Forces on and in the Body

By the end of this section, you will be able to:

1- Explain the forces exerted by muscles.

2- State how a bad posture causes back strain.

3- Discuss the equation of sedimentation and how is used to test rheumatic heart disease, and sickle cell anemia.

Physicists recognize four fundamental forces. In order of their relative strength from weakest to strongest. They are:

1- Gravitational force
2- Electrical force
3- Weak nuclear force
4- Strong nuclear force

Only the gravitational and electrical forces are importance in our study of the forces affecting the human body.

The electrical force important at molecular and cellular levels, e.g. affecting the binding together of our bones and controlling the contraction of our muscles.

Gravitational force, though very much weaker than the electrical force by a factor 1039.

1. How Forces Affect the Body

_The muscular forces that cause the blood to circulate and lungs to take in air.

-In the bones there are many crystals of bone mineral that require calcium. A calcium atom will become part of crystal if it gets close to a natural place for calcium and electrical forces are great enough to trap it. It will stay in that place until local conditions have changed and electrical forces can no longer hold it in place. This might happen if the bone crystals destroyed by cancer.

1-1.Some Effects of Gravity on the Body

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

1-2. Electrical Forces in the Body

The forces produced by muscles are caused by electrical charges attracting opposite electrical charges.

Cells in the body has an electrical potential difference across the cell membrane.

1-3. Frictional forces

Friction and energy loss resulting from friction appear everywhere in our everyday life.

Some diseases of the body, such as arthritis, increase the friction in bone joint.

Force of friction F_f is described by

$$F_f = \mu N$$

N : is normal force

μ: is coefficient of friction between two surfaces

- Friction must be overcome when joints move, but for normal joints it is very small. If a disease of the joint exists, the friction may become large.

Synovial fluid in the joint is involved in lubrication.

The saliva we add when we chew food acts as lubricant.

Most of internal organs in the body are in more or less constant motion and require lubrication each time the heart beats, it moves. The lungs move inside the chest. All of these organs are lubricated by a slippery mucus covering to minimize friction.

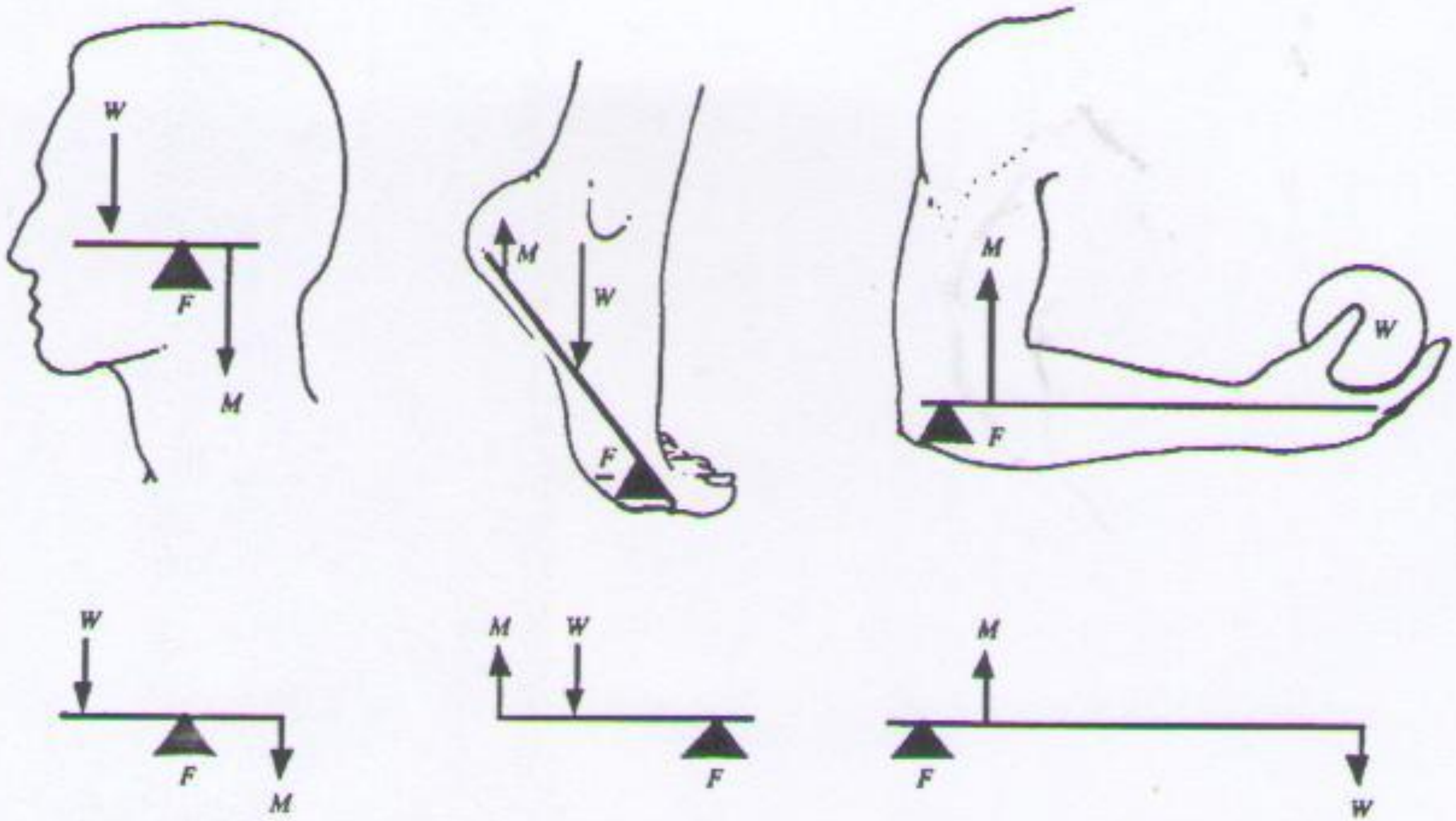
1-4. Forces, Muscles, and joints

1-4-1. Muscle Forces involving levers

For the body to be at rest and equilibrium (static),the sum of the forces acting on it in any direction and the sum of the torques any axis must both equal zero.

Many of muscle and bone system of the body acts as levers.

Levers are classified as first, second, and third class systems



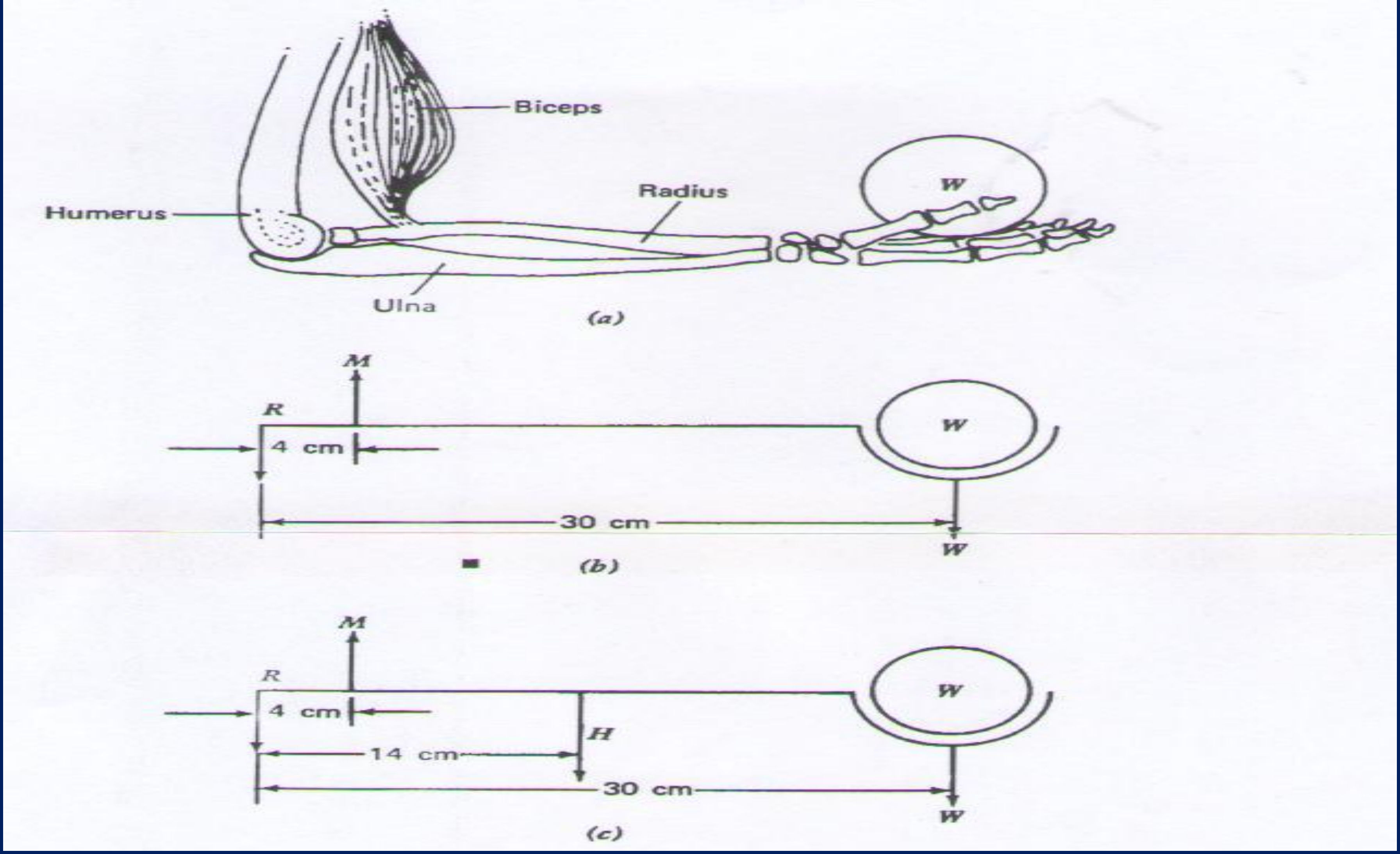
First Class

Second class

Third Class

(Fig.1)The three lever classes in the body and schematic examples of each. W is a force that is usually the weight. F is the force at the fulcrum point, and M is the muscular force. Not that the different levers depend upon different arrangement of the three forces .M, W, and F

Third class levers are most common in the body



(Fig.2)The forearm. (a)The muscle and bone system. (b)The forces and dimensions: R is the reaction force of the hummers 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 forearm H is included. These forces are located at their center of gravity.

A simple example is in the case of biceps muscle and radius bone acting to support a weight W in the hand (Fig 2a),(Fig 2b) shows the forces and dimensions 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 .

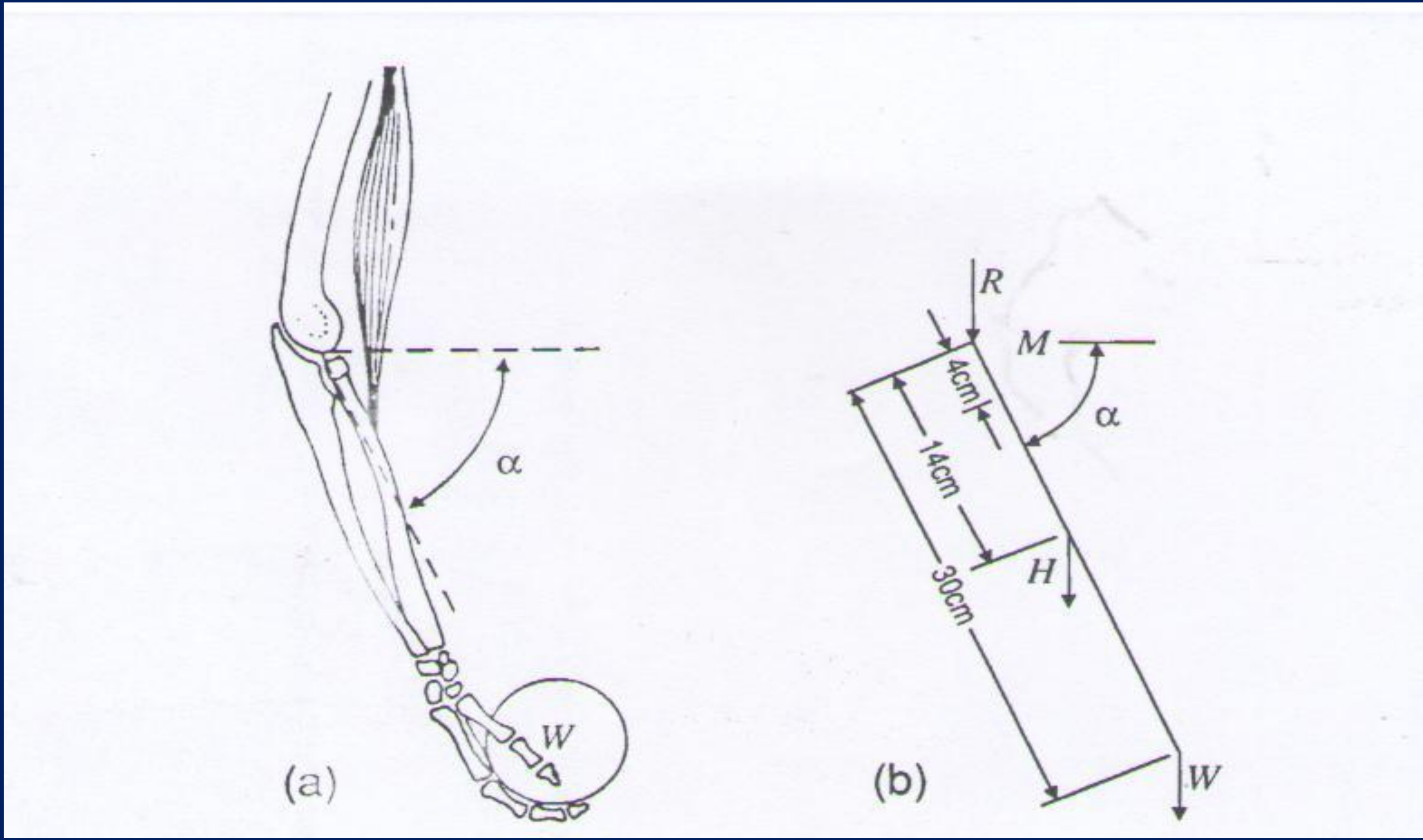
There are only two torques: that due to the weight W, which is equal to 30W acting clockwise and that produced by the muscle force M, which is counterclockwise and of magnitude 4M, with the arm in equilibrium we find that

$4M - 30W = 0$ and $M = 7.5W$

A muscle force 7.5 times the weight, we neglected the weight of the forearm and hand.

Fig 2c shows a more correct representation of the problem with the weight of the forearm and hand H included.

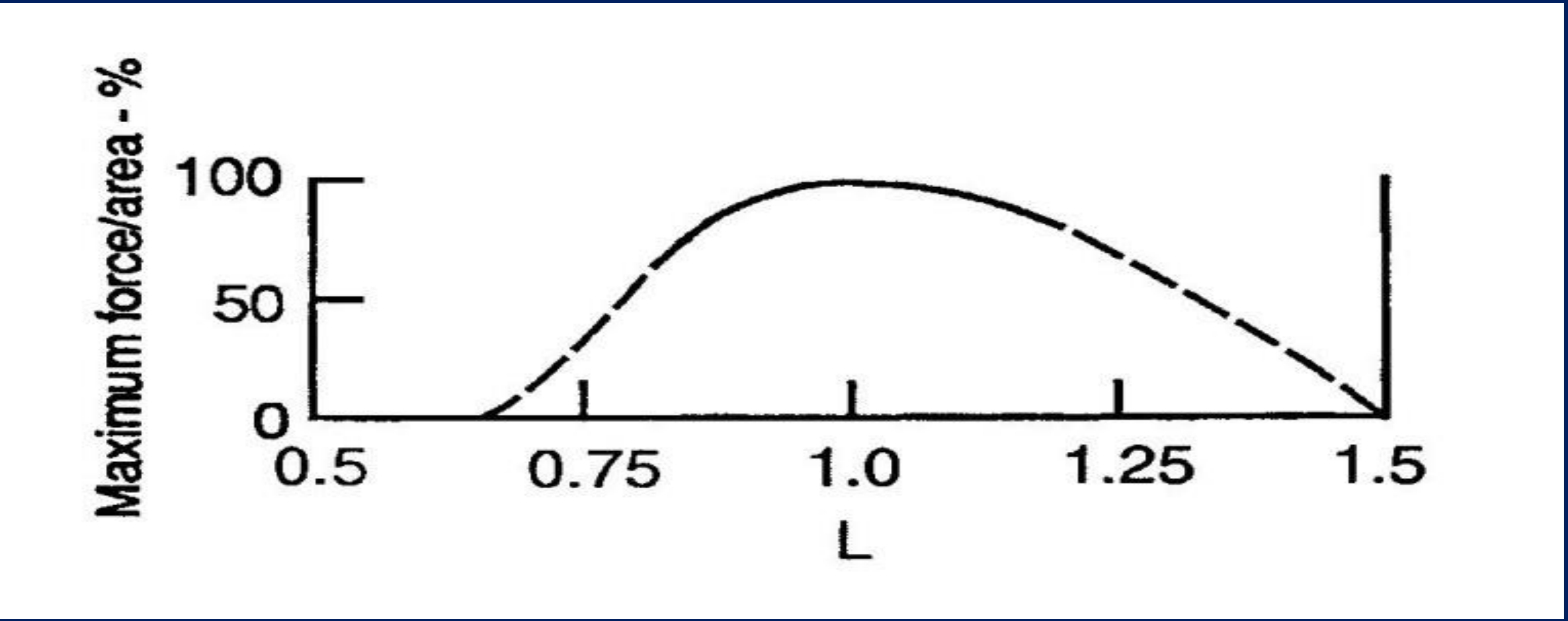
$M = 3.5H + 7.5W$



(Fig.3)The forearm at the angle α to the horizontal. (a) The muscle and the bone system. (b) The forces and dimensions

Let us consider the effect on the muscle force needed as the arm changes its angle as shown in the (Fig. 3a). If we take the torques about the joint we find that M remains constant as α change: 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 maximum length to which it stretched and still faction.

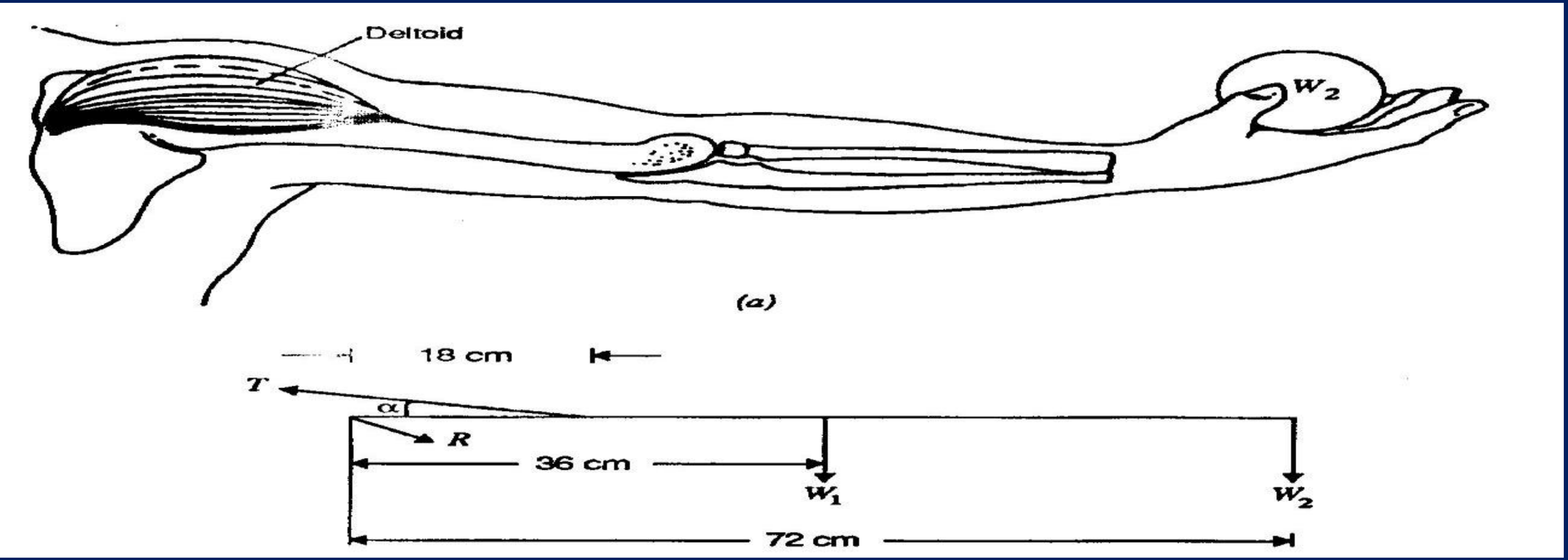
At these two extremes the force the muscle can exert is essentially zero. At some point in between, the muscle can produce its maximum force. (Fig 4). If the biceps pulls vertically the angle of the forearm does not affect the force required but it does affect the length of biceps muscle, which affects the ability of the muscle to provide the needed force.



(Fig.4)At its resting length L a muscle is close to its optimum length for producing force. At about 80% of this length it cannot shorten much more and the force it can produce drops significantly. The same is true for stretching of the muscle about 20%greater than its natural length. A very large stretch of about 2L produces irreversible tearing of the muscle.

-The arm can be raised and held out horizontally from the shoulder by the deltoid muscle (Fig 5a). By taking the sum of the torques about shoulder joint, the tension T can be calculated.

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



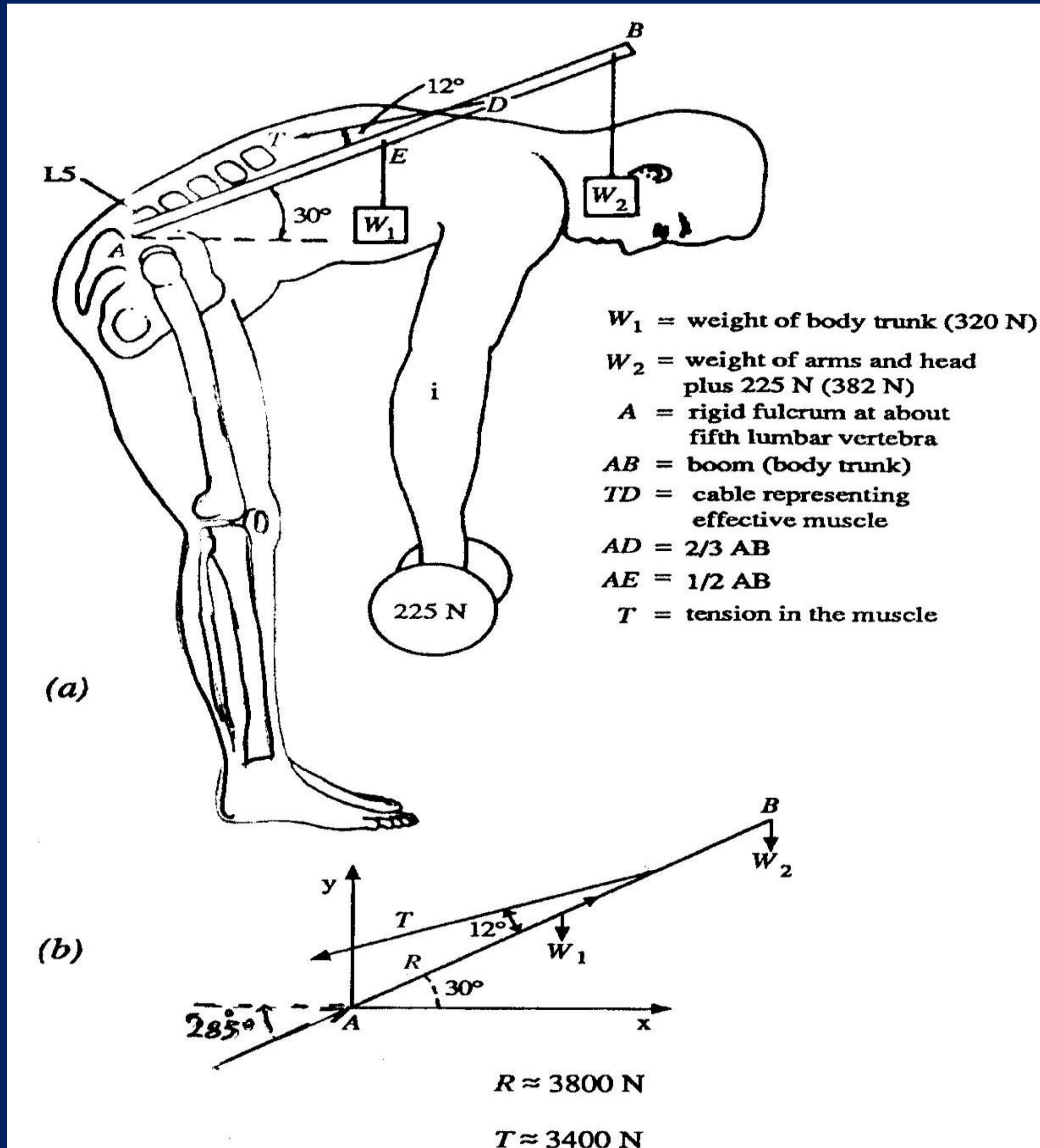
(Fig.5) Raising the right arm. (a) The deltoid muscle and bones involved. (b) The forces on the arm. T is the tension in the deltoid muscle fixed at the angle ,R is the reaction force on the shoulder joint, W is the weight of the arm located at its center of gravity, and W is the weight in the hand.

If α = 16º

W_1 = 68N (the weight of the arm)

W2 = 45N (the weight of the hand)

T = 1145N (the force needed to hold up the arm


B
12°
D
T
E
L5
W2
30°
W1
A
i
225 N
W1 = weight of body trunk (320 N)
W2 = weight of arms and head plus 225 N (382 N)
A = rigid fulcrum at about fifth lumbar vertebra
AB = boom (body trunk)
TD = cable representing effective muscle
AD = 2/3 AB
AE = 1/2 AB
T = tension in the muscle
(a)
B
W2
y
T
12°
W1
(b)
R
30°
285°
A
x
R ≈ 3800 N
T ≈ 3400 N

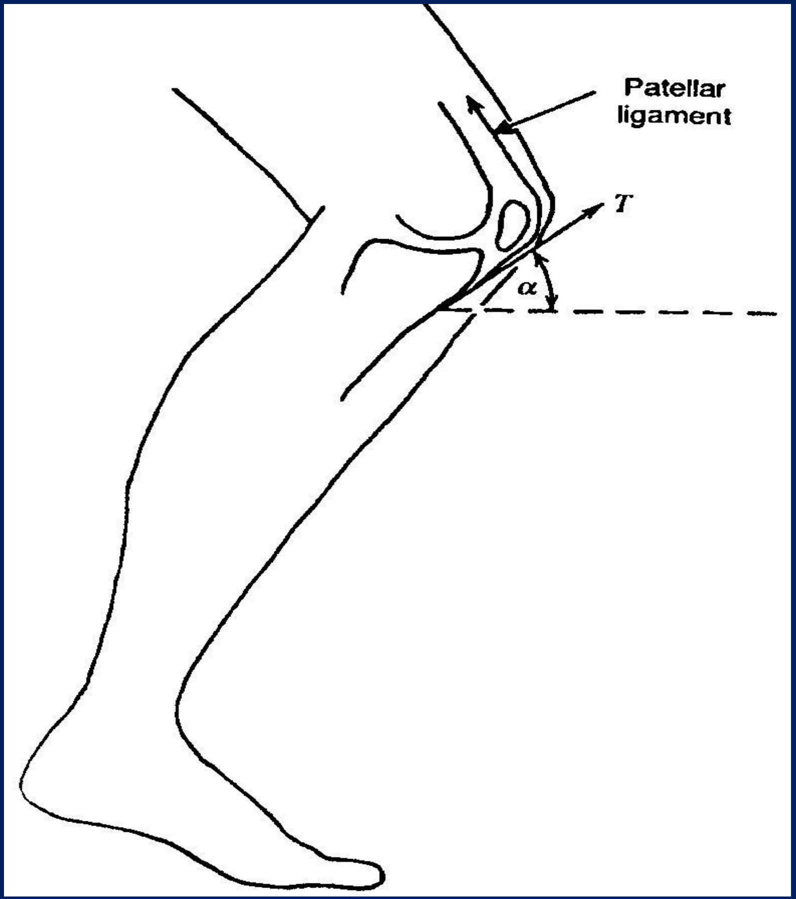
(Fig.6) Lifting a weight. (a) Schematic of forces used. (b) The forces where T is an approximation for all of the muscle forces and R is the resultant force on the fifth lumbar vertebra (L5).

An often abused part of the body is the lumbar (lower back) region. The calculated force at the fifth lumbar vertebra (L_5) with the body tipped forward at 60^o to the vertical and with weight of 225N in the hands can approach 3800N, lifting heavy objects from this incorrect position cause of low back pain.

Some times vertebral bone collapse rather than disc damage occurs. This often happens in elderly women who suffer from weakened bones.

Just as forces can be transmitted over distances and through angles by cable and pulley system, the forces of the muscles in the body are transmitted by tendons.

In the leg, a tendon passes over a groove in the kneecap (patella) and connects to the shin (tibia). With your leg extended you can move the patella with your hand but with your knee flexed cannot; the paella is held rigidly in place by the force from the tendon as shown in (Fig.7). The patella also serves as a pulley for changing the direction of the force. This also acts to increase the mechanical advantage of the muscles that straighten the leg. Some of the largest forces in the body occur at the patella. When you are in a deep squatting position, the tension in the tendons that pass over the patella may be more than two times your weight.



(Fig.7) Diagram of the tensile force on the patellar ligament squatting. The tension T is very large when a person is in a low squat.

Forces on the body where acceleration, the Newton's second low, force equals mass times acceleration .

$$F = ma$$

The force equals the change of momentum $\Delta(mv)$ over a short internal of time Δt or

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

Accelerations can produce a number of effects such as

1-An apparent increase or decrease in body weight

2-Changes in internal hydrostatic pressure

3-Distortion of the elastic tissues of the body

4-the tendency of the solids with different densities suspended in a liquid to separate.

-If the acceleration become large may pool in various regions of the body, the location of the pooling depends upon the direction of acceleration. If a person is accelerated head first the lack of blood flow to the brain can cause blackout.

-Tissue can be distorted by acceleration, if the forces are large, tearing or rupture can take place.

-Oscillatory Motion, for small oscillation amplitudes, the period of a simple pendulum is

$$T = 2\pi (L/g)^{1/2}$$

Where g is the acceleration gravity, L is the length, and T is the period of oscillation.

-Each of our major organs has its own resonant frequency (or natural period) which depends on its mass and elastic forces that act on it. Pain or discomfort occurs if particular organ is vibrated vigorously and its resonant frequency (Fig.8). Shock absorbers are devices to reduce or dampen unwanted vibrational effects. Female athletes often use special bars to dampen the motion of their breasts because they commonly jog at or near the natural frequency of the breast, which is about 2 Hz, a period 0.5s.

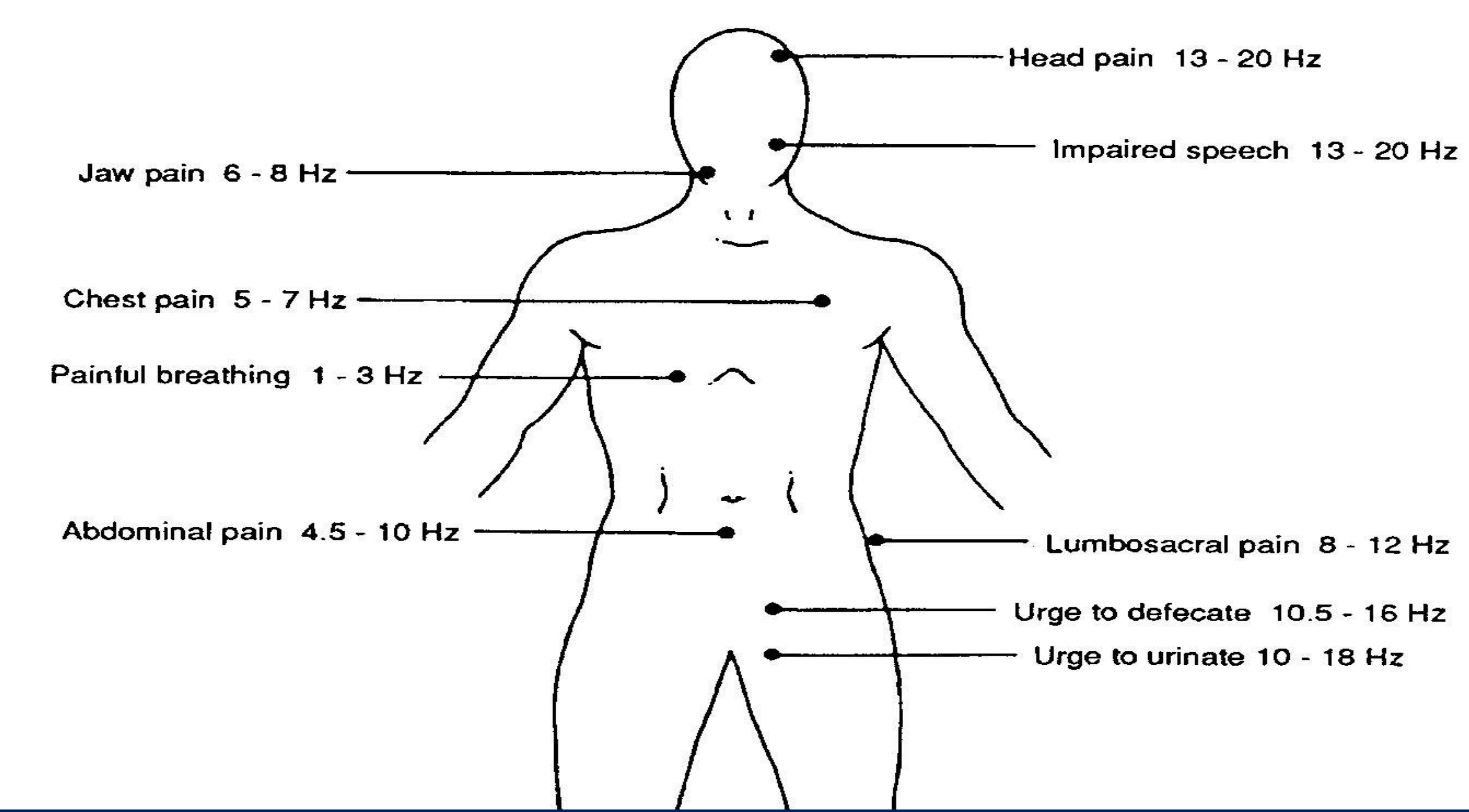


Fig.7) Pain symptoms of human subjected to vibrations from 1 to 20Hz

Excessive vibration often occurs in motor trucks and in some passenger aircraft. This results in fatigue and discomfort to the occupants, and may cause visual disturbances. The vibratory frequency of motorized vehicles, and of such subtle environmental systems as large fans used to distribute air in enclosed buildings, can be around 8Hz or less. While those in aircraft are usually higher.

-Tissue can be distorted by acceleration, if the forces are large , tearing or rupture can take place.

The tendency of the suspended solids of different densities to separate when accelerated by centrifuge. The speed at which small objects fall through a liquid depends on their size, viscosity, acceleration due to gravity g, we can artificially increase g by centrifuge.

Let us consider sedimentation of the small spherical objects of density ρ in the solution of the density ρ_o in the gravitational field g. Stokes has shown that for a spherical object or radius a, the retarding force F_d and terminal velocity V are related by

η: is viscosity of the liquid

$a^3 \rho g$ The force of gravity $F_g = 4/3\pi$

The buoyant force $F_B = 4/3\pi \, \rho_o \, a^3 g$

The retarding force $F_d = 6\eta\pi aV$

In equilibrium $F_g - F_B = F_d$

We obtain the sedimentation velocity

$$V = \frac{2a^2}{9\eta} g(\rho - \rho_o) \ldots$$

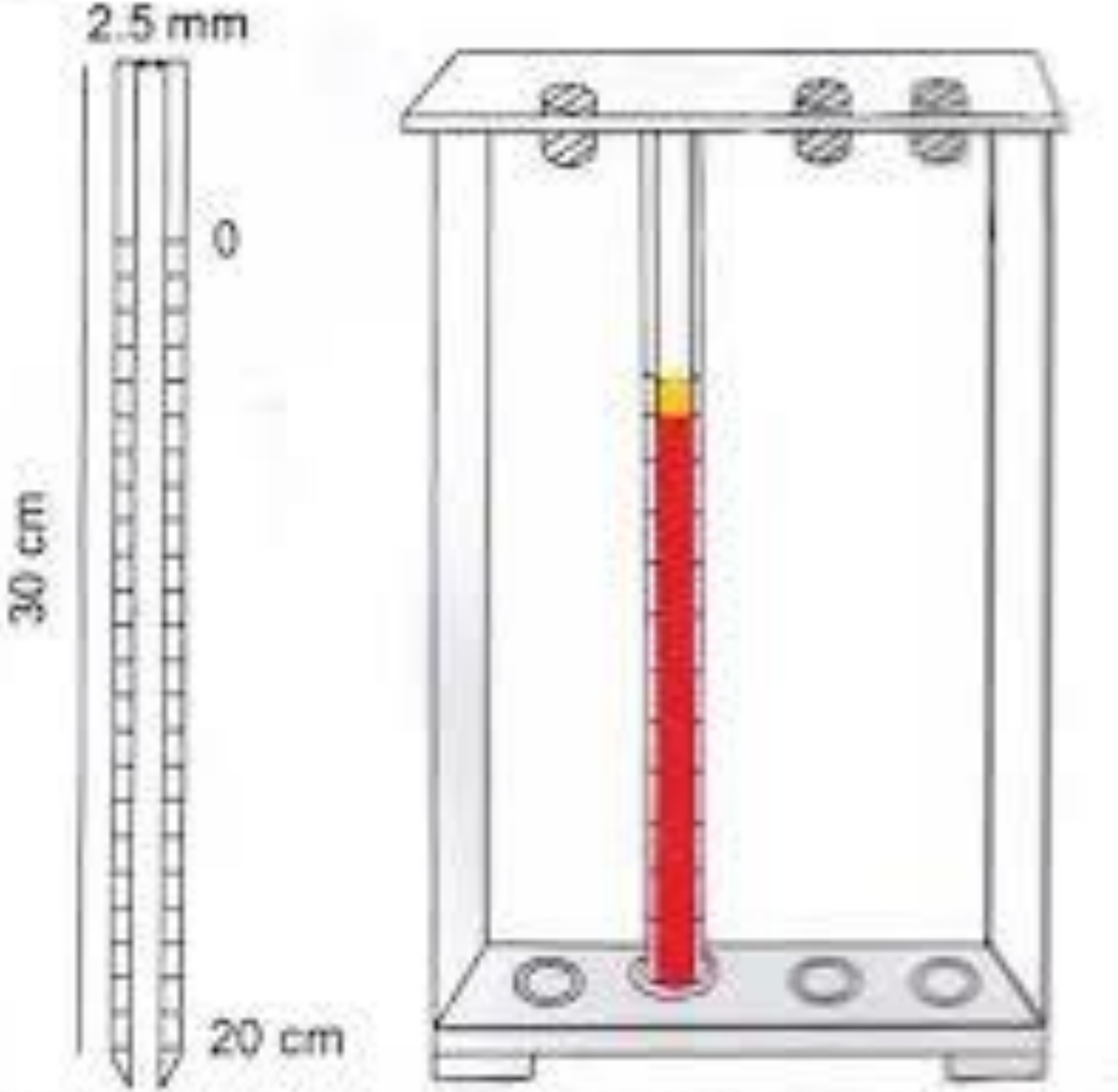
Cellular V is proportional to

Square of cell radius (a^2) or size

-Difference between the densities of the cell and plasma $(\rho - \rho_o)$

-Inverse of the fluid viscosity (η)

In some forms of disease such as rheumatic heart disease, the red blood cells clump together and the effective radius increases; thus an increased sedimentation velocity occurs. In other disease such as hemolytic jaundice and sickle cell anemia, the red blood cells changes shape and break. The radius decreases; thus the rate of sedimentation of these cells in slower than normal.



a) Westergren tube b) Westergren tube on the rack

A related medical test that also depends on the equation of sedimentation velocity, is the determination of the hematocrit, the percent of red blood cells, since the sedimentation velocity is proportional to the gravitational acceleration, it can be greatly enhanced if the acceleration is increased.

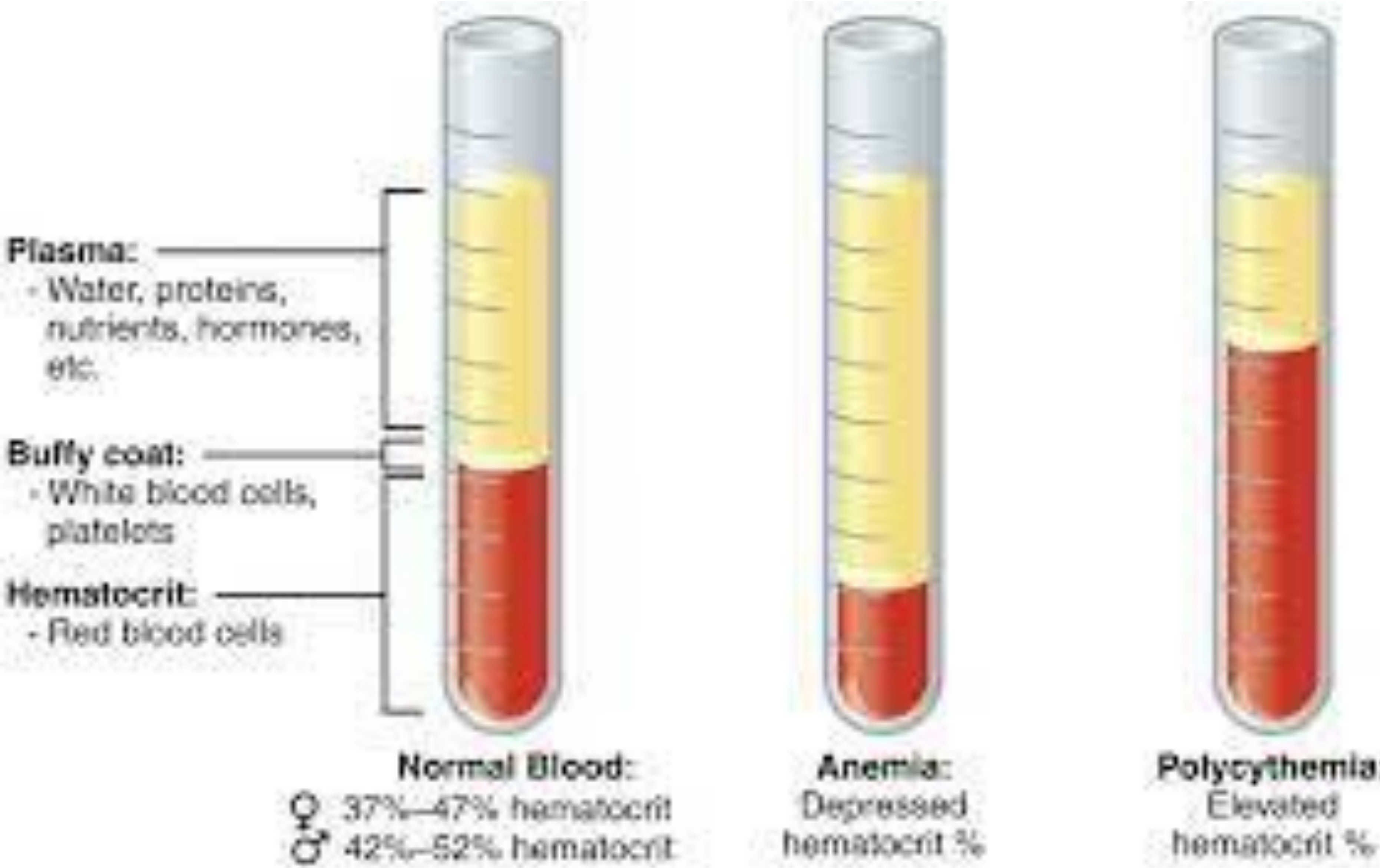
We can increase g by means of a centrifuge, which provides an effective acceleration g_{eff}

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

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

Since the packing of the red blood cells takes place in the centrifuge, the hematocrit obviously depends upon the radius of the centrifuge and the speed and duration of centrifugation. The increase of any these leads to more dense packing of the red blood cells or a smaller hematocrit. One standard method utilizes centrifugation for 30 min at 3000rpm with r = 22cm.

A normal hematocrit is 40 – 60; a value lower than 40 indicates anemia, and a high value may indicate polycythemia vera .


Plasma:
- Water, proteins, nutrients, hormones, etc.
Buffy coat:
- White blood cells, platelets
Hematocrit:
- Red blood cells
Normal Blood:
♀ 37%–47% hematocrit
♂ 42%–52% hematocrit
Anemia:
Depressed hematocrit %
Polycythemia:
Elevated hematocrit %