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# Medical physics

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## Force on & in Body

The force controls all motion in the world, the important force in the body is the muscular forces that cause the blood to circulate and the lungs to take in air and other. Physicists recognize four fundamental forces. In order of their relative strength from weakest to strongest. They are:

1) Gravitational force
2) Electrical force
3) Weak nuclear force
4) Strong nuclear force

In medical physics, forces acting **on** and **in** the body are classified based on their origin and the state of the body (static or dynamic). These forces are governed by Newton's Laws and primarily involve gravitational and electrical interactions.

### 1. Fundamental Origins of Force

While four fundamental forces exist, medical physics focuses on two:

- **Gravitational Force:** Responsible for our weight and physiological functions like blood return from the legs. Lack of gravity (e.g., in space) can lead to bone mineral loss.

Our weight is due to the attraction between the earth and our bodies. The medical effects of gravitational force are the formation of varicose veins in the legs as the venous blood travels against the force of gravity on its way to the heart. Varicose veins are veins that have become enlarged and twisted. Varicose veins are most common in the superficial veins of the legs, which are subject to high pressure when standing. Besides being a cosmetic problem, varicose veins can be painful, especially when standing. Another medical effect of gravitational force is **on** the skeleton (on the bones), in some way contributes to healthy bones, if a person becomes weightless, such as in an orbiting satellite, he may lose some bone mineral.

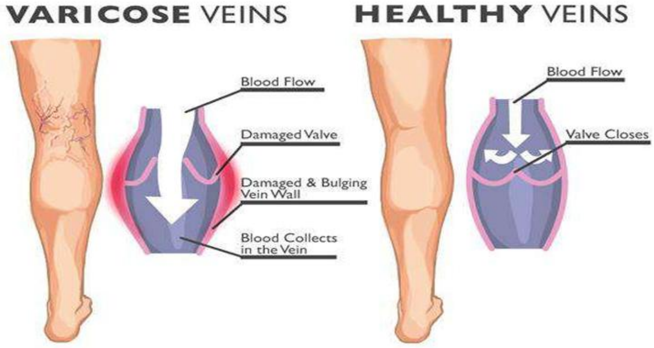



**Fig.(1) shows the cause of varicose veins**

- **Electrical Force:** Crucial at the molecular level, controlling muscle contractions through charge attraction/repulsion and maintaining electrical potential across cell membranes.

This force is more complicated than gravity since it involves attractive and repulsive forces between static electrical charges as well as magnetic produced by moving electrical charges (electric currents). The electrical forces are immense compared to gravitational force, for example the electrical force between an electron (e-) and a proton (P+) in hydrogen atom is about 1039 times greater than the gravitational force between them, as shows in figure (2).

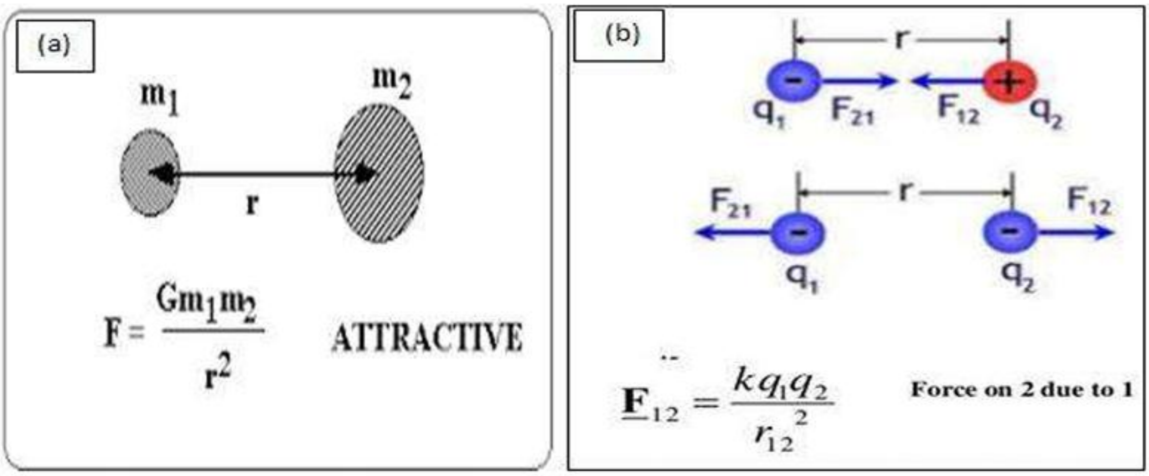



**Fig.(2) Represents (a) Gravitational force, and (b) Electrical force.**

**One life process that appears to be electrically controlled is bone growth.** Bone contain collagen which behave like n-type semiconductor (i.e. conduct current by negative charge), while mineral crystal of the bone (apatite) close to the collagen (as illustrated in figure-3) behave as p-type (i.e. conduct current by positive charge), at this junction the current flows easily from p-type to n-type that induced and control bone growth.

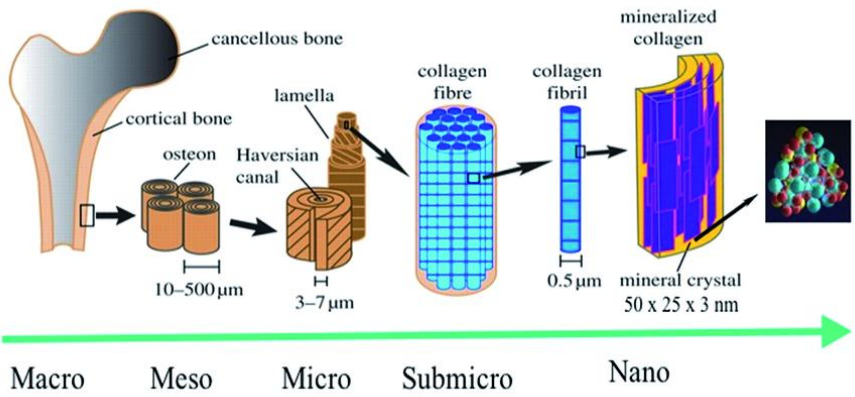
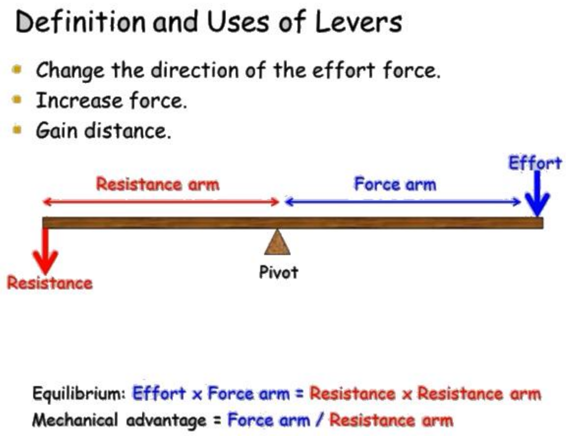



**Fig.3 : Hierarchical structure of bone at various size scales.**

## 2. Forces "On" the Body (Statics & Dynamics)

- **Static Forces:** When the body is in equilibrium, the sum of all forces and torques must be zero.
  - **Lever Systems:** Most muscles and bones act as levers. For example, the **biceps** acting on the forearm is a third-class lever where the muscle must often exert a force significantly larger (e.g., 7.5 times) than the weight being lifted.

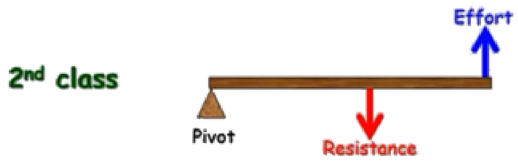



<u>**First-Class Lever**</u>

Arrangement: Effort – Fulcrum – Load
Function: Changes the direction of force.
Example in the body: Head and neck system.

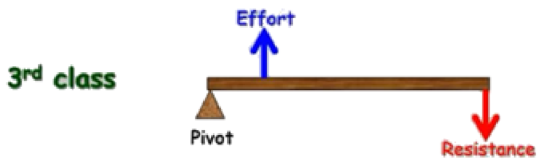

<u>**Second-Class Lever**</u>

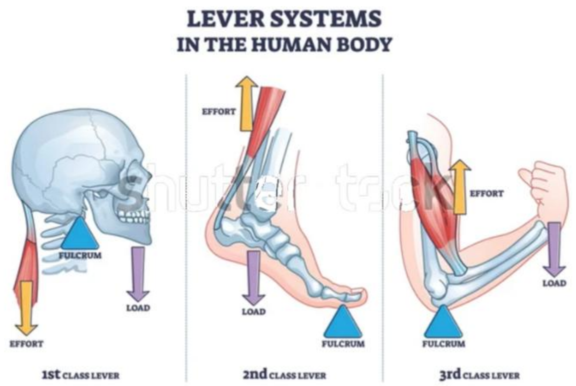
Arrangement: Fulcrum – Load – Effort
Function: Provides the greatest mechanical advantage (less effort needed).
Example in the body: Standing on tiptoes.




<u>**Third-Class Lever**</u>

Arrangement: Fulcrum – Effort – Load
Function: Increases speed and range of motion, not force.
Example in the body: Forearm lifting an object using the biceps muscle.



- **Dynamic Forces:** These occur when the body is accelerating

$$F = ma$$

The types of forces on the body I. **Statics**, when the body in equilibrium. II. **Dynamics**, when the body is accelerated. III. **Friction** is involved in both statics and dynamics.

### 3. Forces "In" the Body

**1- Static friction Fs.**

The effective force between surfaces that are at rest with respect to one another.

$$F_s = \mu_s N$$

$\mu_s$= coefficient of static friction (used to find the max. resistance force on an object can exert before its starters to move). N= normal force.
Fs= the horizontal reaction component supplied by frictional forces.

When the foot touches the ground, Fs between the heel and surface prevent the foot from slipping forward fig(a). while when it leaves the ground, Fs prevents the toe from slipping backward fig (b).



**2- Kinetic (sliding) friction ($F_k$): -**

The effective force between surfaces that are in relative motion.

$$F_k = \mu_k N$$

Where:-

$F_k \propto N$

$\mu_k$= coefficient of kinetic friction, the greater the coefficient values and the greater the friction force.

$\mu_s > \mu_k$ = (Force to start the motion is a greater than needed to keep it moving).

**Measurement of Fs: -**

The value of the horizontal force component (Fs) of the heel as it strikes the ground when a person is walking is given by: Fs ≈ 0.15W, W=mg (persons weight). When μ less than 0.15, his foot slips.

The force on the body under the constant acceleration or deceleration of one dimensional motion. The Newton's second law, force equal mass times acceleration, can be written without vector notation as:- F=ma where: F= The force (N, dyne) , m= The mass (Kg, g) , a= acceleration (cm /sec$^2$ or m/ sec$^2$) Also F = The change of momentum (p) over a short interval of time (t).

$$\therefore F = \frac{\Delta p}{\Delta t}$$

Δp= change of momentum =Δ(mυ) , m=mass, υ= velocity of this mass

Δt = interval of time

**Example:** 60gm of blood is given upward of about 0.1sec in a velocity nearly 1m/s, the force is equal to:

$$F = \frac{m\Delta v}{\Delta t} = \frac{(60 \times 10^{-3}) \times 1}{0.1} = 0.6N$$

**3-Frictional Forces:** Essential for internal and external movement.

- **Lubrication:** Synovial fluid in joints, saliva in the mouth, and fluid around the heart and lungs act as lubricants to minimize friction.
- **Joint Health:** Healthy joints have very low friction; however, diseases like arthritis significantly increase these forces, leading to pain and damage.

**The centrifuge**: it is especially useful for separating in a liquid, the centrifuge works using the sedimentation principle. It speeds up the sedimentation that occur at a slow rate under the force of gravity. In a laboratory centrifuge that uses sample tubes, the acceleration causes denser particles to settle to the bottom of the tube, while low-density substances rise to the top.

**Stoke law**

Let us consider sedimentation of small spherical objects of density ρ in a solution of density $\rho_o$ in a gravitational field g. We know that falling objects reach a maximum terminal velocity V due to viscosity of liquid effects. Stoke has shown that for a spherical object of radius a, the retarding force $F_d$ and terminal velocity V are related by;

**$F_d = 6\pi a\eta V$** **stoke law**

Where:

Fd=retarding force
V= terminal velocity
η= dynamic viscosity of liquid
Stokes' law makes the following assumptions for the behavior of a particle in a fluid: when the particle is moving at a constant speed, the **$F_d$ is an equilibrium** with the difference between the **downward (Fg)** and the **upward buoyant force ($F_B$)**

$$F_d = F_g - F_B$$

$$F_g = \frac{4}{3}\pi a^3 \rho g$$

$$F_g = \frac{4}{3}\pi a^3 \rho_0 g$$

**3. Nuclear forces**

In medical physics, nuclear forces are the fundamental interactions that govern the behavior of atomic nuclei used for diagnosis and therapy. While the **Strong Nuclear Force** maintains the stability of isotopes used in imaging, the **Weak Nuclear Force** is responsible for the radioactive decay processes essential for nuclear medicine

**1. Types of Nuclear Forces in Medical Physics**

- **Strong Nuclear Force (Strong Interaction):** The most powerful fundamental force, it acts as the "glue" holding protons and neutrons together within the nucleus. It must overcome the significant electromagnetic repulsion between positively charged protons to maintain a stable or metastable nucleus.

- **Weak Nuclear Force (Weak Interaction):** Responsible for specific types of radioactive decay, such as **beta decay**. In medical imaging, this force facilitates the emission of particles (like positrons or electrons) from unstable isotopes, which are then detected to create medical images.

- Natural Radioactivity: Small amounts of radioactive isotopes, such as Potassium-40 and Carbon-14, naturally occur in your body. These isotopes undergo decay due to the weak nuclear force, but at levels low enough that the body's natural repair mechanisms can fix the resulting chemical damage.

**Nuclear Forces "On" the Body (Radiation Effects)**

When people speak of nuclear forces acting "on" the body, they usually refer to the effects of **ionizing radiation** released when these forces are disrupted (such as in a nuclear explosion or medical treatment).

- **Acute Radiation Syndrome (ARS):** High doses of radiation (from disrupted nuclear forces) kill rapidly dividing cells.
    - **Bone Marrow:** The first organ system severely affected, leading to a loss of white blood cells and platelets.
    - **Gastrointestinal Tract:** Damage to intestinal linings causes severe nausea, vomiting, and diarrhea. الجهاز الهضمي: يؤدي تلف بطانات الأمعاء إلى الغثيان الشديد والقيء والإسهال.
- **Molecular Damage:** Radiation provides enough energy to eject electrons from atoms (ionization), breaking the chemical bonds in your **DNA**. If not repaired correctly, this can lead to cell death or mutations that cause **cancer**.
- **Physical Force (Blast):** In a nuclear explosion, the sudden release of nuclear energy creates a supersonic shockwave that can physically rupture eardrums, damage lungs, or dislocate internal organs. في الانفجار النووي، يؤدي الإطلاق المفاجئ للطاقة النووية إلى خلق موجة صدمة تفوق سرعة الصوت يمكنها أن تؤدي إلى تمزق طبلة الأذن، أو إتلاف الرئتين، أو خلع الأعضاء الداخلية

**Clinical Applications**

Medical physicists apply the principles of these forces in several key areas:

**1.PET — Positron Emission Tomography**

**What it does:**

Shows how tissues and organs **function at the molecular level**.

**How it works:**

- A radioactive tracer that emits **positrons** is injected (e.g., FDG). **FDG** stands for **Fluorodeoxyglucose**: it is the **most commonly used radiotracer in PET imaging**.
- The positron collides with an electron → produces **two gamma rays** in opposite directions.
- Detectors capture these rays and reconstruct a **3D functional image**.

**Main uses:**

- Oncology: tumor detection, treatment response
- Neurology: brain metabolism, epilepsy, dementia استقلاب الدماغ، الصرع، الخرف
- Cardiology: myocardial viabilityقابلية عضلة القلب للحياة

**2.SPECT — Single Photon Emission Computed Tomography**

**What it does:**
Provides **3D functional images** based on blood flow and organ activity.

**How it works:**

- A tracer that emits **single gamma photons** is injected (e.g., Tc-99m).

  **What is Tc-99m?**
  Technetium-99m is a radioactive isotope that:
  Emits gamma rays only (no beta particles)
  Has a short half-life ≈ 6 hours
  Produces low radiation dose to the patient
  Gives excellent image quality

- A **gamma camera** rotates around the patient to collect data.
- A computer reconstructs cross-sectional images.

**Main uses:**

- Cardiology: myocardial perfusion imagingتصوير تدفق الدم إلى عضلة القلب
- Bone scans
- Thyroid, kidney, and brain studies