Biomechanics

Agenda

- Biomechanics
- Musculoskeletal system
- Musculoskeletal disorders
- Biomechanical modeling
Biomechanics

- *Biomechanics* uses the laws of physics and engineering mechanics to
  - describe the motions of various body segments (kinematics)
  - understand the effects of forces and moments acting on the body (kinetics)
Foci of Biomechanics

- **Exercise and sport biomechanics**
  - Improving athletic performance, reduction of athletic injuries

- **Orthopedic biomechanics**
  - Artificial limbs, joints, and orthoses to improve functional movement capacity
  - Study of natural and artificial biological tissues
  - Rehabilitation

- **Occupational Biomechanics**
  - Ergonomics and Human Factors focus
  - Studies the physical interaction of workers with their tools, machines, and materials
  - Reduction of workplace injuries
  - Enhance the workers’ performance
Occupational Biomechanics

Definition

- “A science concerned with the mechanical behavior of the musculoskeletal system and component tissues when physical work is performed. As such, it seeks to provide an understanding of the physics of manual activities in industry” (Chaffin, 1999)
Biomechanics can be divided into

- Statics
  - Study of systems that are in a constant state of motion, whether at rest with no motion or moving at a constant velocity without acceleration
  - Statics involves all forces acting on the body being in balance resulting in the body being in equilibrium.
    - Equilibrium is a balanced state in which there is no acceleration.

- Dynamics
  - Study of systems in motion with acceleration
  - A system in acceleration is unbalanced due to unequal forces acting on the body
Biomechanics

- Biomechanical description of human body
  - Kinematics
    - Description of motion
      - Displacement
      - Velocity
      - Acceleration
      - Space factors of a system’s motion
  - Kinetics
    - Description of exertion associated with the motion of a body
      - Force
      - Moment
      - Mass
      - At different joints and segments
Biomechanics

- Statics
  - constant state of motion
    - Kinetics of motionless systems
    - Kinematics
    - Kinetics

- Dynamics
  - acceleration present
    - Kinematics
    - Kinetics
Musculoskeletal System

- To learn **basic anatomy** and **properties of various components** of human musculoskeletal system
- To understand how the **functions and properties of soft tissues** influence human **physical capacity and limitations**
- To understand how muscles **contract**
Musculoskeletal System

- Organ system that provides human to physically move using the muscles and skeletal system
- Muscular system + Skeletal system
- Bones are connected each other at the **joints** by **ligaments** or **cartilage**.
- Skeletal muscle is attached to **bones** by **tendons**.
Components

- Connective tissues
  - Bones
  - Ligaments
  - Tendons
  - Fascia
  - Cartilage

- Muscles
- Joints
- Nerves
Connective Tissues

**Function**
- Provide support
- Transmit forces
- Maintain the structural integrity of body parts
Connective Tissues

Two types of fibers

- **Collagen fibers**: high tensile strength (45 to 125 N/m²), resistant to deformation, close to mild steel!
- **Elastic fibers**: low tensile strength

**Notes**: Proportion of the two types influence mechanical properties of connective tissues

**Tensile strength** is a measurement of the **force required to pull something** such as rope, wire, or a structural beam to the point where it breaks.
Ligaments and Tendons

❖ Function

❖ Ligaments
  o connect bone to bone
  o provide stability at joints
  o guide joint motion and prevent excessive motion

❖ Tendons
  o attach muscle to bone
  o transmit tensile loads from muscle to bone, producing joint motion

http://www.aviva.co.uk/health-insurance/home-of-health/medical-centre/medical-encyclopedia/entry/musculoskeletal-system-disorders/
Ligaments and Tendons

Structure

- Connective tissues, similar in structure and function.
- Percentage of collagen fibers: Tendons > Ligaments
- Percentage of elastic fibers: Ligaments > Tendons
- Collagen fibers are organized in parallel bundles in tendons, but densely packed in ligaments

Spa → slow
Ligaments and Tendons

- Factors affecting the biomechanical properties of tendons and ligaments
  - Aging: decreased strength during aging.
  - Pregnancy: decreased strength at the end of pregnancy
  - Physical activity increases strength and immobilization decreases the strength
Ligaments and Tendons

- Occupational injury concerns
  - Direct trauma: lacerations, contusions
  - Indirect trauma: overload, overuse
- Tendon strain
  - Stretching or tearing of muscle-tendon units
  - Injury from excessive muscle contraction force
- Ligament sprain
  - Stretching or tearing of ligaments
  - Injury from excessive joint motion

http://www.aviva.co.uk/health-insurance/home-of-health/medical-centre/medical-encyclopedia/entry/musculoskeletal-system-disorders/
Bone

**Function**

- Protect internal organs
- Provide muscle attachment sites
- Provide rigid kinematic links
- Facilitate muscle action and body movement
Bone

- Mechanical Behavior
  - Strength: Compression > Tension > Shear
    - Various loading modes
Major occupational injury concern

- Fracture
  - Types of fracture

![Diagram of bone fractures](image)
Joints

- Joints are formed by two or more bones that are connected by thick tissues.
- The bone ends are covered with cartilage to prevent bone-to-bone contact.

Function
- Provide stability and mobility

Types of Joints
- Fibrous
- Cartilaginous
- Synovial
Joints

- **Types of Joints**
  - Fibrous: bone-to-bone, **immovable** (e.g. skull).

https://infogr.am/joints-1942570831
Joints

- Types of Joints (continued)
  - Cartilaginous: bone-to-bone, slightly movable (e.g. vertebral discs).

https://infogr.am/joints-1942570831
Types of Joints (continued)

- Synovial: indirect connection of bones by a joint capsule, freely movable (e.g. knee, elbow, shoulder).

http://missionarthritis.org/joints.html
Joints

Cartilage

- Function
  - Absorb shock, distribute loads
  - Prevent direct wear on bones by allowing relative movement of opposing joint surfaces with minimal friction

- Structure and Behavior
  - Viscoelastic
  - No nerves and blood vessels
  - Nutrition supplied through diffusion
Synovial Fluid

- Synovial fluid is present in the capsules of all articulated joints

Function

- Lubricates contact surfaces within synovial joints and tendon sheath
- Reduces friction

Work-related concern

- Prolonged static postures (standing or holding objects for long time) with minimal movement can hinder lubrication and nutrition to cartilage
Joints

- Intervertebral disc
  - Between adjacent vertebrae in the vertebral column
  - Function
    - Bears and distributes loads
    - Restrains excessive motion
  - Structure
    - Nucleus pulposus: incompressible fluid in the core
    - Annulus fibrosus: outer covering composed of layers of fibrocartilage.
Skeletal Muscles

Three types of muscle

- **Skeletal muscle (Voluntary muscles)**
  - Connected to bone by tendons
  - Generating movement and maintaining posture

- **Smooth muscle (Involuntary muscles)**
  - Walls of internal organs
  - Not under conscious control

- **Cardiac muscle (Involuntary muscles as well)**
  - Found in heart
  - Not under conscious control
Skeletal Muscles

❖ Function
  ▪ Provide **strength and protection to the skeleton** by distributing loads and absorbing shock
  ▪ Maintain **joint posture** (static work)
  ▪ Control **relative motion of body segments** (dynamic work)

❖ Unique properties
  ▪ Ability to contract
  ▪ Active tissues
Skeletal Muscles

- **Structure**
  - Connective tissues
  - Muscle nerve
  - Muscle fibers
Skeletal Muscles

Structure

- Connective tissues
  - Provide a **pathway for nerves and blood**
Skeletal Muscles

- **Structure**
  - **Muscle Nerve**
    - Individual muscle fiber is innervated by a **motor neuron axon**
Skeletal Muscles

- Muscle fiber
  - Myofibril
    - Sarcomere
      - Consists of thick filaments (myosin) and thin filaments (actin)
      - All sarcomeres contract simultaneously when a muscle fiber contracts.
Skeletal Muscles

- **Motor unit**
  - Functional unit of the muscle.
  - Single motor neuron + innervated muscle fibers
  - When a motor unit is activated, all of its fibers contract.

[https://www.t-nation.com/training/secret-to-motor-unit-recruitment](https://www.t-nation.com/training/secret-to-motor-unit-recruitment)
Skeletal Muscles

- Mechanism of muscle contraction
  - Sliding Filament Model (Huxley, 1974)
  - Interaction and sliding of the filaments relative to each other.
Skeletal Muscles

Terminology

- **Isometric contraction**: Static positions; muscle does not change length (zero velocity)
- **Isotonic contraction**: Dynamic; constant muscle force throughout exertion
  - Concentric contraction: lifting an object
  - Eccentric contraction: lowering an object
- **Isokinetic contraction**: constant velocity exertion
- **Isoinertial contraction**: work against a constant load
Terminology

- **Agonist muscles**: muscles which *exert* the *intended* torque when contracted

- **Antagonist muscles**: muscles which *oppose* the *intended* torque when contracted

- **Synergistic muscles**: muscles which *work together* to produce the intended torque
Musculoskeletal Disorders

Definition

- Intermediate-term (months/years) effects of body activity upon the nerves, muscles, joints, and ligaments.

Approach to Reducing Musculoskeletal Disorders

- Written program
- Employee involvement and training
- Medical management
- Program evaluation
Musculoskeletal Disorders

- Main Occupational Risk Factors
  - Repetition/duration
  - Joint deviation
  - Force
Musculoskeletal Disorders

- Repetition/duration
  - 30 second rule
    - A job is repetitive if the basic cycle time is <30 seconds.
    - https://www.youtube.com/watch?v=DfGs2Y5WJ14
    - https://www.youtube.com/watch?v=v_PHNUmqRAY
  - Short duration: <1 hour/day
  - Moderate duration: 1 – 2 hour/day
  - Long duration: >2 hour/day
  - Self-repairing
    - The more time the better
Musculoskeletal Disorders

✓ Joint Deviation
  ▪ Ideally, joint deviation should be zero.
  ▪ Express in relative as well as absolute terms.
  ▪ Posture affects joint deviation.
  ▪ Minimize torque about the joints.
Musculoskeletal Disorders

- **Work Postures**
  - Muscles create moments about joints to counteract the moments created by *external forces* acting on the body.
  - Work postures can be classified as good or bad by looking at the moments created by the task at each joint:

  \[
  \text{Large Moment} + \text{Static Posture} = \text{INJURY}
  \]
Musculoskeletal Disorders

- **Work Postures**
  - **Neutral Posture:** Posture *where stress to joints, muscles, vertebrae and tissue is the least*
    - Arms at sides
    - Torso, Neck upright
  - Body is **strongest and most at rest** in this posture
Musculoskeletal Disorders

❖ Work Postures

▪ Awkward postures: Non-neutral postures

<table>
<thead>
<tr>
<th>Assessed Postures</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non- Awkward Posture</td>
</tr>
<tr>
<td>Trunk Flexion¹</td>
<td>&lt;20°</td>
</tr>
<tr>
<td>Trunk Lateral Flexion¹</td>
<td>≤20°</td>
</tr>
<tr>
<td>Neck Deviation²</td>
<td>&lt;30°</td>
</tr>
<tr>
<td>Right Shoulder Deviation²</td>
<td>≤60°</td>
</tr>
<tr>
<td>Left Shoulder Deviation²</td>
<td>≤60°</td>
</tr>
</tbody>
</table>

¹ Keyserling et al. 1992
² Rice 1998
Musculoskeletal Disorders

- **Force**
  - Ideally, internal force on the joint should be low.
  - Reduce *magnitude of external force, moment arm, and duration.*
Musculoskeletal Disorders

- Vibration
  - Interferes with blood flow.
  - Causes mechanical trauma to body.
  - Handtool vibration increases grip forces.
Musculoskeletal Disorders

- Other Risk Factors
  - Exposure to cold temperatures
  - Trauma outside of work
  - Anatomical or physiological imperfections
  - Muscle tension from psychosocial factors
Musculoskeletal Disorders

- Hand/Wrist Problems
  - In the tendons (e.g., tendonitis)
  - In the nerves (e.g., carpal tunnel syndrome)
  - In the neurovascular system (e.g., thoracic outlet syndrome)
  - Example
    - Carpal tunnel syndrome:
    - The median nerve through the wrist tunnel that carries tendons from the arm to the hand becomes pinched.
Musculoskeletal Disorders

Hand/Wrist Problems

- Occupational risk factors
  - High force
    - High grip force, pinch grips
  - Mechanical stress/trauma
    - Using hand as a hammer
  - Awkward postures
  - Repetition
  - Dynamics/motion
  - Vibration
  - Low environment temperature
Musculoskeletal Disorders

- **Hand/Wrist Problems**
  - **Carpal Tunnel Syndrome**
    - **Symptoms**
      - Burning, tingling, itching numbness in the palm and the fingers
    - **Causes**
      - Congenital
      - Traumatic (swelling)
      - Repetitive use of vibrating hand tools,
      - Repeated and/or forced hand movements
      - Excessive deviation (ulna/radial, extension/flexion)
Musculoskeletal Disorders

- Hand/Wrist Problems
  - Vibration White Finger (VWF)
    - Reflex construction of capillaries and blood vessels due to vibration
    - Fingers become white and lose sensitivity