What is biomechanics?

“Biomechanics is the study of the consequences of application of external force on the spine”
Primary Aim

- To understand the underlying mechanical aspects of various spinal disorders and their clinical treatments
- Develop optimal prevention or treatment strategies
Motion segment

- In the biomechanical context, the spine is treated as consisting of motion segments.
- Concept allows laboratory study of biomechanics of the spine in vitro.
- Assuming that behaviour of spinal column can be deduced from summing the behaviour of motion segments is fallacious.
The vertebral column: Basic anatomy

- 33 vertebrae:
  - 7 cervical, 12 thoracic, 5 lumbar, 5 sacral and 4 coccygeal

- Typical vertebra consists of cylindrical body and a dorsal arch

- Dorsal arch consists of pedicle, lamina, pars interarticularis and spinous process.

- 2 primary curvatures - thoracic and lumbosacral kyphosis

- 2 secondary curvatures - cervical and lumbar lordosis
Curvatures maintained by variation in the intervertebral disc heights and vertebral body dimensions.

Center of gravity of the spinal column passes from the dens of the axis to the promontory of the sacrum.
Regional characteristics of the vertebral column
The cervical column

- Vertebrae smaller
- Lamina narrow and overlap
- The pars interarticularis in the cervical spine have been termed the lateral masses
- The superior and inferior facets extend from the pars
The cervical facets from C2-3 to C6-7 are oriented approximately at 45 degrees with respect to the horizontal.

Coronal orientation of the facets.
Thoracic spine

- Thoracic vertebra are heart shaped
- Uniquely, they possess costal facets at the junction of the body and transverse process for articulation with ribs
- Transitional features:
  Upper thoracic (T1-4) resemble cervical, lower (T9-12) resemble lumbar.
- Spinous processes of T1, T2, T11 and T12 are horizontal.
- T3, T4 and T9, T10 are oblique.
- T5 – T8 spinous processes overlap considerably and are long and vertical.
- Thoracic facets are oriented along coronal plane.
- Thoraco-lumbar junction: there is change to assume a more sagittal orientation.
Lumbar spine

- Largest and typically increase in diameter as one descends
- Bodies of L1-2 vertebra are deeper dorsally, that of L4 -5 deeper ventrally while L3 is transitional
- 5th vertebra represents the transition from lumbar to sacral spine
L5 body is taller ventrally contributing to the lumbosacral angle.

Articular facets are oriented obliquely in the sagittal plane limiting axial rotation of the spine.
Sacrum and Coccyx

- Sacrum is triangular, concave and having a relatively smooth pelvic surface.
- Dorsal surface formed by the fusion of costal ligaments and transverse processes of sacral vertebral elements.
- The fused bodies are demarcated by transverse lines that end laterally in four pair of ventral sacral foramina.
Intervertebral discs

- 23 Intervertebral discs are interposed between the vertebral bodies.
- Most rostral - C2-3 disc and distally L5- S1 disc.
- They account for one third to one fifth of the height of vertbral column.
Four concentrically arranged components:
- Outer alternating layer of collagen fibres forming the peripheral rim of annulus fibrosus
- Fibrocartilage component that forms a major portion of the annulus
- Transitional region: annulus and nucleus merge
- Central nucleus pulposus (NP): Mucoprotein gel

Age related disc changes:
- Loss of water content of NP and height
- Number and size of collagen fibres decreases
Structural organisation of the discs permits them to tolerate compression, shear, torsion and bending forces.

During axial loading stress, the first component to fail is the vertebral end plate, due to herniation of the nucleus pulposus into the end plate.
Ligaments

- The longitudinal ligaments
  - Anterior
  - Posterior
- Ligamentum flavum
- Supraspinous ligament
- Interspinous ligament
- Intertransverse ligament
- Capsular ligaments
Anterior longitudinal

- From occiput to sacrum covering a fourth to third of the ventral circumference of vertebral bodies.
- Consisting of three layers
  - Deepest layer binds the edges of disc extending between adjacent vertebrae.
  - Middle layer binds vertebral bodies and disc over three levels
  - Superficial layer extends over four or five levels
  - High collagen content preventing hyperextension and over distraction
- **Posterior longitudinal ligament**
  - Begins at C2 as the tectorial membrane and extends up to sacrum
  - Fibres spread out at the disc level and narrow in the middle of vertebral body
  - The ligament is much thinner over the vertebral body than over the disc
  - Multilayered, maximum thickness in thoracic region
Ligamentum flavum

- Yellow ligament (flava = yellow)
- High elastin content
- Broad paired ligaments - connect the lamina of adjacent vertebrae
- Extend from C1-2 level to L5-S1
• Arise from ventral surface of caudal lamina and attach to dorsal border of adjacent rostral lamina

• High elasticity, assume their original size once a flexed spine straightens or extends

• Loose their elasticity with age, impinge upon the dura when slack
Capsular ligaments

- Attach to vertebra adjacent to articular joints.
- Perpendicular to the plane of facets.
- Primarily prevent distraction of the joint.
Intertransverse ligaments
- Seen only in thoracic and upper lumbar spine.
- Pass between the transverse processes and attach to the deep muscles of the back.

Interspinous and supraspinous ligaments
- Interspinous attach from base to tip of each spinous process
- Supraspinous attach at the tips of spinous processes
- Ligament is weakest in cervical region and becomes progressively stronger caudally
Biomechanical concepts

Deformations
- Application of force to a rigid body like the spine results in deformation
  - Translational: change in length
  - Rotational: change in the angle

Strain
- Change in unit length/angle in body subjected to force
Tensile or compressive stress

Shear stress

Torsion
Spinal motion

- Degrees of freedom is a useful concept in the description
- No of unique independent motion one vertebra can have with respect to another.
- Six degrees of freedom
  - Three translational
  - Three rotational, along three axes
Movements of the spine
Mobility of the normal spine

The image shows a graph illustrating the mobility of the normal spine in different movements. The graph includes sections for combined flexion/extension, one side lateral bending, and one side axial rotation. Each section displays data for different vertebrae levels, from C0-C1 to L5-S1, indicating the range of motion at each level.
Facets

- 18% of compressive load, 45% of torsion strength and variable amount of stability contributed by facet joints

- Do not substantially support axial compressive load unless spine is in extension

- Also changes with orientation of facets
Coupling

- Defined as obligatory movements of the spine (translations and rotations) that accompany a primary motion
- Principal motion is defined as the motion produced in the plane of the force
- Any associated out of phase motion is coupled
Instantaneous axis of rotation

- Defined as the axis perpendicular to the plane of motion and passing through the points within or outside the body which is static during the motion.
- Example, when opening a door, the axis of rotation passes through the hinges.
Functional biomechanics of the spine
Spinal stability

- **Paramount concept**
  Ability of spine to maintain its pattern of displacement under physiologic loads without producing:
  - Incapacitating pain
  - Deformity
  - Neurological deficit
Theories of spine stability

- The two column concept:
  - Advanced by Holdworth
  - Stressed upon the integrity of posterior ligamentous complex in maintaining stability.
  - Unstable fractures involved disrupted PLC and one component of anterior Column.
Three column concept:

- Better agreement with clinical observations regarding spine stability
- For instability 2 out of the 3 columns must be damaged.
Advantages of three column concept

- Assesses bony collapse associated with axial load bearing.
- Also details assessment of distraction, flexion and extension components of injury (injury to dorsal elements).
- Middle column comprises of region of neutral axis.
- Spine considered to be unstable when any of the two columns are involved.
- Thus, in three column concept a burst fracture is considered to be unstable.
Biomechanics of CVJ

- Cervical spine most mobile part of axial skeleton
- Average range of flexion – extension at occipitoatlantal joint 13-15 degree
- Additional 10 degree occurs at atlantoaxial joint
- Flexion extension evenly distributed over entire cervical spine
- Maximally at C5 – C6
- Anterior-posterior translation between dens and anterior atlantal arch 3mm
- In TAL rupture 5mm displacement occurs
- When alar ligaments also rupture, >5 mm separation occurs
Biomechanics of CVJ

- Axial rotation occurs only at atlantoaxial joint
- Maximum limit of rotation is 40-45 degrees
- Beyond 45 degree facets get locked
- Rotation >32 degrees leads to angulation of contralateral vertebral artery
Jefferson fracture
- Diffuse axial loading of cervical spine
- Bilateral anterior and posterior arch fractures
- Biomechanically, stable till the lateral mass displacement more than 5 mm, implying transverse ligament disruption.
Fracture of the dens

Type 1 - avulsion injury of the dens. Stable

Type 2 - dens fractured along the base due to flexion/extension injury. Unstable, because dislocation may increase

Type 3 - produced by flexion or compression forces or both.
Lower cervical spine

- **Burst fractures**
  - Disruption of the body and intervertebral discs
  - Direct axial loading of the spine
  - Theoretically should be stable as the PLC is intact
  - But, mostly associated with PLL damage and disc injury making it unstable
  - Biomechanically, only anterior decompression and fusion is not appropriate as it disrupts viable ALL and PLL
  - Circumferential stabilization may be indicated
Thoracic spine injuries

- Mostly caused by flexion compression forces
- The bending moment developed at the vertebra in question is dependent on the length of the column and distance between the line of gravity and the centrum
Distance from centrum

Gravitational load

Bending moment = Load x distance
In flexion compression injury,

- Distraction and damage of posterior ligament complex may be more pronounced
- Thus these injuries are more unstable than burst fractures.
- The flexion bending moment produced naturally in the lower thoracic spine (T10-12) by anatomic factors
  - Termination of rib cage
  - Normal thoracic kyphosis
  - Orientation of the facets
AO CLASSIFICATION

Arbeitsgemeinschaft für Osteosynthesefragen

- 3 TYPES

TYPE A COMPRESSION FRACTURE

A1 impaction fracture
A2 split fracture
A3 burst fracture
TYPE B  FLEXION/DISTRACTION
B1 POSTERIOR DISRUPTION (LIGAMENTOUS)
B2 POSTERIOR DISRUPTION (OSSEOUS)
B3 ANTERIOR DISRUPTION THROUGH THE DISC

TYPE C ROTATION INJURY
C1 TYPE A + ROTATION
C2 TYPE B + ROTATION
C3 ROTATIONAL SHEAR INJURY
vertebral body fracture

posterior column# or rupture of posterior ligaments

+ rotation

- type B

+ type B3.1

- type A

+ type C
### Thresholds of clinical stability of functional spinal unit

<table>
<thead>
<tr>
<th></th>
<th>Cervical</th>
<th>Thoracic</th>
<th>Lumbar</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Relative sagittal plane translation</strong></td>
<td>&gt;3.5 mm</td>
<td>&gt;2.5 mm</td>
<td>&gt;4.5 mm</td>
</tr>
<tr>
<td><strong>Same</strong></td>
<td>&gt;20%</td>
<td>&gt;10%</td>
<td>&gt;15%</td>
</tr>
<tr>
<td><strong>Relative sagittal plane rotation</strong></td>
<td>&gt;11</td>
<td>&gt;5</td>
<td>&gt;5</td>
</tr>
</tbody>
</table>
Thank you