midcarpal joints or both

Intrinsic ligaments: ligaments between carpal bones.

The movements allowed in wrist joint are:

1-Flexion (65° normal, 10° functional): occurs in sagittal plane and carried out by flexor carpi radialis, flexor carpi ulnaris, palmaris longus

2-Extension (55° normal, 35° functional): occurs in sagittal plane and carried out by extensor carpi radialis longus, extensor carpi radialis brevis, extensor carpi ulnaris.

3- Abduction: flexor carpi radialis, extensor carpi radialis longus, extensor carpi radialis brevis.

4-Adduction: flexor carpi ulnaris, extensor carpi ulnaris.

Reaction force and force transmission of the wrist joint:

Force transmission depends on many factors:

- Position of the wrist.
- Integrity of the ligaments.
- Congruity of the articular surface.

80% of load is carried by distal radius while 20% of load is carried by distal ulna. Ulnar load increases with radial deviation and decreases with ulnar deviation.

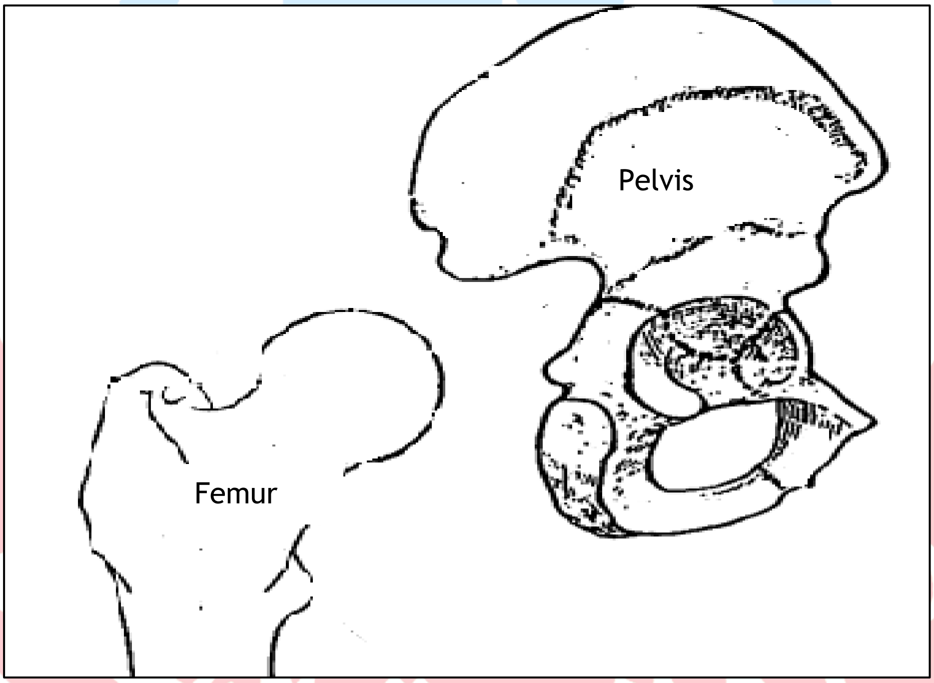
Wrist represents a chain of 3 links formed of radius, lunate and capitate bone.this will enhance motion but decreases the stability of the chain. Head of the Capitate is the center of rotation and it can move by 4 mm.

- scaphoid bridges both carpal rows and radial deviation pushes the scaphoid into flexion and ulnar deviation pushes the scaphoid into extension

Chapter 9
Biomechanics of Hip Joint

Objectives:

- Identify the functional anatomy and movements of hip joint.
- Define the most common factors that maintain stability of the hip joint.
- Identify the difference between materials used in total hip arthroplasty.



Hip joint is a ball and socket joint between the cup-shaped acetabulum and the head of femur. It has a relative low mobility in order to increase stability (the reverse of shoulder joint).

Stability of hip joint

It depends on many factors:

1- Bony factor: the spherical head of femur fits well in the deep cup-shaped acetabulum giving great stability.

2- The labrum: it is a rim of fibrocartilage that deepen the actabulum. Although its role is less than in shoulder its thought that it maintain stability by restrict the movement of synovial fluid maintain negative intra-articular pressure. Tears in the labrum occur mainly at the junction of labrum with articular cartilage.

3- Ligaments:

- The iliofemoral ligament: Y shaped ligament anterior to the hip .it attaches proximally to the ilium and distally to the intertrochentric line. It tighten in extension and it relax in flexion. It is considered the strongest ligament of the body.

- The pubofemoral ligament: the weakest of hip ligaments. It strengthen the antero-inferior aspect of the hip.

- The ischiofemoral ligament: it attaches medially to the ischium and attaches laterally to superolateral aspect of the femoral neck.

4- Hip capsule: is very strong and reinforced by ligaments. However it has two weak points. The first between the iliofemoral and pubofemoral ligaments anteriorly and the second between the iliofemoral and ischiofemoral ligaments posteriorly.

5- Hip muscles: a large number of muscles (22 muscles) which are responsible on stability and movement of the hip joints, The abductor muscles (gluteus medius and minimus) are the main stabilizers of the pelvis in the coronal plane. Also it reduces stress on the femur.

The movements allowed in hip joints are:

1- Flexion: occurs in sagittal plane and carried out by iliopsoas, rectus femoris
2- Extension: occurs in sagittal plane and carried out by gluteus maximus, hamstring.
3- Abduction: occurs in coronal plane and carried out by gluteus medius, gluteus minimus

4- Adduction: occurs in coronal plane and carried out by adductor longus, brevis and magnus

5- External rotation: occurs in horizontal plane and carried out by the 6 lateral rotators

6- Internal rotation: occurs in horizontal plane and carried out by the anterior fibres of gluteus medius, gluteus minimus

Reaction force (RF):

The loads on hip joints are of the body weight, tension in abductor muscles and impact loads transmitted upward from the foot.

Double leg stance: the weight of the lower limb is about one third of the body weight so the weight of the upper segment is 2/3 of the body weight. So during double leg stance, each tip carry 1/3 of the total body weight, abductor muscles are relaxed.

Single leg stance: the abductor muscles of the stance leg contract to prevent drop of the pelvis in the opposite side which is equal to proportional body weight distribution**.** The proportional body weight distribution means that the supported upper segment weight is approximately 5/6 of the total body weight. So the hip RF equals the sum of the 2 forces and is about 1.5 times the total body weight.

In painful hip conditions, reduction of the hip RF will reduce pain and this can occur through:

1- Limping: to get the center of gravity close to the center of femoral head, however this make more energy consumption.

2- Use of a cane: it can reduce hip RF from 50% to 1.5 times of the body weight.

Total Hip Replacement (THR)

THR means replacement of both femoral head and acetabular surface while hemiarthroplasty means replacement of the femoral head only. It can be fixed as cemented or cementless.

Cemented is strongest immediately after insertion of the artificial joint

Cemented fixation is established to have superior long term outcome, but cementless fixation has some advantages as it has better resistance to aseptic loosening in the younger patients, and the long-term outcome of total hip replacements .Cementless THR is associated with an increased proportion of intra-operative fractures due to more hoop stresses production.

Aseptic loosening and instability are the main causes for THR revising. They can occur due to: - Osteolysis: Wear from the acetabular cup produce a reaction that leads to osteolysis.

- Diameter of the femoral head.

Materials used for the prosthetic hip:

1- Metal on polyethylene: the femoral head is formed of metal and the acetabular cup is made of polyethylene (the most commonly used combination)

2- Metal on metal: both the femoral head and the acetabular cup is made of metal. Metals are polished to decrease surface roughness and wear

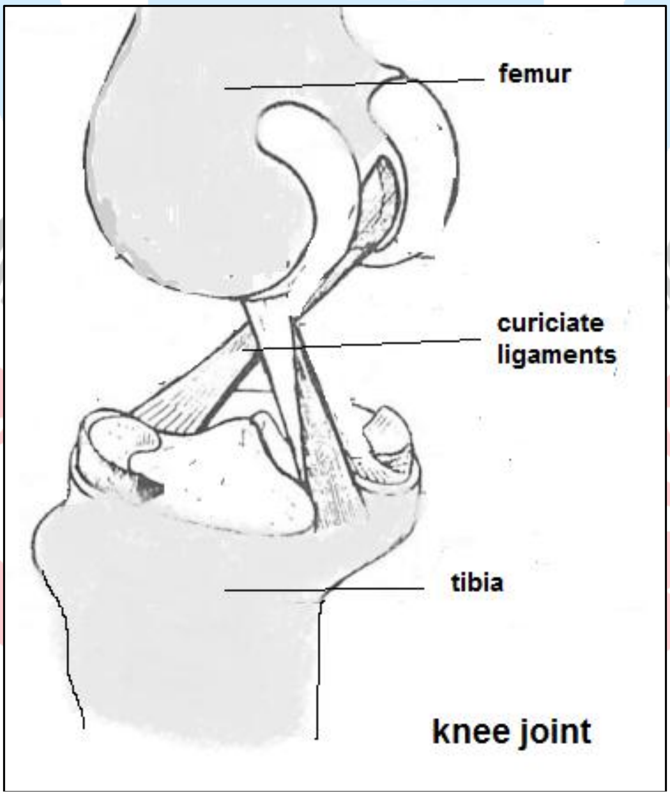
3- Ceramic on ceramic: both the femoral head and the acetabular cup is made of ceramic. Ceramic is harder than metal and can be highly polished so it is very hard and smooth so it has a lower wear rate.

Chapter 10
Biomechanics of knee Joint

Objectives:

- Identify the functional anatomy and movements of knee joint.
- Define the most common factors that maintain stability of the knee joint.

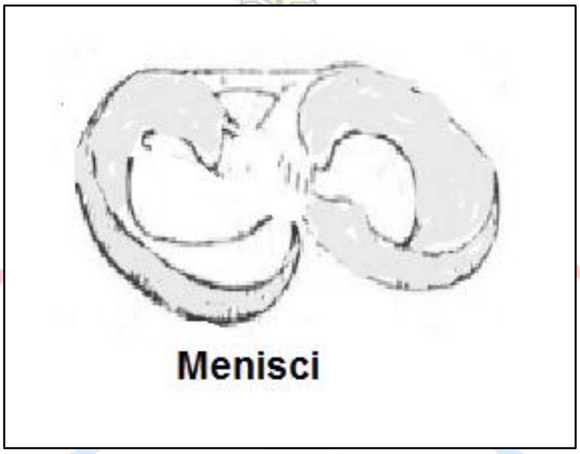
Knee joint is a modified hinge joint between the lower end of femur (femoral condyles) and upper end of tibia (tibial plateau) and the posterior surface of patella. The knee has 2 unique intra-capsular structures (the cruciate ligaments and the menisci).



The medial femoral condyle is larger and extends lower than the lateral femoral condyle.

And the medial tibial plateau is concave and larger than the lateral tibial plateau which has convex upper surface. So there is more constraint of movement in the medial knee compartment.

The menisci:



The medial and lateral menisci are curved plates of fibrocartilage overlying corresponding tibial plateau. They consists of body, anterior horn and posterior horn.

They have many functions that help stability and load bearing e.g

1- Increase the depth of articular surfaces of the tibial plateau and increases congruency of the articular surfaces.
2- Shock absorption (they carry about 70% of the load across the knee joint).
3- Essential for rotatory movement of the knee.
4- Help joint lubrication.

Cruciate ligaments:

Anterior and posterior cruciate ligaments connects the tibia and the femur and they resembles the limbs of letter X and they are named according to their attachment of tibia. They make with their attached bones what is known mechanically as (modified four-bar linkage mechanism.) They limit anterior and posterior translation of the tibia.

Anterior cruciate ligament is stretched in extension and its main function is to prevent hyperextension of the knee and prevents posterior displacement of the femur on the tibia.

Posterior cruciate ligament is stronger than the anterior cruciate ligaments and it is stretched in flexion and its main function is to prevent anterior displacement of the femur on the tibia.

Stability of knee joint

It depends on many factors:

I) Bony factor: the shape of articular surfaces.

II) The menisci.

III) Ligaments:

- The cruciate ligaments.
- Medial and lateral collateral ligaments.

IV) Knee capsule: thin but supported by expansions from surrounding muscles

V) Knee muscles: knee is surrounded by large muscles which are responsible on stability and movement of the hip joints.medial and lateral vastal retinaculum support the patella.

The movements allowed in knee joint are:

1-Flexion (0 to 160°): occurs in sagittal plane and carried out by hamstring (semitendinosus, semimembranosus, and biceps femoris). It can be classified as:

Screw home arc (up to 10 °)

Functional arc (from 10 ° to 120 °)

Deep flexion arc (from 120 ° to 160 °)

2-Extension: occurs in sagittal plane and carried out by quadriceps femoris.

3- Medial rotation (with knee in flexion): occurs in horizontal plane and carried out by popliteus, semitendinosus, sartorius.

4-Lateral rotation: (with knee in flexion): occurs in horizontal plane and carried out by biceps femoris.

Locking and unlocking of the knee

Locking of the knee: with full knee extension, the anterior cruciate ligament becomes tight terminating the movement of lateral femoral condyle while the medial femoral condyle continue movement leading to passive medial rotation of the femur.

This rotation tighten knee ligament and makes the joint rigid.

Unlocking of the knee:

To initiate flexion, the popliteus produces lateral rotation of the femur on the tibia. This relax the tight ligaments.

Reaction force (RF):

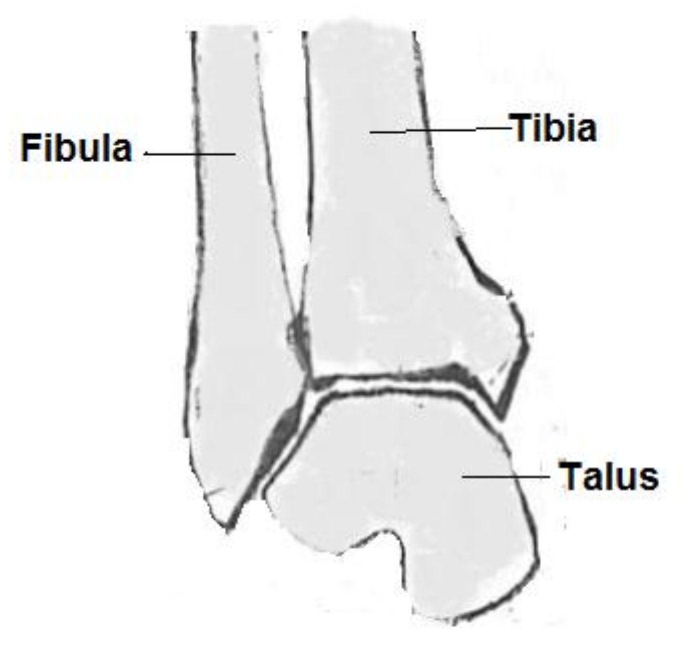
The knee is in extension throughout a single or double leg stance and so the quadriceps muscle is not contracting. The weight of the leg below the knee is only 5% of total body weight, so the compressive force of the body weight is about half the total body weight during the double leg stance and about the total body weight during single leg stance. Knee RF increases markedly with knee flexion. For example during ascending stairs knee flexes about 60 degree and during single leg stance the knee RF becomes 5 times the body weight.

Chapter 11
Biomechanics of Ankle Joint

Objectives:

- Identify the functional anatomy and movements of ankle joint.
- Define the most common factors that maintain stability of the ankle joint.

Ankle joint is a hinge joint between the lower end of tibia and the talus. The lateral malleolus lies distal to the medial malleolus mobility in order to increase stability



Ankle joint

The talus is the most important bone for mechanics of the ankle joint. The talar dome is wider in front than in its back and the lateral aspect of the talus is wider and longer than its medial aspect. This enables the talus to slide and rotate within the joint during ankle movement. Ankle dorsiflexion makes the wider anterior part of the talus to engage with the ankle mortise, while ankle plantarflexion makes the narrower posterior part of the talus to engage with the ankle mortise. So, the ankle joint is more stable in dorsiflexion, and less stable is plantarflexion. Subtalar joint is between the talus and the calcaneus and allows for eversion and inversion

Stability of ankle joint

It depends on many factors:

1) Bony factor: the shape of articular surfaces (ankle mortise).
2) Ligaments: medial collateral ligament (deltoid ligament) and lateral collateral ligament which is weaker.
3) Ankle capsule: weak in front and back to allow plantar and dorsiflexion.

The movements allowed in ankle and subtalar joints are:

1-Flexion (plantar flexion): occurs in sagittal plane and carried out by gastrocnemius, soleus, plantaris, tibialis posterior.

2-Extension (dorsiflexion): occurs in sagittal plane and carried out by tibialis anterior, extensor halluces longus, extensor digitorum.

3- Inversion: occurs in coronal plane and carried out mainly by tibialis anterior and tibialis posterior (subtalar joint).

4- Eversion: occurs in coronal plane and carried out mainly by peroneus longus and brevis (subtalar joint).

Ankle dorsiflexion is usually combined with eversion of the subtalar joint and ankle plantarflexion is usually combined with inversion of the subtalar joint.

Normal walking needs a range of 25 ° (10 ° dorsiflexion and 15 ° plantarflexion), ascending stairs needs a range of 37° and descending stairs needs a range of 56°.

Reaction force (RF):

Ankle RF differ in different stages of gait cycle. It is estimated to be 3 times the total body weight during walking and about 13 times the total body weight during running and jumping.

The articular surfaces contact area differs during various stages of gait cycle as it is greatest in dorsiflexion and least in plantar flexion

Chapter 12
Biomechanics of the Spine

Objectives:

- Identify the functional anatomy and movements of the vertebral column.
- Define the most common factors that maintain stability of the spine.
- Identify forces that act on the spine in various positions.

The vertebral column is composed of 7 cervical vertebrae, 12 thoracic vertebrae, 5 lumbar vertebrae, 5 sacral vertebrae and the coccyx. Each vertebra is composed of vertebral body, pedicle, lamina, facet joints, transverse process and spinous process.

The vertebral body

It is composed of a core of cancellous bone surrounded by a shell of cortical bone. Cancellous bone can resist compression due to horizontal and vertical arrangement of its trabeculae. Cancellous porous bone can convert compressive forces to horizontal tensile force and it is more effective than solid vertebra in tolerating loads as it is more springy and acts as a cushion also it is lighter in weight.

Compression fracture is the most common injury that occurs in osteoporotic spine.

Intervertebral disc:

It is composed of central nucleus pulpous surrounded by annulus fibrosus which is connected to the vertebral end plates. The nucleus pulpous generates hydrostatic pressure due to high water content. It act as a shock absorber

The annulus fibrosus consists of layers of collagen fibers, the vertebral end plat connects the disc to adjacent vertebra and is formed of hyaline cartilage.

With axial loading, the hydrostatic pressure of the nucleus pulposus increases leading to expansion of the annulus fibrosus in transverse plane and decrease in its vertical diameter , so the vertical load is converted to circumferential load,

Facet joint (Zygoapophyseal joint):

It is between superior and inferior articular process and surrounded with joint capsule.

In the cervical and thoracic spine, facet joint are positioned in the coronal plane. In the lumbar spine, the facet joints are positioned in the sagittal plane and progresses to the coronal plane at L5/S1 level.

It has many functions: weight bearing, resist rotational forces and mobility of the spine.

Stability of vertebral column:

It depends on many factors:

1) Bony factor: the vertebral end plates.
2) Ligaments: strong anterior and posterior longitudinal ligaments. The stiffness of the ligaments increases 75 times outside the normal range of motion.
3) Paravertebral muscles: the spine is surrounded by large bulky muscles

Ankle capsule: weak in front and back to allow plantar and dorsiflexion

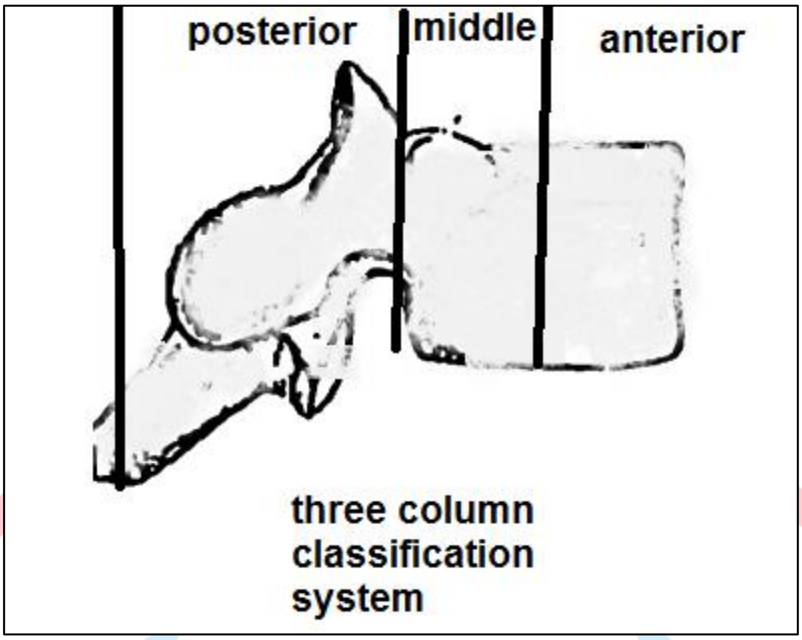
Three column classification system for spinal instability:

The anterior column: the anterior intervertebral ligament and anterior half of vertebral body and disc.

The middle column: the posterior half of vertebral body and disc.

The posterior column: the pedicle, lamina, facet joint and spinous and transverse processes

The lesion that affect only one column is mechanically stable, while injuries that affect two or the three columns are unstable.



The movements allowed in hip joints are:

1- Flexion: occurs in sagittal plane and carried out by rectus abdominus, internal oblique and external oblique.
2- Extension: occurs in sagittal plane and carried out by Multifidus, iliocostalis lumborum and latissimus dorsi.
3- Lateral flexion: occurs in coronal plane and carried out by quadratus lumborun, , internal oblique and external oblique.
4- Rotation: actually almost no rotation occurs at lumbar spine due arrangement of the facet joint in lumbar spine and most of rotation occurs in thoracic spine.

Reaction force (RF):

The most mobile segments of the vertebral column are the cervical spine and lumbar spine and so they are more susceptible to degenerative changes. The lumbar spine is exposed to the greater load than other segments.

The vertebral body is exposed to compressive force while the intervertebral disc is exposed to rotational, bending and compressive forces.

The different body postures affects forces acting on the vertebral column:

In standing position, the center of body weight lies anterior to the 4^{th} lumbar vertebra. This produces a forwards moment on the spinal column that is balanced by spinal muscles and ligaments. The intervertebral disc load between the 3rd and 4th lumbar vertebra is twice the body weight above this level. The intradiscal pressure is increased in sitting position compared to its pressure in standing position. The upper body weight moment arm of the upper body weight increases with forward flexion leading to increased load on spinal segment.

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