Anatomy, Biomechanics and Pathology of the Lumbar Spine

Beth K. Deschenes, PT, MS, OCS

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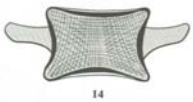
Lumbar Vertebrae

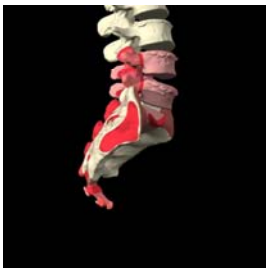
- 4 Functional Components
  - Vertebrae body
  - Pedicle
  - Lamina (post element)
  - Facet joint (post element)

Vertebral Body

- Designed for weight bearing and absorption of longitudinal directed forces
- Boxed shape with flat top and bottom surfaces (external)
- Vertical/Horizontal trabeculae (internal)
  - Vertical load→ transverse tension
  - Dynamic loading

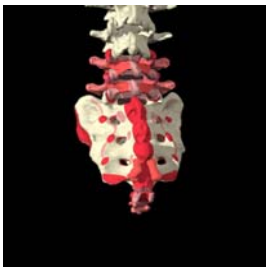


Pedicle



- Bony struts
- Only connection between posterior elements and vertebral body
- Transfer forces from post elements to vertebral body

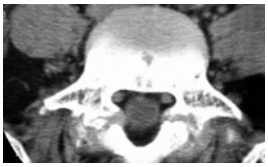
Lamina



- Project from each pedicle towards midline
- Completes formation of neural arch
- Transfer forces from post elements

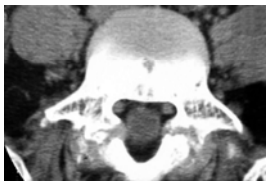
Pars Interarticularis

- Junction between lamina/pedicle
- Area of high bending forces/susceptibility
- Fatigue fracture/spondylolysis



Spondylolysis

- Spondylolysis-defect or break in the area between the superior/inferior articular process- 'fatigue fracture'



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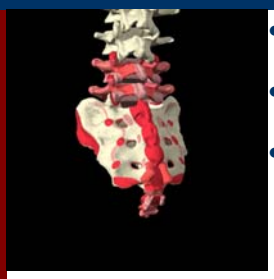
Facet Joint



- "Bony locking mechanism"
- Articulation between SAP/IAP
- Synovial joint with hyaline cartilage

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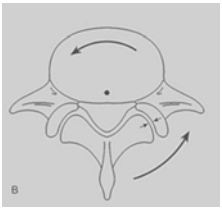
Facet Joint (orientation)



- Typically oriented in the sagittal/frontal plane
- Sagittal orientation-control rotation
- Frontal orientation-control anterior shear
- Protects the disc
- Variability in joint orientation

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Facet Joint (meniscoids)

- Synovial fold projecting into joint (2-5mm)
- Protect exposed articular cartilage during flexion
- Potential for entrapment during return from flexion (space occupying lesion) which may account for "locked back" or acute torticollis in the cervical spine

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Summary-Lumbar Vertebrae

- Vertebral body designed for absorption of longitudinal directed forces
- Bony struts (laminal pedicle) allowing for transfer of forces
- Facet joint ("bony locking mechanism") that protects the disc by controlling anterior translation and rotation.

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Ligaments of the Lumbar Spine

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Ligaments of the Vertebral Bodies

- Annulus fibrosus
- Anterior longitudinal ligament
- Posterior longitudinal ligament

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Anterior Longitudinal Ligament

- Covers the anterior aspect of the lumbar spine
- Continuous into the thoracic and cervical spine
- Primary attachment-anterior vertebral bodies
- Loosely attached to IVD
- Functions during extension motion to resist anterior bowing of the lumbar spine

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Posterior Longitudinal Ligament

- Covers the posterior aspect of the lumbar spine
- Narrowed centrally
- Expands laterally over the IVD (saw-tooth appearance)
- Functions to resist separation of the posterior vertebral body (flexion)

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Ligaments of the Posterior Elements

- Ligamentum flavum
- Interspinous ligament
- Supraspinous ligament
- Iliolumbar ligament

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Ligamentum Flavum

- Short/thick-joins lamina of consecutive vertebrae
- Paired at each level
- Medial aspect forms anterior capsule of facet joint
- 80% elastin/20% collagen

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Ligamentum Flavum

- Resists flexion
- Elastic nature prevents buckling inward during segmental approximation
- Evidence that pathology in this ligament plays a role in the etiology of spinal stenosis
  - Degeneration of elastic fibers
  - Proliferation of collagen fibers
  - Calcification and ossification of ligament

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Interspinous Ligament

- Connects adjacent spinous processes
- Fibers oriented obliquely-anterior to posterior
- Offers little resistance to flexion

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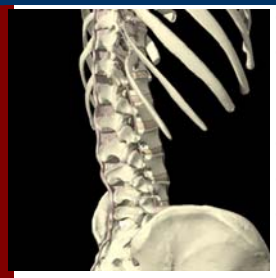
Supraspinous Ligament



- Lies posterior to the spinous process
- Consist of 3 layers composed of:
  - Tendinous fibers from longissimus thoracics
  - Dorsal layer of the TLF
- Well developed in the upper lumbar spine (L_3)
- Regularly absent in lower lumbar spine (L_4/L_5)
- Affords resistance to separation

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Iliolumbar Ligament

- Present bilaterally
- Runs from the TP of L_5 to the ant/med edge of the post ilium
- An L_4 band has been identified
- Some question as to its presence in children/adolescence
- Function: stabilize L_5 on the sacrum

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Anatomy of the Lumbar Lordosis

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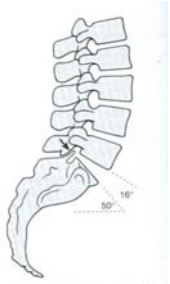
Formation of Lordosis



- Upper surface of sacrum inclined forward
- Lumbar spine must incline back
  - Wedge shape of L_5-S_1 disc
  - Wedge shape of L_5 vertebral body
  - Slight inclination of vertebrae above

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Advantage of the Lordosis

- Axial compression
- Transmitted thru posterior IVD
- Anterior aspect of vertebrae separate
- Tension in ALL
- Energy diverted into stretching ALL

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Liability of the Lordosis

- Tendency for L_5 and L_4 anterior migration
- Liability controlled by:
  - Bony locking mechanism (frontal orientation)
  - Annulus fibrosus (anterior oriented lamella)
  - Iliolumbar ligament
  - Anterior longitudinal ligament

What is Considered a Normal Lordosis?

- Difficult to determine
- Variation between individuals
- Appears to be a correlation between a loss of lordosis and the development of back pain and degenerative changes in the spine ('flat back syndrome')

Summary Lumbar Lordosis

- Shape formed by inclination of sacrum and wedge shape of L_5-S_1 disc and L_5 vertebrae
- Anterior migration of L_5 and L_4 controlled by facet joint/ligaments
- No universally accepted norm
- Loss of may predispose individual to increase compressive load on the IVD

Nerves of the Lumbar Spine

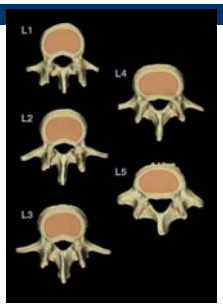
Spinal Cord

- Spinal Cord terminates at L_1-L_2
- Lumbar and Sacral ventral/dorsal roots course inferior (cauda equina)

Spinal Canal

- Surrounds the cauda equina
- Anterior border
  - Vertebral body (posterior)
  - IVD
  - PLL
- Posterior border
  - Lamina
  - Ligamentum flavum
- Lateral border
  - Pedicles

Spinal Canal



- Upper lumbar level- oval
- Lower lumbar level- triangular or trefoil

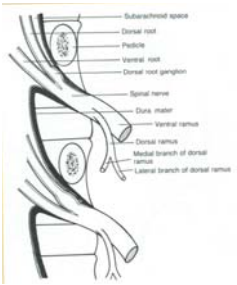
Spinal Canal Dynamics

- Cross-sectional area
  - ↑ with flexion
  - ↓ with extension
  - ↓ with compression

"Rule of Progressive Narrowing"-Penning (1992):

- The more the canal is structurally narrowed by a stenosis the more it will be narrowed by extension
- Cross-sectional area during extension
  - Normal spine- 9% ↓
  - Stenotic spine- 67% ↓

Spinal Nerves



- Nerve roots leave 'dural sac' but take an extension of the dural sleeve
- Merge to form spinal nerve
- Spinal nerve is numbered according to vertebrae beneath which it lies

Intervertebral Foramen

- Anterior
  - Vertebral body/IVD
- Posterior
  - Facet joint
  - Ligamentum flavum
- Superior/Inferior
  - Pedicle

Intervertebral Foramen

Spinal nerve normally occupies superior aspect

Variability in cross sectional area

Generally ↑ from L_{1-2} to L_{4-5}

L_5-S_1-smallest

L_5 spinal nerve most susceptible to foraminal stenosis

Summary

- Spinal cord terminates at L_1-L_2
- Cauda equina extends inferiorly and is surrounded by the spinal canal
- Spinal nerve numbered according to the vertebrae beneath which it lies
- Spinal nerve occupies IVF
- L5 spinal nerve most susceptible to foraminal stenosis
- Extension decreases the size of the spinal canal and IVF
- Flexion increases the size of the spinal canal and IVF

Anatomy of Intervertebral Disc

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Intervertebral Disc

- Annulus fibrosus
- Nucleus pulposus
- Vertebral endplate

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Annulus Fibrosus

- "Sheets" of collagen fibers (lamellae)
- Oriented 65°-70°to the vertical
- Direction of each lamellae alternates
- Anterior/lateral portions-thicker
- Posterior portion-thinner

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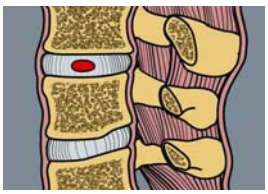
Nucleus Pulposus

- 70%-90% water
- Few collagen cells collagen fibers in a semi fluid ground substance
- Avascular structure



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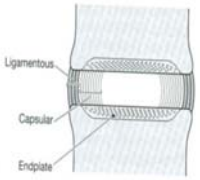
Vertebral Endplate

- Layer of cartilage on inferior/superior surfaces
- Covers nucleus pulposus and part of annulus
- Fibers of annulus fibrosus swing centrally
- Nucleus pulposus completely encapsulated
- 'Critical area' for nutrient supply



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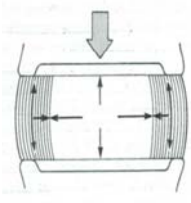
Function in Weight Bearing: The hydrostatic mechanism

- Compression→ increase in pressure in nucleus pulposus
- Pressure exerted radially on annulus
- Tension in annulus ↑ (annular bracing)
- Tension exerted back on nucleus
- Nuclear pressure exerted on the endplate



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Function
(control segmental movement)

- Sliding, rotary and distractive motions- controlled by annular tension

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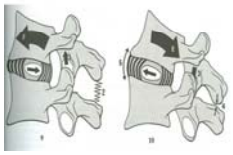
Function
(control segmental movement)

- Rocking motions (flexion/extension) controlled by nuclear/annular deformation
- Forward bend
  - Anterior annulus compressed
  - Posterior annulus tension
  - Nucleus migrates posterior
- Extension
  - Anterior annulus tension
  - Posterior annulus compressed
  - Nucleus migrates anterior



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Summary
Intervertebral Disc

- A design of 3 primary structures: Nucleus, Annulus, and Endplate
- Nucleus/Endplate designed to transmit pressure
- Annulus acts like a ligament to control segmental movement

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Biomechanics the Lumbar Spine

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Lumbar Spine

- Motion segment: two adjoining vertebrae and IVD in between
- Segmental motion
- Neutral/elastic zone

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Motion Segment

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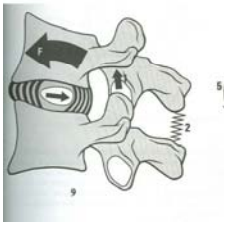
Segmental Motion (Flexion)

- Anterior rotation/translation
- IAP up/forward
- Motion limited by:
  - Ligament/capsule tension
  - Facet joint
- 5°-7°



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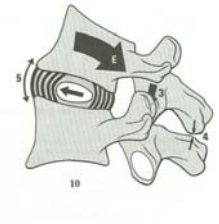
Segmental Motion (Extension)

- Posterior rotation/translation
- IAP moves down/back
- Motion limited by:
  - Interspinous ligament buckling
  - Bony impaction
- 4°-7°



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Segmental Motion (Rotation)

- Closes ipsilateral facet
- Opens contralateral facet
- Motion limited by:
  - Facet orientation
  - Annulus fibrosus
- 1°-3°
- Coupled with sidebend

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Segmental Motion (Sidebend)

- Creates a "extension/flexion" of the facets on the same segment
- Ipsilateral- close
- Contralateral-open
- 2°-5°
- Coupled with rotation

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Opening Movements

- Flexion
- Contralateral rotation
- Contralateral sidebending

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Closing Movements

- Extension
- Ipsilateral rotation
- Ipsilateral sidebending

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Stability vs. Instability

- Stiffness is represented by the stress and strain curve
- Instability is that lack of stiffness

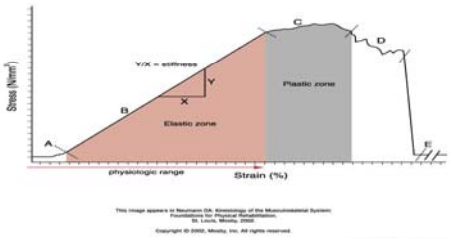
Clinical Instability as Defined by Panjabi

- Inability of the spine under physiological loads to maintain its normal pattern of displacement so there is no neurological damage or irritation, no development of deformity and no incapacitating pain

Neutral/Elastic Zone (Spinal Segment)

- Neutral Zone
  - Initial portion of ROM; toe region of the stress/strain curve
  - The amount of motion present up to the first onset of resistance
  - Zone of movement around the joints neutral position
- Elastic Zone
  - ROM near end range
  - Motion produced against increasing passive resistance

Stress and Strain Curve Review



Sub-systems that Stabilize the Spine

- Passive: vertebral bodies, facets joints and capsules, spinal ligaments and passive tension from spinal mm and tendons.
  - Stabilizes in elastic zone and limits neutral zone
- Active: mm and tendons that generate forces required to stabilize spine in response to changing loads.
  - Controls motion in and size of neutral zone.
- Neural control: through peripheral nerves and CNS.
  - Determines amount of spinal stability needed and acts on mm to produce required forces.

Pathology of the Vertebrae

Vertebral Body Compression Fracture

- Most often occur in thoracic spine T11-12
- Cancellous bone is crushed leading to wedge shape
- Usually due to osteoporosis or hard fall
- Diagnosed when anterior height is less than 80% of posterior
- 40% of women will have one by age 80

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Compression Fracture

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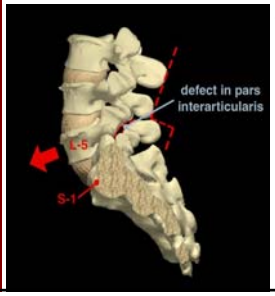
Spondylolytic Spondylolisthesis



- Spondylolisthesis- 'fatigue fracture' with associated slippage of the anterior aspect of the vertebral body

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Spondylolisthesis

- 2-6% of population
- ↑ prevalence between 10-15 years
- debate on progression of 'slip'
  - Lonstein (1999)-rarely progress after skeletal maturity
  - Floman (2000)-slip progression in 9-30% of adults in their 3rd decade

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Spondylolysis

- 6% of the population (Hensinger 1989)
- 5% by age 7
- 6% by adulthood
- 2x more common in boys
- More common in young athletic population
  - Johnson (1993) reported damage to the pars interarticularis in 25-39% sports related LBP
  - Power/weight lifting, racquet, sports, football, gymnastics

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Spondylolysis (Etiology)

- Exact cause-unknown
- 'Congenital' theory
  - Genetically predisposed weakness of the pars interarticularis
- 'Developmental' theory
  - Fatigue fracture 2° excessive mechanical usage on an immature spine

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Degenerative Spondylolisthesis

- Forward slippage of the vertebrae as a whole including the posterior elements
- 2° to degenerative/ degradative changes within the segment
- ↑ risk neural compromise

Spondylolisthesis (Grades)

- Defined by the % of slippage of the vertebral body
  - Grade 1-25% of vertebral body
  - Grade 2-50% of vertebral body
  - Grade 3-75% of vertebral body
  - Grade 4-100% of vertebral body

Clinical Presentation Spondylolysis/ Spondylolytic Spondylolisthesis

- Age-young
- Pain-mild to moderate somatic pain localized to LB, gluteal, and post thigh
- Hypermobility/Instability
- Pain with extension/rotation
- Palpable step (Magee 1997)
- May gradually adopt a posture of PPT, Knee flexion
- Significant hamstring tightness

Clinical Presentation: Degenerative Spondylolisthesis

- age-30-50
- signs/symptoms of spinal stenosis
- Signs/symptoms of instability

Summary- Spondylolysis/Spondylolisthesis

- Spondylolysis is a 'fatigue' fracture of the pars interarticularis theorized to result from either congenital weakening or mechanical overload
- Spondylolisthesis is a forward slippage of the vertebrae 2° to post element damage or degradative/degenerative changes
- Typically a problem of the younger population (unless it is degenerative)

Instability

- Increase in neutral zone leads to increase in laxity CREEP and increase in demand of spine to stabilize
- Panjabi et al suggest that increase in size of neutral zone is better indicator of segmental instability than ROM
- Ability of spine to resists loads depends on age, load specifics and properties of spine

Instability (Symptoms)

- History of chronic, recurrent LBP with associated high levels of disability
- Recurrence may be associated with minimal perturbations
- Short term relief from manipulation
- Poor outcome with 'general' exercise program

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Instability (Symptoms)

- ↑ pain with static postures
- ↓ pain with a change in position
- Descriptions of catching, locking or giving way
- Inconsistent symptomatology
- Positive change in status with supportive device

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Instability (Clinical Signs)

- ROM: WNL with presence of a painful arc vs. end range limitation
- Positive Gower's sign
- Reversal of lumbopelvic rhythm
- Points of hinging
- ↓ pain with deep muscle contraction (multifidus/transverse abdominus) during provocative movement
- Neuro exam: unremarkable
- Positive prone instability test

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Summary-Instability

- Neutral zone is controlled by an interplay between the passive, active and neural systems
- ↑ in size of neutral zone 2° to intersegmental injury (Panjabi)
- Specific clinical signs/symptoms

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Spinal Segment (Hypermobility/Hypomobility)

- Hypermobility
  - Increased motion in the neutral zone
  - Soft end feel
- Hypomobility
  - Motion in the neutral zone is decreased
  - Stiff end feel

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Pathology of the IVF

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Intervertebral Foramen Dynamics

- Cross-sectional area
  - ↑ with flexion
  - ↓ with extension
- Cross-sectional area
  - ↑ with contralateral sidebend, rotation
  - ↓ with ipsilateral sidebend, rotation

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Central Spinal Stenosis

- Narrowing of the spinal canal
- Creates a mechanical and vascular compression of the cauda equina-neurogenic claudication
- Single segment/multiple segments
- Males > females

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Developmental Stenosis


CONGENITAL

- Shape and size of vertebral canal is abnormally small as a result of aberrations in the neural arch
- Short thick pedicles
- Large articular process
- Increases the likelihood of compression in the face of the slightest aberration of the vertebral canal boundaries

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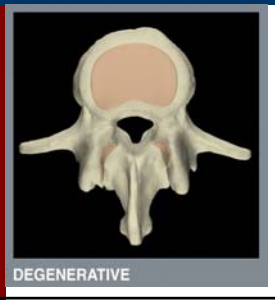
Acquired Stenosis


DEGENERATIVE

- Whenever any structure surrounding the vertebral canal/IVF is affected by disease or degeneration that results in enlargement of the structures into the canal or foramen (Bogduk 1997)
- Age

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Acquired Stenosis (Causes)


DEGENERATIVE

- Osteophytes (facet/vertebral body)
- Buckling of the ligamentum flavum
- Degenerative spondylolisthesis
- Tumors
- Bulging of the posterior annulus
- Hypertrophy of bone grafts/surgical fibrosis

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Central Stenosis (Clinical Presentation)

- Narrowing of the central canal
- Cauda Equina compression-neurogenic claudication
- Somatic LBP
- Bilateral, multisegmental LE pain (somatic), parasthesia
- Aggravating factors-extension activities (standing/walking)
- Easing factors-flexion activities (sitting/bending)

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Foraminal Stenosis

- Narrowing of the IVF
- Decrease IVF height due to disc degradation
- Decrease superior foraminal width
  - Short pedicle
  - Small sagittal diameter of spinal canal (central stenosis)
  - Degenerated/bulging ligamentum flavum

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Foraminal Stenosis

- L_{4-5} foraminal stenosis-L_4 root
- L_5-S_1 foraminal stenosis-L_5 root

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Foraminal Stenosis

- May have unilateral back/LE symptoms or bilateral symptoms with one LE being worse than the other
- LE pain may be somatic or radicular and follow a particular dermatomal pattern depending on the affected spinal nerve
- Aggravating factors-extension/ipsilateral sidebend
- Easing factors-flexion/contralateral sidebend

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Intermittent Vascular Claudication

- Compromise of arterial supply to muscle
- Symptoms may mimic those of spinal stenosis (LE pain with ambulation)
- Pain generally begins in the calf and extends proximally
- Pain not relieved with a flexed posture
- Must stop activity
- May have other signs of vascular disease

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Summary-Spinal Stenosis

- Process that involves narrowing of the spinal canal or IVF. May be developmental or acquired
- Typically effects the cauda equina creating a neurogenic claudication
- May be aggravated by standing and walking and relieved by sitting or flexing
- Should be aware of intermittent claudication as a differential diagnoses

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Pathologies of the IVD

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Pathologies of the Intervertebral Disc

- Internal disc disruption
- Radial fissures
- Disc herniation

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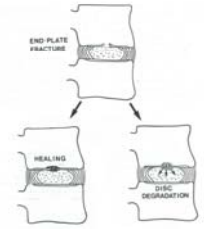
Internal Disc Disruption

- Endplate fracture secondary to compression
  - Sudden compressive loads (3000-10000N)
    - Fall on the buttocks
    - Forceful back muscle activity during a lift
  - Repetitive loading
    - Compression
    - Compression with flexion
  - Not symptomatic/may heal
  - Breakdown of the nucleus pulposus



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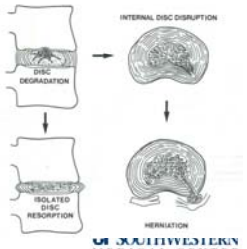
Internal Disc Disruption

- Endplate fracture
- Interference of the delicate homeostasis of the nucleus
- Progressive degradation of the nucleus (disc degradation)
- Overload of annulus and loss of disc height (isolated disc resorption)
- Reactive changes –osteophyte formation around the FJ and outer insertion of the annulus
- May account for up to 39% of patients with CLBP



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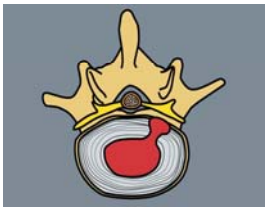
Radial Fissures

- Type of Annular tear
- Defined according to the extent to which they penetrate the annulus
- Creates a "pathway" for herniation of the degraded nucleus (disc herniation)



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Disc Herniation

Disc Herniation (Prolapse)

- Endplate fracture
- Degradation of the nucleus
- Radial fissure
- Migration of nuclear material
- Compression (MOI)
- Flexion, lateral flexion, rotation (MOI)

Disc Herniation (Prolapse)

- Protrusion
- Extrusion
- Sequestration
- Primarily occur in a posteralateral direction
- 90% involve the L_5-S_1/L_{4-5} disc
- age 30-50

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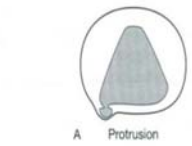
Disc Protrusion



- Marked bulging of the annulus without rupture of the annulus
- No contact between the nucleus and the extradiscal space

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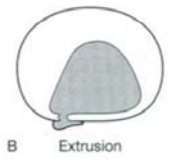
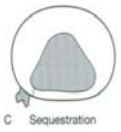
Disc Extrusion

- Annular rupture
- Expelled nuclear material is attached to the rest of the disc



Disc Sequestration

- Annular rupture
- Expelled material is not attached to the remainder of the disc

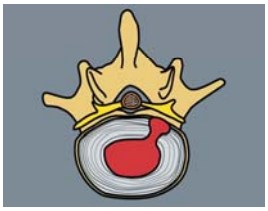


Structures Affected by Disc Herniation

- Annulus
- Dura
- PLL
- Nerve root
- Motion segment

Disc Herniation (Annulus, Dura, PLL)

- Stretching and irritation of outer annular wall, PLL
- Compression/irritation of dura matter
- Somatic pain-deep diffuse ache in a nonsegmental pattern
- Symptoms maybe localized or peripheralized
- O'Neill, et al. (2002) demonstrated that noxious stimulus of the IVD could result in LB and extremity pain. The distal extent of the extremity pain was dependent on the degree of noxious stimuli and could extend below the knee



Spinal Nerve/Disc Herniation

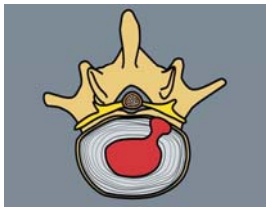
- Spinal nerve occupies posterior superior/lateral corner of IVD
- Unusual for herniation to affect spinal nerve at the same level
- Exception-far lateral herniation

Spinal Nerve/Disc Herniation

- Posterolateral herniation
  - 1 root
  - $L_{4\text{-}5}$ disc-L_5 root
  - L_5-S_1 disc-S_1 root
- Medial herniation
  - More than 1 root
- Central herniation
  - Cauda equina

Disc Herniation (Nerve Root)

- Compression of a undamaged nerve root (parasthesia)
- Compression and inflammation of a previously damaged nerve root or DRG (radicular pain)
- Radicular pain- sharp/lancinating pain that may follow a particular dermatome
- Conduction loss in the axons of a spinal nerve or it's nerve roots (radiculopathy) or nerve root compression



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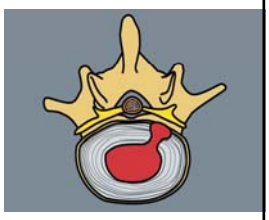
Disc Herniation (Nerve Root)

- L_4 Roots
  - L_{3-4} disc
  - Upper lateral gluteal region, anterior thigh, medial leg/ankle
- L_5 Roots
  - L_4-L_5 disc
  - Lateral gluteal region, posterolateral thigh, anterolateral leg, dorsum of the foot and big toe



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Disc Herniation (Nerve Roots)

- S_1 Roots
  - L_5-S_1 disc
  - Lateral gluteal region, posterolateral thigh leg, lateral border of foot 4th and 5th toes

*The larger the herniation, the greater number of roots affected (large posterolateral herniation at L_5-S_1 may affect the L_5 and S nerve roots

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Central Disc Herniation (Cauda Equina Syndrome)

- A central disc herniation may compress the cauda equina
- Saddle parasthesia
- Bowel/bladder dysfunction
  - Urinary retention-95% specificity/90% sensitivity
- Bilateral sciatic distribution pain
- Medical emergency

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Disc Herniation (Motion Segment)

- Decompression and reduction in motion segment height
- "Slackening" of intervertebral ligaments/capsule
- Motion segment instability

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Clinical Diagnosis of Discogenic Pain (Laslet 2005)

- Centralization of symptoms
  - Specificity 94%
  - Positive likelihood ratio 6.9
- Persitent pain between acute episodes (positive likelihood ratio 4.08)
- Significant loss of trunk extension (positive likelihood ratio 2.01)
- Report of vulnerability when in a semi stooped position or when performing twisting actions (positive likelihood ratio 2.47)

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Disc Herniation (Aggravating/Easing factors)

- Aggravating factors
  - AM discomfort-excessive imbibtion
  - Static WB postures-annular overload sitting > standing
  - Postures placing the spine in varying degrees of flexion
  - Coughing/sneezing-valsalva
- Easing factors
  - Walking
  - Standing
  - Positions of non-weight bearing

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Summary-Disc Herniation

- Process may be initiated by endplate fracture and gradual degradation of the nucleus
- Nuclear migration down a radial fissure
- May effect a # of structures (annulus, dura, PLL, DRG, nerve root) giving rise to either somatic or radicular pain
- May create a motion segment instability

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THANK YOU!!

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