Day 03A

The Biomechanics of Human Bone Growth and of Human Skeletal Articulations

Session Speaker
Dr. M. D. Deshpande
• Session Objectives
  – At the end of this session the delegate would have understood
    • The biomechanics of the bones with an emphasis on their constituents, structural organization and growth
    • Role of exercise, weightlessness and osteoporosis on bones
    • Mechanical loading and bone injuries
    • Joint flexibility and issues involved in Joint injuries
Session Topics

1. Material constituents and structural organization of bone; ability to withstand mechanical loads
2. Normal growth and maturation of bone
3. Effects of exercise and of weightlessness on bone mineralization
4. Osteoporosis and its prevention
5. Different forms of mechanical loading and common bone injuries
6. Articular cartilage and fibrocartilage
7. Material properties of articular connective tissues
8. Joint flexibility
9. Joint injuries and pathologies
Composition and Structure of Bone

- **Stiffness**: It is the force acting on a loaded member by the deformation of the loaded member
- **Compressive Strength**: Ability to resist compression
- **Tensile strength**: Ability to resist pulling or stretching force
- **Calcium carbonate and Calcium phosphate** contributes to stiffness and compressive strength in bone
- **Collagen** contributes to **flexibility and tensile strength** in bone
- **Collagen** is progressively lost and bone **brittleness increases** with aging
Composition and Structure of Bone

• Bone strength is affected by water content and porosity

• Water content of bone, which comprises 25%-30% of bone weight

• Bone porosity or the amount of bone volume filled with pores or cavities

• Bones are categorized as cortical bone and trabecular bone based on porosity

• Cortical bone: compact mineralized bone with low porosity; found in the shafts of long bones

• Trabecular (or cancellous) bone: less compact bone with high porosity; found in the ends of long bones and the vertebrae

Q: Why we have cortical bone in the shaft and Trabecular bone in the ends?
Composition and Structure of Bone

Structures of **cortical (compact)** and **trabecular (spongy)** bone.

- Because **cortical bone** is stiffer than trabecular bone, it can withstand greater stress but less strain.

- Because **trabecular bone** is spongier than cortical bone, it can undergo more strain before fracturing.
Composition and Structure of Bone

- The structure of bone affects its strength.
- Bone is **anisotropic**, it has different strength and stiffness depending on the direction of the load.

(Bone is strongest in resisting compression and weakest in resisting shear)

Q: How does it compare with stone and steel?
Types of bones

- **Axial skeleton**: skull, vertebrae, sternum, ribs
- **Appendicular skeleton**: bones composing the body appendages
- **Short bones**: approximately cubical; include the carpals and tarsals
- **Flat bones**: protect organs & provide surfaces for muscle attachments; include the scapulae, sternum, ribs, patellae, some bones of the skull
- **Irregular bones**: have different shapes to serve different functions; include vertebrae, sacrum, coccyx, maxilla
- **Long bones**: form the framework of the appendicular skeleton; include humerus, radius, ulna, femur, tibia, fibula
Human Skeleton

- Skull
- Maxilla
- Mandible
- Vertebrae
- Scapula
- Humerus
- Elbow
- Radius
- Ulna
- Wrist
- Femur
- Knee
- Tibia
- Fibula
- Metatarsals
- Tarsals
- Metacarpals
- Carpal
- Sacrum
- Pelvis
- Vertebrae
- Ribs
- Clavicle
Bone Growth and Development

- **How do bones grow in length**: the epiphyses, or epiphyseal plates, are growth centres where new bone cells are produced until the epiphysis closes during late adolescence or early adulthood.

- **How do bones grow in circumference**:
  - The inner layer of the periosteum, a double-layered membrane covering bone, builds concentric layers of new bone on top of existing ones.
  - Specialized cells called osteoblasts build new bone tissue and osteoclasts resorb bone tissue.

**Q**: How does the growth of bones compare with the growth in plants?
Bone Response to Stress

• How do bones respond to training?
  • Just like muscle, bones respond to certain kinds of training by hypertrophying
  • According to Wolff’s law, the densities, and to a lesser extent, the sizes and shapes of bones are determined by the magnitude and direction of the acting forces
  • Bone strength increases and decreases as the functional forces on the bone increase and decrease

• How is Wolff’s law carried out?
  • Osteoblasts and osteoclasts are continually building and resorbing bone, respectively.
  • Increased or decreased mechanical stress leads to a predominance of osteoblast or osteoclast activity, respectively
Bone Response to Stress

• Bone hypertrophy: increase in bone mass resulting from a predominance of osteoblast activity

• Bone atrophy: decrease in bone mass resulting from a predominance of osteoclast activity

• What kinds of activity tend to promote bone density?
  • Weight bearing exercise, since the larger the forces the skeletal system sustains, the greater the osteoblast response

• What tends to diminish bone density?
  • Lack of weight bearing exercise
  • Spending time in the water, (since the buoyant force counteracts gravitational force)
  • Bed rest
  • Traveling in space outside of the earth’s gravitational field
Osteoporosis

- **Osteoporosis** is a disorder involving decreased bone mass and strength with pain and one or more fractures resulting from daily activity.
Osteoporosis

• Who is affected by Osteoporosis?
  • Type I (postmenopausal) osteoporosis affects about 40% of women after age 50
  • Type II (age-associated) osteoporosis affects most women and men after age 70
• Are younger people ever affected by osteoporosis?
• The female athlete triad includes:
  • Disordered eating
  • Amenorrhea, and
  • Osteoporosis

The desire to excel at competitive sports cause some female athletes to strive to achieve an undesirable low body weight. This dangerous practice commonly involves a combination of disordered eating, amenorrhea and osteoporosis, a combination that has come to be known as “female athlete triad”
Osteoporosis

- How can **osteoporosis be prevented** and **treated**?
  - Regular weight bearing exercise is the key prevention and treatment
  - Postmenopausal hormone replacement
  - Adequate dietary calcium and vitamin D
  - Avoiding smoking and excessive consumption of protein, caffeine, and alcohol
Common Bone Injuries

• A fracture is a disruption in the continuity of a bone
• The nature of fracture depends on the direction, magnitude, loading rate duration of the mechanical load sustained, as well as the health and maturity of bone at the time of injury
• Simple fracture: bone ends remain within the surrounding soft tissues
• Compound fracture: one or both ends of a bone protrude from the skin
• When the loading is rapid, a fracture is more likely to be comminuted, containing multiple fragments
Different types of Fractures

Q: What kind of stresses may be causing each one of these fractures?
Common Bone Injuries

- **Avulsions** are fractures caused by tensile loading in which a tendon or ligaments pulls a small chip of bone away from the rest of the bone.
- Under excessive bending loads bone tends to fracture on the side loaded in tension.
- An **impacted fracture** is one in which the opposite sides of the fracture are compressed together.
- Fractures that result in depression of bone fragments into the underlying tissues are termed **depressed**.
- **Stress fractures** also known as fatigue fractures result from low magnitude forces sustained on a repeated basis.
- Any increase in the magnitude or frequency of bone loading produces a stress reaction, which may involve microdamage. Bone responds to microdamage by remodeling.
- **Epiphyseal injuries** include injuries to the cartilaginous epiphyseal plate, the articular cartilage, and the apophysis.
Further Reading

• American Academy of Orthopaedic Surgeons  www.aaos.org

• Clinical Orthopaedics and Related Research  www.corronline.com

• Orthopaedic Research Laboratories  http://orl-inc.com/

• Orthopaedic Research Society  www.ors.org

• The American Orthopaedic Society for Sports Medicine  www.sportsmed.org
Laboratory

• Refer laboratory exercises
Joint Architecture

- Joints of the human body largely govern the directional motion capabilities of body segments.

- **Classification of Joints:**
  
  - **Synarthroses:** (immovable)
    - Sutures
    - Syndesmoses
  
  - **Amphiarthroses:** (slightly moveable)
    - Synchondroses
    - Symphyses
  
  - **Diarthroses or synovial:** (freely movable)
    - Characterized by articular cartilage - a protective layer of dense white connective tissue covering the articulating bone surfaces, articular capsule - a double-layered membrane that surrounds the joint, Synovial fluid - a clear, slightly yellow liquid that provides lubrication inside the articular capsule
Joint Architecture

• **Synovial Joints**
  – Gliding
  – Hinge
  – Pivot
  – Condyloid
  – Saddle
  – Ball and socket
Joint Architecture

Functions of articular cartilage

• It spreads loads over a wide area, thereby reducing contact stress

• It provides a protective lubrication that minimizes friction and mechanical wear at the joint

Articular fibrocartilage

• Soft-tissue discs or menisci that intervene between articulating bones, as exemplified by the menisci of the knee above
Joint Architecture

Functions of articular fibrocartilage

• Distributing loads over joint surfaces
• Improving the fit of articulations
• Limiting slip between articulating bones
• Protecting the joint periphery
• Lubricating the joint
• Absorbing shock at the joint

Articular connective tissues

• Tendons - connect muscles to bones
• Ligaments - connect bones to other bones
  • Tendons and ligaments do not have the ability to contract like muscle tissues, but they are slightly extensible. These tissues are elastic.
Joint Stability

Joint stability

• Ability of a joint to resist abnormal displacement of the articulating bones

Factors increase joint stability

• A closely reciprocating match of the articulating bone surfaces (stability is maximal when joints are in the close-packed position)
• A strong array of ligaments and muscle tendons crossing the joint
• Absence of muscle fatigue
Joint Flexibility

Joint flexibility

• A description of the relative ranges of motion allowed at a joint in different directions

• Range of motion (ROM): the angle through which a joint moves from anatomical position to the extreme limit of segment motion in a particular direction

• Range of motion is measured directionally from anatomical position (zero)
Joint Flexibility

Factors influence joint flexibility

• Intervening bony or muscle tissue or fat at the end of the ROM
• Tightness/laxity in the muscle and collagenous tissue crossing a joint
• Muscle fatigue
Techniques for Increasing Joint Flexibility

Sensory receptors influence the extensibility of the musculotendinous unit

- Golgi tendon organs - inhibit tension in muscle & initiate tension development in antagonists
- Muscle spindles - provoke reflex contraction in stretched muscle & inhibit tension in antagonists
## Golgi Tendon Organs and Muscle Spindles: How do they Compare?

<table>
<thead>
<tr>
<th>Location</th>
<th>Golgi Tendon Organs</th>
<th>Muscle Spindles</th>
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<tbody>
<tr>
<td></td>
<td>Within tendons near the muscle-tendon junction in series with muscle fibers</td>
<td>Interspersed among muscle fibers in parallel with the fibers</td>
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<tr>
<td>Stimulus</td>
<td>Increase in muscle tension</td>
<td>Increase in muscle length</td>
</tr>
<tr>
<td>Response</td>
<td>1) inhibit tension development in stretched muscle, 2) initiate tension development in antagonist muscles</td>
<td>1) initiate rapid contraction of stretched muscle, 2) inhibit tension development in antagonist muscles</td>
</tr>
<tr>
<td>Overall Effect</td>
<td>Promote stretch in muscle being stretched</td>
<td>Inhibit stretch in muscle being stretched</td>
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Techniques for Increasing Joint Flexibility

Active and Passive stretching
- Active stretching - produced by active development of tension in the antagonist muscles
- Passive stretching - produced by a force other than tension in the antagonist muscles

Ballistic and Static stretching
- Ballistic stretching - a series of quick, bouncing-type stretches
- Static stretching - maintaining a slow, controlled, sustained stretch over time - usually about 30 seconds

What is PNF?
- Proprioceptive neuromuscular facilitation is a group of stretching procedures involving alternating contraction and relaxation of the muscles being stretched

Proprioception - The ability to sense the position and location and orientation and movement of the body and its parts.
Common Injuries and Pathologies

- Sprains
- Dislocations
- Bursitis
- Arthritis
  - Rheumatoid Arthritis
  - Osteoarthritis

Bursitis—Inflammation of the bursa; especially at the shoulder (Bursa—A small fluid filled sac located between movable parts of the body, especially at the joints.)
Osteoarthritis

- A common, degenerative disease of articular cartilage
- Symptoms include pain, swelling, ROM restriction, and stiffness
- Cause is unknown
- Both too little and too much mechanical stress seem to promote development
Further Reading

• The Center for Orthopaedics and Sports Medicine  www.arthroscopy.com/sports.htm

• Rothman Institute  http://rothmaninstitute.com/index.html

• The Virtual Hospital: Joint Fluoroscopy  www.vh.org/Providers/Textbooks/JoinFluoro/JointFluoroHP.html
Laboratory

• Refer laboratory Exercises
Review

In this session the delegates are taught:

• Constituents and structural organization of bone; ability to withstand mechanical loads
• Normal growth and maturation of bone
• How exercise and of weightlessness affect bone mineralization
• Osteoporosis and its prevention
• Common bone injuries and the role of mechanical loading
• Material properties of articular connective tissues
• Joint flexibility Joint injuries and pathologies
Thank you