Lesson 8   Basis of equilibrium and postural control

This lesson contains 10 screens teaching text, 4 zoomable figures and 6 videos. This lesson requires approximately 2 - 4 hours of study but can vary depending on the student.

Equilibrium

Basic terms

As you remember, torque may be thought as rotary effect of a force about an axis of rotation. **Torque** can be measured as the product of the force and the moment arm of the force where the moment arm is the perpendicular distance between the force's line of action and the axis or fulcrum (Fig.1) (1).

$M = F \times r$, where M is the torque, F is the force, r is the moment arm of the force.

 Line of force is the line where the force is applied. It is the line along which a force or the resultant of any number of forces may be considered to act (Fig.1).

A **moment arm** determines the degree of effectiveness or influence of a force to produce or prevent the rotation of an object around an axis. The moment arm of an applied force can be referred to as the force arm, and the moment arm of a resistance (for example the gravitational force which always directed vertically downward, toward the center of the earth) can be referred to as the resistance arm (Fig.1) (1).
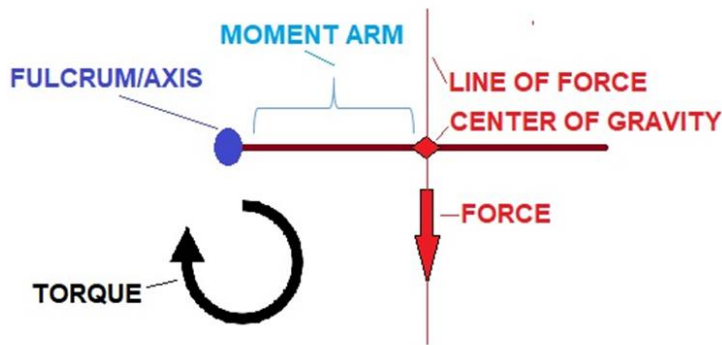
Fig. 1 Acting of gravitational force on a simple bar around a fixed axis.

Equilibrium within the human body

Within the human body, muscle's line of force (pull) describes the direction of muscular force. The relationship between a muscle's line of pull and the axis of rotation of a joint determines the action that the muscle produces. This knowledge allows you to figure out the various actions of any muscle in the body.

Within the human body, the moment arm for a muscle (muscle force arm) with respect to the axis of a joint (center) is the perpendicular distance between the muscle's line of action and the center of the joint. As a joint moves through a range of motion, there are changes in the position of the body part and the moment arm of the muscles crossing the joint will change with every degree of motion. This simply means that the force will have different degrees of influence at every position comprising the range of motion.

Please now watch the following video about changing of muscle moment arm during joint motion:

https://www.youtube.com/watch?v=8kb4wabK3-8

Levers in the human body

Our first lesson about biomechanical principles contains the three major classes of levers, each defined by the location of the applied force/ effort in relation to the load / resistance and the fulcrum.

Please refresh your knowledge about levers with the following video!

https://www.youtube.com/watch?v=d1wS_OlJzmI&t=4s

Mechanically, bones and muscles connected with joints function as levers. Most of the musculoskeletal levers of the human body are classified as third-class levers (1). For instance, the forearm and the elbow, acts as a third-class lever. The biceps brachii muscle, which originates from the scapula, inserts at the proximal part of the elbow. As the muscle contracts, it moves the forearm about the elbow joint, bringing it closer to the body. This motion is called elbow flexion.

Muscle force couple are equal in magnitude and act in opposite directions at different points on a body, thus there is no net force acted upon the body. The forces in a couple are positioned on opposite sides of the axis of rotation and produce torque in the same direction.

Within the human body, a force couple relationship can be defined as a pair of muscle forces that act together on a joint to produce rotation, and these forces may actually exert pulls in opposite directions. These muscles may be synergistic pairs, consisting of prime movers and groups of stabilizers, for instance, or agonist/antagonist pairs. Force couple, then, is actually another way of referring to muscle synergists or a synergistic action.

Please watch the video about muscle force couple:

https://www.youtube.com/watch?v=mm9_WrrGCEc

State of equilibrium means that an object is balanced and all forces acting on it are even.

A body is said to be in **mechanical equilibrium** if the total force acting upon it is zero and the total torque acting on it is zero (7).

A motionless object is in **static equilibrium**. In this case the forces acting on it add up to zero.

An example of static equilibrium is when an object is held in hand with isometric work of the biceps brachii muscle. In this case, mainly two forces act on the forearm. On the one hand, the muscle force resulting from the isometric contraction of the biceps. On the other hand, the gravitational force resulting from the weight of the forearm and object held in hand (Fig. 2).
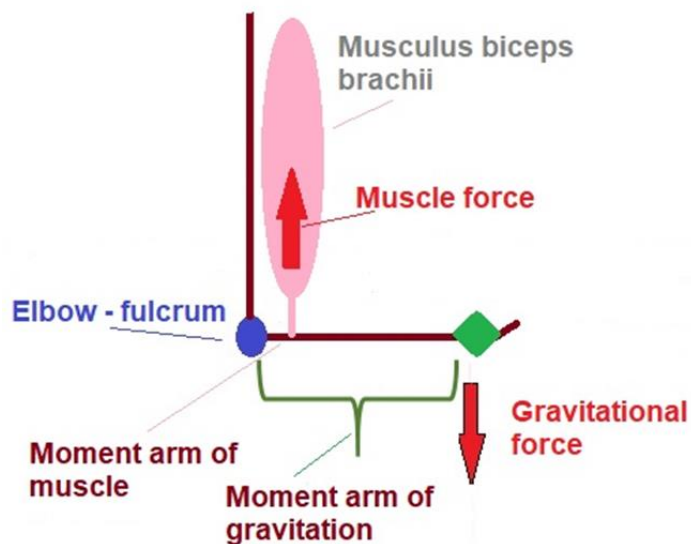
Fig. 2 Static equilibrium generated by a muscle.

What force must the biceps generate to hold the forearm in static equilibrium?

We can use the simple equation - $M = F \times r$ – and the fact that the acting forces/torques add up to zero in static equilibrium, $\sum M = 0$.

$$F_{biceps} \times r_{biceps} = F_{gravitational} \times r_{gravitational}$$

$$F_{biceps} = \frac{F_{gravitational} \times r_{gravitational}}{r_{biceps}}$$

.

When a body is in state of uniform motion and the resultant of all forces acting upon it is zero then it is said to be in **dynamic equilibrium** (1).

Please watch the following video:

https://www.youtube.com/watch?v=mNBPpZdppto

An object is in **translational equilibrium** if it is not accelerating. Translational equilibrium implies that the sum of all external forces applied to the object is zero (1).

Rotational equilibrium is defined as the state of a system for which the total angular acceleration is zero (1).

Within the human body, the relationship between internal (e.g. the muscle force), and external (e.g. gravitational force, friction etc.) forces determine the movement of joints. In addition, the angle at which a muscle pulls on a bone also influences the effectiveness of the muscle-bone lever system (1).The force of muscle tension can be divided into two force components – one perpendicular to the longitudinal axis of the attached and moved bone and one parallel to the longitudinal axis of the attached and moved bone.

The component of muscle force which acts perpendicular to moved bone is the rotary component of the muscle action. It causes the bone move (rotate) about the joint center (fulcrum). The component of muscle force which acts parallel to moved bone pulls it either away from the joint center (a dislocating component) or toward the joint center (a stabilizing component) (1) (Fig. 3).
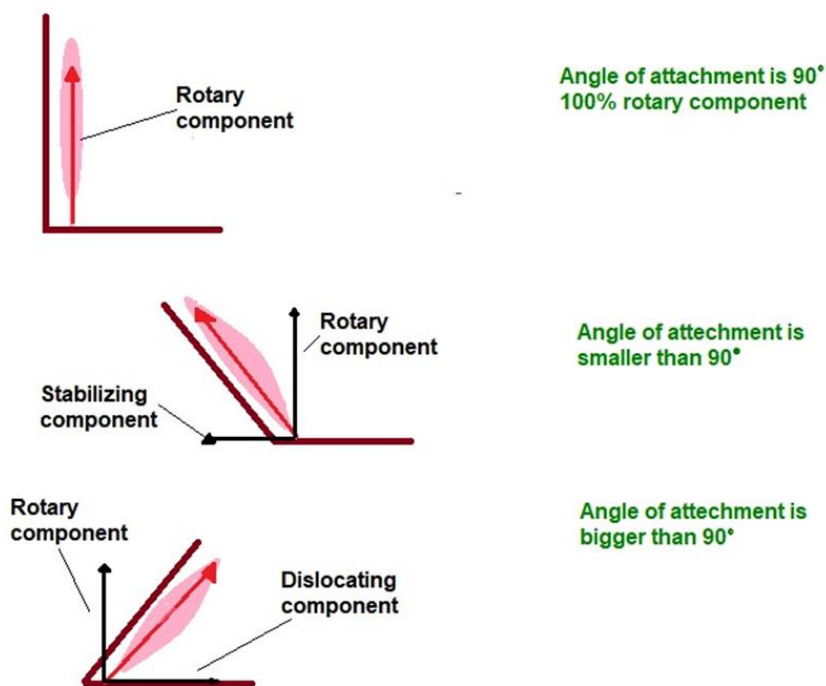

Fig. 3 Relationship between the angle of the biceps brachii muscle and the mechanical effect of the muscle

Stability and balance of the human body

Stability

The ability of an object to balance in a static situation is related to the position of the center of mass or center of gravity and the area of the base of support of that object. **Center of gravity** (COG) is that point about which a body's weight is equally distributed/balanced in all directions. The terms center of mass (COM) and center of gravity are used synonymously.

The COG of a symmetrical object with homogenous density is at the center of the object. The COG of an asymmetrical or multi-segmented object is influenced by the positions of the heavier segments and the lighter segments.

Please watch the following video about center of gravity:

https://www.youtube.com/watch?v=R8wKV0UQtlo

The COG of the human body is a hypothetical point around which the force of gravity appears to act.

When standing, the center of gravity of human body is normally located in front of the sacrum bone, at about the second sacral level.

The size of the **base of support** (BOS) is a significant factor affecting stability. It contains the area enclosed by the farthest edges of the body in contact with the supporting surface.

An object is balanced if the line of gravity of an object falls within the BOS. The object becomes unbalanced, and will fall, if the line of gravity is displaced out of the base of support (hall). For example, it is the area of the imprint of a shoe on a mat in a one foot balance. If a person is balancing on two feet, the base of support is the area of the imprints of both shoes and the surface space between them. Standing with feet close together or on one leg provides a smaller base of support, whereas BOS increases as the distance between the feet increases.

When the line of gravity is within the BOS, an object or person is said to be stable. When the line of gravity falls outside the BOS, the object or person is said to be unstable.

Please watch the following video:

In standing position, the human body can be considered as an inverted pendulum. It consists of a rigid element (in this case the whole body is considered as a rigid element), which turns around the ankle joint as a fulcrum (3).

During quiet standing the body is in continuous movement at all its joints and the COG displays a random looking motion. More precise analysis of the COG motion shows that it repeatedly sways unstably and unpredictably for the duration of standing. Humans can maintain standing balance, at which the system is at equilibrium, by maintaining active control of the position of their COG relative to the fulcrum formed by their feet (2) (Fig. 4)
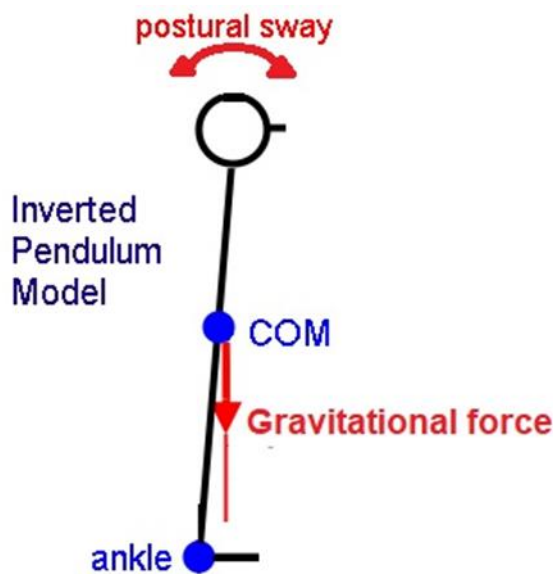
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Fig. 4 Inverted pendulum model - A person standing upright acts as an inverted pendulum with his feet as the pivot, and without constant small muscular adjustments would fall over.

The inverted pendulum model is also used to analyze mechanically the stance phase of gait. The stance phase is that part of gait during which the foot remains in contact with the ground. The swing phase is that part of the gait cycle during which the reference foot is not in contact with the ground and swings in the air.

Balance

A human body has the ability to sense the position of the body in the frame of reference and to use muscular activity to counteract the external forces in order to prevent falling. Thus, a human has control over balance called balance control or postural control (5).

The control of balance has been identified to be associated with three classes of human activity (5):
- The maintenance of a specified posture, such as sitting, standing or walking;
- Voluntary movement, such as the movement between postures;
- The reaction to an external disturbance, such as a slip or a push.

Impaired balance

During upright stance, the human body has a relatively high COG (sacral level) and a relatively small BOS, which complicates the problem of the maintenance of stability (5). Impaired balance is a significant problem and associated with an increased risk of falls (6). Damaged postural control may limit mobility and daily activities, and plays a significant role in the elderly falling (4).

Study questions:

TRUE/FALSE questions

Read each statement below carefully. Choose T if you think a statement is TRUE. Choose F if you think the statement is FALSE.

1. The inverted pendulum model is used to analyze mechanically the swing phase of gait.

   T   or   F

2. Base of support contains the area enclosed by the closest edges of the body in contact with the supporting surface.

   T   or   F

3. The forces in a couple are positioned on same side of the axis of rotation and produce torque in the opposite direction.

4. **T   or   F**

5. Base of support increases as the distance between the feet increases.

   T   or   F

Matching questions

In this exercise, you have to match each word with a definition.

1. Centre of gravity
2. State of equilibrium
3. Rotational equilibrium
4. Dynamic equilibrium
5. Force couple

A. A pair of forces which are equal in magnitude and act in opposite directions at different points on a body.

B. When a body is in state of uniform motion and the resultant of all forces acting upon it is zero.

C. It is that point about which a body's weight is equally balanced in all directions.

D. It is defined as the state of a system for which the total angular acceleration is zero.

E. It means that an object is balanced and all forces acting on it are even.

References

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