Forces Acting on Humans

Objectives:
• Learn what the most common types of forces that act on humans are
• Understand the important characteristics of these forces

Questions to Think About
• Why does it take more force to cause an object to start sliding than it does to keep it sliding?
• Why might it help a football lineman to push up as well as forward during a block?
• How does the resistance applied by a Theraband differ from the resistance during a pool workout?
• When stretching a muscle, why does it help to apply a force for a long period?
• Why is a ligament more likely to tear during rapid ankle inversion than during slow inversion?
• When spotting a bench press, why do you assist more on the way up than on the way down?

Types of Forces

Contact Forces
• Forces pushing against or pulling on an object as the result of physical contact with another object.
• Contact forces in biomechanics include:
  – Forces applied from outside the body
  – Forces originating inside the body
• In general, there will be a contact force anywhere that two objects touch

Non-Contact Forces
• Forces that do not result from direct physical contact (e.g. weight)

Forces from Outside the Body

• Resistive: normal force resulting from pressure against a rigid body
• Friction: acts over area of contact between two surfaces; opposes sliding between surfaces
• Elastic: produced by spring-like objects; elastic force is proportional to deformation
• Viscous: produced by fluids; viscous force is proportional to velocity
• Viscoelastic: combines behavior of a spring and a fluid; force depends on deformation, rate of deformation, and time
• Active: forces generated from added energy
"Resistive" Normal Forces
- If rigid object is resting on or sliding across a surface, the net force normal to the surface will equal zero.
- Reaction force acting normal to a surface is equal in magnitude, opposite in direction to sum of all other normal forces on the object.

\[ R = -\sum F_{\text{normal}} \]

Friction
- Shear force acting over the area of contact between two bodies, and in a direction that opposes motion.
- Two types of friction:
  - Static Friction: applies when the objects are not sliding relative to each other.
  - Kinetic Friction: applies when the objects are sliding relative to each other.

Static Friction (Object Not Sliding)
- Static friction equal in magnitude, opposite in direction to sum of all other shear forces.
- There exists a maximum static friction force:
  \[ F_{\text{friction}} \leq \mu_s R \]
  where:
  - \( \mu_s \): coefficient of static friction (property of the two materials in contact; \( 0 \leq \mu_s \leq 1 \))
  - \( R \): normal force between surfaces.
- If sum of other shear forces exceeds maximum static friction force, object will begin to slide.

Kinetic Friction (Object Sliding)
- Magnitude of kinetic friction force proportional to the normal force between two surfaces:
  \[ F_{\text{friction}} = \mu_k R \]
  where:
  - \( \mu_k \): coefficient of kinetic friction (property of the two materials in contact; \( 0 \leq \mu_k < \mu_s \))
  - \( R \): normal force between surfaces.
- Direction of kinetic friction force always opposite to direction of sliding.
Static & Kinetic Friction

- As shear force on stationary object increases, friction force increases until static limit reached.
- If limit exceeded, object moves and kinetic friction applies until object stops moving

Example Problem #1

A 19 kg curling stone is sliding down the ice at 3 m/s. The coefficient of static friction between the ice and stone is 0.1 and the coefficient of kinetic friction is 0.05.

What is the acceleration of the stone?
How far will the stone travel before coming to rest?

Once the stone comes to rest, what shear force must be applied to start it moving again?

Elastic & Viscous Forces

Elastic Force
- Produced by spring-like objects
- Elastic force is proportional to deformation

Viscous Force
- Produced by fluids
- Viscous force is proportional to velocity

Viscoelastic Forces

- Most body tissues are viscoelastic
- Force produced by stretch increases with rate of stretch
- Under a constant applied force, the tissue will creep (i.e. slowly get longer or shorter)
Ground Reaction Forces

- The reaction forces that result from pushing against the ground or other supporting surface
- Ground reaction force resolved into 3 components:
  - Vertical (normal) force
  - Anteroposterior shear force
  - Mediolateral shear force

Forces from Inside the Body

Forces of primary interest:

- **Joint Contact Force**: compressive force resulting from bone-on-bone contact
- **Musculotendon Force**: active and passive forces generated by a muscle-tendon unit
- **Ligament Force**: passive force produced by stretching of a ligament
- **Intervertebral Force**: force acting on the disk between spinal vertebrae
- **Resultant Joint Force**: net force acting across a joint (due to all sources)

Joint Contact Force

- Results from contact of two adjacent articular surfaces (i.e. bone-on-bone contact)
- Joint contact forces always compressive (directed into the bone)
- Because cartilage causes friction to be very small, joint contact forces are normal to the articular surface

Musculotendon Force

- Acts through the muscle’s tendons onto the bone at the origin and insertion
- Produces tensile forces on bone in the direction given by the tendon’s angle of insertion into the bone
- Forces produced at the origin & insertion are equal
Muscle Force Properties
- Generates passive force when stretched
- Generates active force which depends on:
  - Neural stimulation level
  - Muscle length
  - Muscle shortening / lengthening velocity
  - Time (i.e. it takes time for force to increase or decrease)

Tendon Force Properties
- When stretched, tendon produces a tensile force between the muscle and the bone
- Tendon force on bone = Muscle force on tendon
- Can function to store energy during eccentric contractions

Ligament Force
- When stretched, ligaments produce a tensile force that acts onto the bone at the origin and insertion
- Direction of force given by the ligament’s angle of insertion into the bone
- Forces at the origin & insertion are equal
- Ligaments get stiffer as they’re stretched

Intervertebral Force
- Disk has complex structure and behavior
- Nucleus expands against annulus when compressed
- Annulus fibers provide restraining force as stretched
- Nucleus experiences large compressive stress
- Fibers of annulus experience very large tensile stress
Resultant Joint Force

- In most cases, contact and muscle forces acting at a joint cannot be determined individually.
- Resultant joint force = net force produced by joint contact and by all the structures that act across a joint (muscle, ligament, etc.).
- It acts at the joint center and is the vector sum of all forces acting across the joint.