Biomechanic of musculaskeletal system

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BIOMECHANICS

Bio = Living

Mechanics = Forces & Effects

The application of mechanics to the living organism

- Involves the principles of anatomy and physics in the descriptions and analysis of movement.
- Has many diverse applications to all biological systems
- The study of biological structures, processes and functions by applying the methods and principles of mechanics

AREAS OF STUDY, RESEARCH AND PRACTICE

- Sport and Exercise Science
- Coaching
- Ergonomics
- Equipment Design
- Locomotion
- Orthopedics - Rehabilitation -Physiotherapy, Occupational Therapy
- Motor Control (Neurology, Neuroscience etc.)
- Computer Simulation
- Prosthetics and Orthotics

Muscle and forces

- Physicists recognize four fundamental forces:

- Gravitational
- Electrical
- Weak nuclear
- Strong nuclear

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

1. How forces affect the body

- We are aware of forces on the body such as the force involved when we bump into objects.
- We are usually unaware of important forces inside the body.

WHAT ARE UNAWARE OF IMPORTANT FORCES INSIDE THE BODY?

For example,

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

- We do not attempt to consider all the various forces in the body in this lesson; it would be *impossible task*.

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 of gravity on its way to the heart.
- When a person becomes 'weightless', such as in an orbiting satellite, he/she loses some bone mineral. 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.

ELECTRICAL FORCES IN THE BODY

- Control and action of our muscles is electrical.
- The forces produced by muscle are cause by electrical charges attracting opposite electrical charges.
- Each of the trillions of living cells in the body has an electrical potential difference across the cell mebrane. This is a result of an imbalance of positively and negatively charged ions on the inside and outside of the cell wall.

2. Friction forces

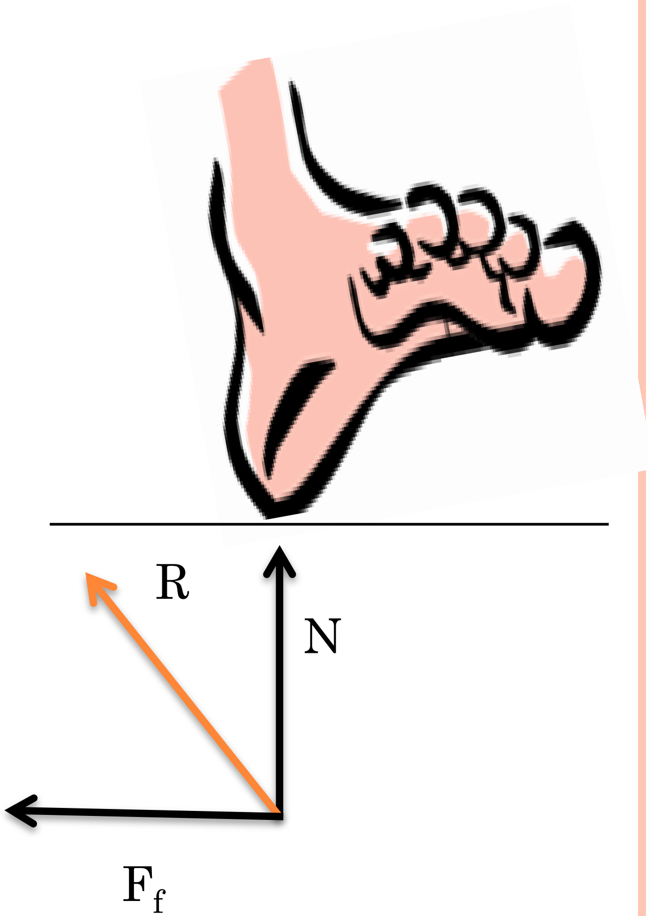
- Friction and the energy loss resulting from friction appear everywhere in our everyday life.
- Frictions limits the efficiency of machines such as electrical generators. On the other hand, we make use of friction when our hands grip a rope, when we walk or run, and in devices such as automobile brakes.
- Friction plays important role when a person is walking. A force is transmitted from the foot to the ground as the heel touches the ground.

Normal walking

- This force can be resolved into vertical and horizontal components.
- The vertical reaction force, supplied by the surface, is labeled N (a force perpendicular to the surface)
- The horizontal reaction component, F_H, must be supplied by frictional forces.
- The maximum force of friction F_f is usually described by

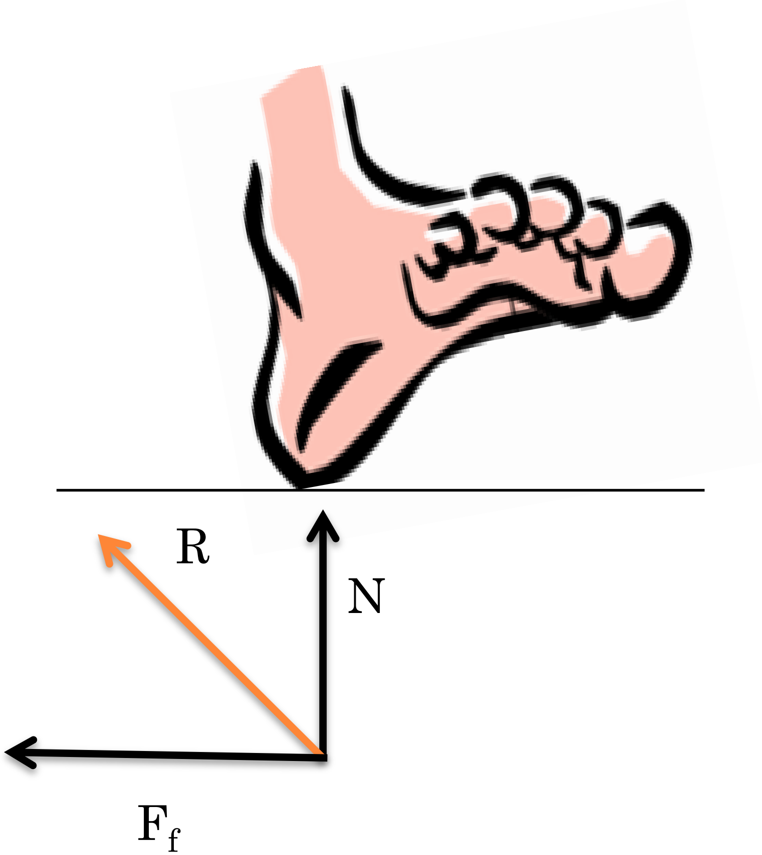
$$F_f = \mu N$$

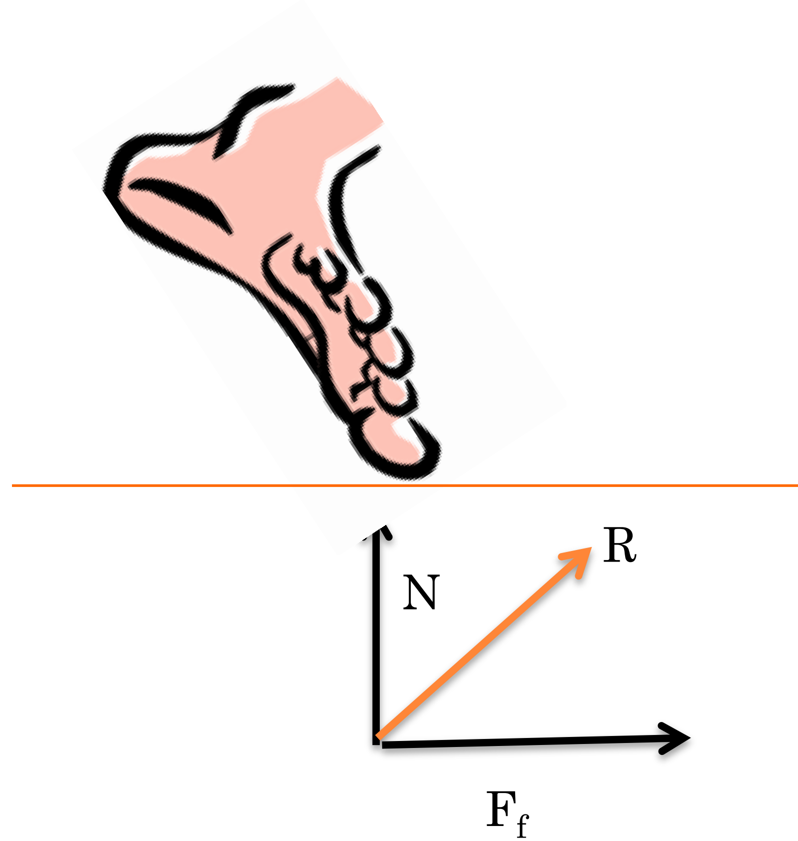
Where N is a normal force and μ is the coefficient of friction between two surfaces.



- The horizontal component of the heel as it strikes the ground when a person is walking has been measured, and found to be approximately 0.15W, where W is the person's weight. This is how large frictional force must be in order to prevent the heel from slippng. If we let $N \approx W$, we can apply a frictional forse as large as $f = \mu W$

- μ: the value of depends upon the two materials in contact, and it is essentially of the surface area.





- A) Both a horizontal frictional component of force, $F_{f,}$ and a vertical component of 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 ground, the frictional component of force, $F_{f,}$ prevents the foot from slipping backward and provides the force to accelerate the body forward.

- The saliva we add when we chew food acts as a lubricant. If you swallow a piece of dry toast you become painfully aware of this lack of lubricant.
- Most of large 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 with each breath, and the intestines have a slow rhythmic motion as they move toward its final destination.

- All of these organs are lubricated by a slippery mucus covering to minimize friction.

3. FORCES, MUSCLES AND JOINTS

- In this section, we discuss forces in the body and forces at selected joints and give some examples of muscle connections to tendons and bones of the skeleton.

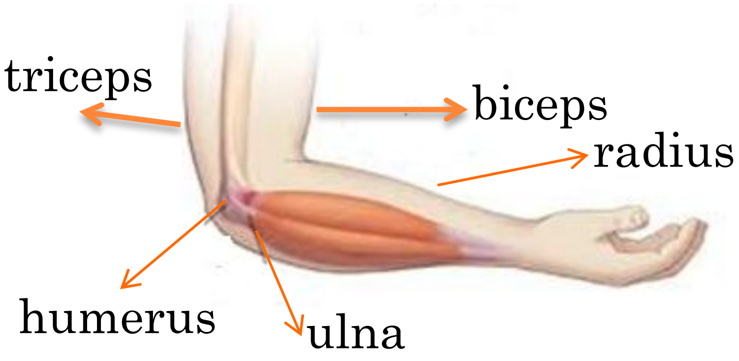
Since movement and live itself depends critall on muscle contraction, we start by examining muscles.

Muscles and their classification

- Skeletal muscles have small fibers with alternating dark and light bands, called striations- hence the name *striated muscle*.
- The other muscle form, which does not exhibit striations, is called *smooth muscle*.

- The fiber in the striated muscle connect to tendons and form bundle.

  Good example are the biceps and triceps depicted in schematic view of the muscle system used to bend the elbow.



Bicep bend the elbow to lift, triceps straighten it.

- During contraction, an electrostatic force of attraction between the bands causes them to slide together, thus shortening the overall length of the bundle. A contraction of 15-20% of their resting length can be achieved in this way. The contraction mechanism at this level is not completely understood. It is evident that electrical forces are involved, as they are the only known force available.
- It should be emphasized that muscle a shortening of the muscle bundle.

- **Smooth muscle** do not form fibers and, in general, are much shorter than striated muscles.

- Example of smooth muscle in the body are circular muscles around the anus, bladder ,and intestines and in the walls of arteries and arterioles (where they control bloodd flow).

- Sometime muscle are classified as to whether their control is voluntary or involuntary. This classification breaks down, however; the bladder has smooth muscle around it, yet is under voluntary control.
- A third method of classifying muscle is based on the speed of the muscle’s response to a stimulus.

  Striated muscle usually contract in times around 0.1 s, while smooth muscle may take several seconds to contract.

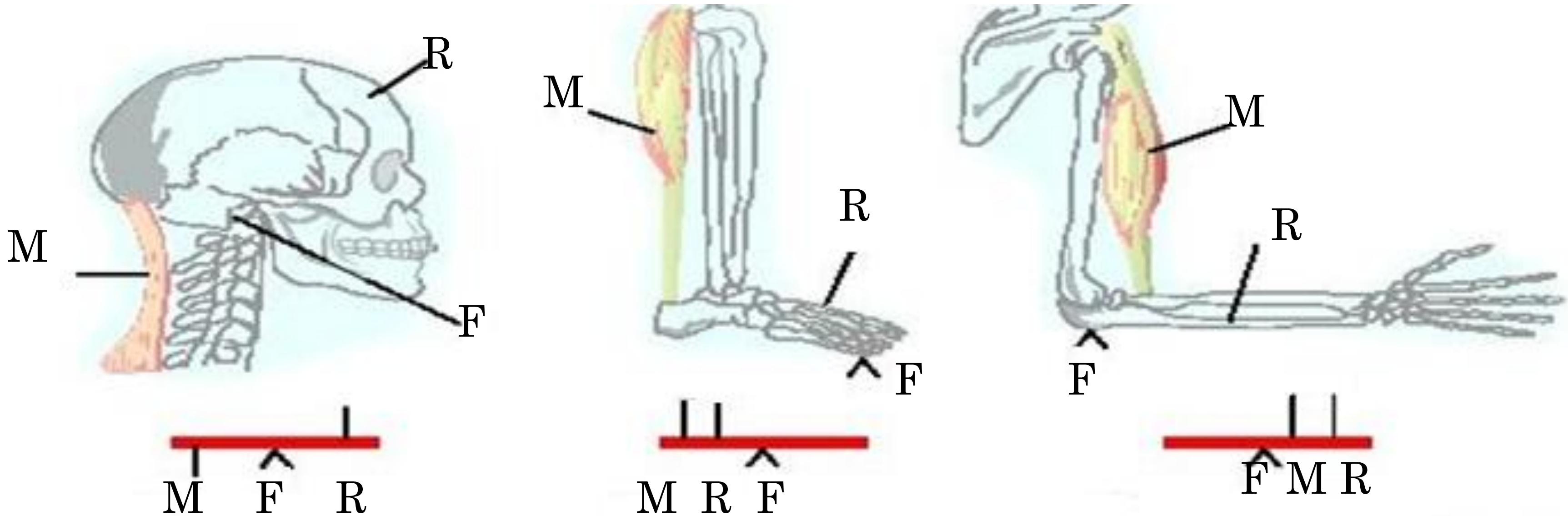
Muscle forces InvolvIng levers

- **For the body to be at rest, the sum of the forces acting on it any direction and the sum of the torques about any axis must both equal zero.**

- Many of the muscle and bone system of the body act as levers.
- Levers are classified as *first-*, *second-* ,and *third-class* systems.

Classes of levers

Third-class levers are most common in the body, while first-class levers are least common



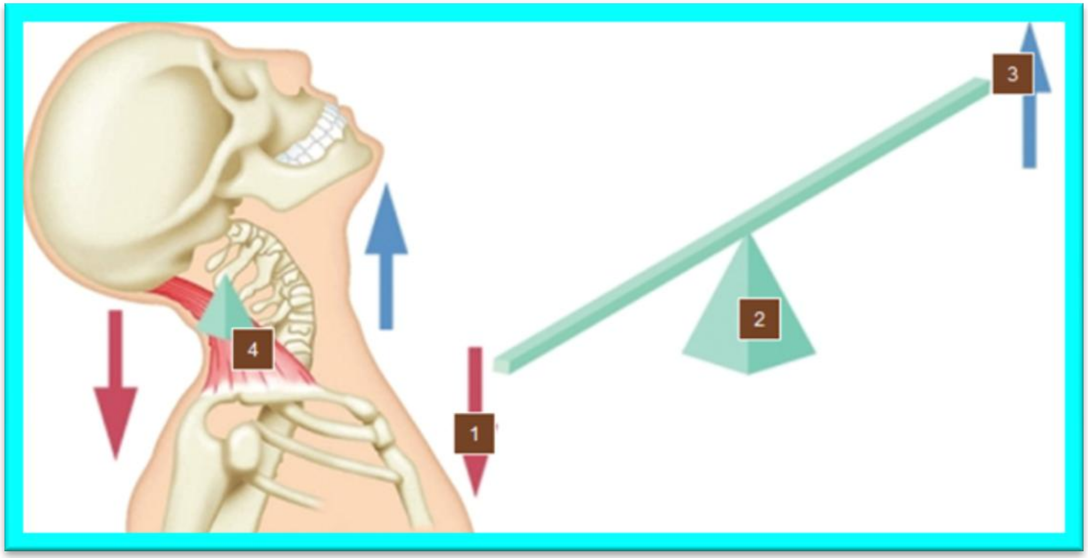
(a) In a first-class lever, the fulcrum (F) is set up between the resistance (R) and the effort (M).

(b) In a second-class lever, the resistance is between the fulcrum and the effort.

(c) In a third-class lever, the effort is between the fulcrum and the resistance.

First-class lever diagram

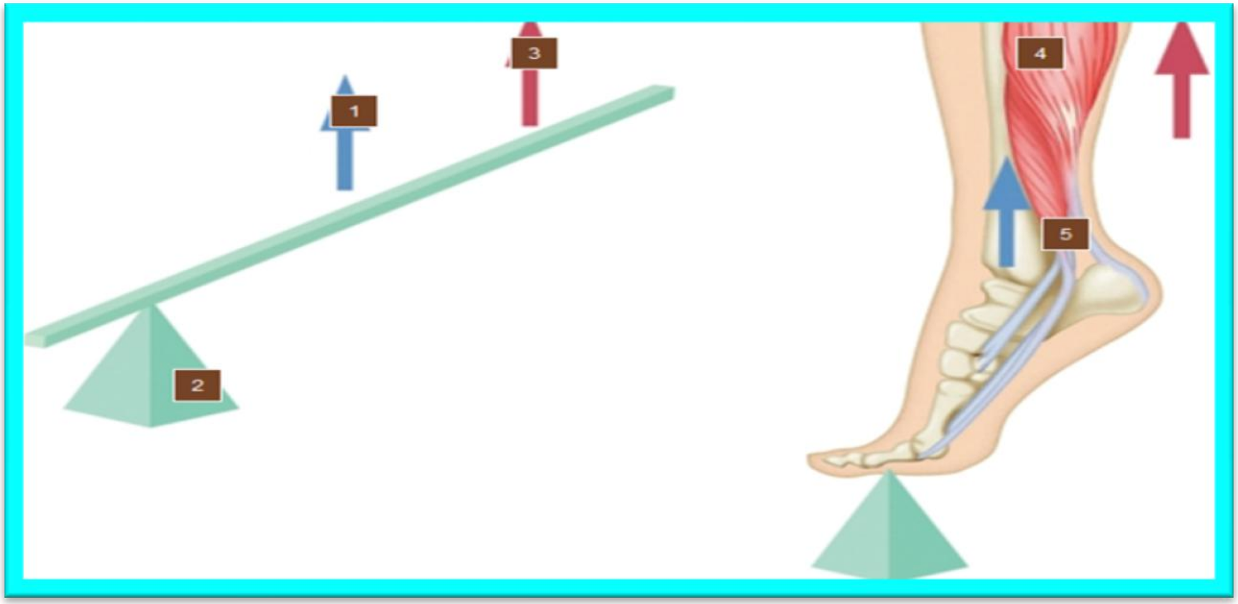
An example is seen in the posterior neck muscles that tilt back the head on the cervical vertebrae.



1 Direction of force
2 Fulcrum
3 Movement of load
4 Trapezius muscle

SECOND-CLASS LEVER DIAGRAM

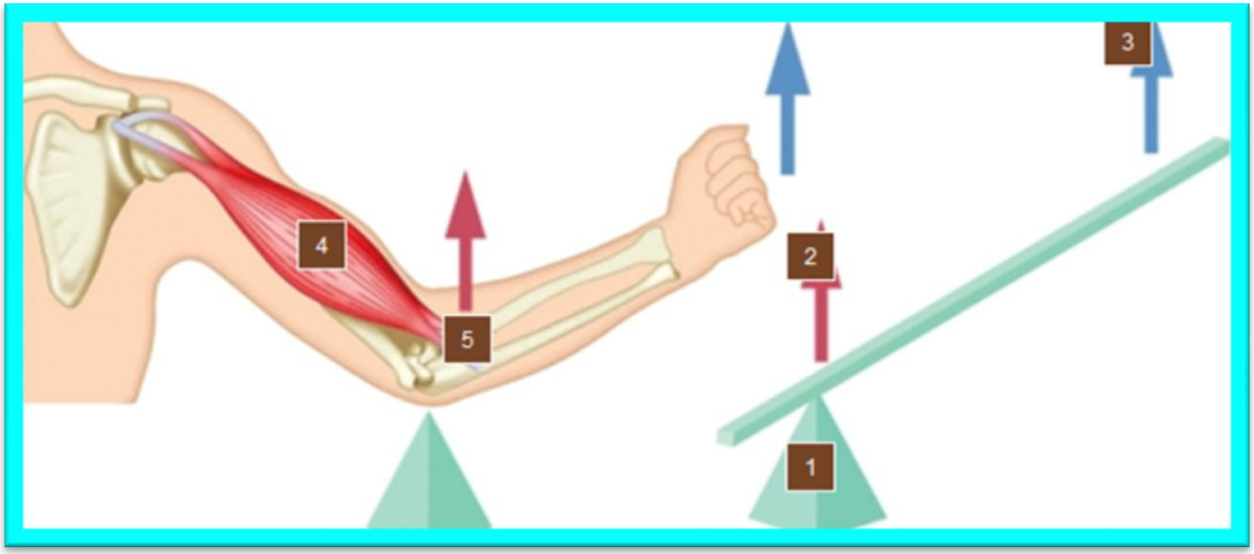
The load lies between the force and the fulcrum. Standing on tip-toe, the calf muscles provide the force, the heel and foot form the lever, and the toes provide the fulcrum.



1 Movement of load
2 Fulcrum
3 Direction of force
4 Gastrocnemius muscle
5 Tendon

Third-class lever diagram

The most common type of lever in the body, the force is applied between load and fulcrum. An example is flexing the elbow joint (the fulcrum) by contracting the biceps brachii muscle.



1 Fulcrum

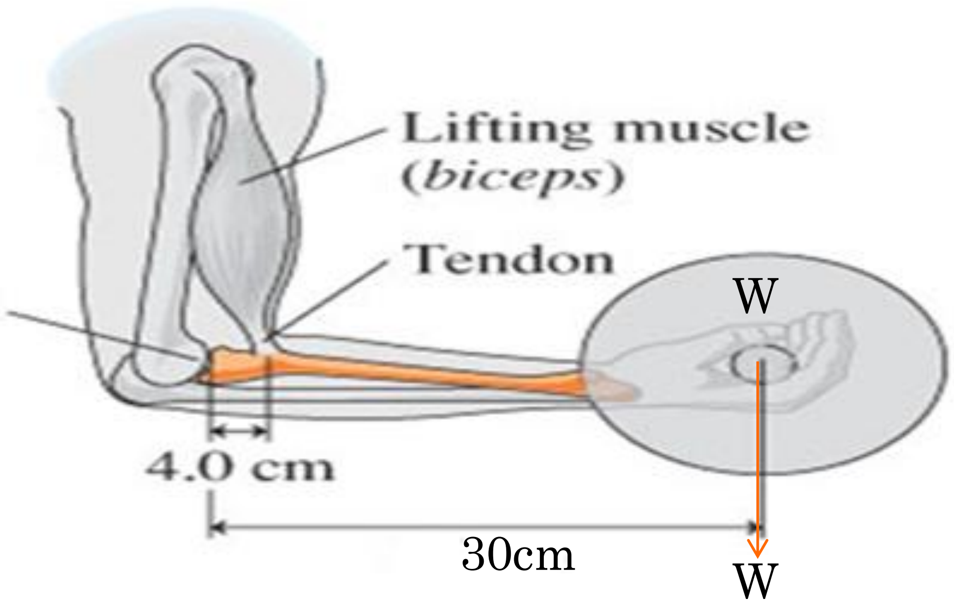
2 Direction of force

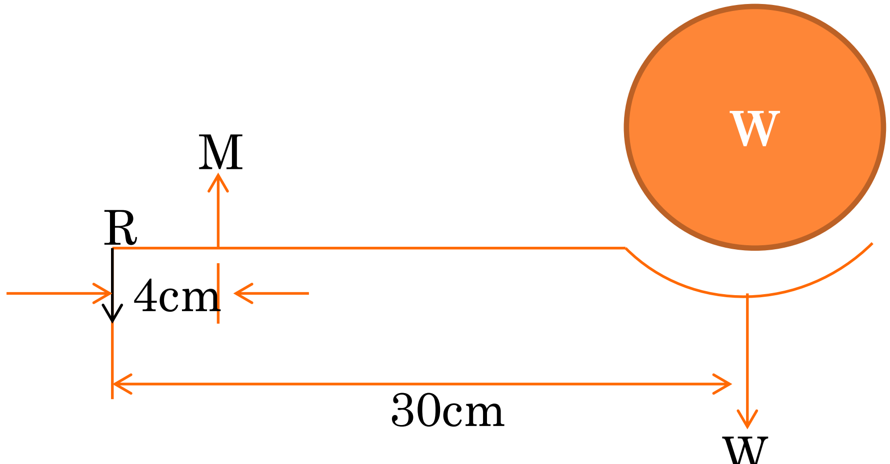
3 Movement of load

4 Biceps brachii muscle

5 Tendon

- Let's consider further the case of the biceps muscle and the radius bone acting to support a weight W in the hand.





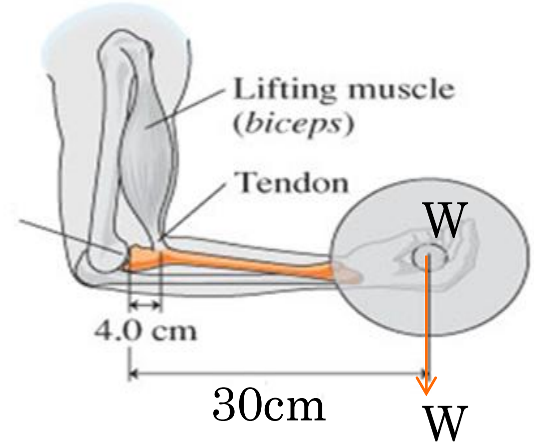
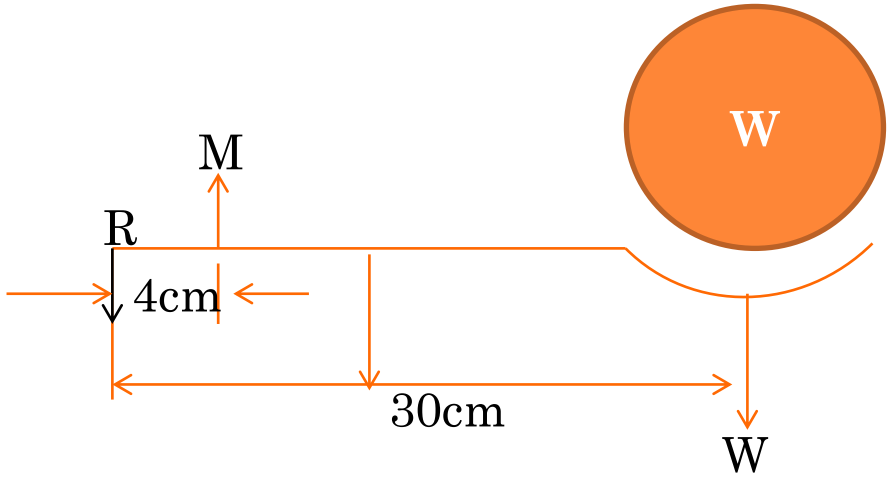


Fig. forces and dimensions of a typical arm:R is the reaction force of the humerus on the ulna, M is the muscle force supplied by the biceps, and W is the weight in the hand.

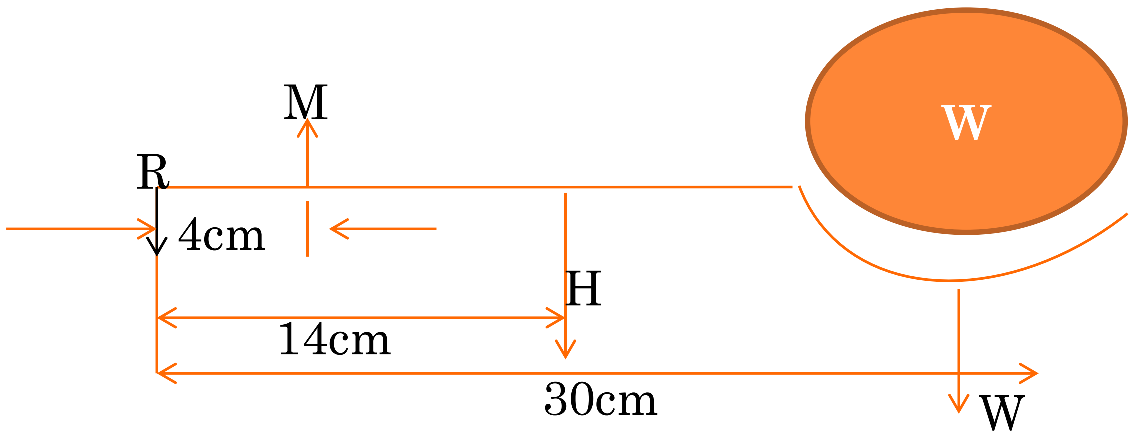
- We can find the force supplied by the biceps if we sum the torques (force times distance-moment arm) about the pivot point at the joint. There are only two torgues; that due to the weight W (which is equal to 30W acting clock-wise) and that produced by the muscle force M (which acts counterclock-wise and magnitude 4M). With the arm in equilibrium 4M must equal 30W, or 4M-30M=0 and M=7.5W.

  Thus, a muscle force 7.5 times the weight is needed. For a 100N weight, the muscle force is 750N.

- For individuals building their muscle through weight lifting, the exercise of lifting a dumbbell as in figure is called a dumbbell curl. A trained individual could probably curl about 200N requiring the biceps to provide 1500N.



- In our simplification of the example in figure, we neglected the weight of the forearm and hand. This weight is not present at a particular point but is nonuniformly distributed over the whole forearm and hand. We can imagine this contribution as broken up into small segments and include the torque from each of the segment. A better method is to find the center of gravity for the weight of forearm and hand and assume all the weigh is at that point.



- Figure 2 shows a more correct representation of the problem with the weight of the forearm and hand, H, included. A typical value of H is 15N. By summing the torques about the joint we obtain 4M= 14 H+30 W, which simplifies to

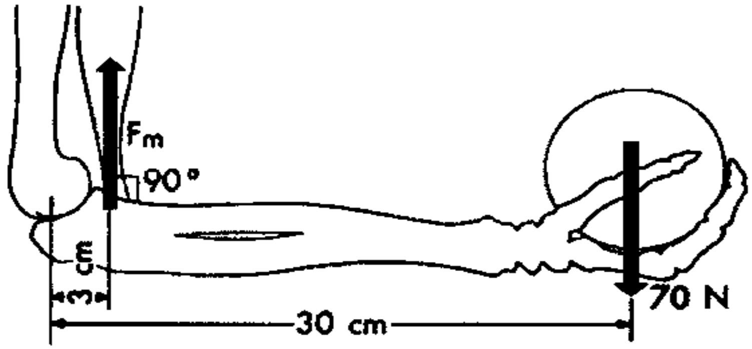
  M=3.5 H+7.5 W

  This simply means that the force supplied by the biceps muscle must be larger than that indicated by our first calculation by an amount 3.5 H= (3.5).(15)=52.5N

How much force must be produced by the biceps brachii, attaching at 90° to the radius at 3 cm from the center of rotation at the elbow joint, to support a weight of 70 N held in the hand at a distance of 30 cm from the elbow joint? (Neglect the weight of the forearm and hand, and neglect any action of other muscles.)

Known

$d_m = 3$ cm
$wt = 70$ N
$d_{wt} = 30$ cm

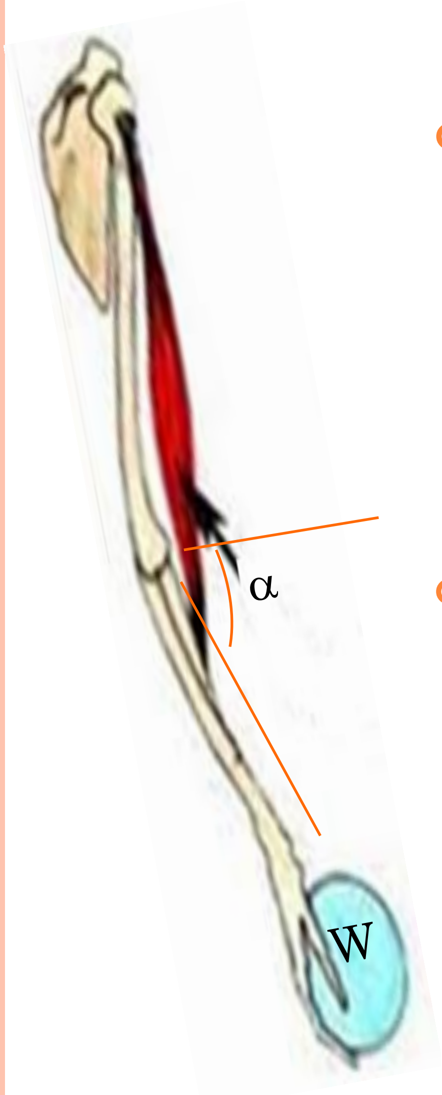


Solution

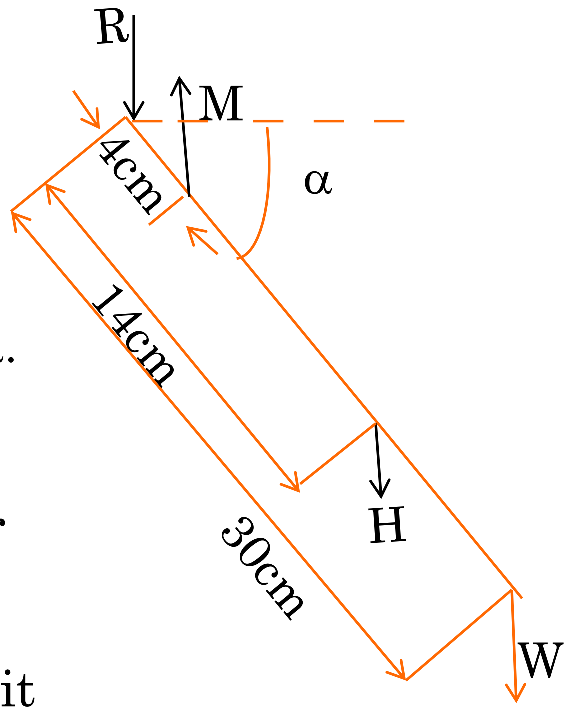
Since the situation described is static, the sum of the torques acting at the elbow must be equal to 0.

$$\Sigma T_e = 0$$
$$\Sigma T_e = (F_m)(d_m) - (wt)(d_{wt})$$
$$0 = (F_m)(0.03 \text{ m}) - (70 \text{ N})(0.30 \text{ m})$$
$$F_m = \frac{(70 \text{ N})(0.30 \text{ m})}{0.03 \text{ m}}$$

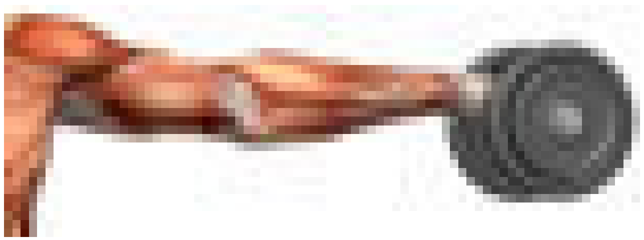
$$F_m = 700 \text{ N}$$

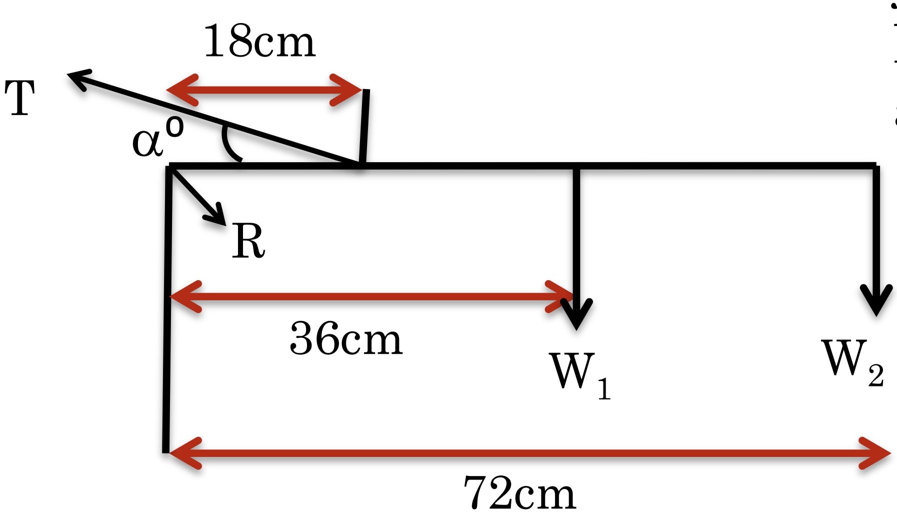


- What muscle force is needed if the angle of the arm changes from the 90° (between forearm and upper arm) that we have been considering so far, as illustrated in figure. Figure shows the forces we must consider for an arbitrary angle α.
- If we take the torques about the joint we find that M remains constant as α changes!! However the lenght of biceps muscle changes with the angle. 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 two extremes, the force the muscle can exert is much smaller.



RAISING THE RIGHT ARM

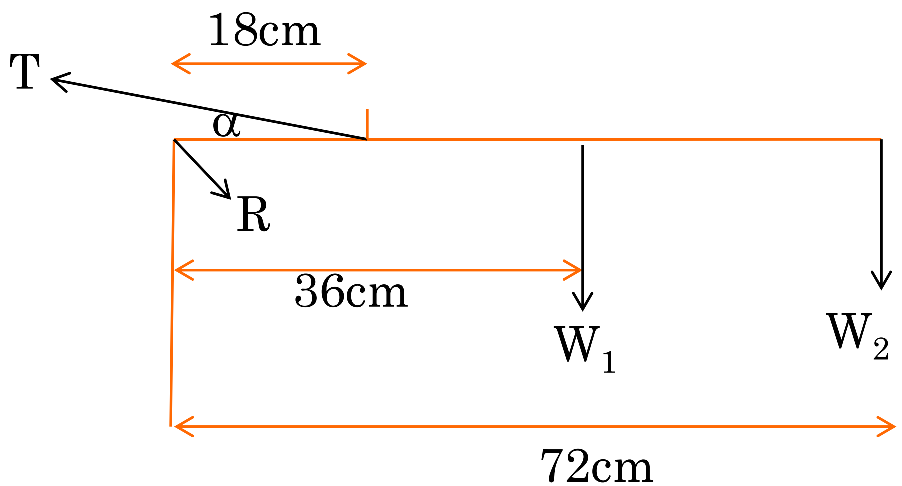




The forces on the arm

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.

- The arm can be raised and held out horizontally from the shoulder by the deltoid muscle. We can show the the forces schematically in figure.



By taking the sum of the torgues about the shoulder joint, the tension T can be calculated from:

$18.T.\ \sin\alpha = 36\ W_1 + 72\ W_2$
$T = (2W_1 + 4W_2)\ /\sin\alpha$

if $\alpha = 16^o$, the weight of the arm $W_1 = 68N$ and, the weight in the hand $W_2 = 45N$, then T=1145N

The force needed to hold up the arm is *surprisingly large*.

The spinal column

- The spinal column has a normal curvate for stabilty. View from the right side the lower portion of the spine is shape like a letter ‘S’ as shown in figure.

Spinal deviations in the shape of the spine

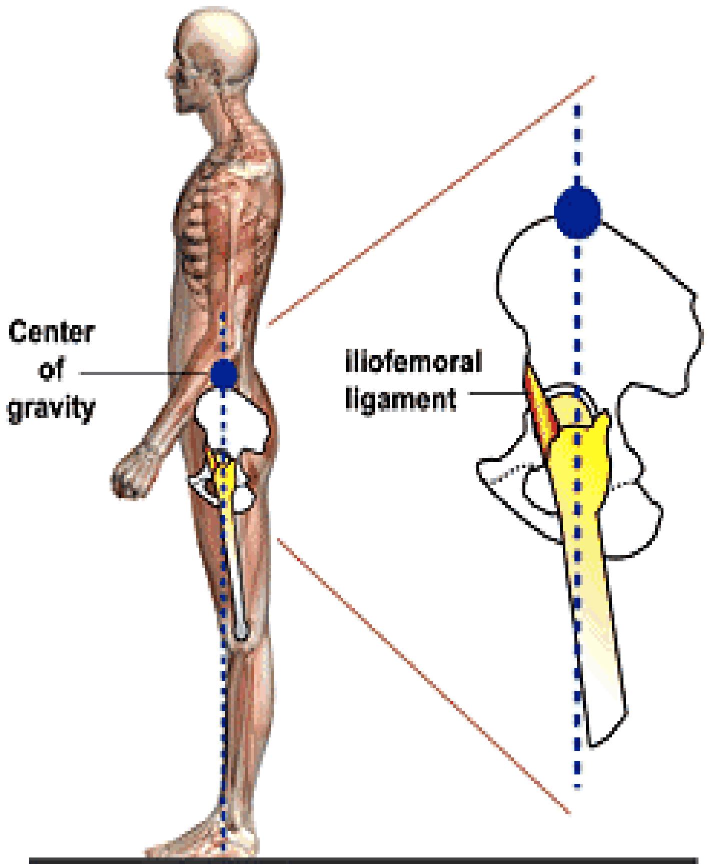
Kyphosis
or
Hunch backed:
it leads to a hump in the back

Lordosis
or
Sway back:
too much curvate

Scoliosis:
is a condition in which the spine curves in an '*S*' shape as seen from the back

STABILITY WHILE STANDING

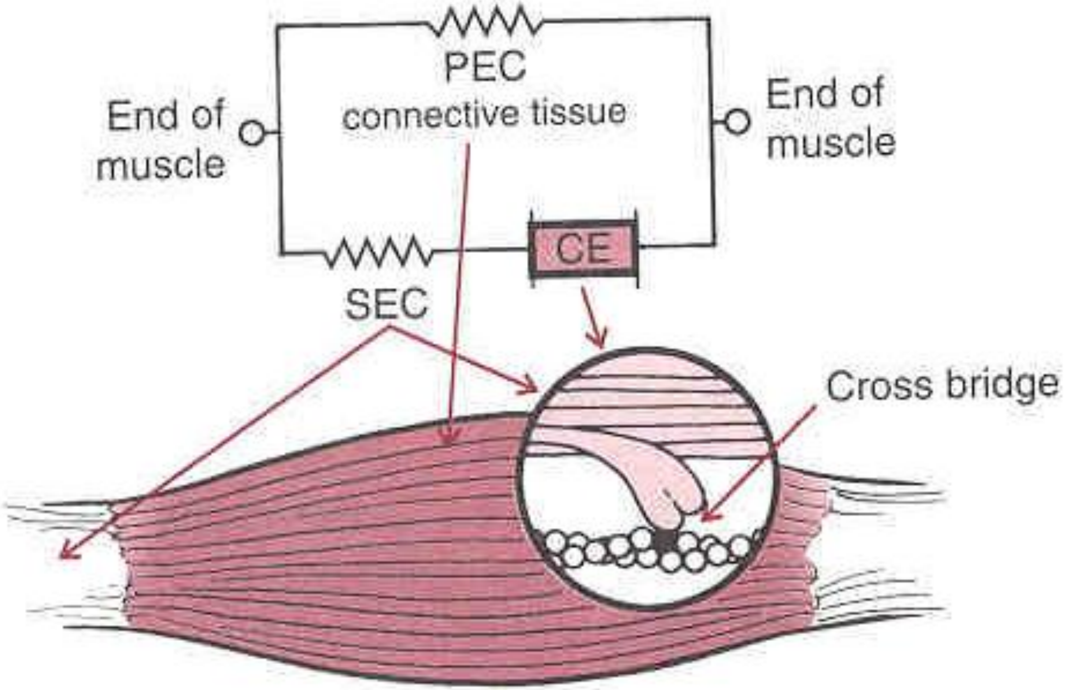
- In an erect human viewed from the back, the center of gravity (cg) is located in the pelvis in front of the upper part of sacrum at about 58% of the person's height above the floor. A vertical line from the cg passes between the feet.



- Poor muscle control, accidents, disease, overweight conditions, or poor posture change the position of the cg to condition an unnatural location in the body.
- An overweight condition lead to forward shift of the cg, moving the vertical projection of it under the balls of the feet where the balance is less stable. The person may compensate by tipping slightly backward.

- The body compensates its stance when lifting a heavy suitcase with one arm. The opposite arm moves out and the body tips away from the object to keep the cg properly placed for balance.
- People who have amputated are in a stituation similar to a person carrying a suitcase. They compensate for the weight of the remaining arm by bending the torso; however, contiuned bending of the torso leads to spine curvature.

Mechanical model of the muscle



The three component mechanical model of the muscle consists of an active component CE, and two passive components SEC and PEC.
CE: the contractile element
located at the myofibril level where cross-bridging occurs.
SEC: is the series elastic component.
in the tendon.
PEC: are the parallel elastic component.
in the connective tissue.

Musculoskeletal machine functions and machines

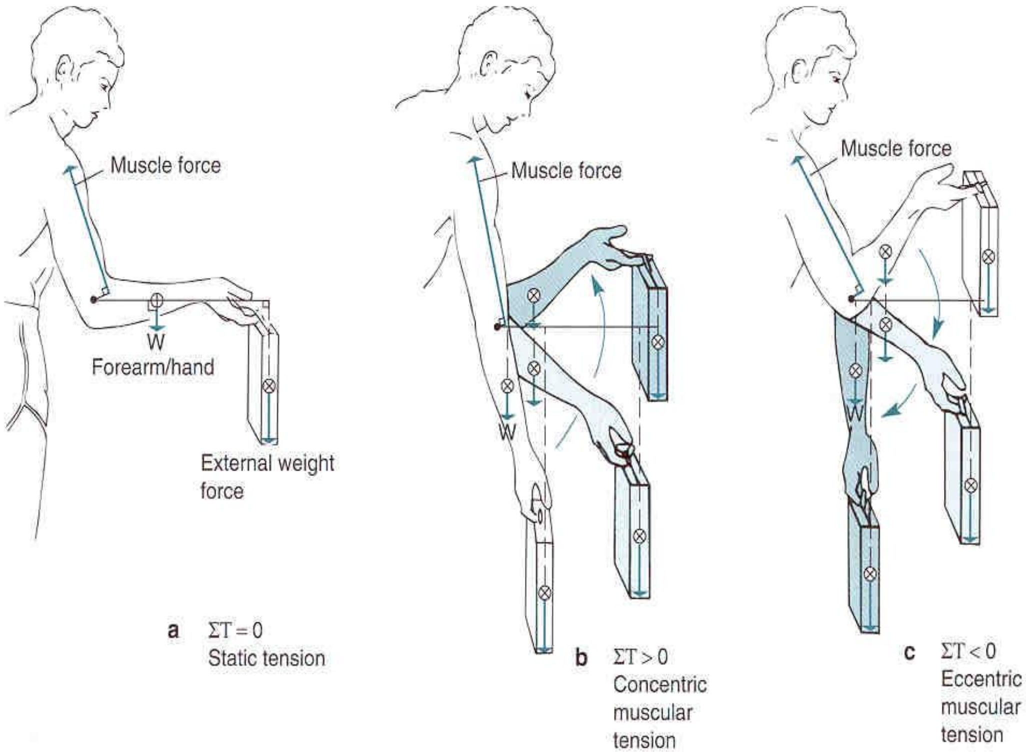
- Most important machine functions found in the human body
  - provide advantage for speed (levers and wheel & axle)
  - change direction of applied force (pulley)
- Three machines found in the body:
  - levers (ex. biceps brachii pulling on radius)
  - wheel and axle (rotator cuff muscles pulling on humerus)
  - pulley (patella, lateral malleolus of fibula)

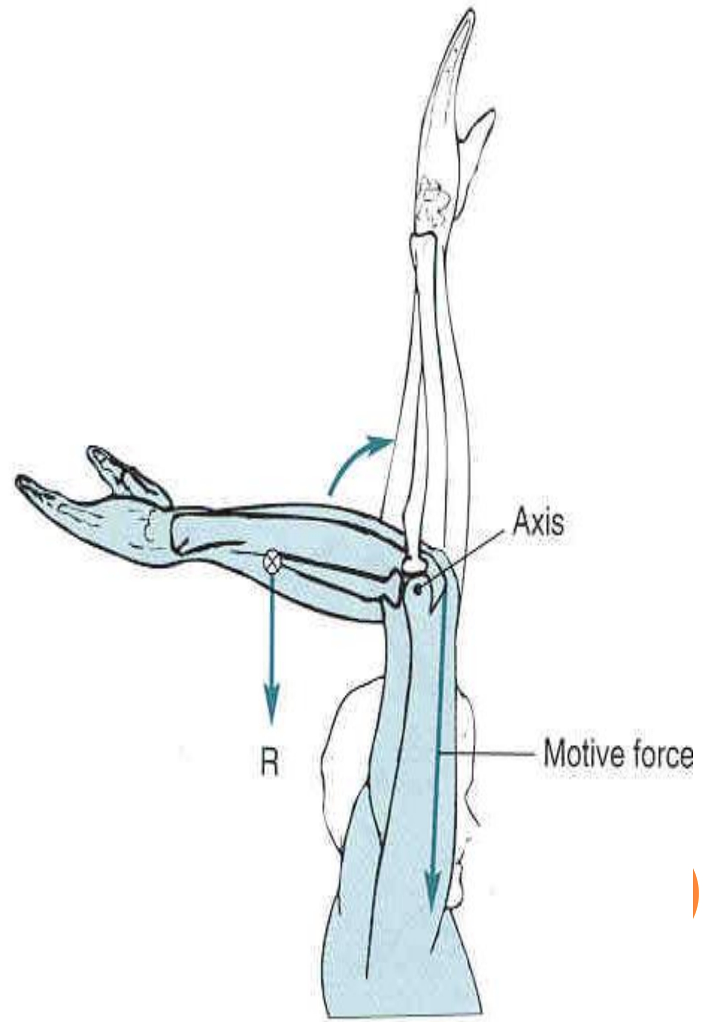
Musculoskeletal Levers

- Elements of levers
  - axis (joint center)
  - rigid bar (long bone)
  - motive and resistance **torques** (muscle pull, gravity, inertia), or **moments**
- Concept of Net Torque
- Law of levers (☜CW torques = ☜CCW torques)
  - Force X Force Arm = Resistance X Resistance Arm
  - or F.f = R.r
- Analysis of musculoskeletal lever system
  - Turning, or rotary component (Fd sin α)
  - Stabilizing and dislocating component (Fd cos α)

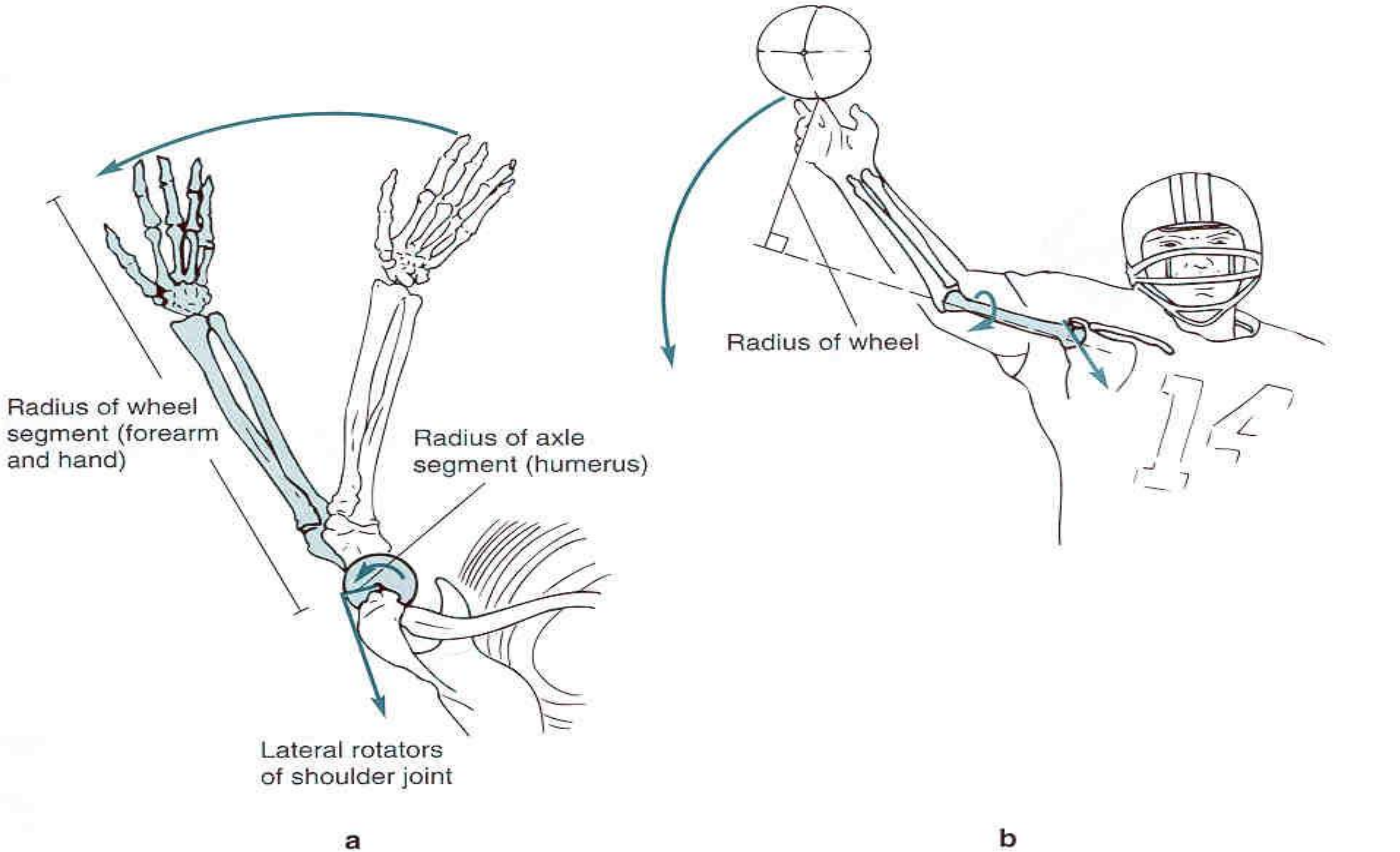
Levers in the Human Body (all amplify movement at expense of force)

Class III:



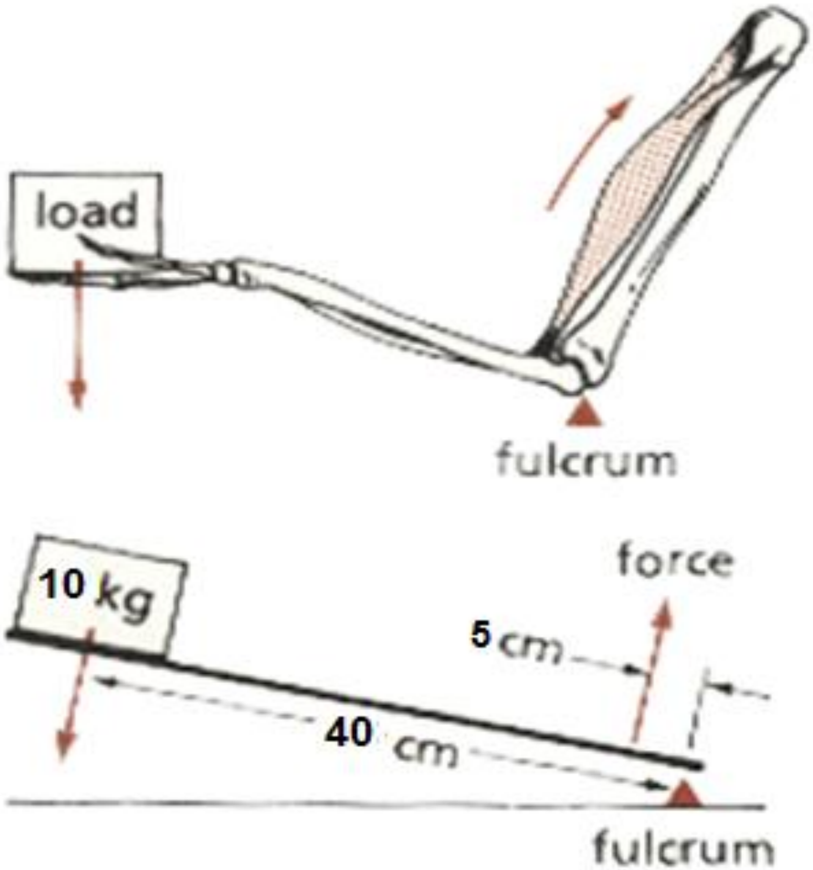


WHEEL& AXLE



a) Cross section of the humerus, showing the wheel-and-axle arrangement of the lateral rotators of the shoulder joint.

b) The humaerus and forearm acting like a wheel-and-axle as a player throws a football pass.

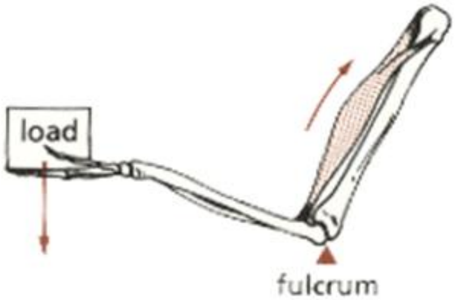


In this system, the elbow acts as a fulcrum. A load of 10 kg is placed in the hand, the center of which is 40 cm from the fulcrum (elbow) The biceps muscle is attached at a point 5 cm from the elbow. How much force (Newton) is exerted by the biceps muscle to raise a load of 10 kg?

A) 80 Newton
B) 800 kg
C) 800 Newton
D) 80 meter x Newton
E) 800 meter x Newton

Answer: C

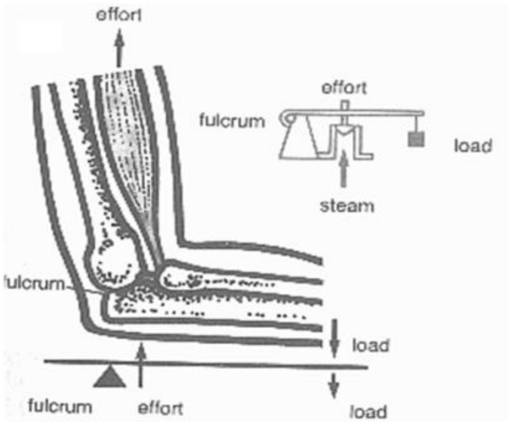
Skeletal muscle acts on the bones as a system of levers. Which class of leverage system is correct for the figure that is given below?

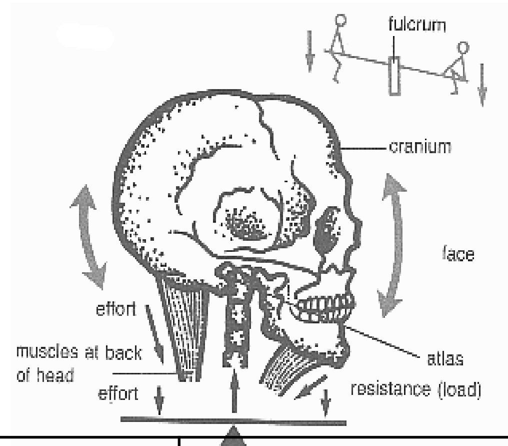


A) First and second class levers together
B) First and third class levers together
C) First-class lever
D) Second-class lever
E) Third-class lever

Answer: E

Skeletal muscles act on the bones as a system of levers. Which of the following muscle actions have been given in appropriate leverage systems.





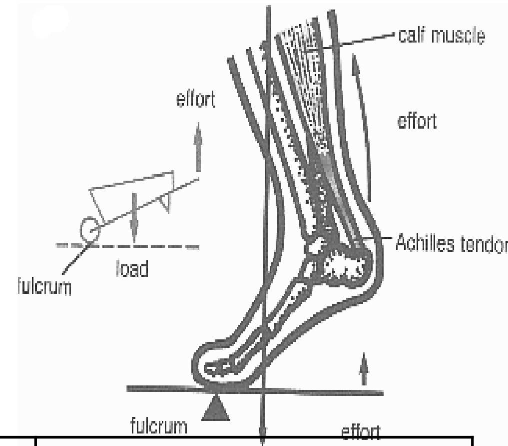


	Figure (a)	Figure (b)	Figure (c)
	First-class lever	Second-class lever	Third-class lever
	Third-class lever	First-class lever	Second-class lever
	Second-class lever	First-class lever	Third-class lever
	Third-class lever	Second-class lever	First-class lever
	First-class lever	Third-class lever	Second-class lever

Answer: B