Al-Mustaqbal University / College of Engineering
Department (Prosthetic and orthotic Engineering)
Class (3ʳᵈ)
Subject (Biomechanics I) / Code (UOMU0103053)
Lecturer (Assist Prof Dr. Firas Thair Al-Maliky)
1ˢᵗ/2ⁿᵈ term – Lecture No. & Lecture Name (Lecture 1: Introduction to Biomechanics)

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Foundations of Biomechanics and Methods of Human Movement Analysis

1. Introduction

Biomechanics is one of the fundamental disciplines within kinesiology, bridging the gap between the biological sciences and mechanical physics. It provides a scientific basis for understanding the forces that act on the human body and the effects these forces produce. Whether the goal is to enhance athletic performance, prevent injuries, or improve rehabilitation outcomes, biomechanics provides the analytical framework through which human movement can be studied, measured, and optimized.

This lecture introduces the key terms and relationships among **biomechanics, statics, dynamics, kinematics, and kinetics**, and distinguishes between **qualitative and quantitative** approaches used in human movement analysis.

2. Definition and Scope of Biomechanics

The term **biomechanics** is derived from the Greek roots *bio* (life) and *mechanics* (study of forces and motion).

Biomechanics examines how internal forces (such as muscle contractions, ligament tension, or joint reaction forces) and external forces (such as gravity, friction, and ground reaction forces) influence motion, stability, and deformation of biological tissues.

Biomechanics encompasses multiple levels of analysis:

- **Macroscopic (gross human movement)**: gait, posture, lifting, jumping, running.

- **Microscopic (tissue and cellular mechanics)**: bone deformation, muscle fiber tension, blood flow.

- **Applied fields**: sports biomechanics, clinical biomechanics, rehabilitation, ergonomics, and occupational safety.

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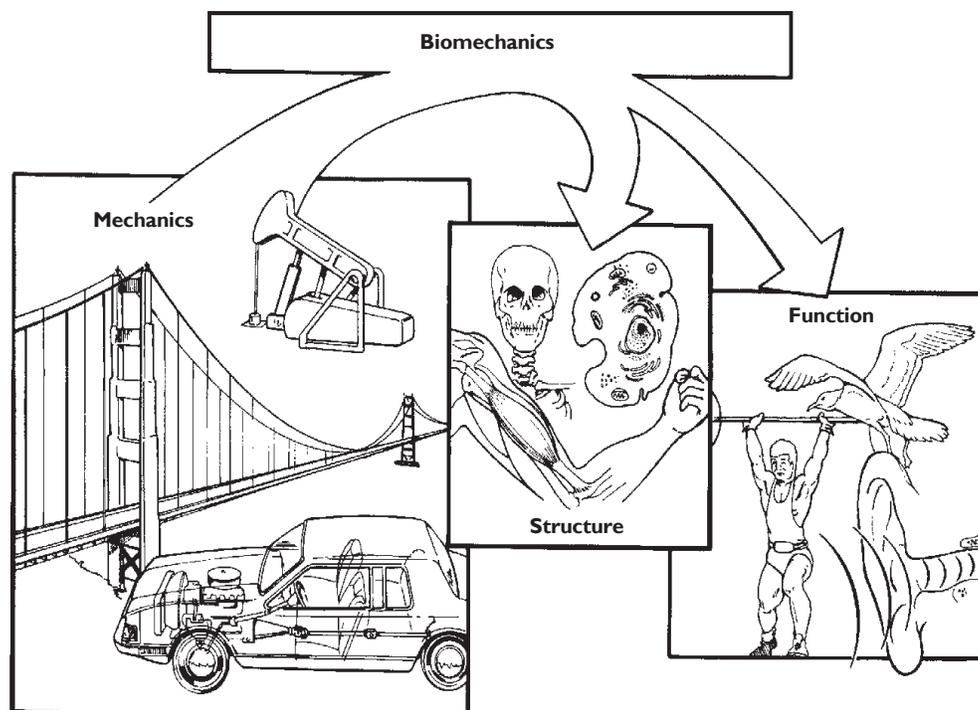
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Biomechanics apply tools and principles from:

- **Physics** – especially Newtonian mechanics and fluid dynamics.

- **Engineering** – especially statics, dynamics, and materials science.

- **Anatomy and physiology** – for understanding biological structure and muscle function.

3. Mechanics and Its Subdivisions

Mechanics is the branch of physics concerned with describing and explaining motion and the effects of forces.

Biomechanics use the tools of mechanics, the branch of physics involving analysis of the actions of forces, to study the anatomical and functional aspects of living organisms (Figure 1).

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Mechanics is divided into two primary branches: statics and dynamics.

Statics refers to the analysis of systems that are in a state of equilibrium—either completely at rest or moving at constant velocity (that is, zero acceleration).

In statics:

- The sum of all forces and moments acting on a body is zero:

$$\Sigma F = 0 \quad \Sigma M = 0$$

Examples in human movement:

- A gymnast holding a handstand position.

- A person maintaining upright posture without swaying.

- An occupational therapist analyzing spinal loading during static lifting postures.

Statical analysis helps understand **joint stability**, **balance**, and **postural control**, and is essential in **ergonomic design** and **orthotic alignment**.

Dynamics is the study of systems in motion where **acceleration** is present. It examines bodies that are acted upon by unbalanced forces.

Dynamics is further divided into:

1. **Kinematics** – describing motion (without regard to forces).

2. **Kinetics** – explaining the causes of motion (forces and torques).

Dynamic analysis allows biomechanics to describe **how** and **why** movement occurs.

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4. Kinematics

4.1 Definition

Kinematics is the branch of mechanics that describes the *geometry of motion* in terms of **displacement**, **velocity**, and **acceleration**—without considering the forces that cause these changes.

Mathematically, kinematic quantities include:

- **Linear displacement (s)** – change in position.

- **Velocity ($v = \Delta s/\Delta t$)** – rate of change of displacement.

- **Acceleration ($a = \Delta v/\Delta t$)** – rate of change of velocity.

4.2 Types of Motion

1. **Linear (translational) motion** – All parts of a body move in the same direction and distance (e.g., a sprinter running straight ahead).

2. **Angular (rotational) motion** – Motion around an axis (e.g., rotation of the forearm around the elbow joint).

3. **General motion** – Combination of linear and angular motion (e.g., running involves limb rotations producing linear body translation).

4.3 Applications

Kinematic analysis is central in:

- **Sports performance**: optimizing stride length, release angle, or limb sequencing.

- **Rehabilitation**: quantifying gait abnormalities or joint range of motion.

- **Clinical diagnostics**: detecting movement asymmetries or motor control disorders.

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5. Kinetics

5.1 Definition

Kinetics deals with the *forces* and *torques* that cause or result from motion. Force is a vector quantity capable of changing a body's motion or shape.

Basic kinetic quantities include:

- **Force (F)** = mass × acceleration (Newton's Second Law).

- **Torque (T)** = Force × perpendicular distance from the axis of rotation.

- **Impulse (I)** = Force × time (influences momentum changes).

5.2 Internal and External Forces

- **Internal forces**: generated within the body (muscle contractions, joint reaction forces, ligament tension).

- **External forces**: act on the body from the environment (gravity, friction, ground reaction, air resistance).

5.3 Applications

Kinetic analysis helps determine:

- How much force a muscle must generate to lift a weight.

- The joint loads experienced during walking or jumping.

- The mechanical stress on bones and tendons during repetitive tasks.

Biomechanical modeling and instrumentation—such as **force plates**, **electromyography (EMG)**, and **motion capture systems**—allow researchers to measure and analyze these forces quantitatively (Figure 2)

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(a)   (b)

Fig (2) The experimental setup. (a) The force-plate-instrumented treadmill with the motion tracking system recorded movements of lower limbs and (b)

6. Qualitative vs. Quantitative Analysis of Human Movement

6.1 Qualitative Analysis

- **Definition:** Non-numeric description of movement quality, technique, or coordination.

- **Purpose:** To evaluate performance and identify movement errors.

- **Method:** Observation by experts (coaches, therapists).

- **Example:** "The athlete's arm lags behind during the throwing motion," or "The patient exhibits excessive hip drop during gait."

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Advantages:

- Immediate feedback.

- Requires minimal equipment.

- Useful for coaching and clinical decision-making.

Limitations:

- Subjective; depends on observer skill and experience.

- Lacks precise measurement.

6.2 Quantitative Analysis

- **Definition:** Numeric measurement of movement variables using scientific instruments.

- **Purpose:** To provide objective, measurable data on motion and forces.

- **Techniques:**

  - High-speed video or motion capture (for kinematics),

  - Force platforms (for kinetics),

  - EMG for muscle activation.

Examples:

- Hip flexion angle during gait = 32°.

- Peak ground reaction force = 2.8 × body weight.

- Joint torque at knee = 85 Nm.

Advantages:

- Objective and reproducible.

- Enables statistical and biomechanical modeling.

- Useful for research and advanced diagnostics.

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Limitations:

- Requires equipment and time.

- May not always be practical in the field.

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