Spine Biomechanics,
Intervertebral Disc & LBP
Lateral (Side) View of Normal Spinal Column

- Cervical (C1 through C7)
- Thoracic (T1 through T12)
- Lumbar (L1 through L5)
- Sacral (S1 through S5)
- Coccygeal or Coccyx (Tailbone)
Cervical Spine

- Seven vertebrae
  - C 1-7
- More flexible
- Supports the head
- Wide range of motion
  - Rotation to left and right
  - Flexion
    - Up and down
- Peripheral nerves
  - Arms
  - Shoulder, Chest and diaphragm
Thoracic Spine

- Mid-back or dorsal region
- Twelve vertebrae
  - T 1-12
- Ribs attached to vertebrae
- Relatively immobile
- Peripheral nerves
  - Intercostal
Lumbar Spine

- Lower back
- Five vertebrae
  - L 1-5
- Carries the weight of the upper body
  - Larger, broader
- Peripheral nerves
  - Legs
  - Pelvis
**Sacral and Coccygeal region**

- **Sacrum**
  - Triangular structure
  - Base of the spine
  - Connects spine to pelvis
  - Nerves to pelvic organs

- **Coccyx**
  - Few small bones
  - Remnant of tail
**Lordosis**

- In the sagittal plane
  - ‘S’ shape
- As a small child
  - When starts to sit
  - **Cervical lordosis**
- Toddler and adult
  - When starts to stand
  - **Lumbar lordosis**
  - Allows spring-like action
Compressive Strength of Spine

![Graph showing the compressive strength of the spine across different spinal levels. The graph indicates a generally increasing trend from cervical to lumbar levels, with a sharp peak at the lumbar region.](image-url)
Stress-Strain Curve

A-B = Neutral zone
B-C = Elastic zone
C-D = Plastic zone
D-E = Failure zone
Motion Segment

- Two adjacent vertebrae
- Intervertebral disc
- Six degrees of freedom
  - Flexion-extension
  - Lateral flexion
  - Axial rotation
Types of motion
Motion Segment

Sagittal View
Forward bending

Posterior View
Rotation to the right

Pedicle
Spinous process
Intervertebral disc
Motion of Entire Spine
Motion of Entire Spine

Allowed Movement (degrees)

Cervical
Thoracic
Lumbar

Spinal Level

Flex.-Ext.
Lat. Bending
Axial Rot.
Weight bearing properties of motion segment unit

Posterior oblique view of a functional segment unit
**Intervertebral Disc**

- Soft fibro-cartilaginous cushions
  - Between two vertebra
  - Allows some motion
  - Serve as shock absorbers
- Total – 23 discs
- \( \frac{1}{4} \) th of the spinal column's length
- Avascular
- Nutrients diffuse through end plates
Intervertebral Disc Functions

- Movement of fluid within the nucleus
  - Allows vertebrae to rock back and forth
  - Flexibility
- Act to pad and maintain the space between the twenty-four movable vertebrae
- Act as shock absorbers
- Allow extension and flexion
**Intervertebral Disc Anatomy**

- **Spongy center**
  - *Nucleus pulposus*

- **Surrounded by a tougher outer fibrous ring**
  - *Anulus fibrosus*
**Anulus Fibrosus**

- Strong radial tire–like structure
- Series of lamellae
- Concentric sheets of collagen fibers
  - Connected to end plates
  - Orientated at various angles
  - Under compression
    - Become horizontal
- Encloses nucleus pulposus
Annulus

- **In Bending**
  - Increased tensile force posteriorly
  - Increased compressive force anteriorly

- **In Rotation**
  - Reorientation of collagenous fibers
  - Tightening of fibers traveling in one direction
  - Loosening of fibers traveling in opposite direction
Nucleus Pulposus

- Has more water and PGs
- PG are macro-molecules
  - Attract and retain water
  - Hydrophilic gel–like matter
    - Resists compression
- Amount of water
  - Activity related
  - Varies throughout the day
Theory of weight bearing

- Nucleus pulposus *imbibes water*
- Develops internal pressure
- Pressure exerted in all directions
  - Lateral forces
    - Against annulus
  - Superiorly and inferiorly directed forces
    - Against end plates
  - Increases stiffness
    - Of end plate and annulus fibrosus
Theory of weight bearing (cont’d)

Vertebral body
Nucleus pulposus
Annulus fibrosus
Vertebral end plate

when uneven loading takes place
Mechanical Characteristics

Tensile stiffness of the disc annulus in different directions
Highest along – 15°
Lowest along – the disc axis
**Strength**

Highest – Along normal direction of annulus fibers
(3 times stronger than that along horizontal direction)
## Stiffness Coefficients of IV disc

<table>
<thead>
<tr>
<th>Authors</th>
<th>Stiffness Coefficients*</th>
<th>Maximum Load*</th>
<th>Spine Region</th>
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<tbody>
<tr>
<td><strong>Compression ((-F_y^+))</strong></td>
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<tr>
<td>Virgin, 1951</td>
<td>2.5 MN/m</td>
<td>4500 N</td>
<td>Lumbar</td>
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<tr>
<td>Hirsch &amp; Nachemson, 1954</td>
<td>0.7 MN/m</td>
<td>1000 N</td>
<td>Lumbar</td>
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<tr>
<td>Brown, et al., 1957</td>
<td>2.3 MN/m</td>
<td>5300 N</td>
<td>Lumbar</td>
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<tr>
<td>Markolf, 1970</td>
<td>1.8 MN/m</td>
<td>1800 N</td>
<td>Thoracic &amp; lumbar</td>
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<tr>
<td>Moroney, et al., 1988</td>
<td>0.5 MN/m</td>
<td>74 N</td>
<td>Cervical</td>
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<tr>
<td><strong>Tension ((+F_y^+))</strong></td>
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<td></td>
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<tr>
<td>Markolf, 1970</td>
<td>1.0 MN/m</td>
<td>1800 N</td>
<td>Thoracic &amp; lumbar</td>
</tr>
<tr>
<td><strong>Shear ((F_x, F_z^+))</strong></td>
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<td></td>
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<tr>
<td>Markolf, 1970</td>
<td>0.26 MN/m</td>
<td>150 N</td>
<td>Thoracic &amp; lumbar</td>
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<td>Moroney, et al., 1988</td>
<td>0.06 MN/m</td>
<td>20 N</td>
<td>Cervical</td>
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<tr>
<td><strong>Axial Rotation ((My^+))</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Fairfan, et al., 1970</td>
<td>2.0 Nm/deg</td>
<td>31 Nm</td>
<td>Lumbar</td>
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<tr>
<td>Moroney, et al., 1988</td>
<td>0.42 Nm/deg</td>
<td>1.8 Nm</td>
<td>Cervical</td>
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</tbody>
</table>

* N = newton, kN = 1000 newton, MN = 1,000,000 newton, Nm = newton meter

To convert to the inch-pound system, multiply by the following numbers:

\[(\text{MN/m}) \times 5600 = \text{lbf/in} \quad (\text{Nm/deg}) \times 0.738 = \text{in lbf/deg} \quad (\text{N}) \times 0.225 = \text{lbf} \quad (\text{Nm}) \times 0.738 = \text{in lbf}\]

* See Figure 1–32 and text for details.
Creep Characteristics

Grade 0 - Non-degenerative disc (more viscoelastic)
Grade 2 – Mild degenerative disc (less sustenance)
Grade 3 – Severe degenerative disc (more deformation)
Shear & Tensile Characteristics

- In direct shear tests
  - Shear stiffness in horizontal direction
    - 260 N/mm²
- Spine rarely fails in pure shear
- Similarly under normal physiologic activities
  - Pure tensile loading doesn’t occur
  - But annulus undergoes tensile loading during
    - Bending
    - Axial rotation
    - Extension
Compressive load characteristics

- Cancellous bone
  - Large deformation
    - Up to 9.5% before failure

- Cortical bone
  - Small deformation
    - Up to 2% before failure
Measurements of In vivo Loads

- Needle pressure transducer
- Calibrated
  - Introduced into nucleus pulposus of cadaveric functional unit
- Inserted in vivo in L3-4 disc
Pathology of Intervertebral Disc Injury

- **Annular Injury**
  - Annular rings
    - Softened
    - Overstretched
    - Torn
  - Normal viscoelasticity is exceeded
  - Cannot stabilize or limit motion
  - Nucleus pulposus exerts pressure on weak part
  - Buckling occurs - *Disc Bulge*
Pathology of Intervertebral Disc Injury

- **Extrusion**
  - Fragmentation of nucleus pulposus
  - Nuclear material dissects its way through breaches in annulus fibrosus

Disc extrusion with rupture of capsule
Pathology of Intervertebral Disc Injury

- **Prolapses**
  - Fissures provide pathway for irritating nuclear fluid to escape onto perineural tissue *
  - Persistent and chronic back pain

* - Hampton et al
Back Pain

- Pain is a protective mechanism
- Nerve endings near the spine receive abnormal stimulation
- Signals are transmitted from affected area to the brain
  - They are interpreted as pain
- A reflex action follows in the back
  - Muscles go into spasm
    - To protect the back
    - To keep the damaged area immobile
**Types of pain**

- **Based on source**
  - Mechanical
  - Chemical

- **Based on affected region**
  - Local
  - Referred

- **Based on nature**
  - Transient
  - Acute
  - Chronic
Causes of LBP

- Dysfunction
- Predisposing factors
  - Postural stress
  - Work related stress
  - Disuse and loss of mobility
  - Obesity
  - Debilitating conditions
- Precipitating factors
  - Misuse
  - Overuse
  - Abuse or trauma
Examinations to locate back pain

- **Standing**
  - Observation and Palpation
    - Iliac crest
    - Posterior superior iliac spine (PSIS)
    - Anterior superior iliac spine (ASIS)
    - Spinous processes
    - Muscle tightness
    - Gait
Examinations of back pain

- Movement Testing
  - Forward bending
  - Backward bending
  - Lateral bending
  - Rotation
  - Leg extension and backward bending
Forward bending

- Hands are pushing in opposite direction
- Tissues from skin to central core
  - Elongate posterior
  - Compress anterior
- Assessing lumbo-pelvic congruency
  - Palpation from cervical spine to pelvis
Back Examination

- Nerve tension signs
- Nerve compression signs
Examination of back pain

- **Supine Testing**
  - Passive hip flexion
  - Faber position
  - Straight leg raise (SLR)
  - Force is directed to right femur
    - Posterior to anterior force directed to femur
      - In flexed and vertical position
  - Passive knee flexion in a prone position
  - Passive internal and external hip rotation
    - Knee at 90° of flexion
Passive hip flexion

- Hip hyperflexed
  - Lumbar spine flattened
    - Over 90° of flexion
- Force transmission
  - To extensor of hip
    - Posterior rotary movement on ilium
  - Spinal flexion
**Straight leg raise (SLR)**

- Straight leg raised
- Femoral flexion
- Adduction
- Internal rotation
- Increase in tensile force
  - On sciatic nerve
    - Related to ischial tuberosity
Phases of Treatment for lumbopelvic disorders

- Treatment of pain
  - Modalities
  - Medication
    - Support the region
    - Biomechanical counseling / rest
- Continue support
  - Begin non-destructive movement
  - Decrease destructive behavior
Phases of Treatment for lumbopelvic disorders (cont’d)

- **Discontinue support**
  - Begin proprioceptive and kinesthetic strength training
    - Neuromuscular efficiency
    - Dynamic stabilization

- **Establishment of limits**
  - Movement
  - Loads
  - Positions
  - Frequencies
Treatment Options

- Cryotherapy
- Thermotherapy
  - Superficial heating
  - Deep Heat
- Injection Therapy & Soft tissue injections
- Electrotherapy
  - Transcutaneous electrical nerve stimulation (TENS)
Treatment Options (cont’d)

- Manipulation
- Traction
- Massage
- Physical therapy and exercises
- Acupuncture
- Corsets and braces
- Surgical treatment
Scoliosis

- A medio-lateral curve of the vertebral column *Exceeding 10°*
  - Types
    - Structural
    - Neuromuscular
    - Idiopathic
    - Non-structural
  - Treatment
    - Exercises
    - Bracing
Detection of Scoliosis
**Kyphosis**

- An exaggerated curvature in the sagittal plane
- Long rounded curve *(round back)*
- Sharp posterior angulation *(hump back)*
- Possible causes
  - Wedge compression fracture
  - Ankylosing spondylitis
  - Senile osteoporosis
  - Destructive tumors of spine
Video on description of Spinal Column