

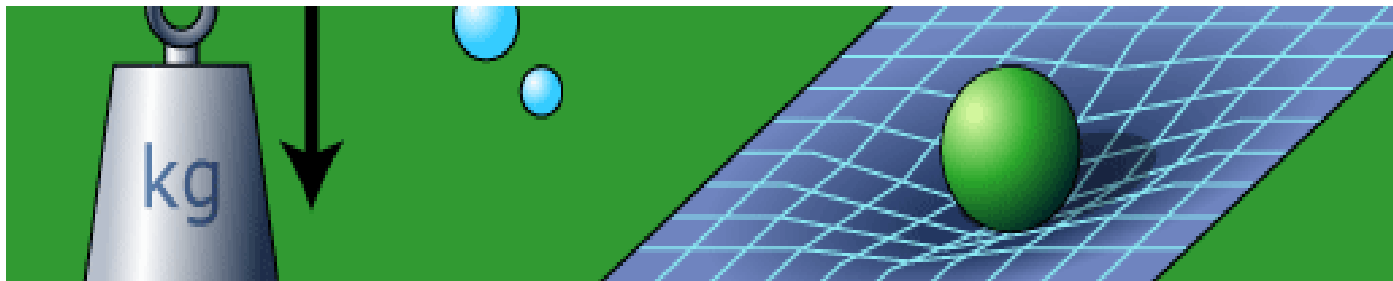
Medical Physics

Force in and on the body

Dr. Enas S. AL-Mizban

$$F = ma$$

N kg m/s²



Medicine College -University of Anbar
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Force in the body

- ❑ a *force* is any interaction that cause physical change, or tends to change the state of rest or motion of a body.
- ❑ From the macroscopic point of view we can imagine many different kinds of force that act at impact but also forces that act over a distance such as the gravitational one .
- ❑ So there are four basic force between the matter particles: *gravitational, electrical, strong and weak nuclear force.*
- ❑ Only the gravitational and electrical forces are important in our study of the forces affecting the human body.

1-Gravitational force

- ❑ The first quantitative theory of gravitation based on observation was formulated by Isaac Newton in 1687, he wrote that the gravity force that acts on the sun and planets depends on the quantity of matter that they contain.
- ❑ Our weight is due to the attraction between the earth and our bodies.

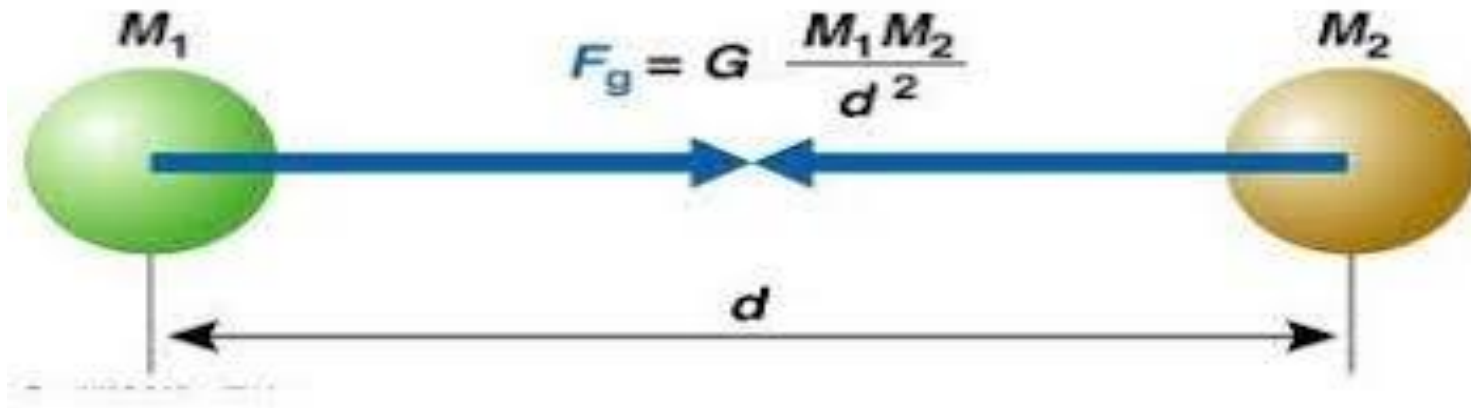


Gravitational force

- Newton law states that “there is a force of attraction between any two objects which is proportional to the product of their masses and inversely proportional to the square of the distance between them.

$$F_g = G \frac{m_1 m_2}{d^2}$$

G: is the gravitational constant = $6.67 \times 10^{-11} \text{ Nm}^2/\text{Kg}^2$



Some Effects of Gravity on the Body

- ❑ One of the important medical effects of gravitational force is the formation of **varicose veins** in the legs as the venous blood travels against the force of gravity on its way to the heart



- ❑ Another medical effect of gravity is on the bones, Bone loses some bone mineral when a person becomes **weightless** such in an orbiting satellite , this may be a serious problem on very long space journeys.

2-Electrical force

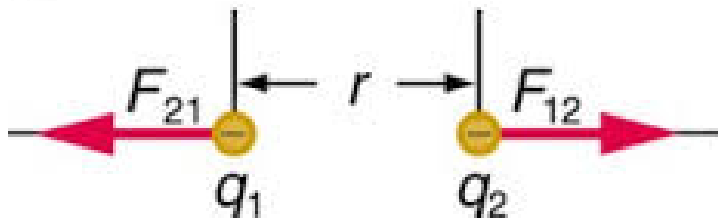
- For two static bodies with charges e_1, e_2 and distance between them r , the theory lead to coulomb's law giving the force F between the two bodies:

$$F_e = K \frac{e_1 e_2}{r^2}$$

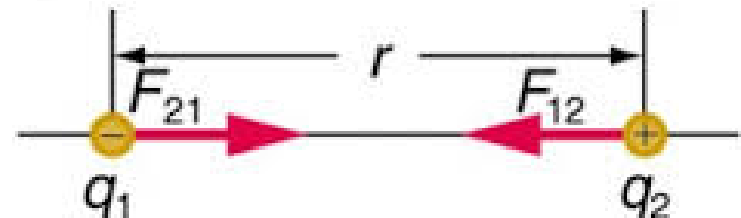
where again K is proportionality constant $= 8.9875 \times 10^9 \text{Nm}^2\text{C}^{-2}$.



(a)

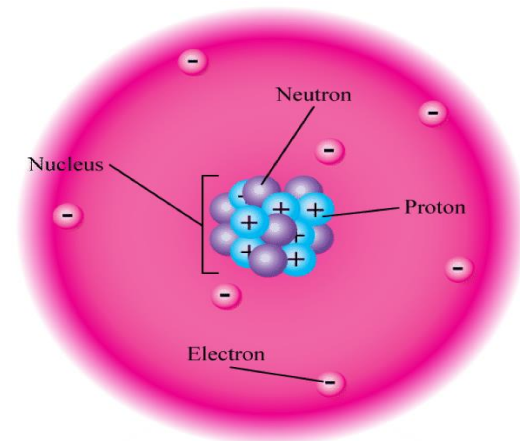


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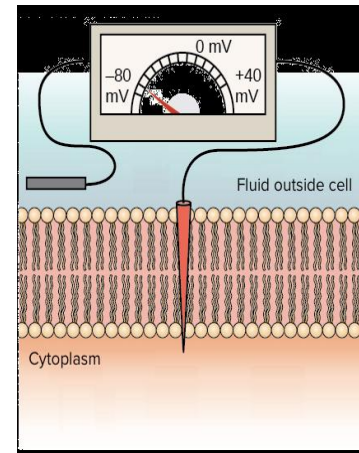
Electrical force

- ❑ This force is more complicated than gravity since it involves **attractive and repulsive force** between static electrical charges as well as magnetic force produced by moving electrical charge (electric currents).
- ❑ The electrical force between an electron and proton in a hydrogen atom is about 10^{39} times greater than the gravitational force between them.



Electrical Force in the Body

- ❑ Our bodies are basically electrical machines. **The forces produced by the muscles are caused by electrical charges** attracting or repelling other electrical charges.
- ❑ Control and action of our muscles is primarily electrical.
- ❑ Cells in the body has an electrical potential difference across the cell membrane.
- ❑ The resultant potential difference is about 0.1 V.



3- Strong and weak nuclear forces

- ❑ Eugene Wigner explained the nuclei as consequence of two different nuclear forces .
- **The strong nuclear force** is an attractive force between protons and neutrons that keep the nucleus together.
- **The weak nuclear force** is involved with electron (beta) decay from the nucleus.
- ❑ It was realized that the strong force is much larger than the other.

Force on the body

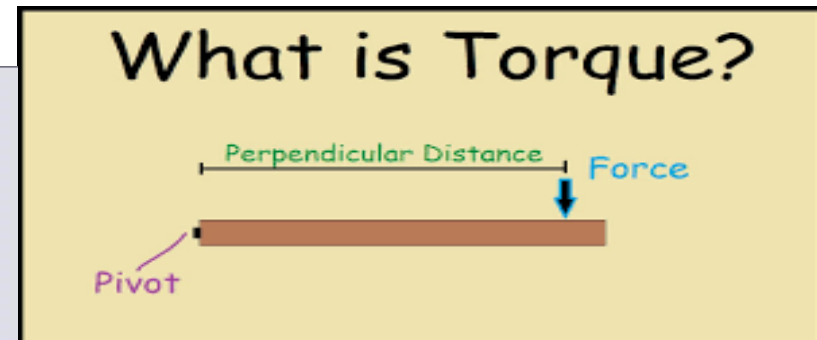
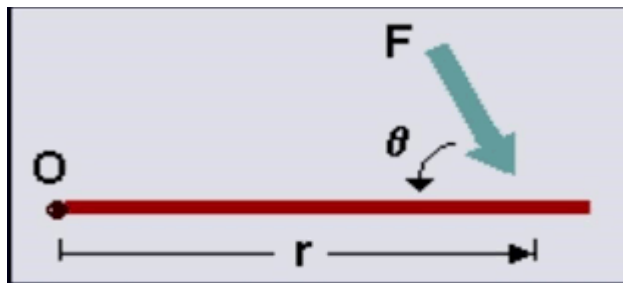
- There are two types of forces on the body, those where the body is in equilibrium (**static**) and those where the bodies accelerated (**dynamic**) .**Friction** is involved in both static and dynamic.

1-Statics forces:

- The study of the force balance of an object at rest is called **static**. In this section we will discuss forces involved with muscles, bones and tendons .
- Each force F can be resolved into components in the x , y and z directions (F_x , F_y , F_z).
- In static condition the sum of the force F in each x , y and z direction is zero.

Force on the body

- ❑ Not; **forces** describe changes in **linear** motion ,which means changes in velocities ,While **torques** describe how these same forces change **angular motion**, which means changes in angular velocities.
- ❑ Body at rest and in equilibrium (static), the sum of the forces acting on it in any direction equal zero, and the sum of the torques about any axis must equal zero.
- ❑ Torque is defined by the force F applied at the distance r from the pivot point $\tau = F \times r$



Muscular Forces

- ❑ Muscle exerts **force** by converting chemical energy (created during **respiration**) into tension and contraction.
- ❑ When a muscle contracts, it shortens, pulling a bone like a lever across its hinge.
- ❑ Muscles move and this causes us to move. We are capable of performing a wide variety of movements, but, **muscle itself moves only by becoming shorter**. They shorten and then they rest - **a muscle can pull but it cannot push**.



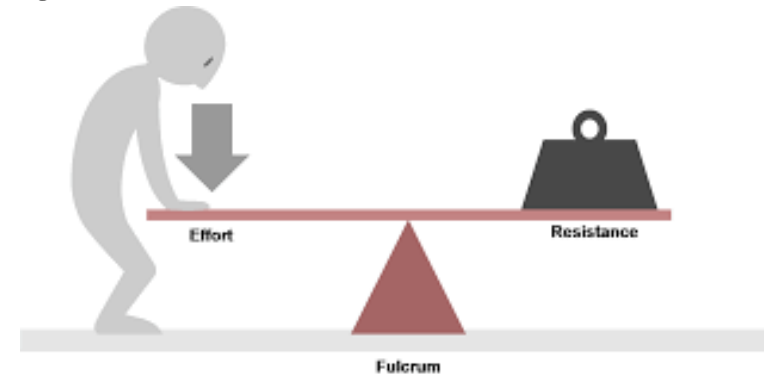
Muscular Forces and Bones as Levers

- ❑ Many of muscle and bone systems in the body acts as **levers**.
- ❑ The action of a muscle pulling on a bone often works like a type of simple machine called a **lever**.
- ❑ Most of the bones of the **limbs** (arms & legs) act as **levers**. These levers are powered by muscles.



Muscular Forces and Bones as Levers

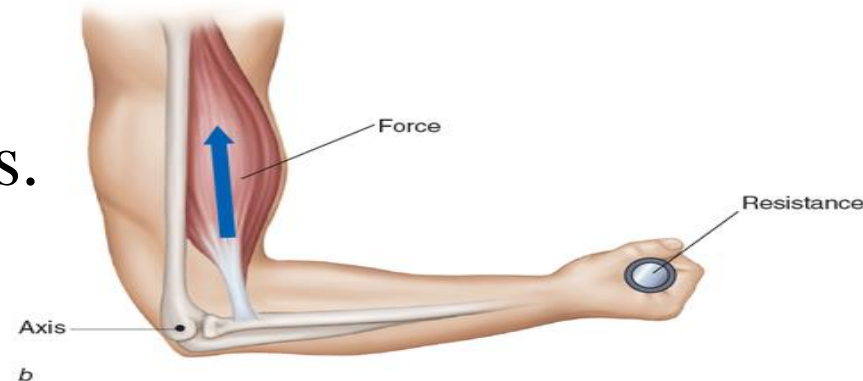
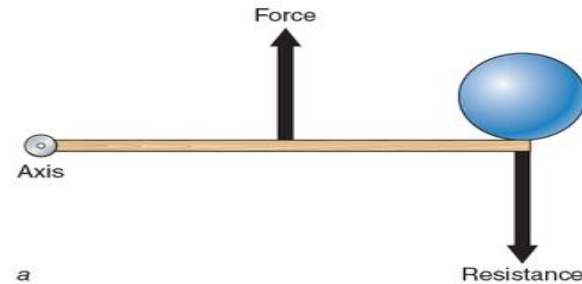
- ❑ A lever is a rigid rod able to rotate about a fixed point known as a **fulcrum**, formed by the **joint**.



- ❑ Any **force** applied to the lever is called the **effort**.
- ❑ A force that resists the motion of the lever, such as the downward force exerted by a weight on the bar, is called the **load** or the **resistance**.
- ❑ Bones of the body act as levers (a mechanical device) which create a mechanical advantage of **strength** or **speed**.

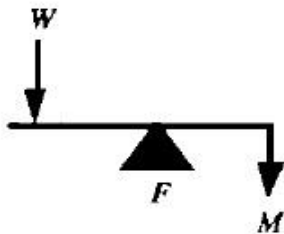
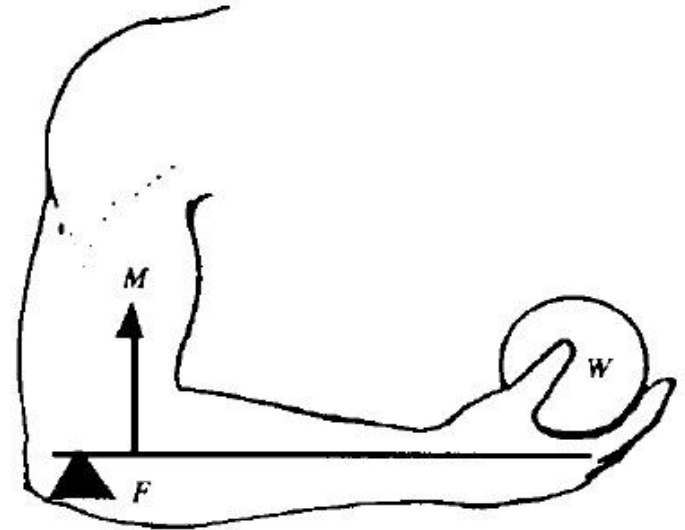
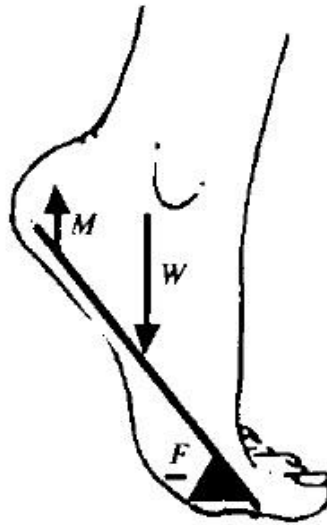
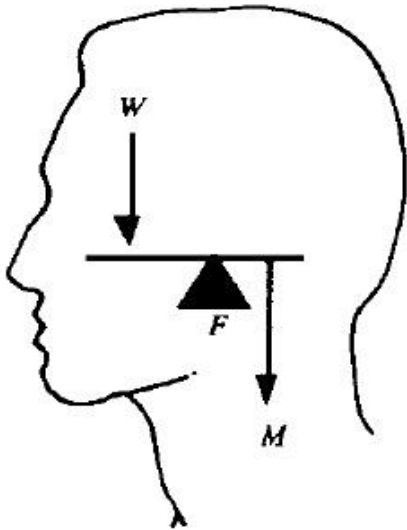
Types of Levers in the Body

- ❑ There are three classes of levers, identified as **first**, **second**, and **third class** levers.
- ❑ Levers are classified according to the **positions** of the fulcrum, effort and load or resistance.
- ❑ Each of the three types of levers can be found in the human body.
- ❑ In your body, the **effort** is the **force** that your muscles apply to the lever.
- ❑ The **load** is the **weight** that resists the pull of your muscles.
- ❑ Connections between **joints** called **fulcrums**.

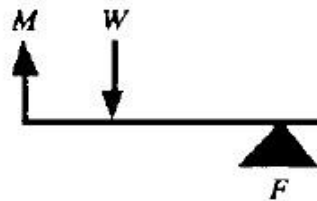


Types of Levers in the Body

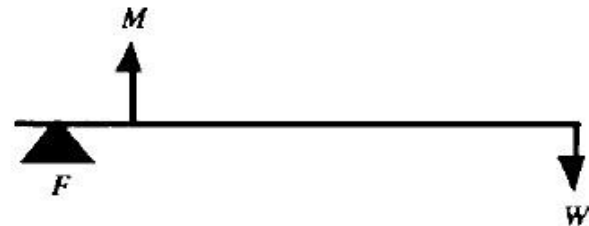
□ The first, second, and third class levers.



First Class



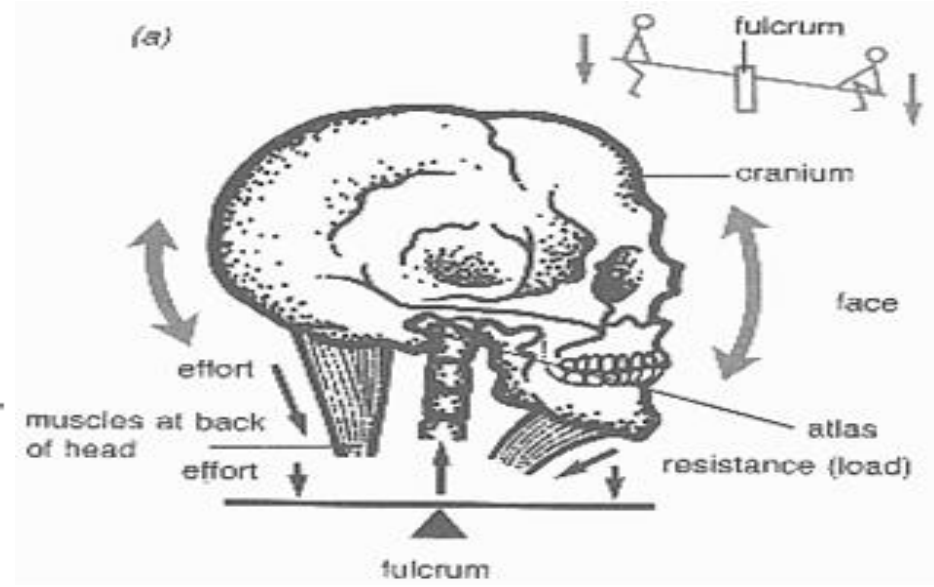
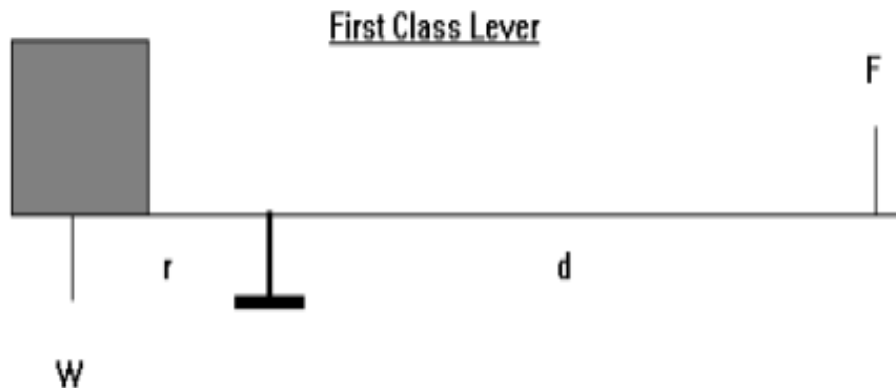
Second class



Third Class

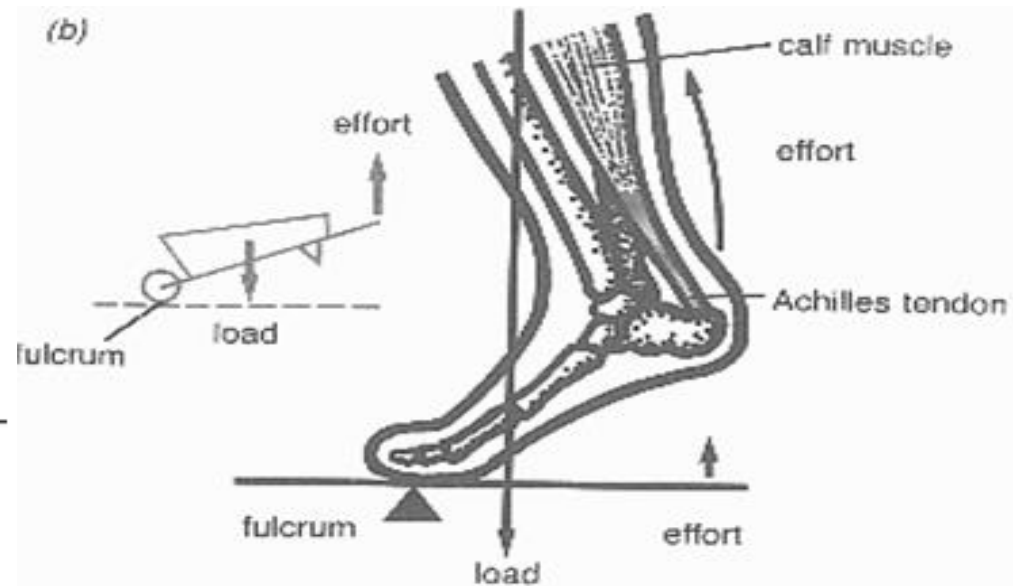
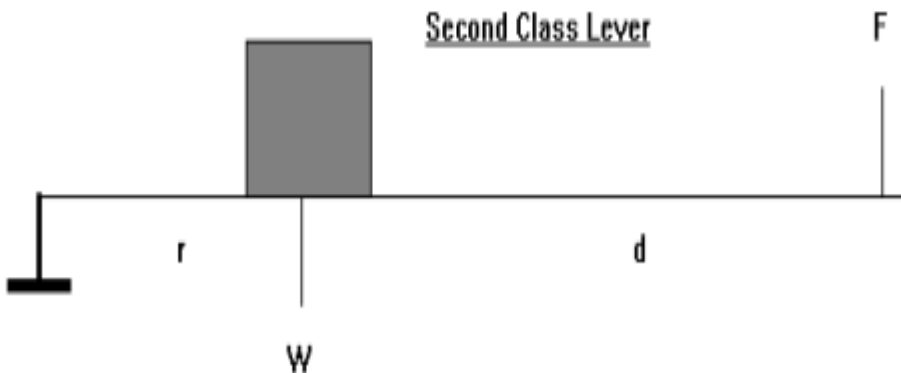
First Class Lever

- ❑ In a first class lever, the weight and force are on opposite sides of the fulcrum:
- ❑ A small force can be used to **advantage** over a heavy weight if a long force arm or lever arm can be used.
- ❑ An example of a **first-class lever** is the joint between the **skull and the atlas vertebrae** of the spine: the spine is the fulcrum across which trapezius and sternocleidomastoid muscles of the neck lift the head.



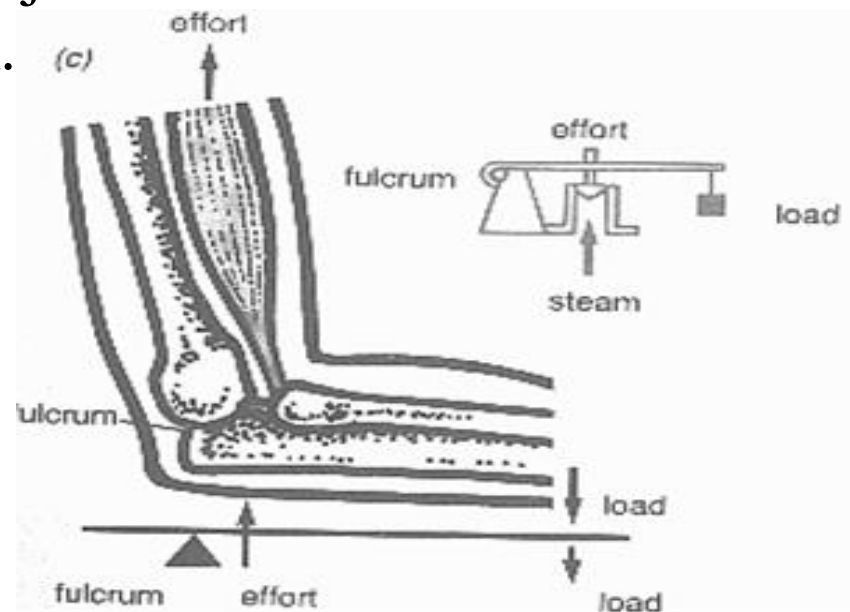
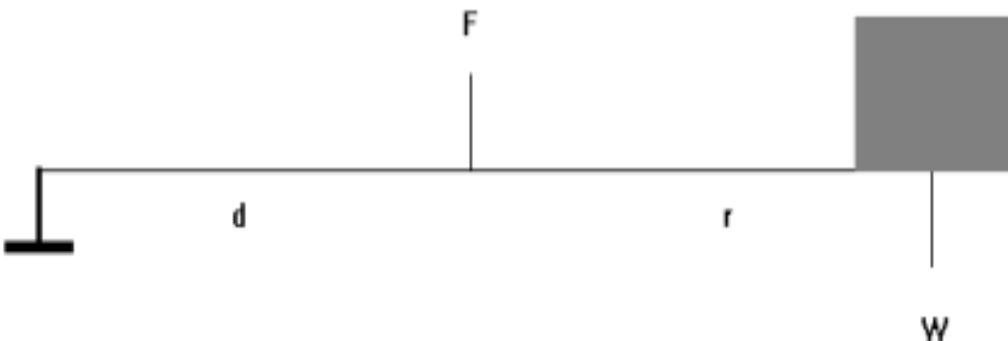
Second Class Lever

- ❑ In the second class lever, the load is between the fulcrum and the force.
- ❑ A smaller effort can be used to advantage over a larger weight.
- ❑ An example in the human body of a second-class lever is the **Achilles tendon**, pulling across the heel of the foot.



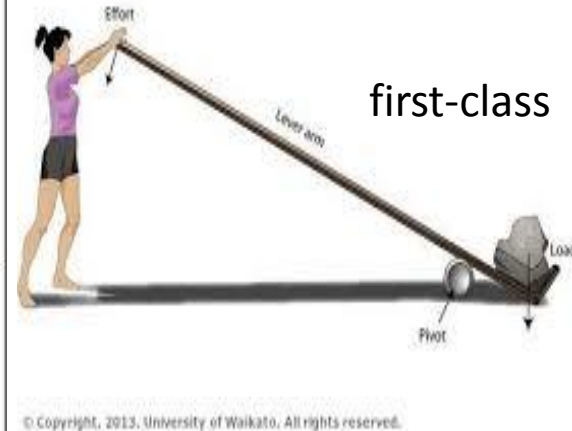
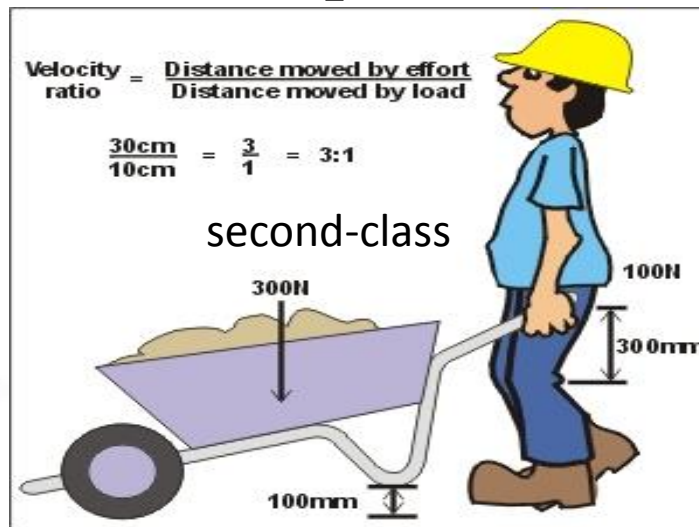
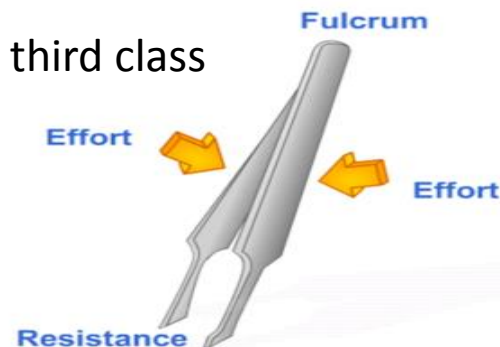
Third Class Lever

- ❑ In the third class lever, the force is between the fulcrum and the load.
- ❑ In this case, there is no force advantage – force is NOT increased. In fact, a larger force is actually needed to move a smaller weight, so there is a force **disadvantage**. The use of this lever is in the gain in **speed** of movement of the weight.
- ❑ An example of a **third-class** lever in the human body is the **elbow joint**: when lifting a book, the elbow joint is the fulcrum across which the biceps muscle performs the work.



Mechanical Advantage

- ❑ The benefits gained by using a machine is measured by a ratio called mechanical advantage.
- ❑ Mechanical advantage is a measure of how many times a simple machine multiplies an effort applied to a load.
- ❑ First-class and second-class levers can have a significant mechanical advantage.
- ❑ Third-class levers increase speed, but they **cannot increase force**.



Mechanical Advantage

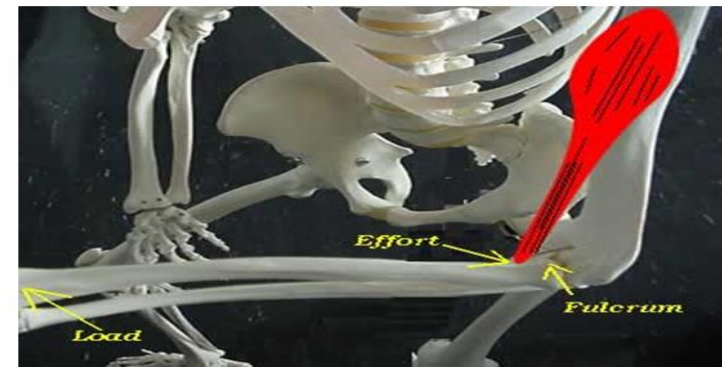
- ❑ Bones of the body act as levers (a mechanical device) which create a mechanical advantage of **strength** or **speed**.
- ❑ A lever is characterized by a fulcrum, a force arm and a weight arm.
- ❑ The **force arm** is the distance from the fulcrum to the point where force is applied.
- ❑ The **weight arm** is the distance from the fulcrum to the center of gravity of the weight.
- ❑ **Strength advantage** = resistance(weight) / effort(force)
- ❑ **Speed advantage** = weight arm / force arm

Mechanical Advantage

- ❑ First Class levers can give the advantage of strength or speed depending on where the fulcrum is located.
- ❑ Second class levers give the advantage of strength.
- ❑ Most of the movements of the body are produced by third class levers.
- ❑ Since the human body is made up mostly of third-class levers, its movements are adapted more to speed than to strength. (Short force arm/long weight arm).

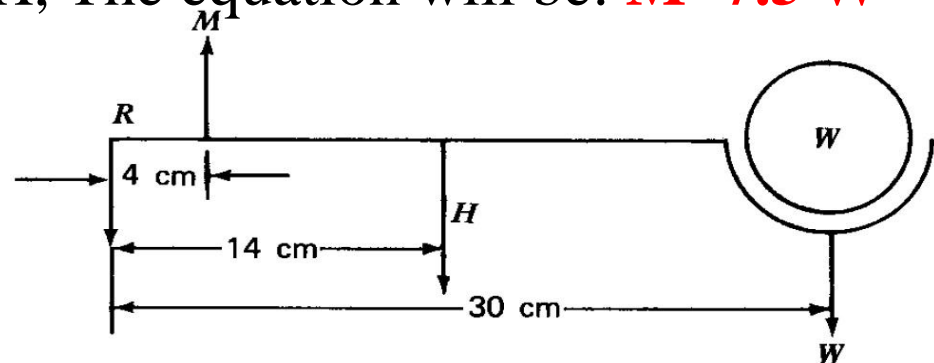
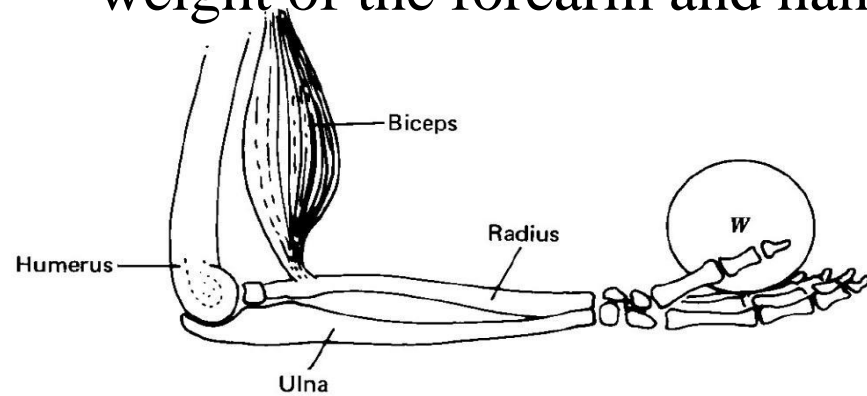
Application

- **Levers** = humerus, radius, and ulna
- **Effort**= contraction of biceps
- **Load**= weight of the arm, gravity...
- **Fulcrum** or axis of rotation = humeroulnar joint



Examples of Muscular Forces and Torques

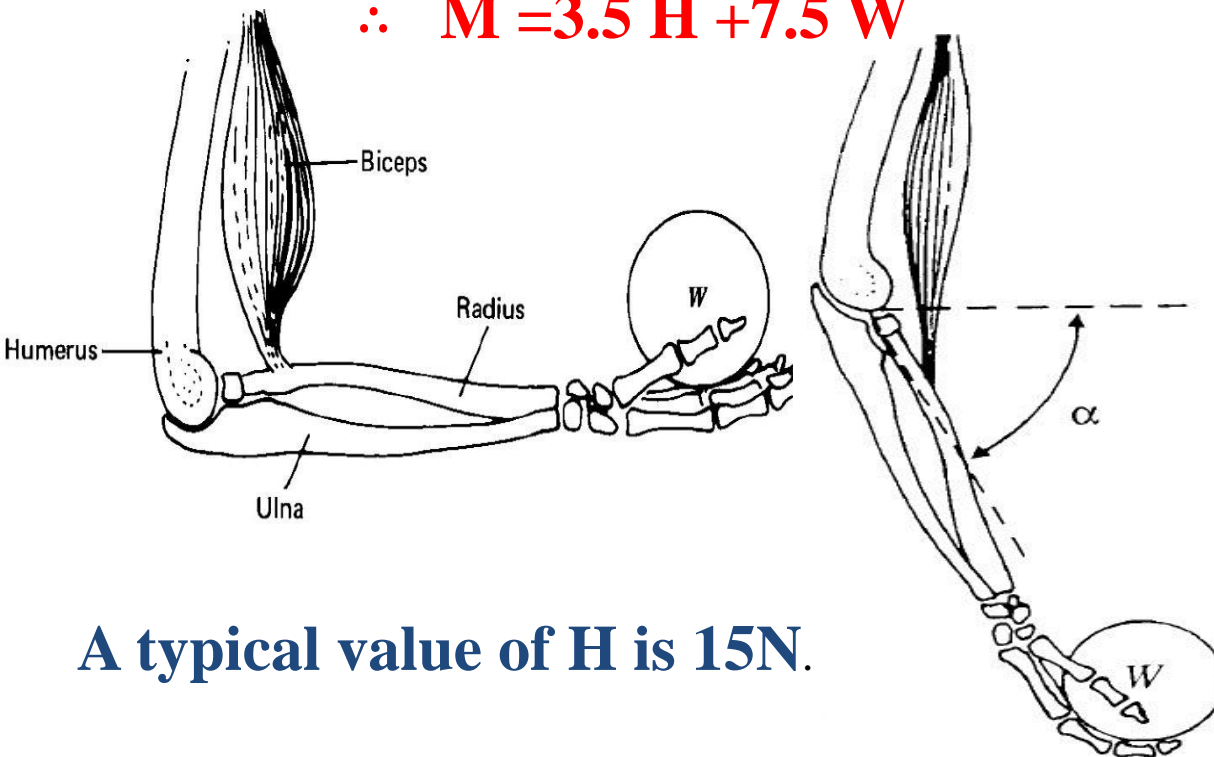
- ❑ A simple example of a lever system in the body is the case of the biceps muscle and the radius bone acting to support a weight W in the hand. We do not neglect the weight of the forearm and hand H .
- ❑ We can find the force supplied by the biceps if we sum the torques about the pivot point at the joint
- ❑ With the arm in equilibrium : $\sum_i \tau_i = 0$ we find that;
 $4M = 14H + 30W \longrightarrow M = 3.5 H + 7.5 W$, when we neglect the weight of the forearm and hand H , The equation will be: $M = 7.5 W$



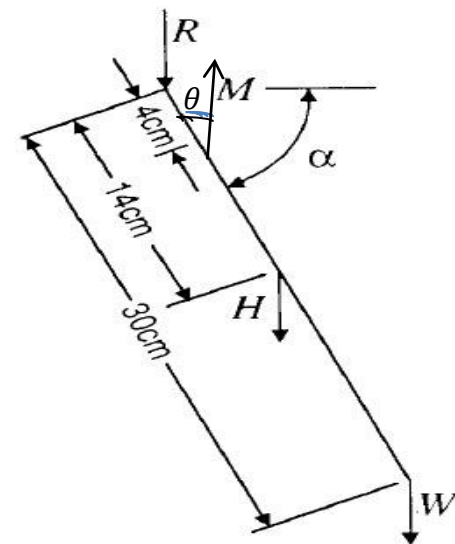
Examples of Muscular Forces and Torques

- The figure shows the force we must consider as the arm changes its angle α . If we take the torques about the elbow joint, we find that **M remains** constant as alpha α changes i.e.: **$4M \sin\theta = 14H \sin\theta + 30W \sin\theta$**

$$\therefore M = 3.5 H + 7.5 W$$



A typical value of H is 15N.



Examples of Muscular Forces and Torques

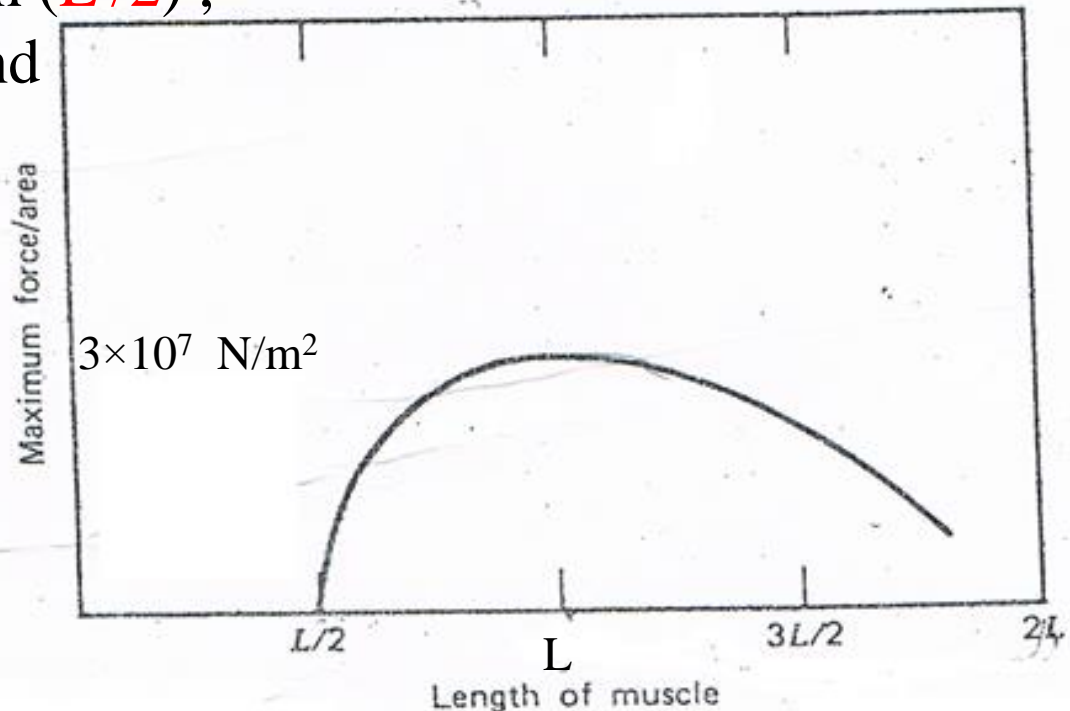
- ❑ If the arm changes its angle α , the length of the biceps muscle changes with the angle, which affects the ability of the muscles to provide the needed force.
- ❑ In general, each muscle has a **minimum length** to which it can be contracted and a **maximum length** to which it can be stretched and **still function**.
- ❑ At these tow extremes, the force the muscle can exert is essentially **zero**.
- ❑ At some point between, the muscle can produce its maximum force.



Examples of Muscular Forces and Torques

From the diagram we notes that :

- 1) At the rest of the muscle (resting length) **L** , it is close to its optimum length for producing force .
- 2) The maximum force of muscle at it optimum length is $3 \times 10^7 \text{ N/m}^2$.
- 3) At about **half** muscle length (**L/2**) , it can not shorten farther and the force that the muscle produce drops to zero .
- 4) At stretch of about **double** length (**2L**) , irreversible tearing of muscle takes place.



Examples of Muscular Forces

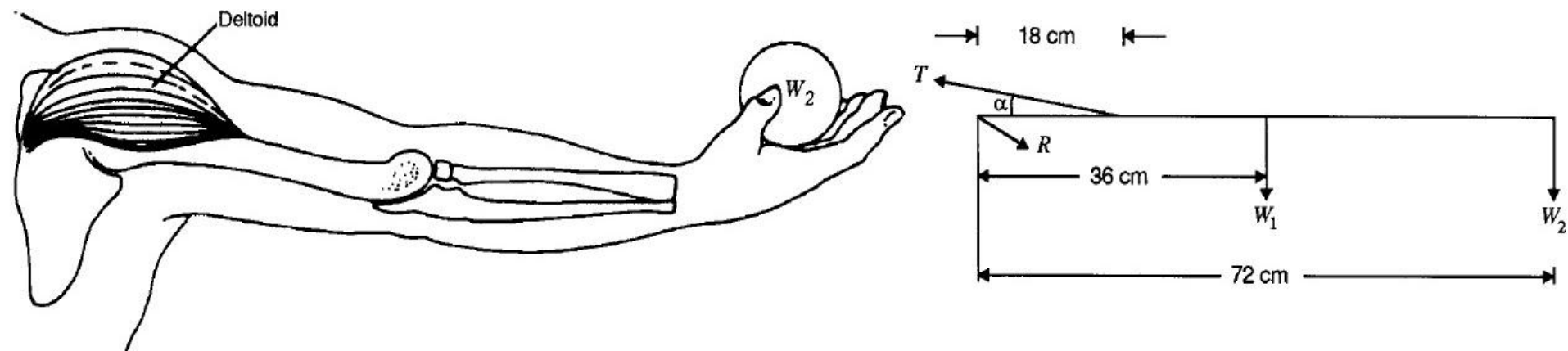
❑ The arm can be raised and held out horizontally from the shoulder by deltoid muscle.

❑ By the sum of the torques about the shoulder joint, the **tension T** can be calculated from: $\sum_i \tau_i = 0$

$$18 T \sin \alpha - 36 W_1 - 72 W_2 = 0 \longrightarrow 18 T \sin \alpha = 36 W_1 + 72 W_2$$

$$T = \frac{36 W_1}{18 \sin \alpha} + \frac{72 W_2}{18 \sin \alpha} \longrightarrow T = \frac{2 W_1 + 4 W_2}{\sin \alpha}$$

W_1 : weight of the arm at its center of gravity., W_2 : weight in the hand.

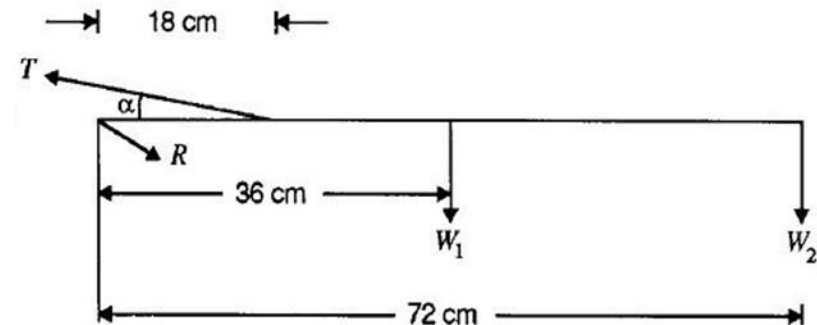


Examples of Muscular Forces and Torques

Ex: let $\alpha = 16^\circ$, $W_1 = 68 \text{ N}$, $W_2 = 45 \text{ N}$ find T .

$$T = \frac{2W_1 + 4W_2}{\sin \alpha}$$

$$T = \frac{2 \times 68 + 4 \times 45}{\sin 16} \approx 1146 \text{ N}$$



Examples of Muscular Forces and Torques

Ex: The action of chewing involves a third- class lever system, the Figure shows the jaw and chewing muscle. M is the force supplied by chewing muscle that close the jaw about the fulcrum F. W is the force exerted by the front teeth.

a. if $L_2 = 3L_1$ and $W = 100 \text{ N}$ find M.

b. if the front teeth have a surface area of 0.5 cm^2 in contact with an apple , find the force per unit area (N/m^2) for part a.

a. $\sum_i \tau_i = 0$ about the fulcrum F.

$$M L_1 - W(L_1 + L_2) = 0$$

$$M L_1 = W L_1 + W L_2$$

if $L_2 = 3L_1$ then

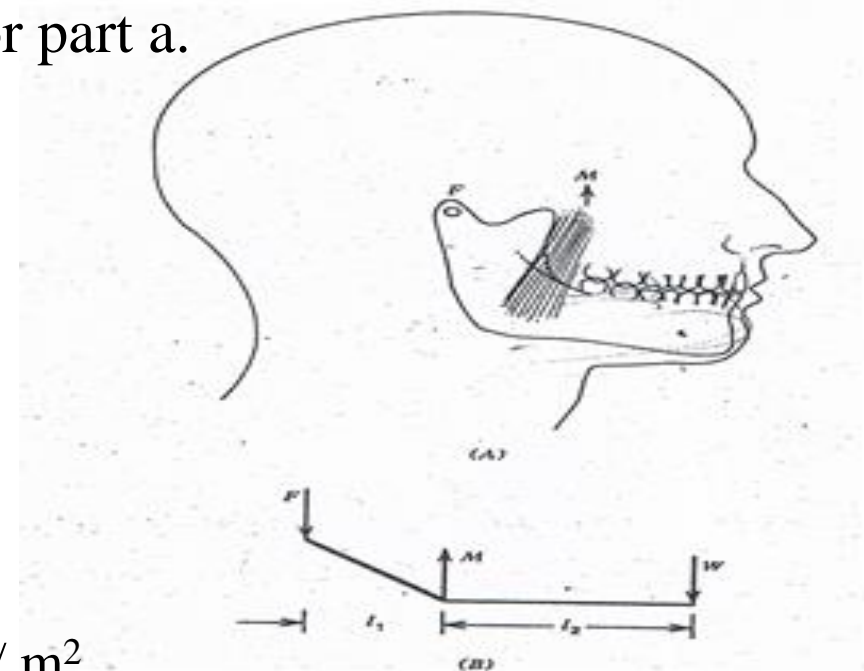
$$M L_1 = W L_1 + 3 W L_1$$

$$M L_1 = 4 W L_1$$

$$M = 4W = 4 \times 100 = 400 \text{ N.}$$

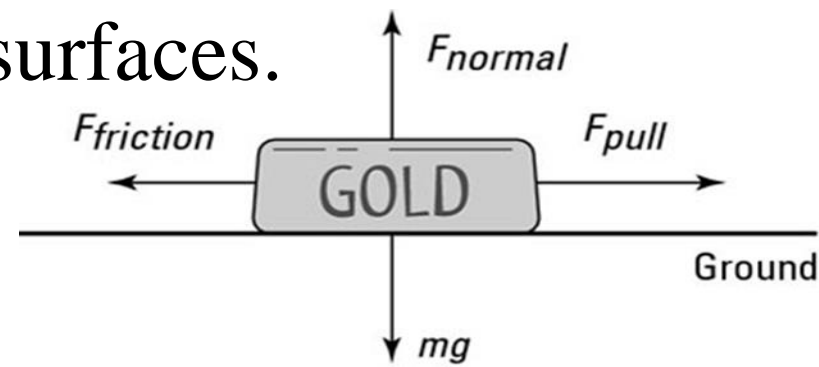
b. $A = 0.5 \text{ cm}^2 = 0.5 \times 10^{-4} \text{ m}^2$

$$\text{Stress} = P = 100 \text{ N} / 0.5 \times 10^{-4} \text{ m}^2 = 2 \times 10^6 \text{ N/ m}^2.$$



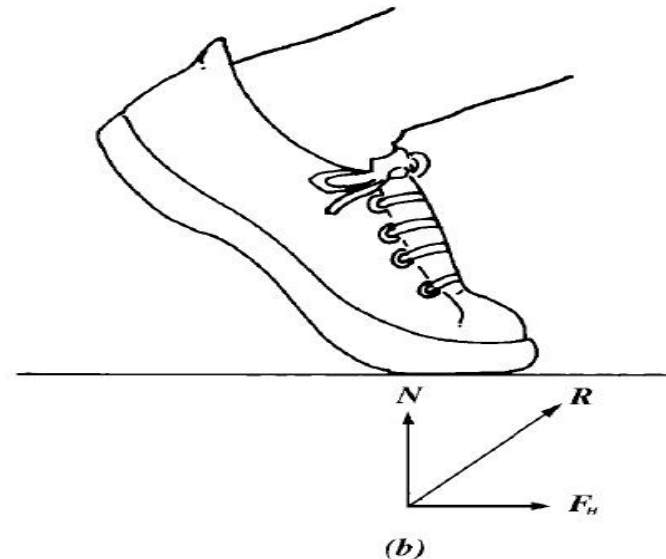
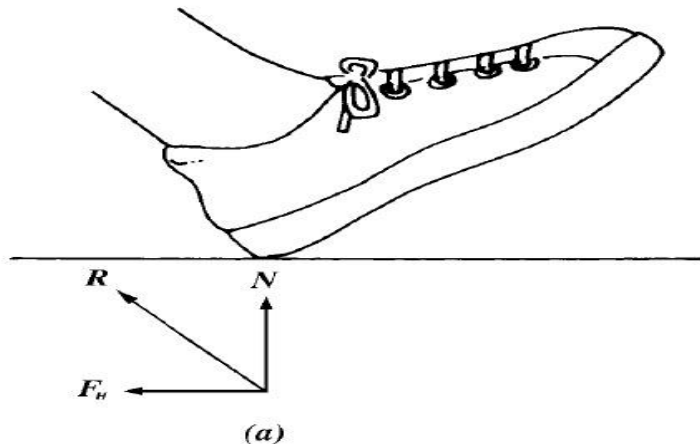
Frictional Force (F_f)

- ❑ Frictional force refers to the force generated by two surfaces that contacts and slide against each other.
- ❑ Friction and the energy loss due to friction, appear every where in our every day life .
- ❑ Friction between two surfaces produces a frictional reaction force F_f that opposes motion.
- ❑ The force of friction is usually described by $F_f = \mu N$, where N is a normal force and μ is the coefficient of friction between the two surfaces.



Friction effects on the body

- ❑ When a person is walking, as the heel of the foot touches the ground, a force is transmitted from the foot to the ground.
- ❑ We can resolve this force into horizontal and vertical components.
- ❑ The vertical reaction force is supplied by the surface and is labeled (a normal force N).
- ❑ The horizontal reaction component must be supplied by frictional forces F_f .



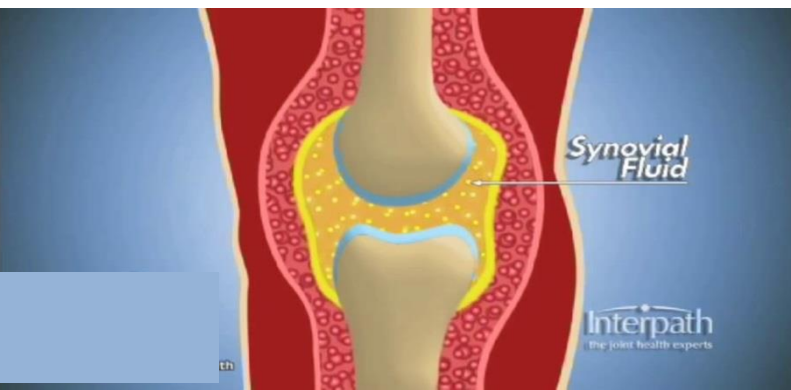
Friction effects on the body

- ❑ In general ,the frictional force is large enough both when the heel touches down and when the toe leaves the surface to prevent a person from slipping.
- ❑ The value of μ depends upon :
 - 1.The two materials in contact.
 - 2.Essentially independent of the surface area.
- ❑ Person slips on an icy, wet, or oily surface where is μ less than 0.15.
- ❑ $\mu = 0.003$ for lubricated bone joint.



Friction in Body

- ❑ Synovial fluid in the bone joint helps in lubrication
- ❑ Some diseases of the body, such as arthritis, increase the friction in bone.
- ❑ The saliva we add when we chew food acts as a lubricant.
- ❑ The heart, lungs and intestines are lubricated by a slippery mucus covering to minimize friction.

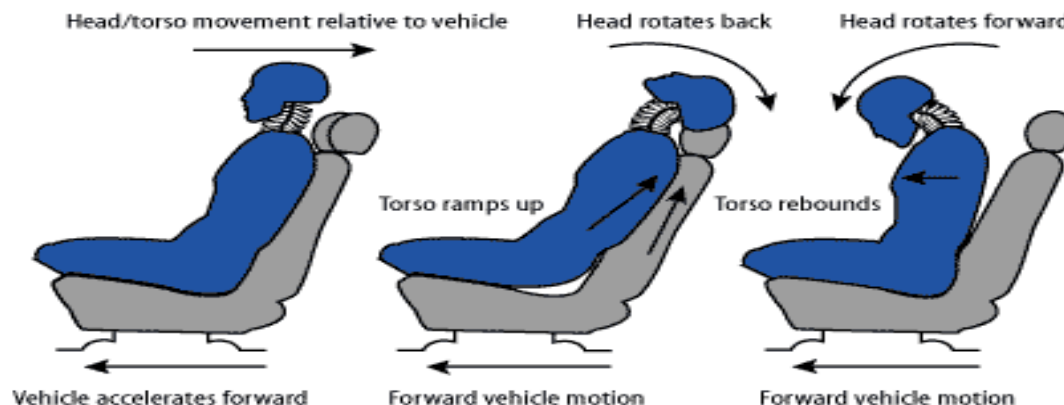


DYNAMICS FORCES

- ❑ This force is important when the body is moving and hitting another body .
- ❑ It appears on the body where acceleration or deceleration is involved.
- ❑ Newton wrote the second law that measure this force :

$$F = \frac{\Delta(mv)}{\Delta t}, \quad \frac{\Delta v}{\Delta t} = a \Rightarrow F = ma$$

Where: $F = \text{Force}$, $m = \text{mass}$, $v = \text{velocity}$, $a = \text{acceleration}$.



DYNAMICS FORCES

Example:

a. A person walking at 1 m/sec hits his head on a steel beam. Assume his head stops in 0.5cm in about 0.01sec. If the mass of his head is 4kg, what is the force developed ?

$$\Delta(mv) = (4Kg)(0\text{ m/sec}) - (4Kg)(1\text{ m/sec}) = -4Kg\text{ m/sec}$$

$$F = \frac{\Delta(mv)}{\Delta t} = \frac{4kg\text{ m/sec}}{0.01\text{ sec}} = 400Kg\text{ m/sec}^2 \text{ or } 400N$$

b. If the steel beam has 2 cm of padding and is increased to 0.04 sec what is the force developed ?

$$F = \frac{\Delta(mv)}{\Delta t} = \frac{4kg\text{ m/sec}}{0.04\text{ sec}} = 100N$$



The Effects of Acceleration on body

- 1-An apparent increase or decrease in body weight .**
- 2-Changes in the internal hydrostatic pressure .**
- 3-Distortion of the elastic tissues of the body, and if the forces are very large, tearing can take place .**
- 4-If the acceleration becomes large, the body will lose control because it does not have the adequate muscle force to work against the larger acceleration force.**
- 5-Under certain conditions ,the blood may pool in various regions of the body, the location of pooling depends upon the direction of acceleration. If the person accelerated in the head ,the lack of blood flow to the brain can cause blackout and unconsciousness.**

**Thank
you**