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CH. 2

Forces on and in the Body 1\16

Physicists like to consider the very fundamental origins of forces:

1- Gravitational force (Medical effects; varicose veins, ''healthy bones''….).
2- Electrical force (note that electrical forces in H atom is about 10^{39} times greater than G between e and p). *(our body is basically an electrical machine; control of the muscles)*
3- Nuclear force (involve the nucleus of the atom).
   (strong NF and a weaker NF; electron ((beta)) decay from the nucleus)

There are two types of problems involving forces on the body:

1- Static (stationary); the body is in equilibrium.
2- Dynamic (= = = accelerated).

Note: (Friction is involved in both statics and dynamics).

2-1 STATIC (forces involved with muscles, bones, and tendons)

- 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:

1-First class system (*least common)*, 2-Second class, and 3- Third class *(most common)*

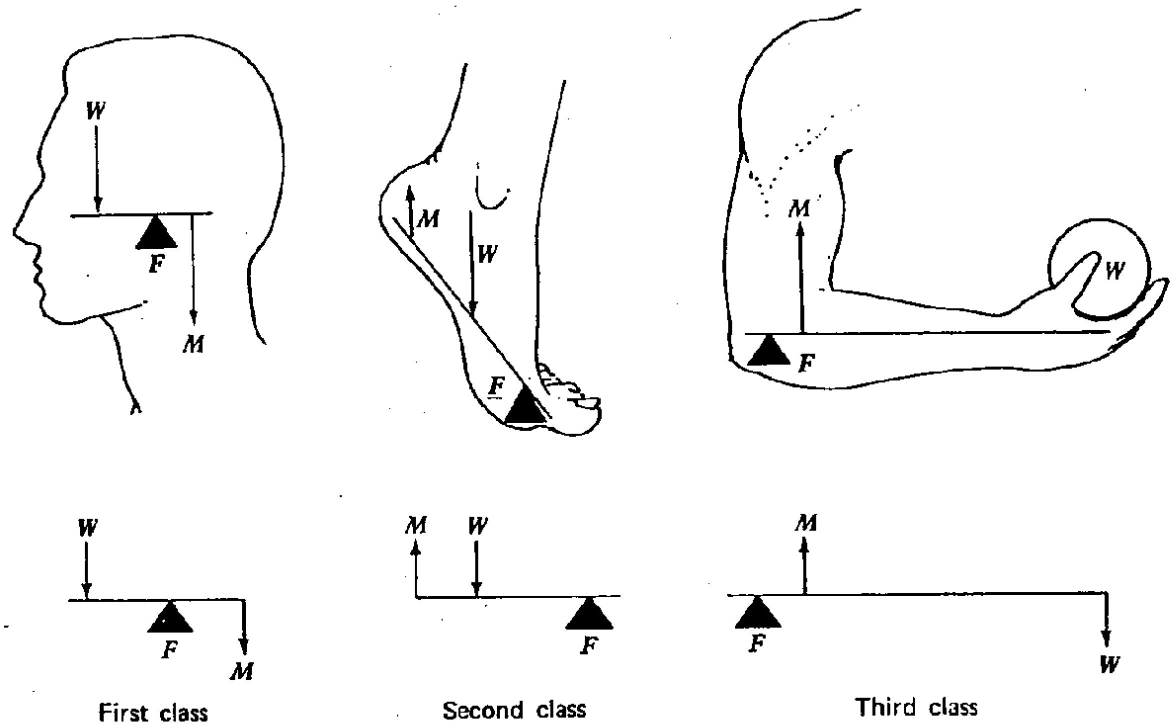


Figure 2.1. The three lever classes and schematic examples of each in the body. *W* is a force that could be the weight, *F* is the force at the fulcrum point, and *M* is the muscle force.

Example, (p.18), Find the force supplied by the biceps :

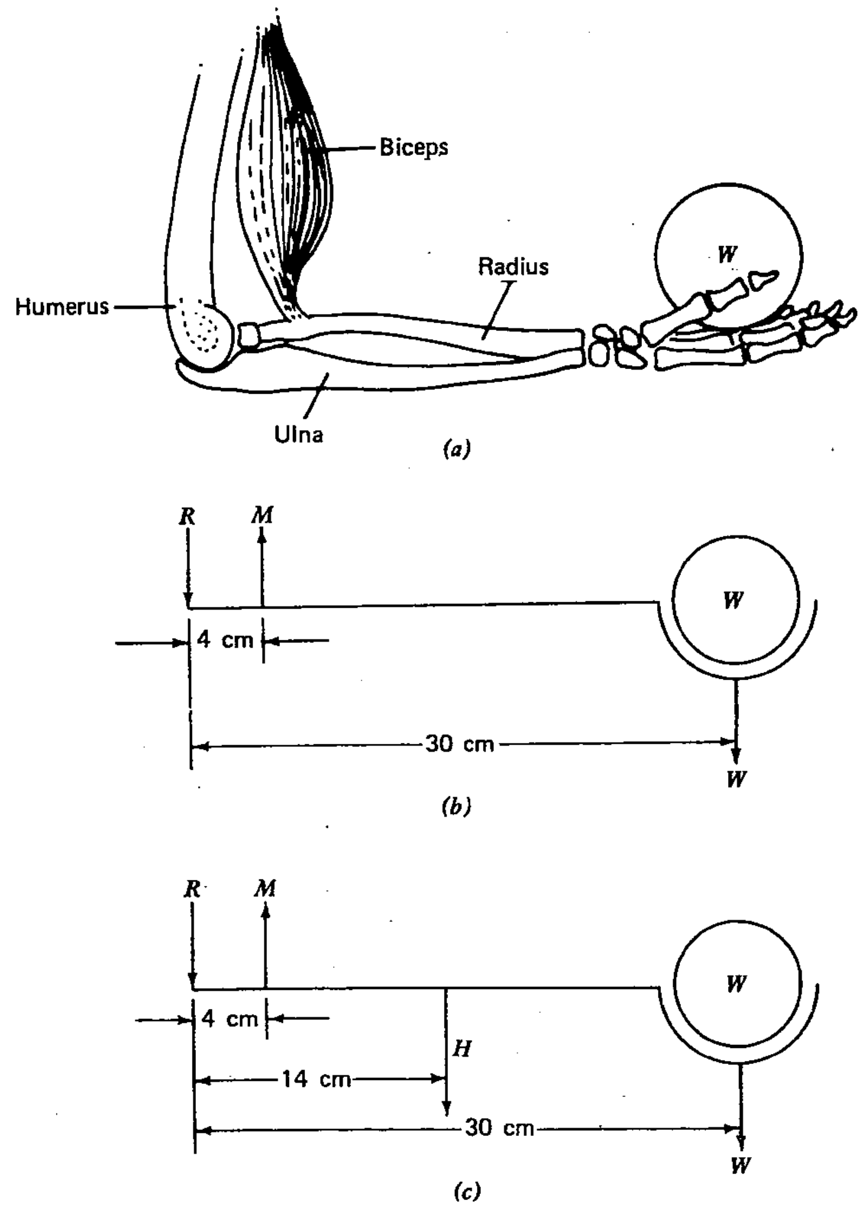


Figure 2.2. The forearm. (*a*) The muscle and bone system. (*b*) The forces and dimensions: *R* is the reaction force of the humerus on the ulna, *M* is the muscle force supplied by the biceps, and *W* is the weight in the hand. (c) The forces and dimensions where the weight of the tissue and bones of the hand and arm *H* is included and located at their center of gravity.

Sol: there are two torques, *(H is excluded):*

30 *W = 4*M , 4M – 30W = 0

M=7.5W (muscle force 7.5 times the weight is needed)

For W =100N (~ 22lb) the force needed is 750 N (~ 165 lb) .

(H is involved):

$$30W + 14H = 4M \qquad , \qquad 7.5W + 3.5H = M$$

For H = 15N (3.3 lb) , 3.5H = 52.5N (~ 11.8 lb).

* Consider: The Forearm at an angle α to the horizontal,

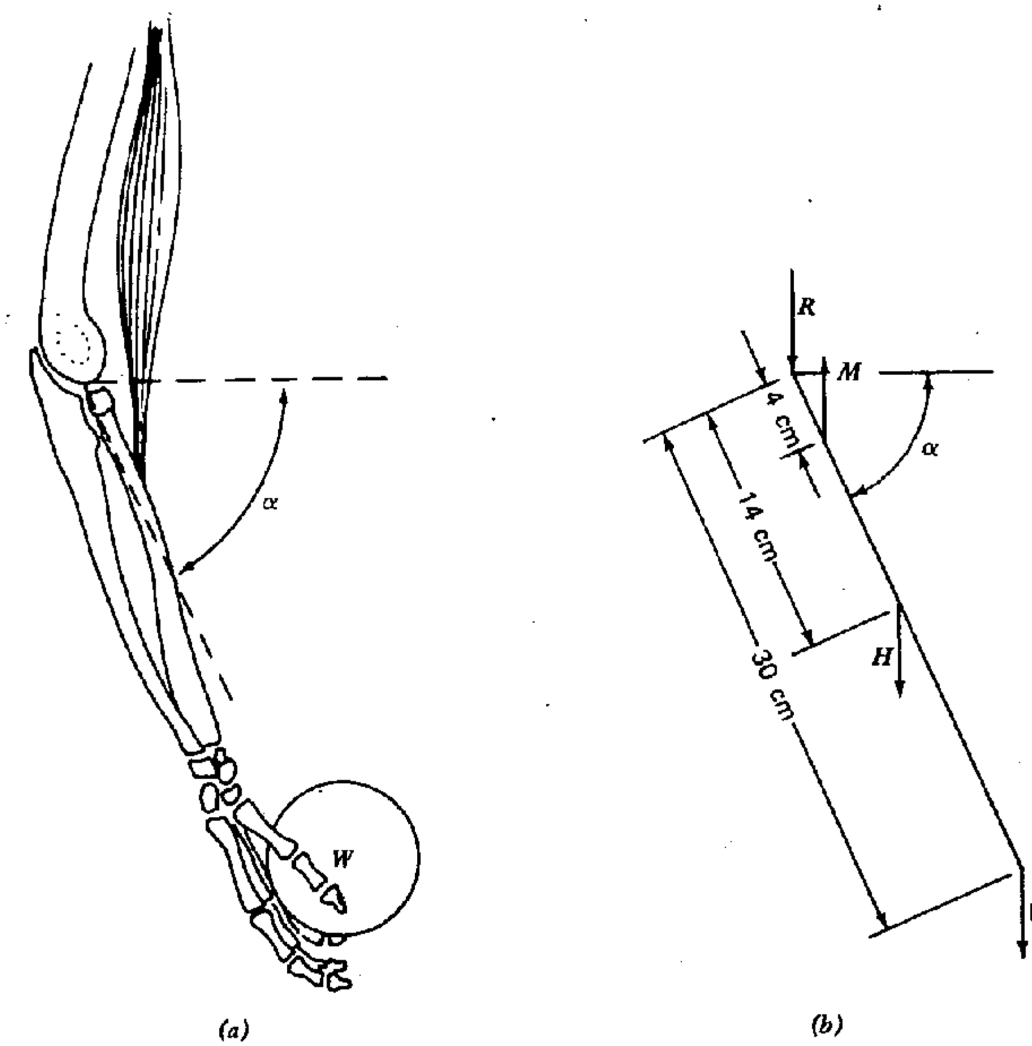


Figure 2.3. The forearm at an angle α to the horizontal. (a) The muscle and bone system. (b) The forces and dimensions.

Take the torques about the joint:

$30W \cos \alpha + 14H \cos \alpha = 4M \cos \alpha$

$30W + 14H = 4M$

M remains constant as α changes, however, the biceps changes with α.

(M ~0 , minimum length, M~0 maximum length), See Fig. 2.4

<u>Case of raising the arm</u>: *the arm can be raised and held out horizontally from the shoulder by the deltoid muscle.*

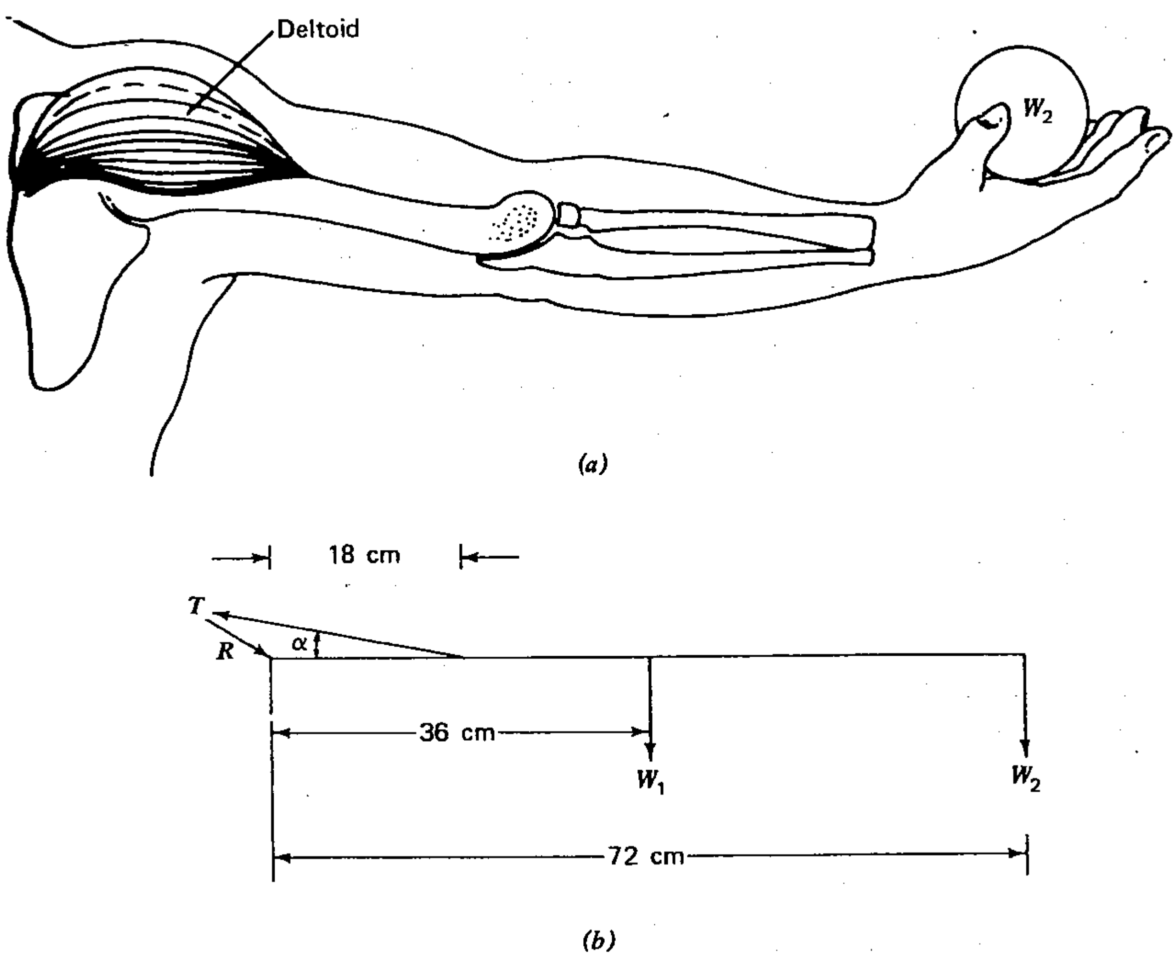


Figure 2.5. Raising the arm. (*a*) The deltoid muscle and bone structure involved. (*b*) The forces on the arm. *T* is the tension in the deltoid muscle fixed at the angle *α*, *R* is the reaction force on the shoulder joint, *W*₁ is the weight of the arm located at its center of gravity, and *W*₂ is the weight in the hand. (Adapted from L.A. Strait, V.T. Inman, and H.J. Ralston, *Amer. J. Phys.*, 15, 1947, p. 379.)

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

$4W_2 + 2W_1 = T \sin \alpha$, T (tension) = $(2W_1 + 4W_2)/\sin\alpha$

If $\alpha = 16^o$, W_1=68N (~15lb), and W_2= 45N (~10lb) then T=1145N (250 lb) (surprisingly large)

- An often abused part of the body is the lumbar (lower back) region, (fifth lumbar vertebra).

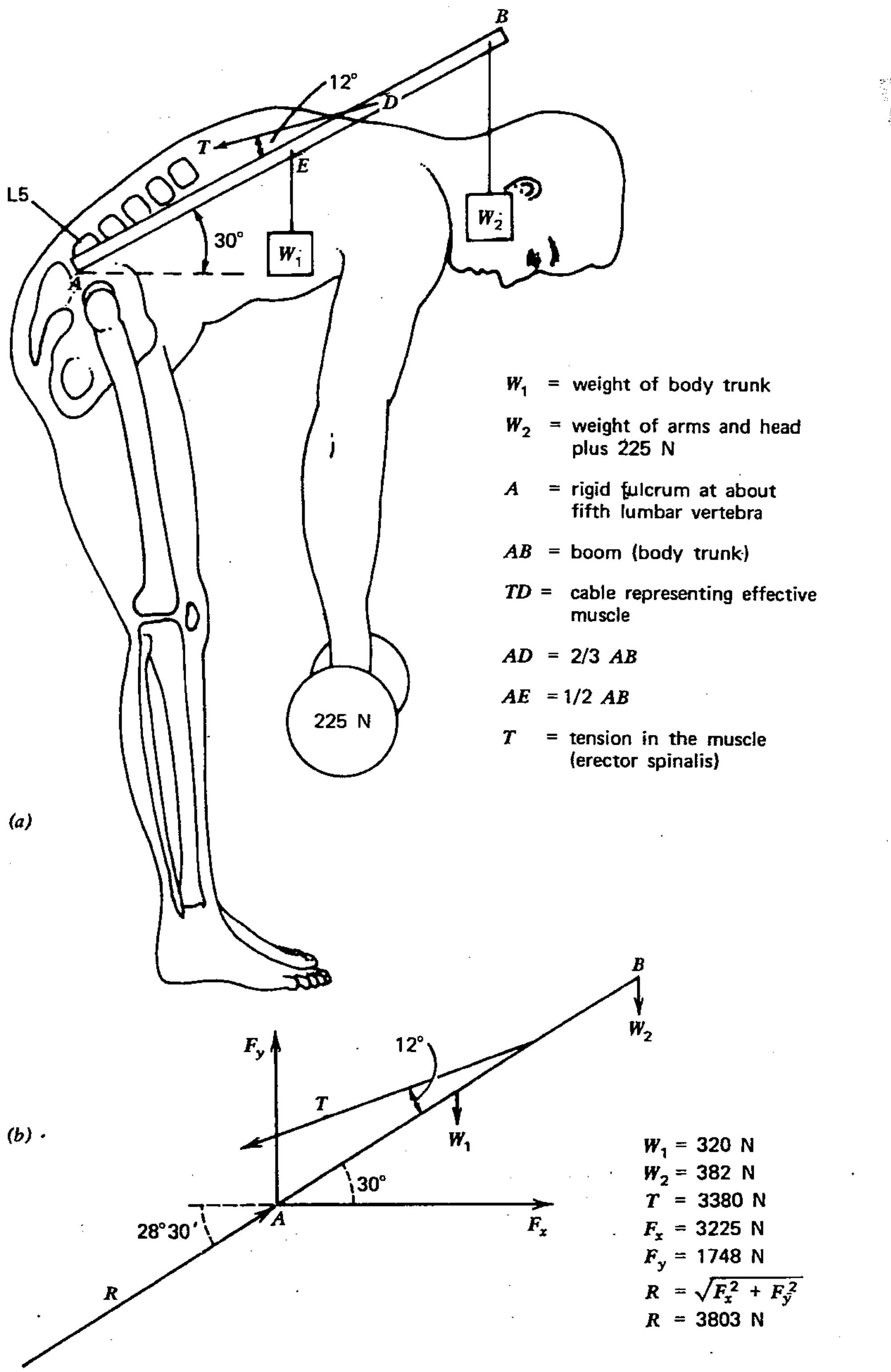
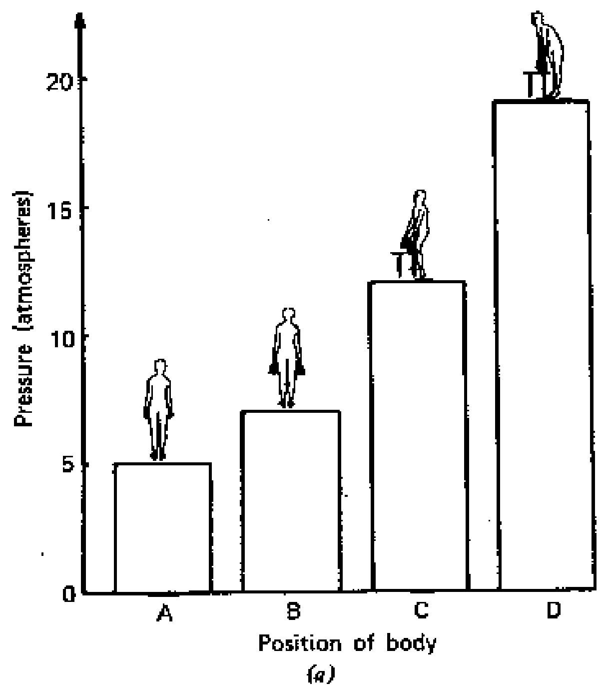


Figure 2.6. Lifting a weight. (*a*) Schematic of forces used. (*b*) The forces. Note that the reaction force *R* at the fifth lumbar vertebra is quite substantial. (Adapted from L.A. Strait, V.T. Inman, and H.J. Ralston, *Amer. J. Phys.*, 15, 1947, pp. 377–378.)



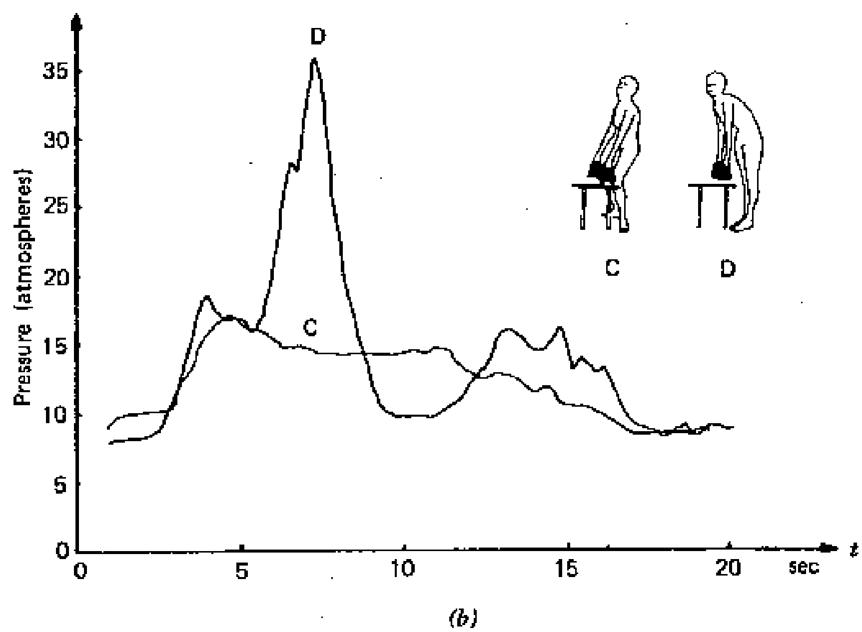


Figure 2.7. Pressure on the spinal column. (*a*) The pressure on the third lumbar disc for a subject (A) standing, (B) standing and holding 20 kg, (C) picking up 20 kg correctly by bending the knees, and (D) picking up 20 kg incorrectly without bending the knees. (*b*) The instantaneous pressure in the third lumbar disc while picking up and replacing 20 kg correctly and incorrectly. Note the much larger peak pressure during incorrect lifting. (Adapted from A. Nachemson and G. Elfstrom, *Scand. J. Rehab. Med.*, Suppl. 1, 1970, pp. 21–22.)

- Forces of muscles in the body are transmitted by tendons. Tendons minimize the bulk at a join.
- Example, in the leg, tendons pass over grooves in the knee cap (patella, also serves as a pulley) and connect to the shin bone (tibia). Some of the greatest forces in the body occur at the patella.

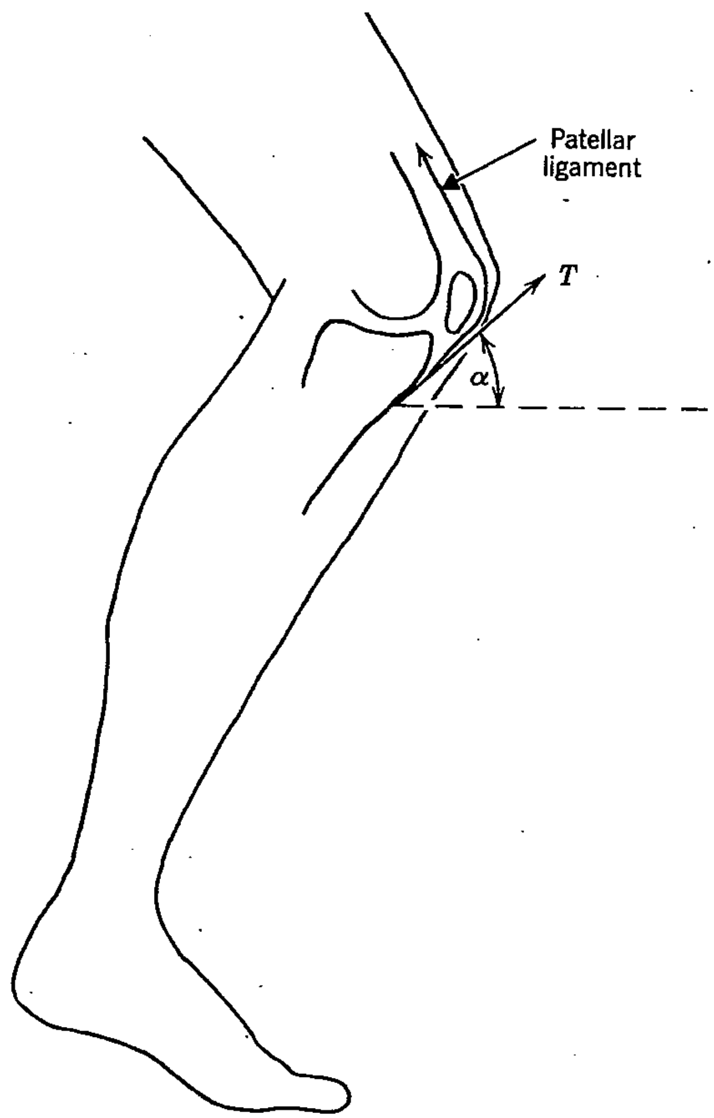


Figure 2.8. Diagram of the tensile force on the patellar ligament during squatting. The tension *T* may be quite large when a person is in a low squat.

2.2 Frictional Forces: Friction and energy loss due to friction appear everywhere in our life. It limits the efficiency, however, we can make use of it in many devices. Example, normal walking.

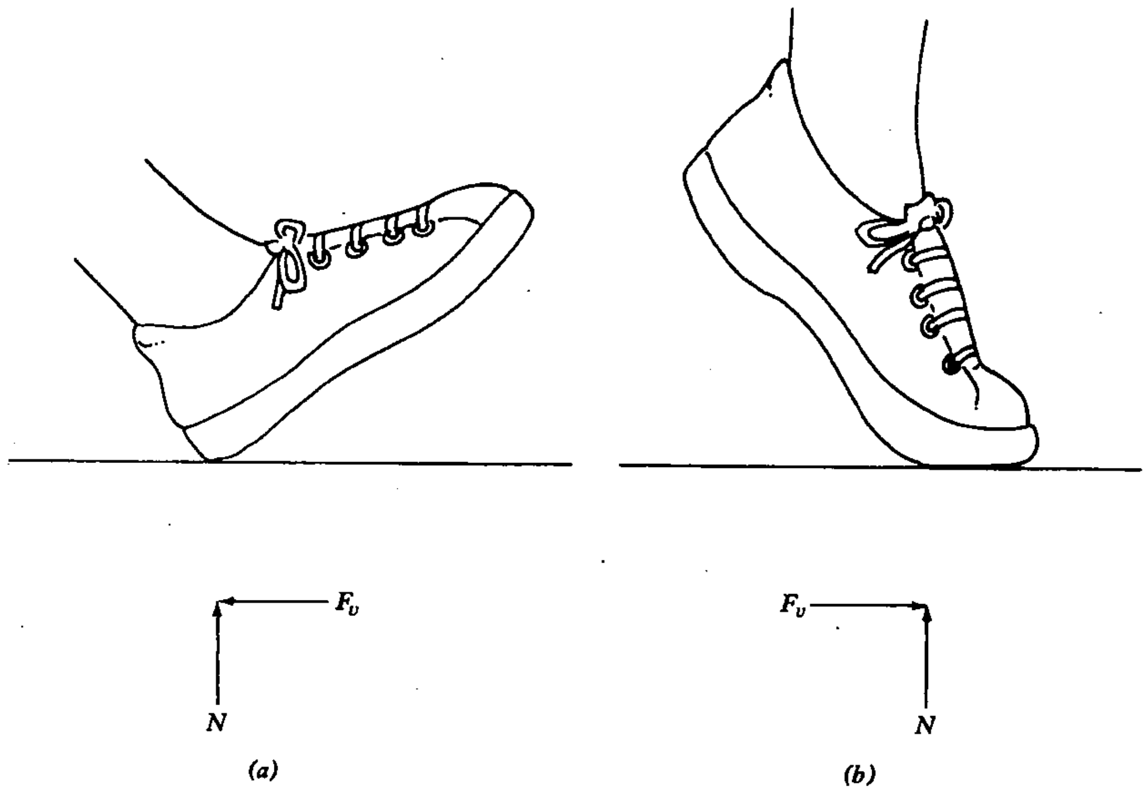


Figure 2.9. Normal walking. (*a*) Both a horizontal frictional component of force F_v and a vertical (normal) component of force *N* exist on the heel as it strikes the ground. Friction between the heel and surface prevents the foot from slipping forward. (*b*) When the foot leaves the ground the frictional component of force F_v prevents the toe from slipping backward. (Adapted from Williams, M., and Lissner, H.R., *Biomechanics of Human Motion*, Philadelphia, W.B. Saunders Company, 1962, p. 122, by permission.)

Maximum force of friction $f = \mu N$, where μ is the coefficient of friction between two surfaces, and N is the normal force.

When N=W, then f=0.15W and for μ=1, f=W which is larger than needed.

- The synovial fluid in the joint is involved in the lubrication.
- The saliva add when chew food acts as a lubricant.
- Organs (heart, lungs, intestines) are lubricated by slippery mucus covering to minimize friction .

Examine forces on the body where acceleration or deceleration is involved.

Newton's Second Law (F = ma). In fact Newton said force equals the change of momentum Δ (m*v*) over a short interval of time Δt, $F=\Delta(mv)/\Delta t$. See, Examples 2.1and2.2.

Example 2.1

A 60 kg (~ 135 lb) person walking at 1 m/sec (~ 2 mph) bumps into a wall and stops in a distance of 2.5 cm in about 0.05 sec. What is the force developed on impact?

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

$F = \Delta(mv)/\Delta t$ = 60 kg m/sec/0.05 sec =1200 kg m/sec^2

or 1200 N (~ 270 lb, or ~ 2 times her weight)

Example 2.2

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 4 kg, what is the force developed?

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

$F = \Delta(mv)/\Delta t$ = 4 kg m/sec /0.01 sec = 400 N (~ 90 lb)

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

$F = \Delta(mv)/\Delta t$ = 4 kg m/sec / 0.04 sec =100 N (~ 22.5 lb)

An example of a dynamic force in the body is the apparent increase of weight when the heart beats (systole).

Example: About 60g of blood is given a velocity of about 1m/s upward in about 0.1sec. Then;

(the upward momentum) Δ (mv) = 0.06 kg * 1m/s =0.06 kg.m/s.

(the downward reaction force) (Newton's Third Law) F=0.06/0.1=0.6kg.m/sec^2.

Or F=0.6N (~2oz).

Example on deceleration, consider the landing force.

- Headrests (whiplash injury), seat belts, shoulder belts, air bags, absorbing steering columns, penetration resistance windshields, and side door beams have helped to reduce injuries.

<u>Effects of accelerations:</u>

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.

<u>Resonance behavior:</u> Each of our major organs has its own resonant frequency depending on its mass and the elastic forces that act on it.

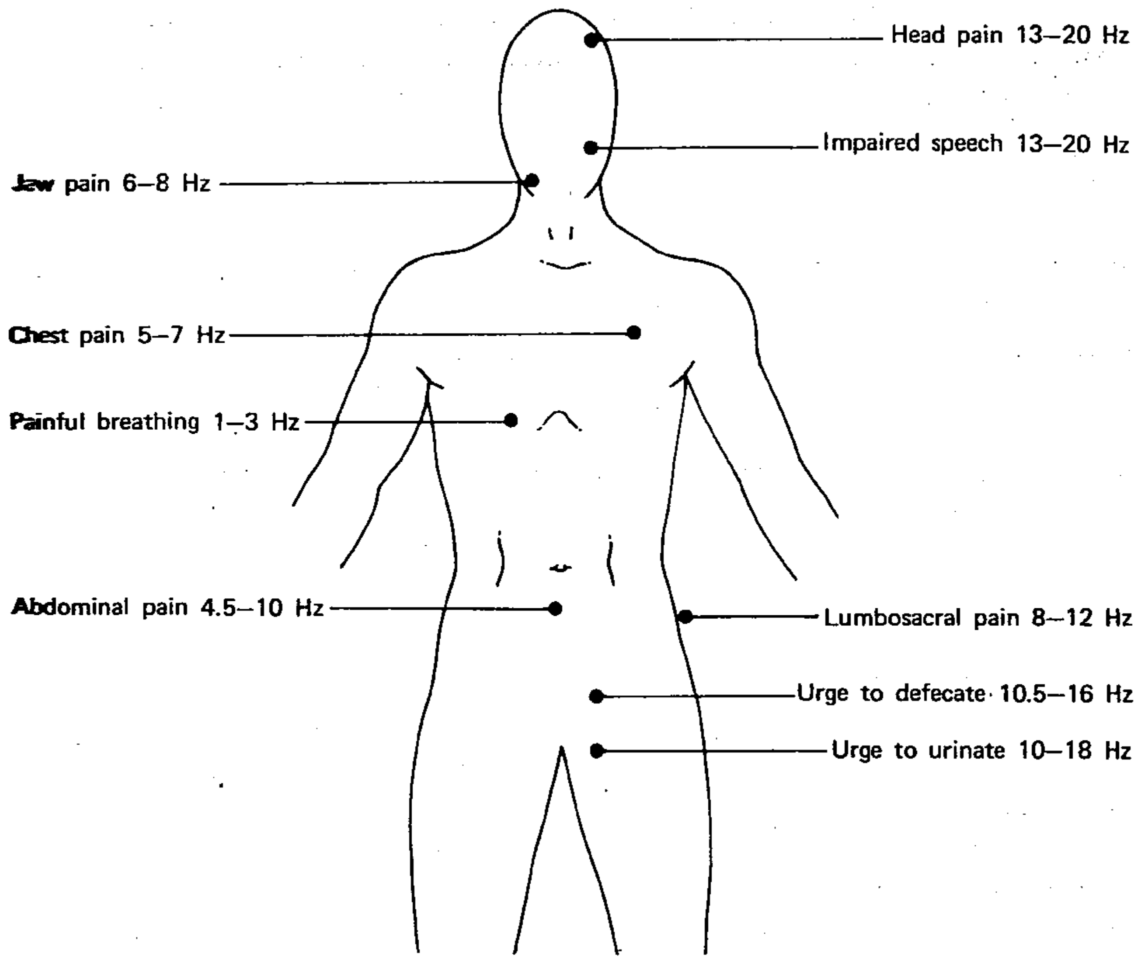


Figure 2.13. Symptoms of humans subjected to vibrations from 1 to 20 Hz. (Adapted from E.B. Magid, R.R. Coermann, and G.H. Ziegenruecker, "Human Tolerance to Whole Body Sinusoidal Vibration," ***Aerospace Med.***, **31, 1960, p. 921.)**

The centrifuge is a way to increase apparent weight. It speeds up the sedimentation rate. We can artificially increase the gravity (g) by spinning the fluid in a centrifuge.

Consider sedimentation of small spherical (radius a) objects of density ρ in a solution of density ρ_o in a gravitational field g.

Stokes has shown that the retarding force $F_d = 6\pi a\eta v$, where η is the viscosity(in Pas or poise) and v is the terminal velocity.

When the particle is moving at a constant speed, F_d is in equilibrium with $F_g - F_B$, that is to say $F_g - F_B = F_d$. We have:

1- The force of gravity $F_g = \frac{4}{3}\pi a^3 \rho g$ (downward)
2- The buoyant force $F_B = \frac{4}{3}\pi a^3 \rho_0 g$ (upward)
3- The retarding force $F_d = 6\pi a\eta v$

$\frac{4}{3}\pi a^3 \rho g - \frac{4}{3}\pi a^3 \rho_0 g = 6\pi a\eta v$

$\frac{4}{3} g a^2 (\rho - \rho_o) = 6\eta v$

$v = \frac{2}{9}\frac{a^2}{\eta} g (\rho - \rho_o)$ is the terminal velocity (sedimentation velocity),

v is proportional with a^2 g.

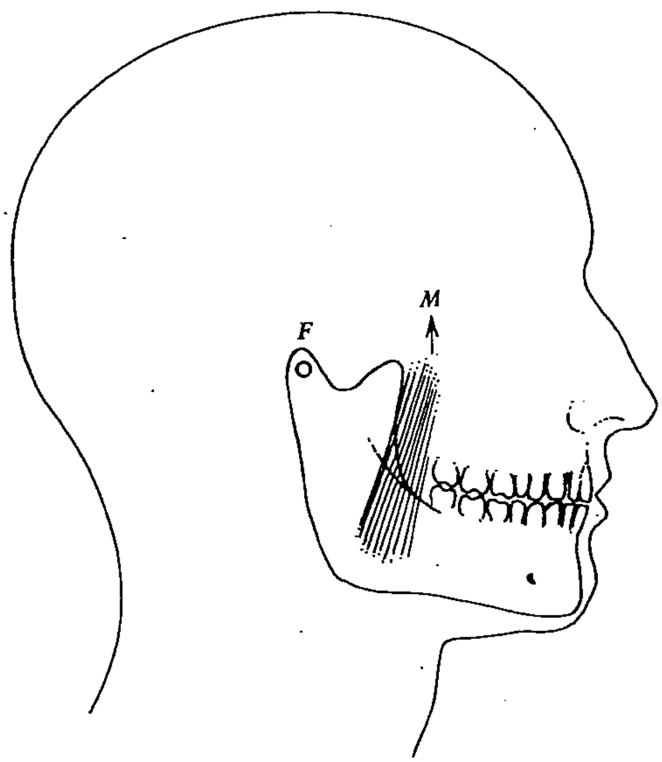
This equation can be used to determine the *hematocrit (the percent of red blood cells in the blood).* (g) can be increased by means of a centrifuge, thus provides:

g_{eff}(effective acceleration) = $4\pi^2 f^2 r$,where f is the rotation rate and r is the position on the radius of the centrifuge.

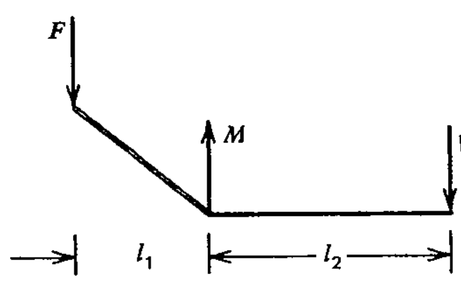
- Standard method
  time =30 min
  f =3000 rpm
  r=22 cm
  normal hematocrit is 40 to 60
  anemia < normal
  polycythemia vera > normal

REVIEW QUESTIONS (CH. 2)

R.Q.6. The action of chewing involves a third-class lever system. Fig. A shows the jaw and chewing (Masseter) muscle; Fig. B is the lever diagram. M is the force supplied by the chewing muscles that close the jaw about the fulcrum F. W is the force exerted by the front teeth.



(A)



(B)

(a) *If $l_2 = 3l_1$ and $W = 100N$, 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) The sum of the torques about F = 0.

$W(l_1 + l_2) = Ml_1$

$W(l_1 + 3l_1) = Ml_1$

$M = 4W = 400\ N$

(b) $\frac{100\ N}{0.5 * 10^{-4}\ m^2} = 2 * 10^6\ N/m^2$

<u>R.Q.10.</u> Find the effective acceleration (in terms of g) at a radius r=22 cm for a centrifuge rotating at 3000 rpm ($g = 9.8\ m/sec^2$).

$g_{eff} = 4\pi^2 f^2 r = 4\pi^2 (3000/60)^2 (0.22) \approx 21{,}700\ m/sec^2 \approx 2200\ g$ where g , the acceleration of gravity, is $9.8\ m/sec^2$.