Biomechanics

Kinesiology is the science of, or study of, human motion. It brings together the fields of anatomy, physiology, biomechanics, physics and geometry relating them to human movement.

Bio refers to living
Mechanics refers to forces acting on objects and with the results of these forces in terms of equilibrium and movement.
Therefore **biomechanics** is the application of the principles of mechanics to the living human body.

Mechanics is divided into:
 Static – bodies in balance (equilibrium)
 Dynamic – bodies in motion

State of equilibrium is when the sum (or net effect) of forces acting on a body equals zero

Dynamic systems can be divided into **Kinetics** and **Kinematics**

Kinetics – deals with forces which produce, arrest or modify motions of bodies. Force is a push or pull

When a body or object is in equilibrium the sum of the net forces acting on it equals zero; to produce motion, forces act to disturb equilibrium. To arrest or stop motion, the forces return the body to a state of equilibrium.

Newton's first law: Law of inertia or law of equilibrium. It deals with objects in equilibrium, bodies at rest tend to stay at rest; bodies in motion tend to remain in motion OR
An object at rest will remain at rest or in uniform motion unless acted upon by an unbalanced force

Newton's third law: Law of reaction. Forces always come in pairs. For every reaction there is an equal and opposite reaction
OR
When an object applies a force to a second object, the second object simultaneously applies a force of equal magnitude and in the opposite direction as the first object

All forces acting on a body must be identified. These are the "force system"
If all forces are in the same line = linear force system

Example: A book on the table has two forces

1. Gravity's downward force = weight of the book
2. Table exerts an upward force = weight of book.

Sum of net forces = zero, therefore the book is in equilibrium

Primary forces which act on the human body are:

Gravity Externally applied resistance

Muscle Contraction Friction

Force System

- Identification of all the forces acting on an object
- Linear force system = all forces are in the same line
- Parallel force system = two or more parallel forces acting on the same object but at some distance from each other. The lever system is this type.
- Lever = Rigid bar that can rotate about a fixed point when a force is applied (bones)
- Axis = fixed point about which the lever rotates
- Weight = resistance that must be overcome
- Force = usually muscular contraction in the human body
- Weight arm = (resistance) distance between the fulcrum and the weight
- Force arm = distance between the fulcrum and the force

Lever Systems – 1st, 2nd, and 3rd class

First Class Lever

- The axis is located between the force and the weight (resistance)
- Designed best for **balance**
- Example: seesaw; atlanto-occipital joint

Second Class Lever

- Axis is located at one end, resistance is in the middle and the force at the opposite end
- Designed best for **power**
- Example: wheelbarrow; rising up on toes; PROM

Third Class Lever

- Axis is at one end, force is in the middle and the resistance at the opposite end
- Designed for ROM (mobility); most common lever system in humans
- Example: hinged door; normal muscle contraction

Torque – when a force acts on a rigid bar (lever) it may cause a rotary motion around the fixed point (axis). Torque, or moment of force, is the measurement of the ability of a force to cause rotation of the lever. T = F x D

T = Torque (foot pounds)
F = Force (pounds)
D = Distance (feet) – the length of a line drawn perpendicular to the action line of the force from the axis

Torque is an important measurement because a force applied further from the point of rotation, or axis, requires less force to produce movement.
Example: resistive exercise and body mechanics

Mechanical Advantage – deals with the relationship between the length of the force arm and the length of the weight arm

$$MA = \frac{\text{Force Arm}}{\text{Weight Arm}}$$

Mechanical advantage is related to the concept of torque.
If F = W and dF is greater than dW, then F has the advantage
The lever arm will move in the direction of the force (F)
Increasing dF or decreasing dW will **increase** the MA of F

Equilibrium in some ways can be said to be a stable situation. A joint is stabilized when the sum of the net forces acting on it equal zero

Remember the importance of proximal stability to isolated joint motion and in utilizing body mechanics when we want to increase stability

Gravity is probably the most important force. When you consider gravity, its point of application is called the Center of Gravity (COG). COG is a hypothetical point at which all mass would appear to be concentrated and is the point at which the forces of gravity appears to act.

In a symmetric object COG is the geometric center
In an asymmetrical object COG is toward the heavier end

COG can be thought of as the <u>balance point</u>
COG in humans is just anterior to S_2 (sacrum) in the anatomical position

For an object to be stable, the COG must fall within the Base of Support (BOS)

In the principles of body mechanics:

- The larger the BOS, the greater the stability of an object/person
- The lower the COG goes toward the BOS, the more stable the object/person

<u>Kinematics</u>

- Concerned with the geometry of motion without regard to the forces acting to produce motions.

- Involves description, measurement, and recording of bodily motion
- In PT, that means ROM measurements, cardinal planes, axis of motion etc.

Cardinal Planes: Sagittal, frontal, transverse
Secondary Planes: Those parallel to the cardinal planes
Planes and exies of motion: Plane describes the motion (motion parallel to the plane). Axis is the line about which the body part revolves
Types of joints: synovial joint structure and classification of synovial joints
Degrees of Freedom: number of main axes of motion possible

Kinematic Chains
A combination of several joints uniting successive segments
Open kinematic chain – the distal segment terminates free in space
Closed kinematic chain – the distal segment is fixed either by forming a closed ring (ribs attached to vertebrae and sternum) or by external force (the ground in weight bearing)

Clinical Use: If one joint is limited in the amount of motion available, then the other joints in the chain may compensate, but, this puts increased stress on the joint structures (especially the adjoining joints) which may result in hypermobility, decreased stability and pain

Surface Motions = **arthrokinematics**

- Rolling – each subsequent point meets a new point on other surface (wheels of a car moving)
- Sliding – anterior/posterior glide or lateral glide (skidding motion of wheels)
- Spinning – rotation with no translatory motion (wheels spinning in mud)
- Combined rolling and sliding
- Compression – joint surfaces coming closer together
- Traction (distraction) – joint surfaces pulled apart

Joint Play = the minimal amount of passive motion allowed by gliding of joint surfaces.

- Not an angular motion
- May involve compression/distraction, lateral gliding, anterior/posterior gliding
- Joint play is important to ROM. Without joint play there is joint dysfunction, pain and decreased ROM

Re-establishing joint play is the basis for **mobilization** techniques.
The greatest amount of joint play is in the **open-packed** position **or**, the position where these is the least stability from bony structures and ligaments
Closed pack position is where the joint is the most stable

- Maximum amount of contact between surfaces
- A position that has the maximum stability from bony structures and ligaments; where the surfaces best match each other and little muscle action is needed to maintain the position

Surface Motion relates to the distal end of a body part.

- Joint surfaces are primarily ovoid
- One is convex
- One is concave

If the bone with the <u>convex</u> surface moves on the bone with the <u>concave</u> surface, then the articular (arthrokinematic) surface will move in the **opposite** direction of the distal segment (osteokinematic)

If the bone with the <u>concave</u> surface moves on the bone with the <u>convex</u> surface, the articular (arthrokinematic) surface will move in the **same** direction as the distal segment

Examples:

The shoulder joint: the head of the humerus (convex) moves downward during shoulder flexion and abduction as the arm (distal segment) moves up

The elbow joint: the trochlear notch of the ulna (concave) moves upward during elbow flexion as the forearm moves upward

*** This concept is important when you are doing PROM to increase joint movement and is the <u>key</u> to mobilization techniques***

Another View

Biomechanics is used with many of the interactions with patients: Gait, AROM, PROM, RROM, Transfers and many other treatments. By understanding the way the body moves while using the levers and forces, the systems can be more efficiently used to maximize the muscular efforts of the body. This can make it easier and safer on the patient and on the therapist.

The lever rotates about the axis as a result of force being applied to it to cause its movement against resistance or weight. In the body, the bones represent the bars, the joints are the axes, and the muscles contract to apply the force. The amount of resistance can vary from maximal to minimal. In face, the bones themselves or weight of the body segment may be the only resistance applied. All lever systems have each of these three components in one of three possible arrangements.

The arrangement or location of these three points in relation to one another determine the type of lever and for which kind of motion it is best suited. These points are the axis, the point of force application (usually the muscle insertion), and the point of resistance application (sometimes the center of gravity of the lever and sometimes the location of an external resistance).
When the axis (A) is placed between the force (F) and the resistance or weight (W), a **first-class** lever is produced.
In **second-class** levers the resistance is between the axis and the force.
If the force is placed between the axis and the resistance, a **third-class** lever is created.

First-class Levers

Typical examples of first-class lever are the crowbar, seesaw, and elbow extension. An example of this type of lever in the body is seen with the triceps applying the force to the olecranon (F) in extending the nonsupported forearm (W) at the elbow (A). Other examples of this type of lever may be seen in the body when the agonist and the antagonist muscle groups on either side of a joint axis are contracting simultaneously with the agonist producing force while the antagonist supplies the resistance. A first-class lever is designed basically to produce balanced movements when the axis is midway between the force and the resistance. When the axis is close to the force, the lever produces speed and range of motion (triceps in elbow extension). When the axis is close to the resistance, the lever produces force motion (crowbar).

In applying the principle of levers to the body it is important to remember that the force is applied where the muscle inserts in the bone and not in the belly of the muscle. For example, in elbow extension with the shoulder fully flexed and the arm beside the ear, the triceps applies the force to the olecranon of the ulna behind the axis of the elbow joint. As the applied force exceeds the amount of forearm resistance, the elbow extends.

This type of lever may be changed for a given joint and muscle, depending on whether the body segment is in contact with a surface such as a floor or wall. For example, we have demonstrated the triceps in elbow extension being a first-class lever with the hand free in space where the arm is pushed upward away from the body. By placing the hand in contact with the floor, as in performing a push-up to push the body away from the floor, the same muscle action at this joint now changes the lever to second class because the axis is at the hand and the resistance is the body weight at the elbow joint.

Second-class Levers

This type of lever is designed to produce force meovements, since a lage rsistance can be moved by a relatively small force. An example of a second-class lever is a wheelbarrow. Besides the example given before of the triceps extending the elbow in a push-up another similar example of a second-class lever in the body is plantar flexion of the foot to raise the body up on the toes. The ball of the foot (A) serves as the axis of rotation as the ankle plantar flexors apply force to the calcaneus (F) to lift the resistance of the body at the tibial articulation (W) with the foot. There are relatively few occurrences of second-class levers in the body.

Third-class Levers

With this type of lever the force being applied between the axis and the resistance, are designed to produce speed and range of motion movements. Most of the levers in the hman body are of this type, which require a great deal of force to move even a small resistance. Examples include a screen door operated by a short spring and application of lifting force to a shovel handle with the lower hand while the upper hand on the shovel handle serves as the axis of rotation. The biceps brachii is a typical example in the body. Using the elbow joint (A) as the axis, the biceps applies force at its insertion on the radial tuberosity (F) to rotate the forearm up, with its center of gravity (W) serving as the point of resistance application.

The brachialis is an example of true third-class leverage. It pulls on the ulna just below the elbow, and since the ulna cannot rotate, the pull is direct and true. The biceps brachii, on the other hand, supinates the forearm as it flexes, so that the third-class leverage applies to flexion only.

Other examples include the hamstrings contracting to flex the leg at the knee while in a standing position and using the iliopsoas to flex the thigh at the hip.

Relationship of the length of lever arms

The **resistance arm** is the distance between the axis and the point of resistance application.
The distance between the axis and the point of force application is known as the **force arm**.
There is an inverse relationship between force and the force arm just as there is between resistance and the resistance arm. The longer the force arm, the less force required to move the lever if the resistance and resistance arm remain constant. In addition, if the force and force arm remain constant, a greater resistance may be moved by shortening the resistance arm.

There is also a proportional relationship between the force components and the resistance components. For movement to occur when either of the resistance components increase, there must be an increase in one or both of the force components. Even slight variations in the location of the force and resistance are important in determining the effective force of the muscle. Decreasing the amount of resistance can decrease the amount of force needed to move the lever.

The system of leverage in the human body is built for speed and range of movement at the expense of force. Short force arms and long resistance arms require great muscular strength to produce movement. In the forearm, the attachments of the biceps and triceps muscles clearly illustrate this point, since the force arm of the biceps is 1 to 2 inches and that of the triceps less than one inch. Many other similar examples are found all over the body. From a practical point of view, this means that the muscular system should be strong to supply the necessary force for body movements, especially in strenuous activity.

Most human activity, and especially strenuous activity, involves several levers working together. As with throwing a ball, levers in the shoulder, elbow, wrist, hand, and lower extremities combine to propel the ball. It almost assumes the effect of one long lever from hands to feet. The longer the lever, the more effective it is in imparting velocity.

Laws of Motion

There are basically two types of motion: linear and angular. Linear is also referred to as translatory motion, is motion along a line. If the motion is along a straight line, it is rectilinear motion. If it moves along a curved line its known as curvilinear motion. Angular motion involves rotation around an axis. In the human body the axis of rotation is provided by the various joints. In a sense, these two types of motion are related, since angular motion of the joints can produce the linear motion of walking. Newton's Laws explain all the characteristics of motion and are fundamental to understanding human movement.

Law of Inertia
A body in motion tends to remain in motion at the same speed in a straight line; a body at rest tends to remain at rest unless acted on by a force
Inertia may be described as the resistance to action or change. The resistance to acceleration or deceleration. It is the tendency for the current state of motion to be maintained, regardless of whether the body segment is moving at a particular velocity or is motionless.
Muscles produce the force necessary to start, stop, accelerate, decelerate or change motion. To overcome inertia, a force is needed. Since force is required to change inertia, it is obvious that any activity that is carried out at a steady pace in a consistent direction will conserve energy, and any irregularly paced or directed activity will be very costly to energy reserves.
Law of Acceleration
A change in the acceleration of a body occurs in the same direction as the force that caused it. The change in acceleration is directly proportional to the force causing it and inversely proportional to the mass of the body.
Acceleration is the rate of change in velocity. To attain speed in moving the body, a strong muscular force is generally necessary (weight). Weight or, mass (gravity) affects the speed and

acceleration in physical movement. It requires a much greater force from the muscles to accelerate a 230-pound man than it does a 130-pound man to the same running speed. The force to walk at slower speed is less than the force required to walk fast.

Law of Reaction

For every action there is an opposite and equal reaction

As we place force on a supporting surface by walking over it, the surface provides an equal resistance back in the opposite direction to the soles of our feet. It is easier to run on the road than in sand because of the difference in the reactions of the two surfaces. The road resists the force and the reaction drives the body forward. The sand dissipates the force and the reaction force is reduced therefore reducing the forward motion.

Balance, Equilibrium, and Stability

Balance is the ability to control equilibrium, either static or dynamic. With human movement, equilibrium refers to a state of zero acceleration where there is no change in the speed or direction of the body. When at rest and motionless the body is at static equilibrium. Dynamic equilibrium occurs when all the applied and inertial forces acting on the moving body are in balance, resulting in movement with unchanging speed or direction. Stability is the resistance to a change in the body's acceleration or more appropriately the resistance to a disturbance of the body's equilibrium. Stability may be enhanced by determining the body's center of gravity (COG) and changing it appropriately.

Balance is important for the resting body as well as a body in motion. In order to enhance equilibrium, maximize stability and achieve balance:

- The COG falls within the base of support (BOS)
- The larger the BOS, the greater the balance
- The greater the weight, the greater the balance
- Stability can be improved by placing the COG nearer the side of BOS expected to receive a force
- Equilibrium increased by increasing the friction between the body and the surfaces it contacts
- Rotation about an axis aids balance (moving bike easier to balance than stationary one)

Balance and its components of equilibrium and stability are essential in all movements. They are all affected by the constant force of gravity as well as by inertia. Walking is an activity in which a person throws the body in and out of balance with each step. Running inertia as high, the individual has to lower the COG to maintain balance when stopping or changing direction. Jumping activities attempt to raise the COG as high a possible. Your patient's balance, equilibrium and stability can be greatly affected by paralysis, weakness, pain and the many other physical impairments seen in physical therapy. It is essential to keep in mind the many factors that can make movements easier or more difficult depending on the goal of the treatment.

Credit to:
Thompson, C.W., & Floyd, R.T. (1994). Manual of Structural Kinesiology