Lesson1 - Biomechanical principles

This curriculum has been made at the University of Szeged, and supported by the European Union. Project identity number: EFOP-3.4.3-16-2016-00014.

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

Biomechanics is the study of how the systems and structures of biological organisms react to various forces and external stimuli.

In humans, biomechanics often refers to the study of how the skeletal and musculature systems work under different conditions.

Please now watch the following video:

https://www.youtube.com/watch?v=RgUNSxQfiSs&t=5s

Biomechanics provides the mechanical basis of the human movement analysis that helps the physiotherapist to build up the correct and effective therapeutic plan. Biomechanics can play a crucial role in both injury prevention as well as performance enhancement. Furthermore, biomechanics of the human musculoskeletal system contains the mechanical properties and behavior of the human body tissues as well as bone, cartilage, tendon, ligament, peripheral nerve and skeletal muscle, based on their composition and structure (8).

The biomechanics of human musculoskeletal system is one of the sub-disciplines of the study of human movement (kinesiology).
Biomechanics uses the principles of mechanics. See the figure 1 below for **the branches of the classical mechanics** and the meanings of this areas (4).

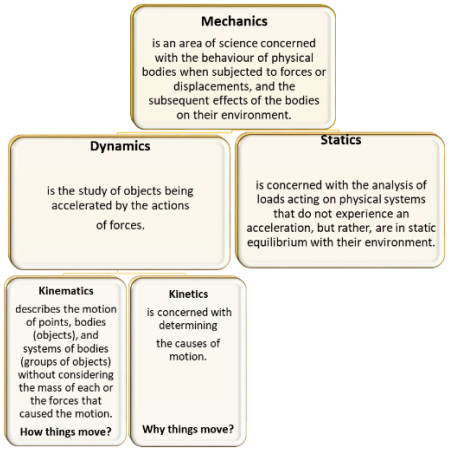

Fig. 1 The branches of the classical mechanics.

Scientific research of physiotherapy regularly uses biomechanical approach to investigate a functional problem, based on applications of mechanical principles in solving specific problems in the human body.

Basic definitions and principles of the biomechanics

Anthropometry involves the systematic measurement of the physical properties of the human body. When we complete a biomechanical analysis, to fully assess the status of the human body, we need to utilize various anthropometric measurements, which are systematic measurements of the size, shape, weight, and composition of the human body. See the figure 2 below for more examples.

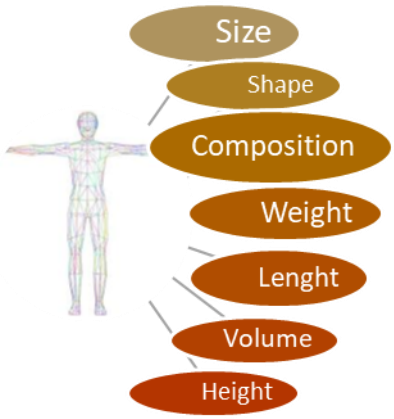

Fig. 2 Anthropometric parameters of the human body.

Analysis of the human movements may apply qualitative or quantitative descriptions and both aspects play important roles in the biomechanical investigations.

Qualitative analysis refers to a method of the description of quality without the use of numbers (2). It is may be general or detailed. For example, we may note that our subject sitting down slowly, or we may register additional details, as the movement appears to be leaning to the right, using armrest etc.

Quantitative analysis involves numeric description of the characterization of the movements (2). In this regard, we may notice e.g. in seconds the time needed to perform the movement.

SZÉCHENYI 2020
MAGYARORSZÁG KORMÁNYA
Európai Unió
Európai Szociális Alap
BEFEKTETÉS A JÖVŐBE

Please watch this video about the qualitative vs quantitative observations:

https://www.youtube.com/watch?v=0g9ugQqv7PA

See the figure 3 below for examples of qualitative and quantitative parameters.

Fig. 3 Examples of qualitative and quantitative parameters.

Please, revive your knowledge about some basic principles of mechanics using the next part of the lesson before going into biomechanics.

Motion

Motion is the action of changing location or position.

The motion may be divided into three basic types

— translational, rotational, and oscillatory.

Translational motion

The motion where the body linearly moves but not rotates from one point to another.

Rotational motion

The motion deals with the rotation of a body about its fixed axis.

Oscillatory (vibratory) motion

Repeated motion in which an object

repeats the same movement over and over.

Please now watch the following video:

https://www.youtube.com/watch?v=Jn7ernc7rI0

SZÉCHENYI 2020
MAGYARORSZÁG KORMÁNYA
Európai Unió
Európai Szociális Alap
BEFEKTETÉS A JÖVŐBE

Periodic motion

A motion that is regular and repeating is referred to as a periodic motion. One complete repetition of the motion is called a cycle. The duration (the time required for one repetition) of each cycle is the **period**.

The **frequency** is defined as the number of cycles per unit time (2).

Newton's laws of mechanics - based on The Feynman lectures on physics (1)

1. A body will maintain its stationary (or moving) state, until and unless a net force is applied to it that changes its state.

   Inertia:

   There is a natural tendency of objects to resist changes in their state of motion. This tendency to resist changes in their state of motion is described as inertia (5).

   Force:

   A force may be thought of as any influence which tends to change the motion of an object. A force has both magnitude and direction,
   making it a vector quantity (6).
   The standard international (SI) unit of force is
   one Newton, which is the amount of force
   required to change the acceleration
   by 1 meter/second^2 of a mass of 1 kg.

   Balanced force:

   When the acting forces are of equal magnitude and in opposite directions, they balance each other.

   Unbalanced force:

   An object is said to be acted upon by an unbalanced force
   only when there is an individual force
   that is not being balanced
   by a force of equal magnitude
   and in the opposite direction (5).

SZÉCHENYI 2020
MAGYARORSZÁG KORMÁNYA
Európai Unió
Európai Szociális Alap
BEFEKTETÉS A JÖVŐBE

Please now watch the following video:
https://www.youtube.com/watch?v=5oi5j11FkQg

2. When a net force 'F' is applied to a body of mass 'm', it changes the body's acceleration by 'a'. These three quantities are related to each other by the equation F = m x a.

Vector:

Vector is a quantity that is fully described by both a magnitude and a direction. Vectors are pictured by arrow-shaped symbols. The magnitude of a vector is its size, and its orientation represents the direction of the vector quantity (5).

We can use the technique of vector composition to calculate the magnitude and the direction of the sum of several forces. Two equivalent techniques exist for vector composition. We can add vectors in a "head-to-tail" manner (Fig. 4) or by using a "parallelogram" method (Fig. 5).

Head-to-tail

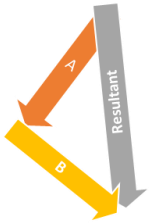

Fig. 4 Vector composition using the "head-to-tail method.

Paralellogram

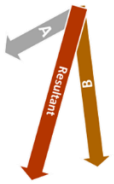

Fig. 5 Vector composition using the "parallelogram" method.

Net force:

The net force is the vector sum of all the forces that act upon an object.

Mass:

Mass is that quantity that is solely dependent upon the inertia of an object. The more inertia that an object has, the more mass that it has. A more massive object has a greater tendency to resist changes in its state of motion.

Acceleration:

Acceleration, in physics, is the rate of change of velocity of an object with respect to time. An object's acceleration is the net result of any and all forces acting on the object (5).

Please now watch the following video:
https://www.youtube.com/watch?v=8YhYqN9BwB4

3. Each force has an equal and opposite reaction force. In every interaction, there is a pair of forces acting on the two interacting objects.

Pair of forces:

The forces are an interaction pair, which is a set of two forces that are in opposite directions, have equal magnitudes and act on different objects.

Please now watch the following video:
https://www.youtube.com/watch?v=TVAxASr0iUY&list=PLmdFyQYShrjcoTLhPodQGjtZKPKIWc3Vp

Mechanical loads on the human musculoskeletal system

Every second of the day, different forces act on our body. They affect the body and its structures at rest and during movement. The effects of these forces on the body are called mechanical loads.

Let us see the basic concepts of mechanical loads related to the human body.

Weight:

It is the attractive force that the Earth exerts on a body, through the gravitational acceleration (acceleration on an object caused by the force of gravitation - conventional standard value is 9.80665 $m/s^2 \approx 10$ m/s2. In physics, weight is the force with which the body presses the support or pulls the suspense.

Density:

Density is a characteristic property of a substance.
The density of a substance is the relationship between the mass of the substance and how much space it takes up (volume).

Center of Mass - Center of Gravity:

The center of mass (COM) is the unique position at which the weighted position vectors of all the parts of a system sum up to zero. If we push on a rigid object at its center of mass, then the object will always move as if it is a point mass. It will not rotate about any axis, regardless of its actual shape.

The center of gravity (COG) is a geometric property of any object, it is point around which a body's weight and mass are equally balanced in all direction, the point at which the entire weight of a body may be thought of as centered so that if supported at this point the body would balance perfectly.

COM tells us about the properties of elements the body is made up of. For mechanics, we consider it to be a point at which you can represent the entire mass to be concentrated at. It the property of element/atomic weight/density (mass = density x volume).
Whereas COG, tells us how and where the gravitational force acts on body. It is a weighted average of the gravitational force acting on each individual element. Surely it will depend on MASS of individual element but also depends on gravitational force 'g' (force = mass x g).

So if the gravitational force is uniform and homogeneous, COM will be same as COG (2).

Simple machines in the human body - Levers

Levers are simple machines consisting of a bar that pivots at a fixed point, called a fulcrum. The three types of levers are categorized according to the position of the effort force and the resistance force relative to the fulcrum.

First class lever - first-class lever has the fulcrum located between the resistance force and the effort force, as you can see on figure 6 below.

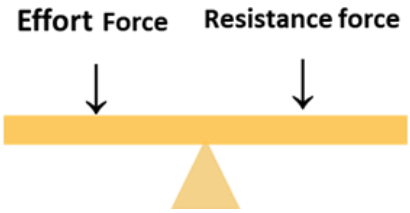

Fig. 6 First class lever.

Examples of a first class lever used in everyday life: the pair of scissors, the plier, the nail clipper, the crowbar. Example of a first class lever in the human body: first-class levers in the human body are rare. One example is the atlantooccipital joint. The resistance force is the weight of the head, the fulcrum is the joint, and the effort force comes from the posterior muscles attaching to the skull, such as the suboccipital muscles (2).

Second class lever - In a second-class lever, the resistance force is located between the fulcrum and the effort force (Fig. 7).

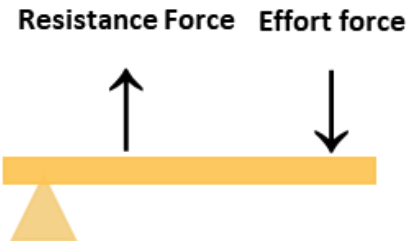

Fig. 7 Second class lever.

Examples of a second class lever used in everyday life: the nutcracker, the stapler, the bottle opener, the wheelbarrow.

Example of a second class lever in the human body: second-class lever is found in the lower leg when someone stands on tiptoes. The fulcrum is formed by the metatarsophalangeal joints, the resistance force is the weight of the body, and the effort force is applied to the calcaneus bone by the gastrocnemius and soleus muscles through the Achilles tendon (2).

Third class lever - In a third-class lever, the effort force is applied between the resistance force and the fulcrum (Fig. 8).

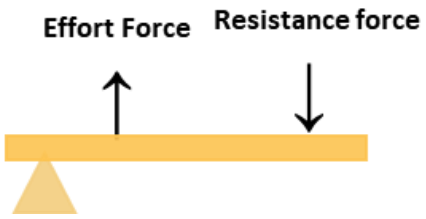

Fig. 8 Third class lever.

Examples of a third class lever used in everyday life: the fishing rod, the tweezer, the shovel, the ice tongs.

Example of a third class lever in the human body: there are numerous third-class levers in the human body, one example is the elbow joint. The joint is the fulcrum. The resistance force is the weight of the forearm, wrist, and hand. The effort force is the biceps muscle when the elbow is flexed (2).

Please now watch the following video:

https://www.youtube.com/watch?v=d1wS_OlJzmI

Forces acting on the human musculoskeletal system

During many activities, the human body experiences several types of forces and loads simultaneously. Different forces affect the body, these can be divided into internal and external forces. The effects of these forces on the body are called mechanical loads. See the examples of internal and external loads on figure 9 below.

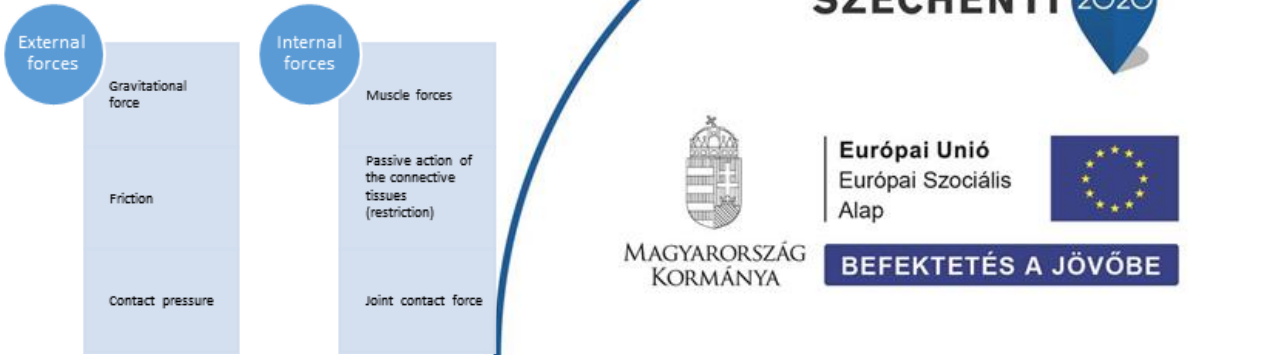

Fig. 9 Examples of internal and external loads on the human body.

Mechanical loads that affect the body include compression, tension, bending, torsion, and shear loads.

Please now watch the following video:

https://www.youtube.com/watch?v=8IN544ZKzmQ

Torque

Torque is the ability of a force to produce rotation around an axis. Therefore, torque can be thought of as a rotary force. The amount of torque on a lever has depends on two things:

1. The amount of force (F) exerted.
2. The distance between the force and the axis of motion, is called the moment arm (r).

$M = r \times F$

The SI units of torque is a Newton-meter (Nm).

Imagine pushing a door to open it. The force of your push (F) causes the door to rotate about its hinges (the pivot point, O). How hard you need to push depends on the distance you are from the hinges (r) (and several other things, but let's ignore them now). The closer you are to the hinges (i.e. the smaller r is), the harder it is to push. This is what happens when you try to open a door on the wrong side. The torque you created on the door is smaller than it would have been if you pushed the correct side (away from its hinges) (7).

Please now watch the following videos:

https://www.youtube.com/watch?v=5Zrphnd_0VI

https://www.youtube.com/watch?v=D116V8rYR1s

Torque in the human body

Muscle torque follows the basic standard.

The basic force comes from a group of muscles,

the axis in the equation is the joint

that is controlled by the muscles.

A third factor in the calculation is

the length of the limb or muscle

SZÉCHENYI 2020
MAGYARORSZÁG KORMÁNYA
Európai Unió
Európai Szociális Alap
BEFEKTETÉS A JÖVŐBE

group involved, which determines the leverage used to apply the force. All these factors come into play when calculating muscle torque (7).

Collagen

Collagen forms the structural basis for much of the extracellular matrix of our tissues, therefore biomechanical properties of the collagen are very important to understand the biomechanical behavior of the musculoskeletal tissues.

Collagen is a macromolecule. Collagen molecules are linked to each other building collagen fibrils. More than 12 types of collagen have been identified. The most common collagen is type I, which can be isolated from any tissue, it can be found especially in dermis, tendon, ligaments and bone (3). The type II collagen is located in articular cartilage, nucleus pulposus of intervertebral discs.
The most common collagen type (I) consists of three polypeptide chains which compose the triple-helical structure of collagen molecule (9).
Collagen molecules have intra- and interchain bonding, or cross-linking, moreover cross-links also formed between collagen molecules which build collagen fibrils.
The cross-linked character of the collagen fibrils gives the strength and tensile stiffness to the connective tissues (8).

SZÉCHENYI 2020
MAGYARORSZÁG KORMÁNYA
Európai Unió
Európai Szociális Alap
BEFEKTETÉS A JÖVŐBE

Study questions:

TRUE/FALSE questions

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

1. During translational motion the body linearly moves and rotates from one point to another. **T or F**
2. A motion that is regular and repeating is referred to as a periodic motion. **T or F**
3. One complete repetition of the periodic motion is called a period. **T or F**
4. In physics, weight is the force with which the body presses the support or pulls the suspense. **T or F**
5. Torque is the ability of a force to produce a linear motion. **T or F**
6. Examples of a first class lever used in everyday life: the nutcracker, the stapler, the bottle opener, the wheelbarrow. **T or F**
7. The center of gravity (COG) is a volumetric property of any object. **T or F**
8. Vector is a quantity that is fully described by both a magnitude and a direction. **T or F**

Multiple-choice questions

Read each question and answer choice carefully and choose the ONE best answer.

1. **Which parameter is a quantitative measure of inertia?**
   - A. Force
   - B. Weight
   - C. Acceleration
   - D. Mass

2. **What is the unit of measurement for muscle torque?**
   - A. Pa
   - B. J
   - C. Nm
   - D. N

SZÉCHENYI 2020
MAGYARORSZÁG KORMÁNYA
Európai Unió
Európai Szociális Alap
BEFEKTETÉS A JÖVŐBE

3. **Which statement about collagen is incorrect?**

   A. Collagen is a macromolecule.
   B. The most common collagen is the type I collagen.
   C. Collagen molecules have intra- and interchain bonding.
   D. The most important mechanical property of the collagen fibers is the elasticity.

References

1. Feynman RP, Leighton RB Sands: The Feynman lectures on physics, vol. I. The New Millennium Edition: Mainly Mechanics, Radiation, and Heat. 2013 California Institute of Technology
2. Hall SJ: Basic biomechanics 2014 McGraw-Hill Education; 7th edition
3. Holzapfel, GA (2001). Biomechanics of soft tissue. The handbook of materials behavior models, 3, 1049-1063.
4. Kibble, Tom W.B.; Berkshire, Frank H. (2004). Classical Mechanics (5th ed.). Imperial College Press. ISBN 978-1-86094-424-6.
5. Kieser J, Taylor M, Carr D: Forensic Biomechanics 2013 John Wiley & Sons
6. Nave CR (2014): "Force". Hyperphysics. Dept. of Physics and Astronomy, Georgia State University.
7. Neumann DA: Kinesiology of the Musculoskeletal System: Foundations for Rehabilitation. 2009 Mosby 2nd Edition
8. Nordin M, Frankel VH: Basic Biomechanics of the Musculoskeletal System. 2014. Wolters Kluwer Health; 4th Edition
9. Shoulders MD, Raines RT. Collagen structure and stability. Annu Rev Biochem. 2009; 78:929-58.