Karbala University-College of veterinary medicine

Medical Physics-Lecture (2)

Force on and in the body

Force controls all motion in the world; we are usually unaware of important forces in the body, for example, the muscular forces that cause the blood to circulate and the lungs to take in air.

Forces

Forces in the body

1-Gravitational force

2-Electrical force

3-Nuclear force

Forces on the body

1- Static force

2-Dynamic force

3-Frictional force

Forces in the body

1-Gravitational forces:

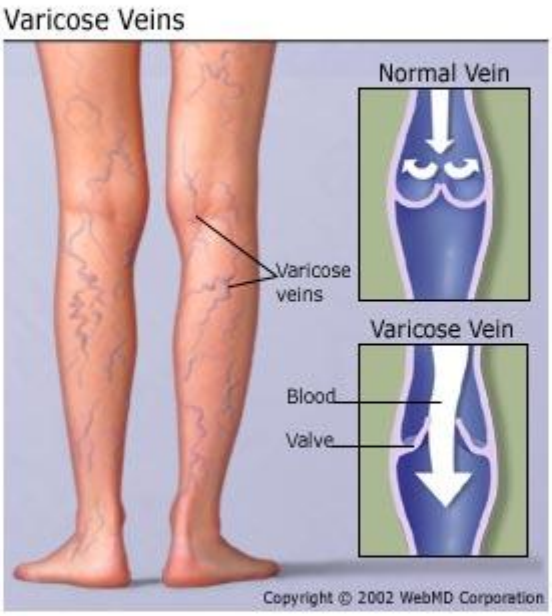
Newton formulated the law of universal gravitation (قانون الجذب العام). This law states that there is a force of attraction between any two objects; our weight is due to the attraction between the earth and our bodies.

W=gm

W: the weight (N, dyne), g: acceleration due to gravity (cm/sec^2 or m/sec^2), m: the mass (g, kg)

Medical effects of gravitational force

- 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.



- Medical effects of gravitational force on the skeleton (On the bones), in some way contributes to "healthy bones". If a person becomes "weightless" such as in an orbiting satellite(سفن فضائية), he may lose some bone mineral, and this may be a serious problem on very long space journeys. Long-term bed rest is similar in that it removes much of the force of body weight from the bones which can lead to serious bone loss.

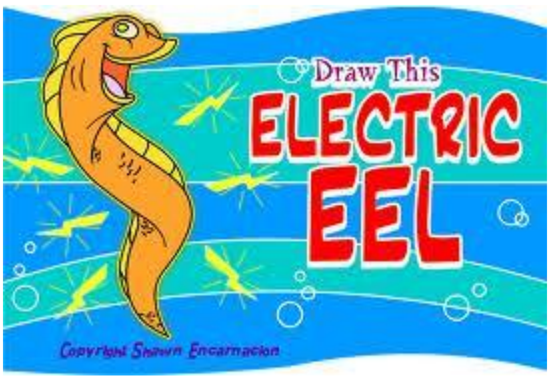
- في حالة عدم حمل العظم لاي وزن فانه يبدء بفقدان معادنه ويصبح ضعيفا و العكس صحيح في حالة تعرض العظم لحمل مستمر فانه يصبح أقوى لذا فان عظام الرياضيين اقوى من عظام غيرهم.

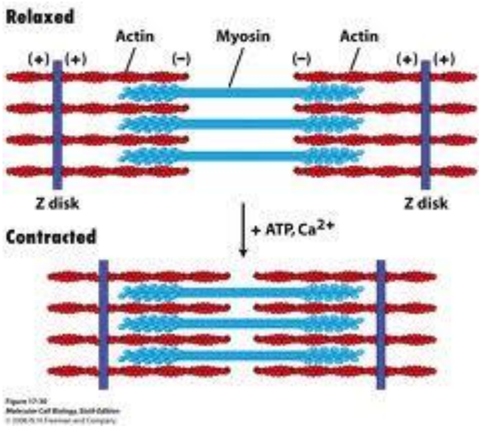
2-Electrical forces:

This force more complicated than gravity since it involves attractive and repulsive forces between static electrical charges as well as magnetic force produced by moving electrical charges (electrical current).Electrical forces are immense (هائلة) compared to gravitational force. For example, the electrical force between an electron and a proton in a hydrogen atom is about 10^{39} times greater than the gravitational force between them.

Biological examples of electrical forces:

- Control and action of our muscles is primarily electrical. The forces produced by muscles are caused by electrical charges attracting opposite electrical charges.
- Electric eels and some other marine animals are able to add the electrical potential from many cells to produce a stunning voltage of several hundred volts.





3-Nuclear forces:

Its acts as the force to hold the nucleus together against the repulsive forces produced by the protons on each other.

Forces on the body

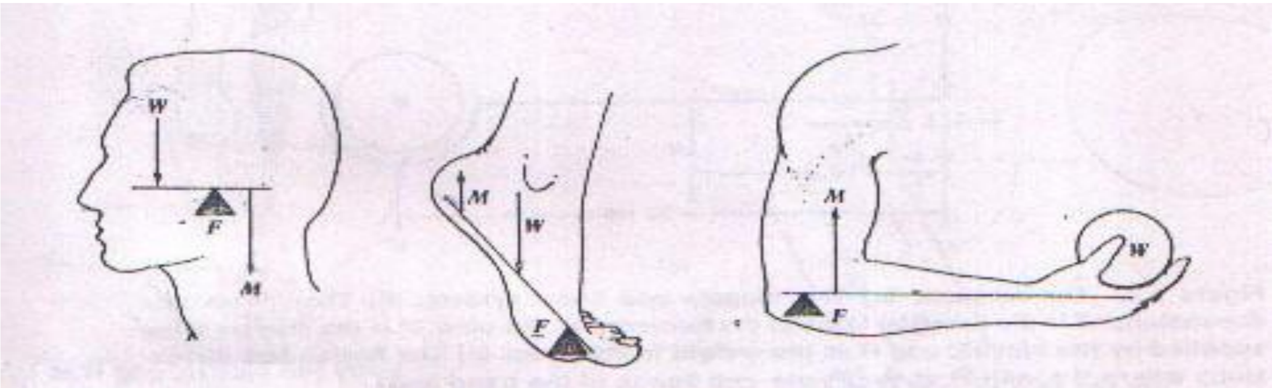
1-***Statics*** : When objects are stationary (static) (ساكن) they are in a state of equilibrium. The sum of the forces in any direction is equal to zero, and the sum of the torques (عزوم) about any axis is also zero.

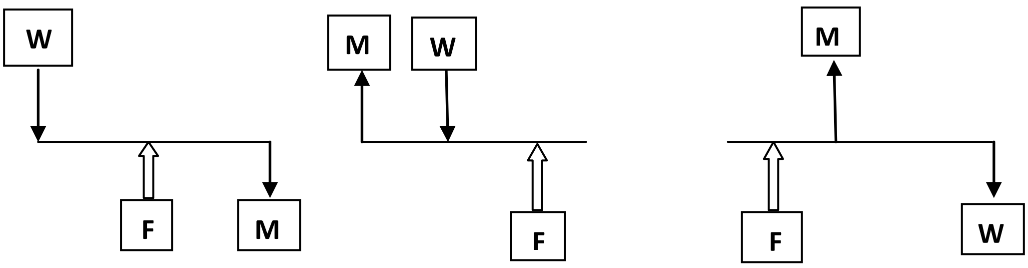
Many of the muscle and bone systems act as levers (عتلات) which are classified to:

a-**First class levers**: They are least common in the body. The fulcrum point (نقطة المرتكز) (F) is between the muscle forces (M) and the weight (W), for example the head.

b-**Second class levers**: They are found more than first class levers. Weight (W) is between the fulcrum point (F) and muscle forces (M), for example standing on the toes (أصابع القدم).

c- **Third class levers**: They are most common in the body. Muscle forces (M) is between fulcrum point (F) and weight (W).For example, the arm in the elbow (المرفق) joint.





(First class) (Second class) (Third class)

Figure1: The three levers classes and schematic example of each in the body. W is a force that could be the weight, F is the fulcrum point and M is the muscle force.

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 (*Figure 2a*).

(*Figure 2b*) shows the forces and dimension of a typical arm. We can find the force supplied by the biceps if we sum the torques about the pivot point at the joint. There are only two torques: that due to the weight W, which is equal to 30W acting clockwise, and that produce by the muscle force M which counterclockwise and of magnitude 4M.With the arm in equilibrium we find that:

$$4M-30W=0 \longrightarrow M=7.5W$$

Or that a muscle force 7.5 times the weight is needed (we neglected the weight of the forearm and hand).

(Figure 2c) show a more corrects representation of the problem with weight of the forearm and hand H included. By summing the torques about the joint we obtain **M= 3.5 H+7.5W**

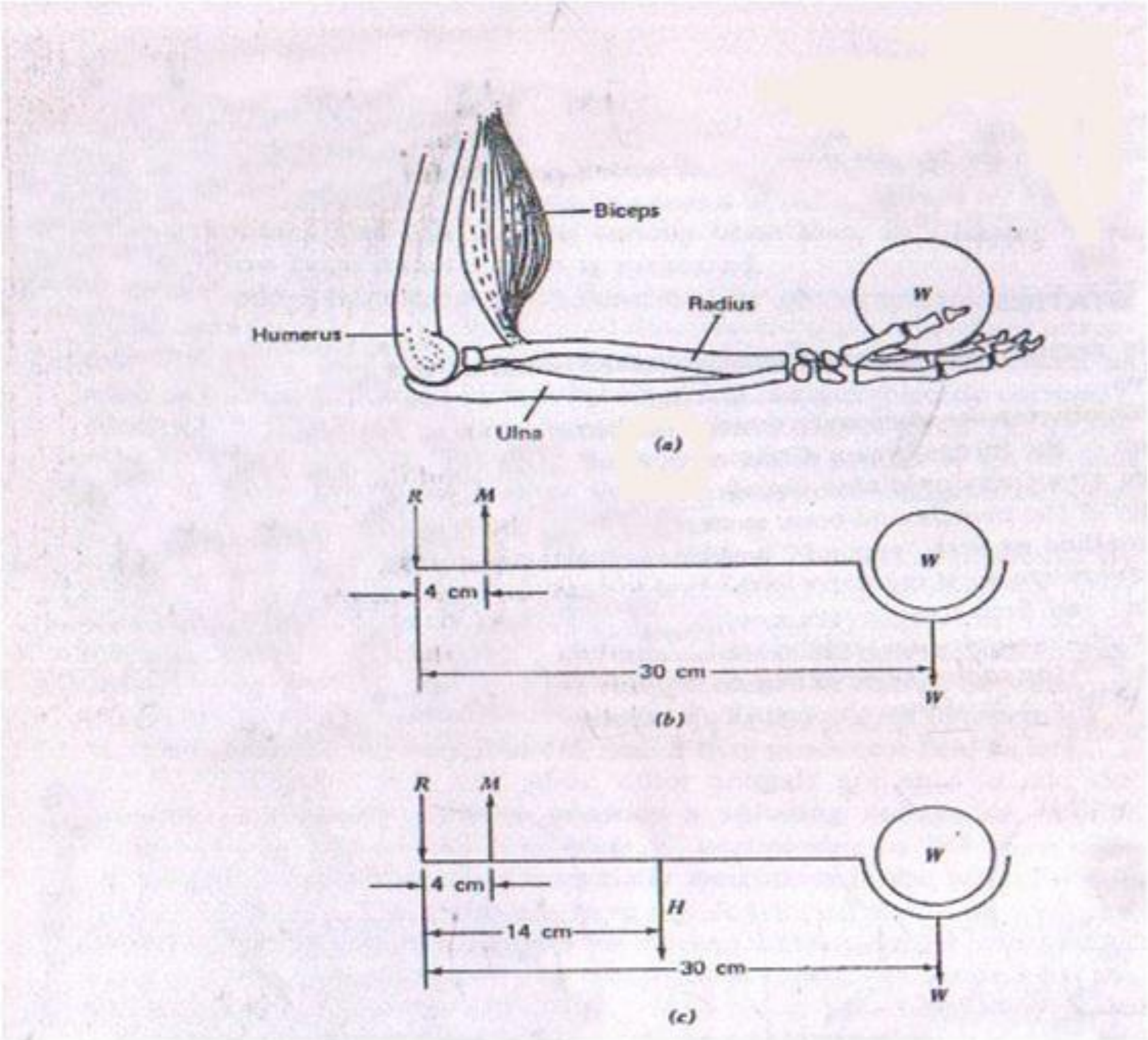


Figure2: The forearm (a) the muscle and bone system.(b) the forces and dimensions, R is the reaction force of the humerus on the ulna. M is the muscle force supplied by the biceps and W is the weight in the hand. (c) The forces and dimensions where the weight of the tissue and bones of the hand and arm H is included and located at their center of gravity

Let us now consider the effect on the muscle force needed as the arm changes its angle as shown in (figure *3a). Figure 3b* shows the forces we must consider for an arbitrary angle α. If we take the torques about the joint we find that M remains constant as α changes!.

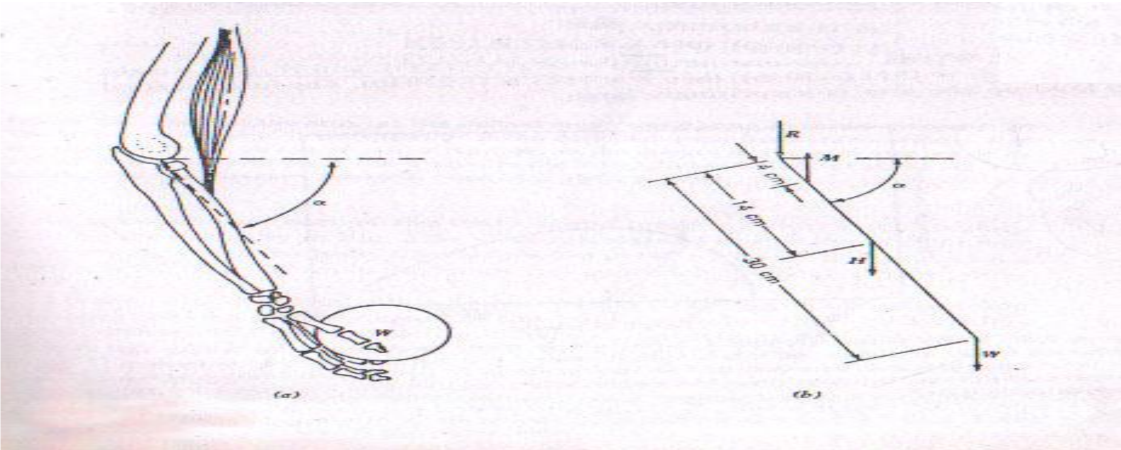


Figure3. The forearm at an angle α to the horizontal.(a) the muscle and bone system.(b) the force and dimensions.

However, the length of the biceps muscle changes with the angle. 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 some point in between, the muscle can produce its maximum force (*figure 4*).

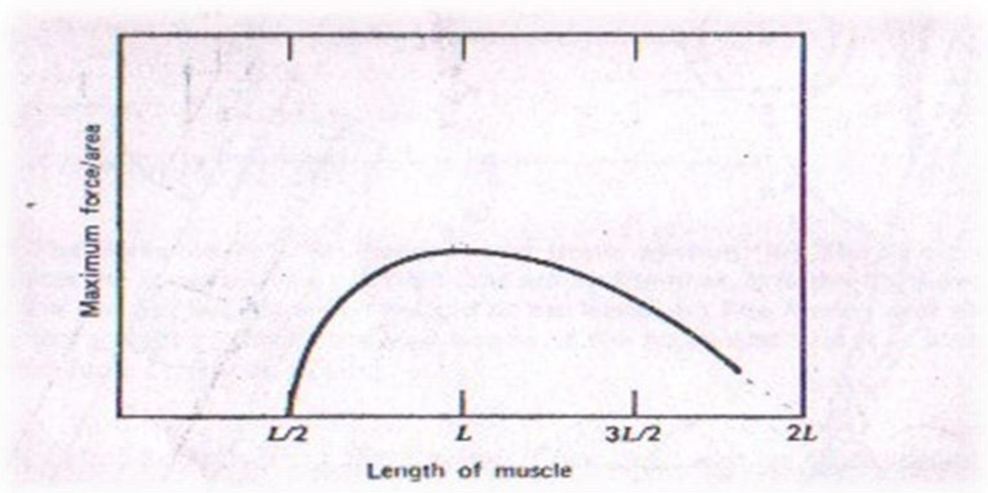


Figure4. At its resting length L a muscle is close to its optimum length for production force. At about half this length it cannot shorten further and the force it can produce drops to (0), whereas at a stretch of about 2L irreversible tearing of the muscle takes place.

If the biceps pulls vertically, the angle of the forearm(الساعد)does not affect the force required but it does affect the length of the biceps muscle which affects the ability of the muscle to provide the needed force.

The arm can be raised and held out horizontally from the shoulder by the deltoid muscleعضلة الكتف(*figure5 a*); we can show the forces schematically (*figure5* b).

By taking the sum of the torques about the shoulder joint ,the tension T can be calculate from

$$\mathbf{T} = \frac{2W1 + 4W2}{\sin\alpha}$$

W_1(the weight of the arm),and W_2(the weight in the hand).

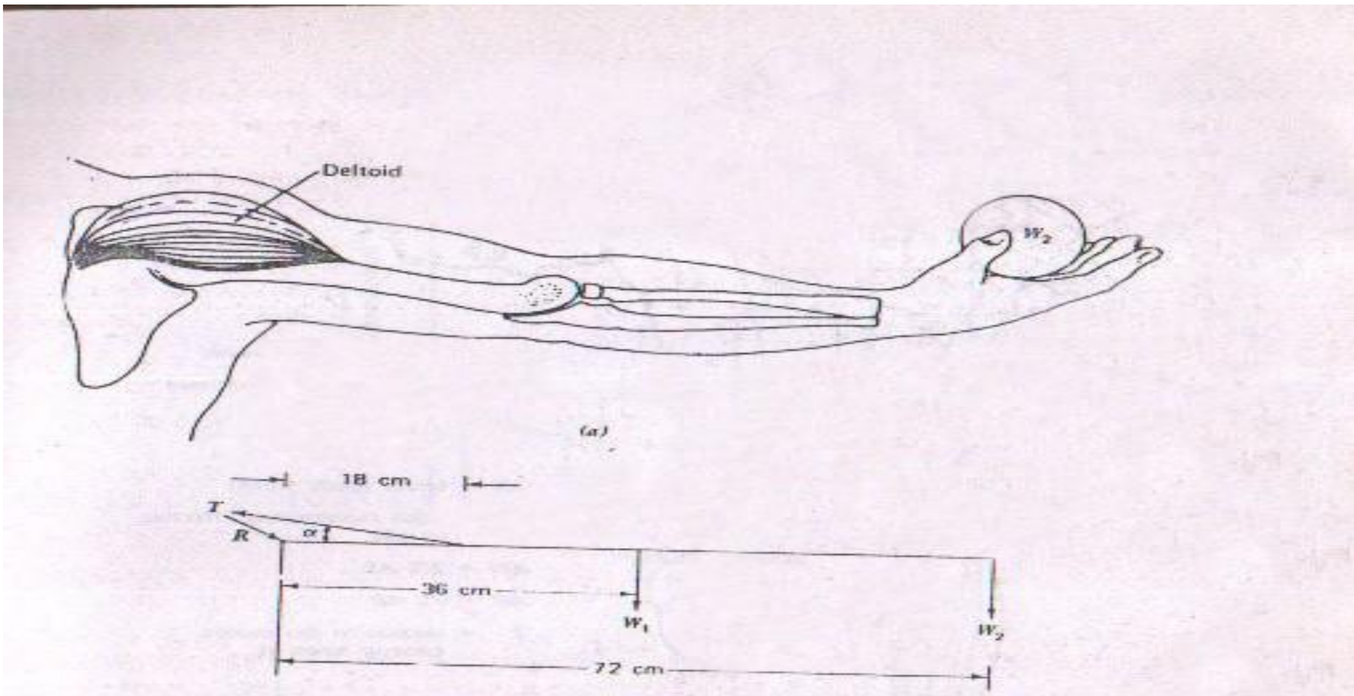


Figure5. Raising the arm.(a) The deltoid muscle and bone structure involved.(b)The forces on the arm. T is the tension in The deltoid muscle fixed at the angle α, R is the reaction force on the shoulder joint, W_1 is the weight of the arm located at its center of gravity, and W_2 is the weight in the hand.

If alpha =16 deg.

W1(The weight of the arm)=68N.

W2 (the weight in the hand)=100N.

Then T=1985.2 N.

I.e., the force needed to hold up the arm is surprisingly large.

2-***Dynamic***: Let us examine forces which are important when the body is moving and hitting another body. They appears on the body where acceleration or deceleration is involved.

The Newton's second law, force equals mass times acceleration.

F=ma

Newton said" force equals the change of momentum $\Delta(mv)$ over a short interval

of time Δt "

$$F = \frac{\Delta(mv)}{\Delta t}$$

Example 1: A(60 kg) person walking at(1 m/sec)bumps into a wall and stops in a distance of(2.5 cm)in a about(0.05sec) .what is the force developed on impact?

Sol.

$\Delta(mv)$ = (60 kg)(1m/sec) – (60 kg)(0 m/sec) = 60 kg m/sec

$$F = \frac{\Delta(mv)}{\Delta t} = \frac{60 \text{ kg m/sec}}{0.05 \text{ sec}} = 1200\, kg\, m/\sec^2 \quad \text{or} \quad 1200 \text{ N}$$

Example 2: a-A person walking at (1 m/sec) hits his head on a steel beam . Assume his head stops in (0.5 cm) in about 0.01 sec. If the mass of his head is (4kg), what is the force developed?

Sol.

$\Delta(mv)$ = (4 kg)(1m/sec) – (4 kg)(0 m/sec) = 4 kg m/sec

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

b- If Δt is increased to (0.04 sec), what is the force developed?

Sol.

$$\boldsymbol{F} = \frac{\Delta(\boldsymbol{mv})}{\Delta \boldsymbol{t}} = \frac{4\ \text{kg m/sec}}{0.04\ \text{sec}} = 100\ kg\ m/\sec^2 \qquad \text{or} \qquad 100\ \text{N}$$

Applications

1) If a person jumps from a height of 1m. land stiff –legged , he is in for shock.

Under these conditions, deceleration of the body takes place mostly through compression of the feet.

The body is traveling at about 4.5m/sec. just prior to hitting ,if the body stops in about 0.005 Sec. the force in the legs is almost 100 times the persons weight.

2) Because of the large velocity of modern cars riders have a momentum larger than when walking. In an accident the car stops in a short time, producing very large forces. The results of these large forces on the passengers can be broken bones internal injuries and sometimes death.

Viscosity

Small objects fall through a liquid depends on their size, the viscosity of the liquid and the acceleration due to gravity *g*.

We can artificially increase g by spinning the fluid in a centrifuge. This will cause very fine particles to separate from the fluid.

Let us consider first sedimentation of small spherical objects of density p in a solution of density p_o in a gravitational field g . We know that falling objects reach a maximum (terminal) velocity due to viscosity effects. Stoke has shown that for a spherical object of a radius a , The retarding force F_d and terminal velocity v are related by

$$F_d = 6\pi a v \eta$$

Where η is the viscosity of the liquid through which the sphere is passing .The SI unit for viscosity is the Pascal second (Pas), The cgs unit for viscosity is the poise (1Pas= 10 poise).

When the particle is moving at a constant speed, the retarding force is in equilibrium with the difference between the downward gravitational force and the upward buoyant force (قوة الطفو نحو الاعلى) (the weight of the liquid the particle displaces). Thus we have:

- The force of the gravity ⟶ $F_g = 4/3\,\pi\, a^3\, \rho g$
- The buoyant force ⟶ $F_B = 4/3\,\pi\, a^3\, \rho_o g$
- The retarding force ⟶ $F_d = 6\pi a v \eta$

F_g acts downward and F_B acts upward, and the difference is equal to F_d

$$F_d + F_B = F_g$$

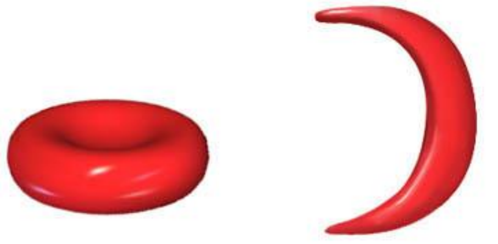
$$F_d = F_g - F_B$$

We obtain the expression for the terminal velocity (sedimentation velocity),

$$v = \frac{2a^2}{9\eta} g(\rho - \rho_0)$$

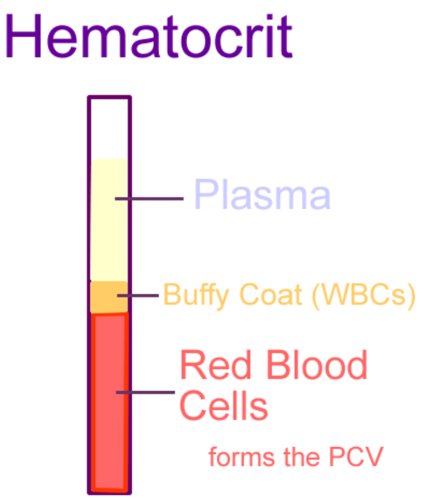
In some forms of disease such as rheumatic fever, rheumatic heart disease, and gout, the red blood cells clump together and the effective radius increases; thus an increased sedimentation velocity occurs.

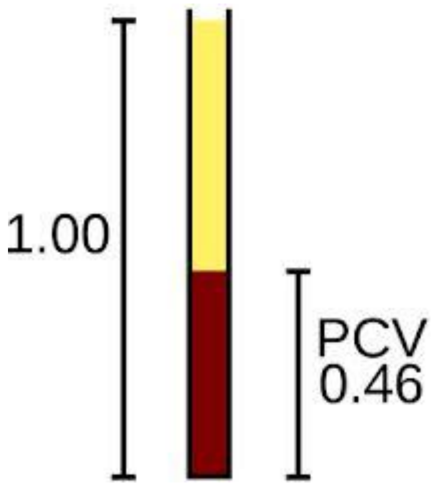
In other diseases such as sickle cell anemia, the red blood cells change shape or break. The radius decrease; thus the rate of sedimentation of these cells is slower than normal.



Normal red blood cell Sickled red blood cell

Hematocrit (packed cell volume PCV) is the percent of red blood cells in the blood.





Since the sedimentation velocity is proportional to the gravitational acceleration, it can be greatly enhanced if the acceleration is increased. We can increase g by means of a centrifuge, which provides an effective acceleration g_{eff}

$$g_{eff} = 4\pi^2 f^2 r$$

Where f is the rotation rate in revolution per second and r is the position on the radius of the centrifuge where the solution is located.

Hematocrit depends upon:

- Radius of centrifuge.
- Speed of centrifuge.
- Duration of centrifuge.

3-Frictional forces:

Frictional and the energy loss due to friction appear everywhere in our everyday life. Friction limits the efficiency of most machines such as electrical generators and automobiles. On the other hand, we make use of friction in devices such as rubber tires and automobiles brakes.

In the body, friction effects are often important. When a person is walking, as the heel (الكعب) of the foot touches the ground, a force is transmit from the foot to the ground (*figure 7a*). We can resolve this force into horizontal and vertical components. The vertical reaction force is supplied by the surface and is labeled N (a normal force).

The horizontal reaction component must be supplied by frictional force. The maximum force of friction f is usually describe by

$$f = \mu N$$

Where N is a normal force and μ is a coefficient of friction between the two surfaces. The value of μ depends upon the two material in contact, and it is essentially independent of the surface area. Measurements have been made of the horizontal force component of the heel as it strikes the ground when a person walking (*figure 7a*), and it has been found to

be approximately 0.15W,where W is the person's weight. This is how large the frictional force must be in order to prevent the heel from slipping. If we let N=W then we can apply a friction a force as large as

$$f = \mu N .$$

In general, the frictional force is large enough both when the heel touches down and when the toe leaves the surface (figure *7b*) to prevent a person from slipping. Occasionally person is on an icy, wet, or oily surface where μ is less than 0.15 and his foot slips. This in not only embarrassing (محرج); it may result in broken bones.

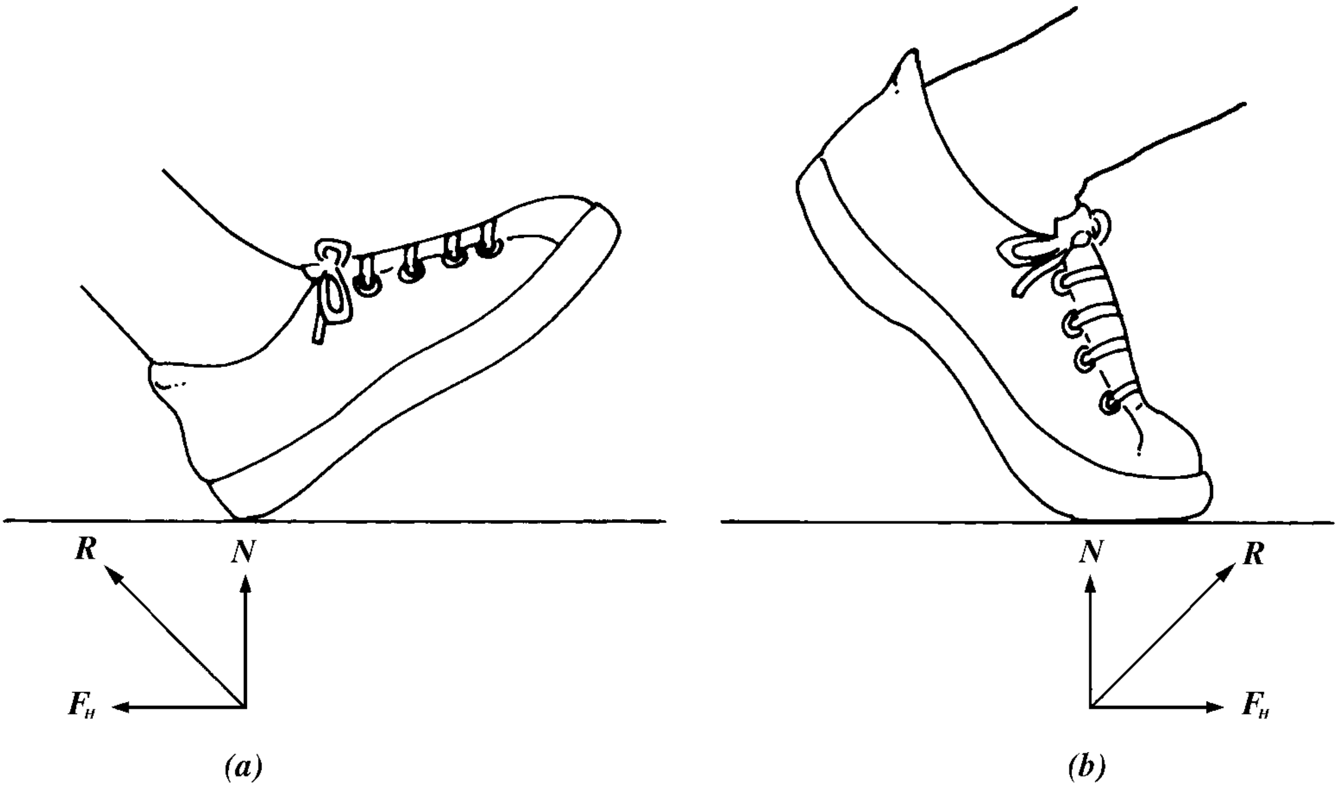
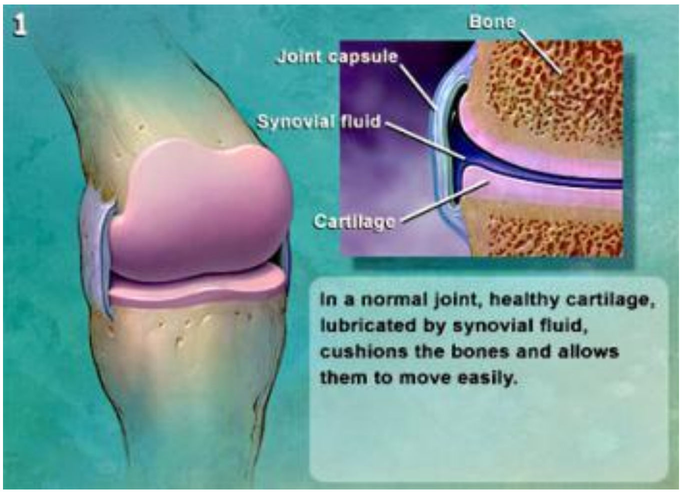


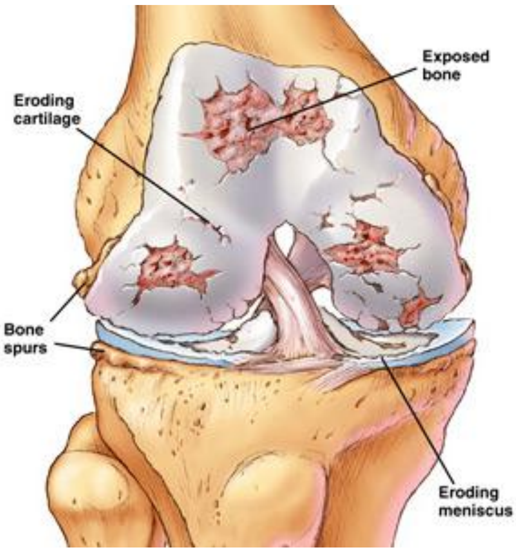
Figure7. Normal walking. (a) Both a horizontal frictional component of force, F_H, and a vertical component of force N with resultant R exist on the heel as it strikes the ground, decelerating the foot and body. The friction between the heel and surface prevents the foot from slipping forward. (b) When the foot leaves the ground, the frictional component of force, F_H, prevents the foot from

slipping backward and provides the force to accelerate the body forward.

Friction must be overcome when joints move, but for normal joints it is very small. The coefficient of friction in bone joints is usually much lower than in engineering-type material.



If a disease of the joint exists, the friction may become large. The synovial fluid in the joint is involved in the lubrication.



The saliva(لعابه) act as lubricant, Most of the large organs in the body are in more or less constant motion .Each time the heart beat its moves, the lungs move inside the chest with each breath, and the intestines (أمعاء) have a slow rhythmic motion (peristalsis) as they move food toward its final destination. All of these organs are lubricated by slippery mucus covering to minimize friction.