Biomechanics of Human Spine
Cervical Spine

- Seven vertebrae C 1-7
- More flexible
- Supports the head
- Wide range of motion
  - Rotation to left and right
  - Flexion extension
    - Up and down
    - Side flexion (Rt, Lft)
- Peripheral nerves (8)
The cervical vertebrae are identified by *foramina transversaria* for vertebral artery. Facet joints b/w each upper & lower articular facet of adjacent vertebrae.
ATYPICAL C-VERTEBRAE, C1, C2, C7

Atypical Cervical Vertebrae

- **C1 – Atlas**
  - No body
  - No Spinous Process
  - Superior Articular facets are kidney shaped

- **C2 – Axis**
  - Odontoid Process = Dens
  - Other features typical
Atypical Cervical Spine – C7

C7 vertebra:

- It has long spinous process, which is not bifid.
- Its transverse processes are large and directed downward which allow differentiation from T1 Spine that has upward directed transverse process.
• From C3 to T1 there is a total 10 saddle-shaped, diarthrodial articulation between the uncinate (lateral) process of adjacent body known as uncovertebral joints.
• They also facilitate the mobility of lower cervical spine.
Thoracic Spine

- Mid-back or dorsal region
- Twelve vertebrae
  - T 1-12
- Ribs attached to vertebrae
- Relatively immobile
- Peripheral nerves(12)
  - Intercostal nerves
Typical thoracic vertebra.
Thoracic Vertebrae (T1-T12)

- Larger and stronger bodies
- Longer transverse & spinous processes
- Demifacets on body for head of rib
- Facets on transverse processes (T1-T10) for tubercle of rib
Lumbar Anatomy

- 5 vertebrae L1-L5
- 5 intervertebral discs
- 5 pair of exiting nerve roots
- Lumbar lordosis L1-S1
  - The apex of lumbar lordosis L3-L4
- Lower back
- Carries the weight of the upper body
Lumbar Vertebrae (5)

- Spinous process is short, rectangular, projects dorsally
- Superior Articular Facets face Medially
- Inferior Articular Facets face Laterally
- Vertebral Foramen is Triangular
- Body is large and Kidney-shaped
atypical

5th lumbar vertebra

- **Body** is largest among all the lumbar vertebrae
- **Transverse process** is thick, short and pyramidal in shape
- **Transverse process** is attached to body and pedicle
- The distance between superior articular processes is same as that inferior ones
- **Spine** is short and rounded at the tip
**Sacral and Coccygeal region**

- **Sacrum**
  - Triangular structure (from S1-S5 vertebrae)
  - Base of the spine
  - Connects spine to pelvis
  - Nerves to pelvic organs

- **Coccyx**
  - 4 small bones unite to form the tail bone of the spine
Curves of spine.

- In the sagittal plane
  - ‘adult spinal curve is S’ shape
- As a small child (c shaped)
  - When starts to sit → **Cervical Lordosis**
- Toddler and adult
  - When starts to stand → **Lumbar Lordosis**
  - Allows spring-like action
- Action of Both lordotic curve compensatory kyphosis curve developed in thoracic region.
Orientation of facet joints with respect to transverse plane

Vertèbre cervicale

Vertèbre dorsale

Vertèbre lombaire
Lumbar Spine ligaments

1. Anterior longitudinal ligament
2. Posterior longitudinal ligament
3. Ligamentum flavum
4. Interspinous ligaments
5. Nucal ligament
6. Intertransverse ligaments
Compressive Strength of Spine

![Graph showing compressive strength of spine by spinal level.]

- **Spinal Level**: Cervical, Thoracic, Lumbar
- **Compression Strength (newtons)**: 0 to 8,000

The graph illustrates the compressive strength for different spinal levels, with Lumbar showing the highest strength.
**Failure Strength of Spinal Ligaments**

![Graph showing failure strength of spinal ligaments across different regions.]

- **ALL** = anterior longitudinal ligament
- **PLL** = posterior longitudinal ligament
- **LF** = ligamentum flavum
- **CL** = capsular ligament
- **ISL** = interspinous ligament
The L5-S1 Segment is the most common site of problem in the spine ???

- This level bears more weight.
- COG pass directly through this vertebra
- Transition L5 Mobile and S1 Stable
- Large angle B/w L5 & S1
- Great amount of movement
Motion Segment

1. Two adjacent vertebrae
2. Intervertebral disc
3. (facet joints)
   - Six degrees of freedom
     - Flexion-extension
   - Axial rotation or Rotation (RT & LT)
   - Lateral Flexion / Side bending (RT & LT)
Motion segment

- Movement at the spinal segment in relation to the spinal articulations effect each other mobility, as
  - Motion at the v.bodies and facet joints are interdependent
- **Amount of motion**
  - Primarily depends upon the size of the disc
- **Direction of motion**
  - Primarily depends upon the orientation of the articulating facets
Motion segment:
Factors on which spinal mobility depends upon

- **The Disc thickness to vertebral Height ratio**
  - Greater ratio, greater mobility
  - 2:5 ratio in Cervical (most mobile), 1:5
  - Thoracic; least mobile, 1:3 ratio in Lumbar spine

- **The Vertebra’s Width to Height ratio**
  - Least ratio, greater mobility
  - C Vertebra has relatively small anteroposterior and transverse diameters in relation to the body height (more mobile)
Orientation of Articular processes

- Superior articular facet of C Spine faces posteriorly and slightly laterally, more mobility,
- T- Spine facets faces posteriorly more rotation,
- Lumbar spine facets faces medially
- OR smaller the angle more will be mobility but in thoracic Ribs:
  - Ribs approximate on side of spinal concavity restrict movement on thoracic spine.
- The extent of Mechanical Displacement depend on ligaments, slack on midrange, taut in end range.
**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 cushion and maintain the space between the twenty-four movable vertebrae
- Act as shock absorbers
Intervertebral Disc Anatomy

- Spongy center
  - *Nucleus pulposus*
- Surrounded by a tougher outer fibrous ring
  - *Annulus fibrosus*
**Annulus Fibrosus**

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

- **In Bending (flexion)**
  - Increased tensile force posteriorly
  - Increased compressive force anteriorly (vice versa)

- **In Rotation**
  - Reorientation of collagenous fibers
  - Tightening of fibers in one direction
  - Loosening of fibers 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 pulpous *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
The water binding capacity of the disc decreases with age and degenerative changes begin to occur after the 2nd decade of life.

The disc contains 85% to 90% of water, but the amount decreases up to 65% with age.
Shear & Tensile compressive load Characteristics

Shear stiffness/strength was measured 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, and extension.

Cancellous bone showed large deformation

- Up to 9.5% before failure

Cortical bone: Small deformation: Upto 2% before failure
Total load on third lumbar disc in a subject of 70 kg.

Position of body
Measurements of In vivo Loads

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

- Herniation:
  
a general term used when there is any change in the shape of the annulus that causes the nucleus to bulge beyond its normal perimeter
Pathology of Intervertebral Disc injury, disc bulge

- **Prolapses**

- Fissures provide pathway for irritating nuclear fluid to escape onto perineurial tissue **OR**
  - rupture of the nuclear material into the vertebral canal
    - Persistent and chronic back pain
Extrusion

- Extension of nuclear material beyond the confines of the posterior longitudinal ligament or above and below the disc space, as detected on MRI, but still in contact with the disc OR
  - Nuclear material dissects its way through breaches in annulus fibrosus
Free sequestration

- the extruded nucleus has separated from the disc and moved away from the prolapsed area
Muscles of the Spine

- Muscles of neck and trunk named in pairs, with one on the left and the other on the right side of body
- Anterior Aspect
- Posterior Aspect
- Lateral Aspect
Anterior Aspect

- **Cervical spine**: Bilateral tension development results in flexion of head.
- Unilateral tension development in prevertebrals contributes to:
  - lateral flexion of head toward contracting muscles or,
  - to rotation of head away from contracting muscles

  - **Anterior Thoracic muscles**

- **Abdominals**
Cervical Muscles Group

- Superficial Posterior
- Deep Posterior
- Superficial Anterior
- Deep Anterior
Cervical Muscles Group

- Trapezius
- Levator Scapulae
- Splenius Capitis
- Splenius Cervicis

Superficial Posterior
Cervical Muscles Group

Deep Posterior

Multifidi

Suboccipital

Cervical Muscles Group
Suboccipital muscles.

Rectus capitis posterior major muscle
Rectus capitis posterior minor muscle
Obliquus capitis superior muscle
Obliquus capitis inferior muscle
Cervical Muscles Group

- Superficial Anterior
- SCM
- Scalenus
Posterior Aspect

Thoracic and Lumbar Muscle groups:
- erector spinae (iliocostalis, longissimus, spinalis)
- Semispinalis
- deep segmental spinal muscles (multifidi, rotators)
Semispinalis

- Thoracis
- Cervicis
- Capitis
2a. Semispinalis

capitis
cervicis
thoracis
• The **multifidus** muscle is comprised of repeated bundles of short muscles that span just one single vertebrae each,
• located on either side of the spine,
• Attaching on the **transverse and spinous processes**.
• contribute to side bending on same & rotation on opposite side like rotatores.
• The **multifidus**, like the rotatores and other deep back muscles, play a role in upright posture and spinal stability
• Lie just below the multifidus muscles.
• Like the multifidus, the rotatores are small muscles located on either side of the spine.
• They attach on the transverse process of the vertebrae.
• But unlike the multifidus, whose other attachment site is the spinous process, the rotatores insert on the lamina of the same vertebra.
Abdominals

Rectus abdominis

Transverse abdominus

Internal oblique

External oblique
Lateral Aspect

- Many muscles of neck and trunk cause lateral flexion when contracting unilaterally, but either flexion or extension when contracting bilaterally.

- **Muscles:** sternocleidomastoid, levator scapulae, scalenus anterior, posterior and medius

- **Lumbar region:** quadratus lumborum, psoas major
Loads on the Spine

- Forces acting on spine:
  - Body weight
  - Tension in the spinal ligaments
  - Tension in surrounding muscles
  - Intraabdominal pressure
  - Any applied external loads
- Body Movement Speed
MECHANICAL STABILITY OF THE LUMBAR SPINE

- IAP (intra-abdominal pressure)
- Co contraction of the trunk muscles
- External support
Intra-Abdominal Pressure

- IAP contribute to both unloading and stabilization of the lumbar spine.
- IAP within the abdominal cavity by a coordinated contraction of the diaphragm and the abdominal and pelvic floor muscles
- Act as a "pressurized balloon/rigid cylinder “ attempting to separate the diaphragm and pelvic floor
- This creates an extensor moment that decreases the compression forces on the lumbar discs & increases stability.
Diaphragm

Abdomen

BRACING

Outward pressure

Pelvic Floor

Downward Pressure

Erectors

Stability pressure

Resistance

Glottis Closes

Inhale

Pressure Supports Lumbar Spine

Creates Intra-abdominal Pressure

Diaphragm Contracts

Diaphragm Pushes Downward
Recent studies using fine-wire EMG of the deeper abdominal muscles found that the transversus abdominis is the primary abdominal muscle responsible for IAP generation.

Current research suggests that the transversus abdominis muscle, together with the diaphragm, plays an important role in stabilizing the spine in preparation for limb movement.
Trunk Muscle Co-Contraction

- With higher levels, co-contraction produce spine compression and trunk muscle stiffness, decrease spine stability occurred through repetitive loading of spine beyond endurance limit.

- Repetitive continuous motions that fatigue the trunk muscles Ultimately leads to spinal weakness & instability. The reduction in the functional capacity of the flexion extension muscles was compensated for by secondary Muscle groups and led to an increased couple motion pattern that is more injury prone.
External Stabilization
lumbar belts or corsets

- Restrict motion at any level may increase motion at another level.
- The use of back belts as a means of preventing low back injury to restrict movement, remains controversial.
- **Originally** it was believed to assist in increasing IAP as a way of unloading the spine during lifting or other activities→ Provide support & stability of spinal region.
Low Back Pain

- 75-80% of population will experience it at some time in their life
- Mechanical stress plays a significant role
- Relative Stability of Spine
- 60% of cases is idiopathic (unknown origin)
- Abdominal & back extensors exercises help in treatment
Soft Tissue Injuries
1: Contusions
Laceration, Muscle Strains, Ligament Sprains
Acute Fractures

- Transverse or Spinous fractures from hard blow (contact sports) or extremely forceful contraction
- Extremely serious because of fragile spinal cord.
- Rib fractures usually due to blows from sports, cause pain with each inhalation.
  - Potential for serious damage to underlying soft tissues (lungs)
Stress Fractures

- When osteoporosis has made your bones weak, the chances are higher that they’ll crack or break, even the bones of your spine.
- These spine fractures, also called vertebral compression fractures, can cause severe back pain that makes it hard to stand, walk, sit, or lift objects.
- Most common type of vertebral stress fracture is called Spondylolysis (most at L5).
Spondylolysis & spondylolisthesis.

- **Spondylolysis** compression fracture of vertebrae. More specifically due to defect in the pars interarticularis of vertebral arch.
- Spondylolysis can progress until one or more vertebrae slip out of place which is then called **spondylolisthesis**.
  - Due to fracture of pars Interarticularis bilaterally; It can result in
    - Narrowing of posterior joint space, Stress to spinal nerves, the spinal cord, or the cauda equina
    - Pain can lead to reduced mobility. Inactivity can result in weight gain, loss of bone density, and loss of muscle strength and flexibility of other areas of the body.
Disc injuries

- Protrusion of part of nucleus pulposus from the annulus Cause 1-5% back pain.
- Traumatic or stress related.
- **Common sites:** disc between 5\(^{th}\)-6\(^{th}\) and 6\(^{th}\)-7\(^{th}\) cervical vertebrae and 4\(^{th}\)-5\(^{th}\) lumbar and 5\(^{th}\) lumbar and 1\(^{st}\) sacral.
- Sensory nerves supplying anterior and posterior longitudinal ligaments generate pain signals.
Motor vehicle accidents continue to be the leading cause of injury-related deaths in the United States.

Studies generally concluded that front seat occupants are adequately protected against frontal impact if belts are worn in an airbag equipped vehicle.
- Unbuckled occupants can be hurt or killed by an airbag.
- Passenger-side airbags pose a lethal threat to children riding in the front seat of an automobile.
- The back seat is the safest place for children of any age to ride.
- Never put an infant (less than 1 year old) in the front of a car with a passenger-side airbag. Make sure everyone is buckled up.
Whiplash Injuries

- Relatively common sprain/strain injury of cervical region.
- Usually from automobile collisions, where neck undergoes sudden acceleration and deceleration.

**Symptoms:**
- Neck pain, muscle spasm, pain or numbness radiating from neck to shoulders, arms, hands and a headache (present in 50-60% of most cases)