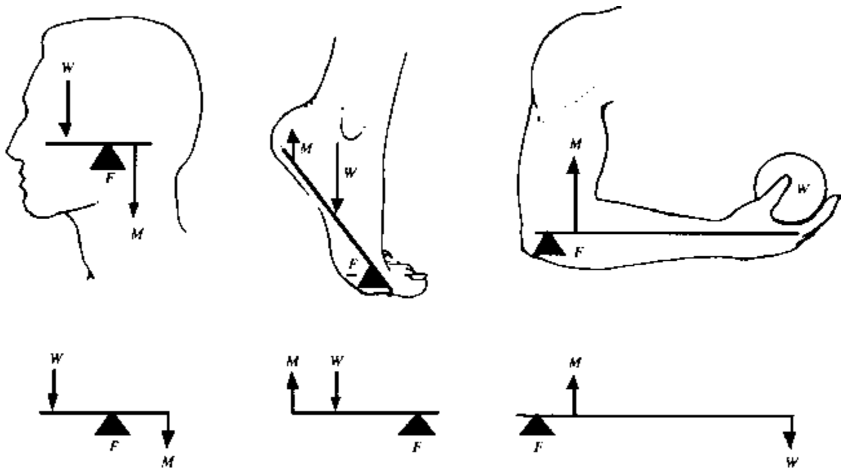
Force on & in body

Statics

Forces involved with muscles, bones, and tendons discussed.

When objects are stationary (static) 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 about any axis also equals zero.

Many of the muscle and bone systems of the body act as levers. Levers are classified as first-, second-, and third-class systems (Fig. 1). Third-class levers are most common in the body, Second-class levers are next in number, and first-class levers are least common.



First class Second class Third class

Figure. 1 The three lever classes and schematic examples of each in the body.

W is a force that could be **the weight**, **F** is the force at 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 (Fig. 2a). Figure 2b shows the forces and dimensions of a typical arm.

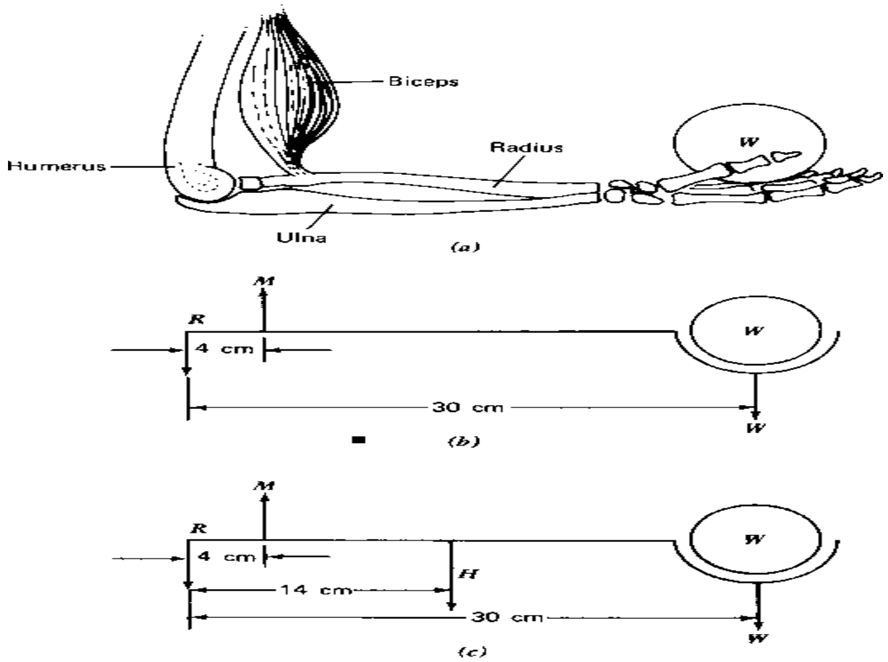


Figure 2. The forearm. (a) The muscle and bone system. (b) The forces and dimensions: R is the reaction force of the humerus on the ulna, M is the muscle force supplied by the biceps, and W is the weight in the hand. (c) The forces dimensions where the weight of the tissue and bones of the hand and arm H is included and located at their center of gravity.

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 or that a muscle force 7.5 times the weight is needed.

In figure 2c shows a more correct representation of the problem with the weight of the forearm and H hand included. By summing the torques about the joint we obtain M=3.5H+7.5W, which simply means that the force supplied by the muscle must be larger than that indicated by our first calculation (Fig. 2b).

Let us now consider the effect on the muscle force needed as the arm changes its angle as shown in Fig. 3a. Figure 3b shows the force 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! However, the length of the biceps muscle changes with the angle.

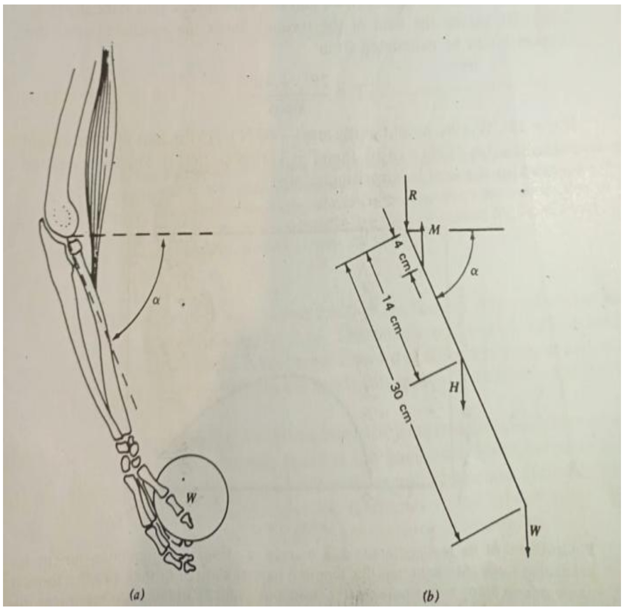


Figure 3

The arm can be raised and held out horizontally from the shoulder by the deltoid muscle (Fig. 4a); we can show the forces schematically (Fig. 4b). By taking the sum of the torques about the shoulder joint, the tension T can be calculated from

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

If $\alpha = 16^{\circ}$, W_1=68 N and W_2=45N, then T=1145 N. The force needed to hold up the arm is surprisingly large.

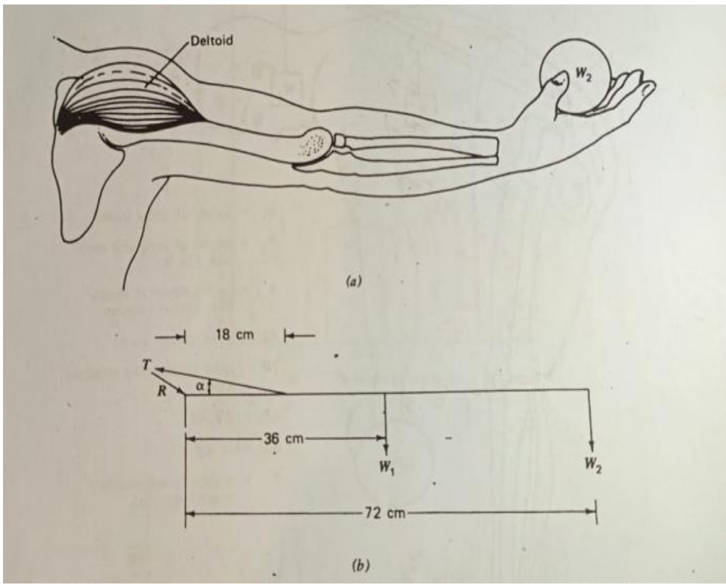


Figure 4

An often abused part of the body is the lumbar (lower back) region, shown schematically in Fig. 5a. The calculated force at the fifth lumbar vertebra (L5) with the body tipped forward at 60° to the vertical and with a weight of 225 N in the hands can approach 3800 N (Fig. 5b).

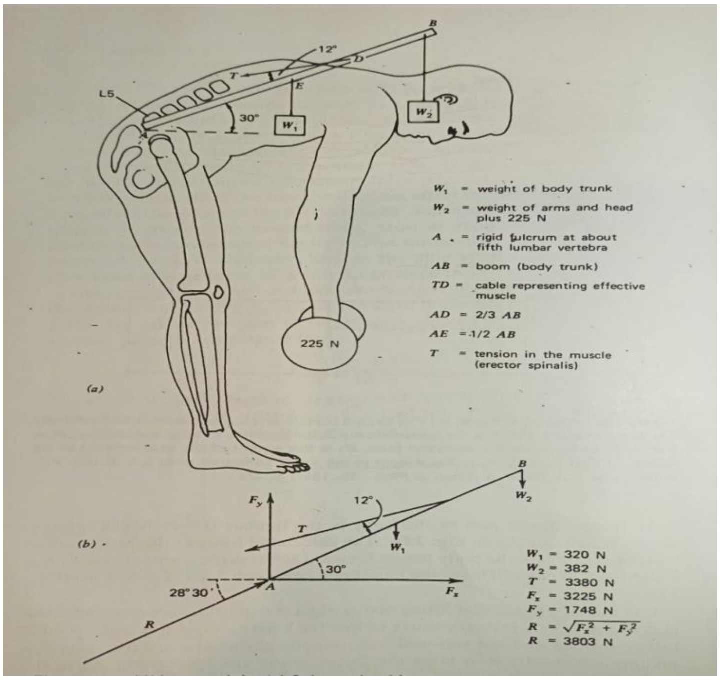


Figure 5

Sometimes of the greatest forces in the body occur at the patella. When a person is squatting, the tension in the tendons that pass over the patella may be more than two times his weight (Fig. 6)

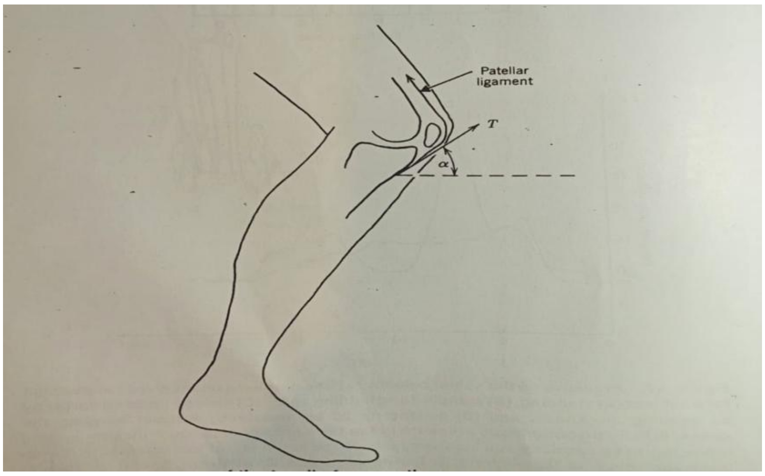


Figure 6

Frictional forces

In the body, friction effects are often important. When a person is walking, as the heel of the foot touches the ground a force is transmitted from the foot to the ground (Fig. 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 forces. The maximum force of friction f is usually described by

$$f = \mu N$$

where N is a normal force and μ is the coefficient of friction between the two surfaces. The value of μ depends upon the two materials in contact, and it is essentially independent of the surface area.

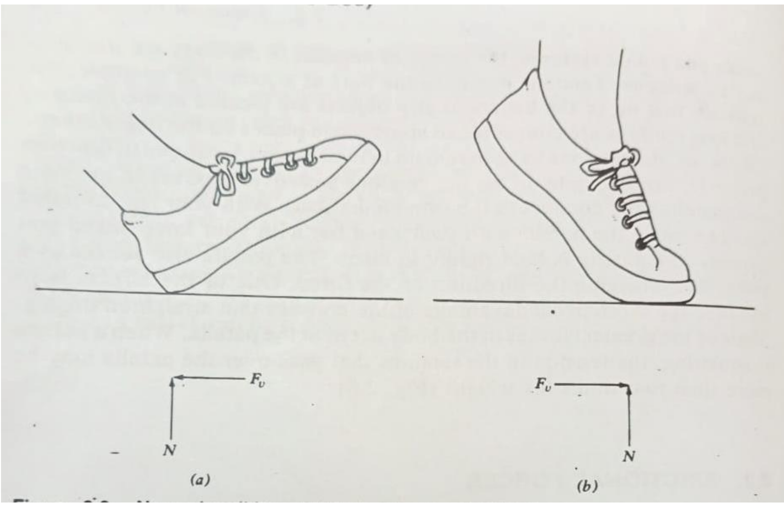


Figure 7

In general, the frictional force is large enough both when the heel touches down and when the toe leaves the surface (Fig. 7b) to prevent a person from slipping. Occasionally, a person is on an icy, wet, or oily surface where μ is less than 0.15 and his foot slips.

The coefficient of friction in bone joints is usually much lower than in engineering-type materials. 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 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

Let us now examine forces on the body where acceleration or deceleration is involved; for simplicity, we will usually consider cases in which the acceleration or deceleration is constant. If we limit ourselves to one dimensional motion, then Newton's law, force equals mass times acceleration, can be written without vector notation as

$$F = ma$$

This is not the way Newton originally wrote the law; he said force equals the change of momentum $\Delta(m\nu)$ over a short interval of time Δt or

$$F = \frac{\Delta(m\nu)}{\Delta t}$$

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 solids with different densities suspended in a liquid to separate.

We have thus far concerned ourselves with linear acceleration and deceleration. If we subject the body to oscillatory motion, resonance behavior can occur. Each of our major organs has its own resonant frequency depending on its mass and the elastic forces that act on it. Pain or discomfort occurs in a particular organ if it is vibrated at its resonant frequency.

The centrifuge is a way to increase apparent weight. It is especially useful for separating a suspension in a liquid. It speeds up the sedimentation that occurs at a slow rate under the force of gravity.

Let us consider first sedimentation of small spherical objects of density ρ in a solution of density $\rho_\circ$ in a gravitational field g. We know that falling objects reach a maximum (terminal) velocity due to viscosity effects. Stockes has shown that for a spherical object of radius a, the retarding force F_d and terminal velocity ν are related by

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

where η is the viscosity of the liquid through which the sphere is passing.

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

1. The force of gravity $F_g = \frac{4}{3}\pi a^3 \rho g$
2. The buoyant force $F_B = \frac{4}{3}\pi a^3 \rho_\circ g$
3. The retarding force $F_d = 6\pi a\eta v$

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

From F_g- F_B= F_d we obtain the expression for the terminal velocity (sedimentation velocity),

$$v = \frac{2a^2}{9\eta} g(\rho - \rho_\circ) \dots\dots\dots\dots\dots (1)$$

Equation 1 is valid only for spherical particles; however, we can use it as a guide to the behavior of particles with a more complicated shape.

Gravitational force

Newton formulated the law of universal gravitation. 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.

Electrical force

The forces produced by muscles are caused by electrical charges attracting or repelling other electrical charges. Each of the billions of living cells in the body has an electrical potential difference across the cell membrane because of a difference in charge between the inside and outside of the cell.

Forces on teeth

Forces on teeth arise from several sources. Figure 8 shows how the masseter muscles provide the force in the lever system involved in chewing and biting. Lever models can be used to examine the quasistatics of chewing and biting.

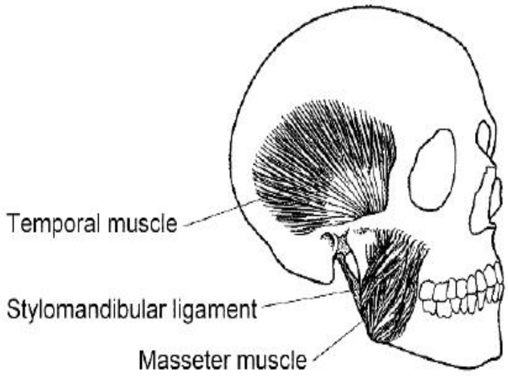


Figure 8

The physics in orthodontics

Orthodontics is the practical application of biomechanics to move teeth using forces applied by *appliances*, such as wires, brackets, and elastics. Each tooth has a center of mass, but since teeth are not free bodies –they are restrained by the periodontium – a more useful position in the tooth is defined, the *center of resistance*. This is the balance point for the tooth.

Figure 9 shows how forces and torques (moments) applied to the crown of a tooth, can be designed to create a lateral force at the center of resistance, but no torque about it. Appliances can affect several teeth, such as the intrusion

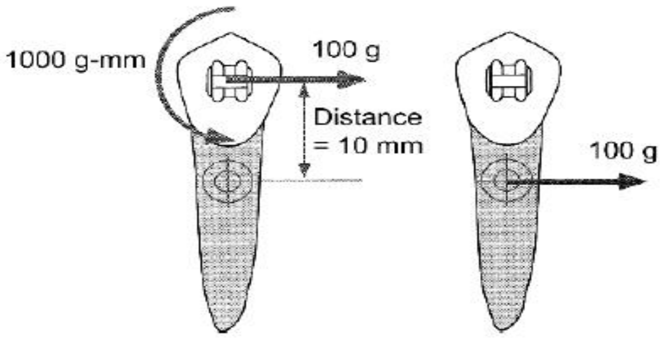


Figure 9

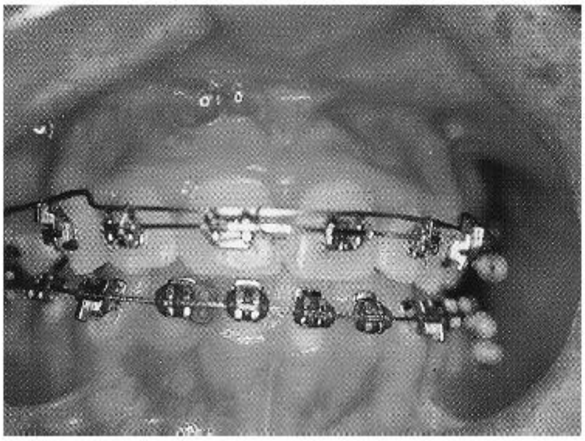


Figure 10

arch shown in Fig. 10, which leads to the application of forces and torques shown in Fig. 11.

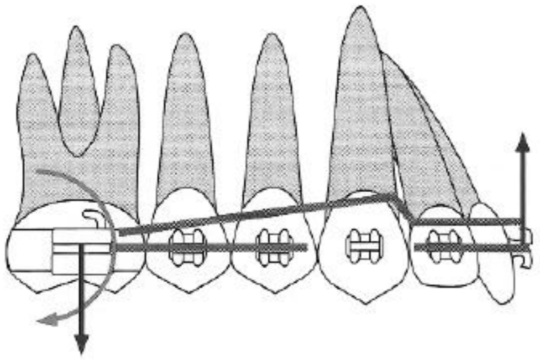


Figure 11