Arvin Hariri
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Osteoradiology Fellowship Presentation

IMAGING OF THE POST-OPERATIVE SPINE

Functions of the Spine

- Provides stability and allows for motion
- Protects spinal canal and nerves
- Acts as shock absorber for load bearing
- Structural foundation for head, shoulders, and pelvic girdle

Five Basic Spine Movements

- Flexion
- Extension
- Rotation
- Lateral Bending
- Axial Loading

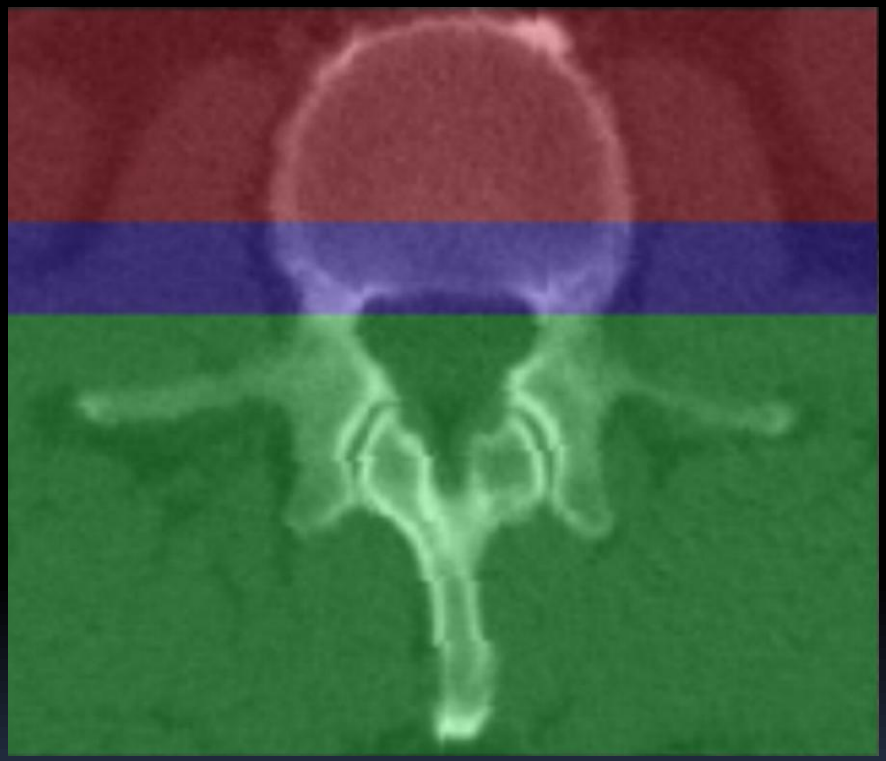
General Indications for Spine Surgery

- Degenerative deformities
  - Spondylolisthesis, disk disease, inflammatory/degenerative arthritis, spinal stenosis
- Trauma
- Infection
- Tumor
- Congenital anomalies
  - Spinal stenosis, spondylolysis/listhesis

Instability of the Spine

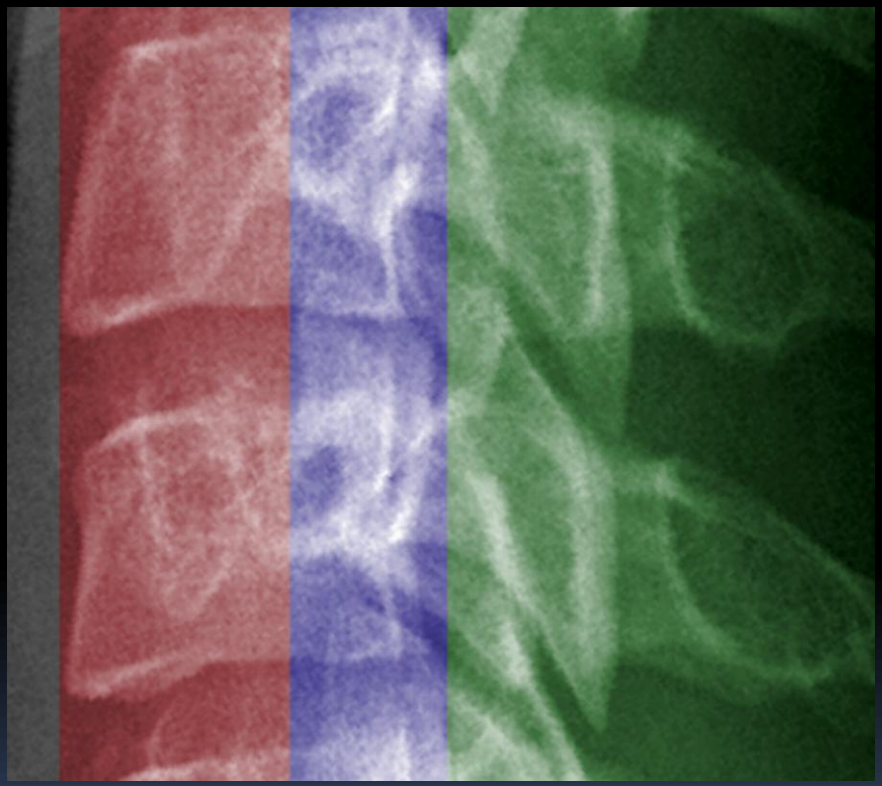
- Clinically determined
- In trauma, can be suggested by radiologists based on Denis' three column model
- More objective checklists have also been developed based on ligament transection experiments
  - Modified with results from other laboratory experiments and clinical observations
- Criteria not universally agreed upon

Denis' Three Column Model



- Anterior
  - ALL
  - Ant 2/3 of vertebral body + annulus fibrosis/nucleus pulposis
- Middle
  - Post 1/3 of vertebral body + annulus fibrosis/nucleus pulposis
  - PLL
- Posterior
  - Pedicles
  - Facets
  - Ligamentum flavum
  - Interspinous and supraspinous ligs

Denis' Three Column Model



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Denis' Three Column Model

- Generally, if 2 of 3 columns fail, spine considered unstable
- Functions of Columns:
  - Anterior
    - Bear axial load
    - Resist extension
  - Middle
    - Resist flexion
    - Bears some axial load
  - Posterior
    - Resist flexion
    - Provide stability during rotation and lateral bending

C-spine Instability Checklist

ELEMENT (Points)

- Anterior elements destroyed/unable to fxn (2)
- Posterior elements destroyed/unable to fxn (2)
- Positive stretch test: > 1.7 mm w/ head distraction (2)
- Radiographic criteria (2 each)
  - Flex-ex XR's: (1) sag plane transl >3.5 mm or 20%, (2) sag plane rotation >20 degrees
  - Resting XR's: (1) sag plane displ >3.5 mm or 20%, (2) rel sag plane angulation >11 degrees
- Abnl disc narrowing (1)
- Developmentally narrow (<13 mm) spinal canal (1)
- Spinal cord or nerve root injury (1 each)
- Dangerous loading anticipated (1)

*5 or more points considered unstable

T-spine Instability Checklist

ELEMENT (Points)

- Anterior elements destroyed/unable to fxn (2)
- Posterior elements destroyed/unable to fxn (2)
- Radiographic criteria (2 each)
  - (1) sag plane displ >2.5 mm, (2) rel sag plane angulation > 5 degrees
- Spinal cord or cauda equina damage (2)
- Disruption of costovertebral articulations (1)
- Dangerous loading anticipated (1)

*5 or more points considered unstable

L-spine Instability Checklist

ELEMENT (Points)

- Anterior elements destroyed/unable to fxn (2)
- Posterior elements destroyed/unable to fxn (2)
- Radiographic criteria (2 each)
  - Flex-ex XR's: (1) sag plane transl >4.5 mm or 15% (2) sag plane rotation (a) >15 degrees at L1-2 through L3-4, (b) >20 degrees at L4-5, and >25 degrees at L5-S1
  - Resting XR's: (1) sag plane displ >4.5 mm or 15%, (2) rel sag plane angulation >22 degrees
- Cauda equina damage (1)
- Dangerous loading anticipated (1)

5 or more points considered unstable

Basic Principles of Spine Surgery

- Purpose to achieve bony fusion and stabilize spine
- Internal fixators/hardware
  - Provide and maintain anatomic reduction
  - Temporary, will eventually fail or loosen
  - Decrease the risk of pseudoarthrosis
  - More effective than immobilization/external bracing
  - Decrease recovery time and need for bed rest

Implant Failure

- Can be immediate or delayed
- Immediate
  - Load applied to implant exceeds static strength of implant
- Delayed
  - Much more common than immediate
  - Due to cumulative damage related to critical loading
- Average spine undergoes 3 million cycles/yr

Types of Implants

- Multisegmental Fixation Implants
  - 1. Anchors
  - 2. Longitudinal members
  - 3. Cross-connectors
  - 4. Accessories
- Abutting Implants

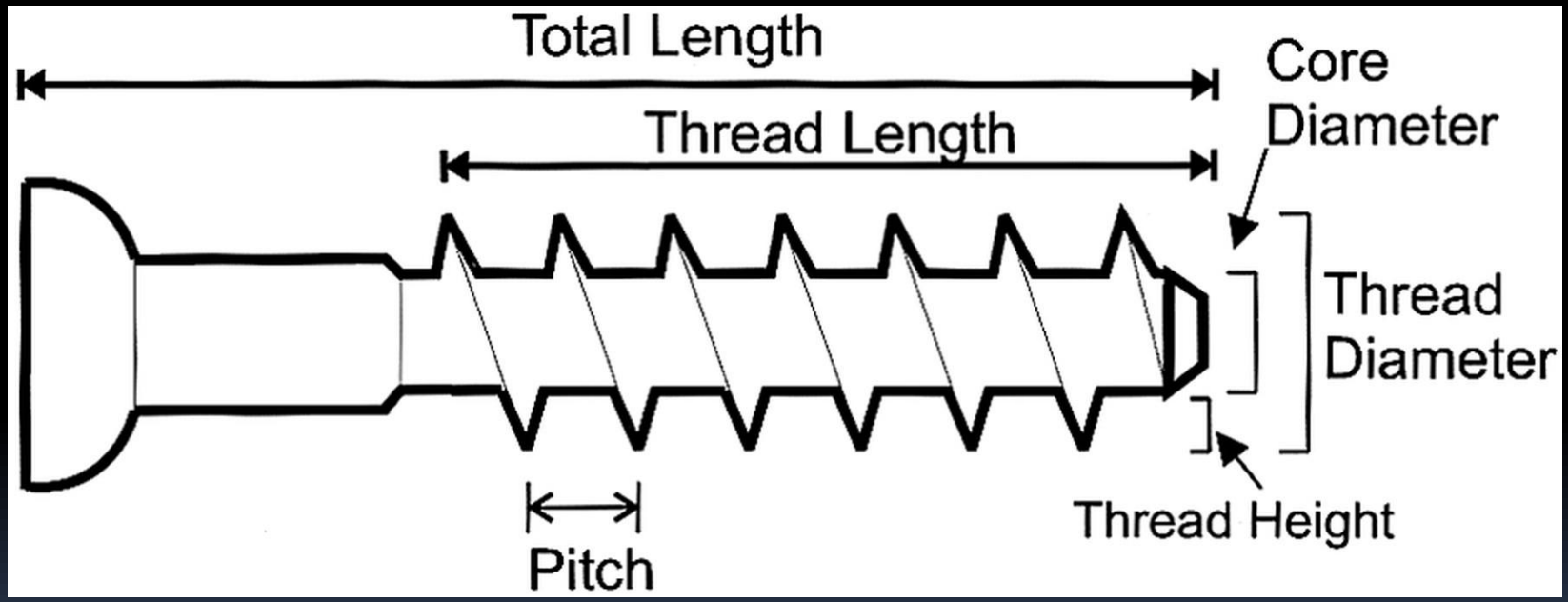
Anchors

- Penetrating
  - Screws
  - Staples
  - Nails
  - Spikes
- Gripping
  - Hooks
  - Wires

Screws

- Penetrating implants with pullout resistance
- Pullout resistance dependent on qualities of the following:
  - Screw
  - Bone
  - Surgical placement

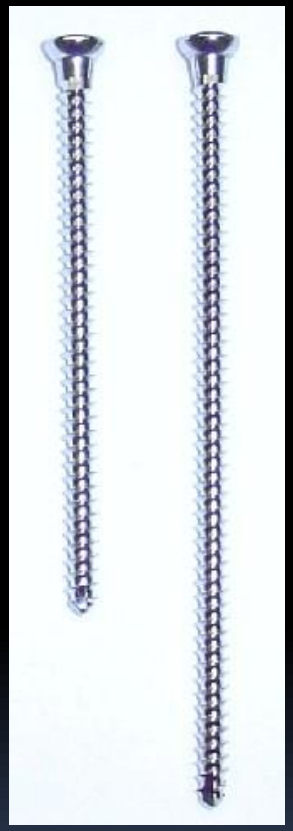
Anatomy of a Screw



Anatomy of a Screw

- Pullout resistance dependent upon volume and quality of bone between threads
- Can increase pullout resistance by
  - Increasing thread depth/diameter or thread length
  - Increasing pitch
  - Stronger bone (ie cortical bone)
  - Cortical penetration
  - Triangulation
    - Toed-in and toed-out demonstrate equally increased pullout resistance
    - Toed-out resists axial loads more than toed-in

Types of screws[A]



Cortical

Cancellous

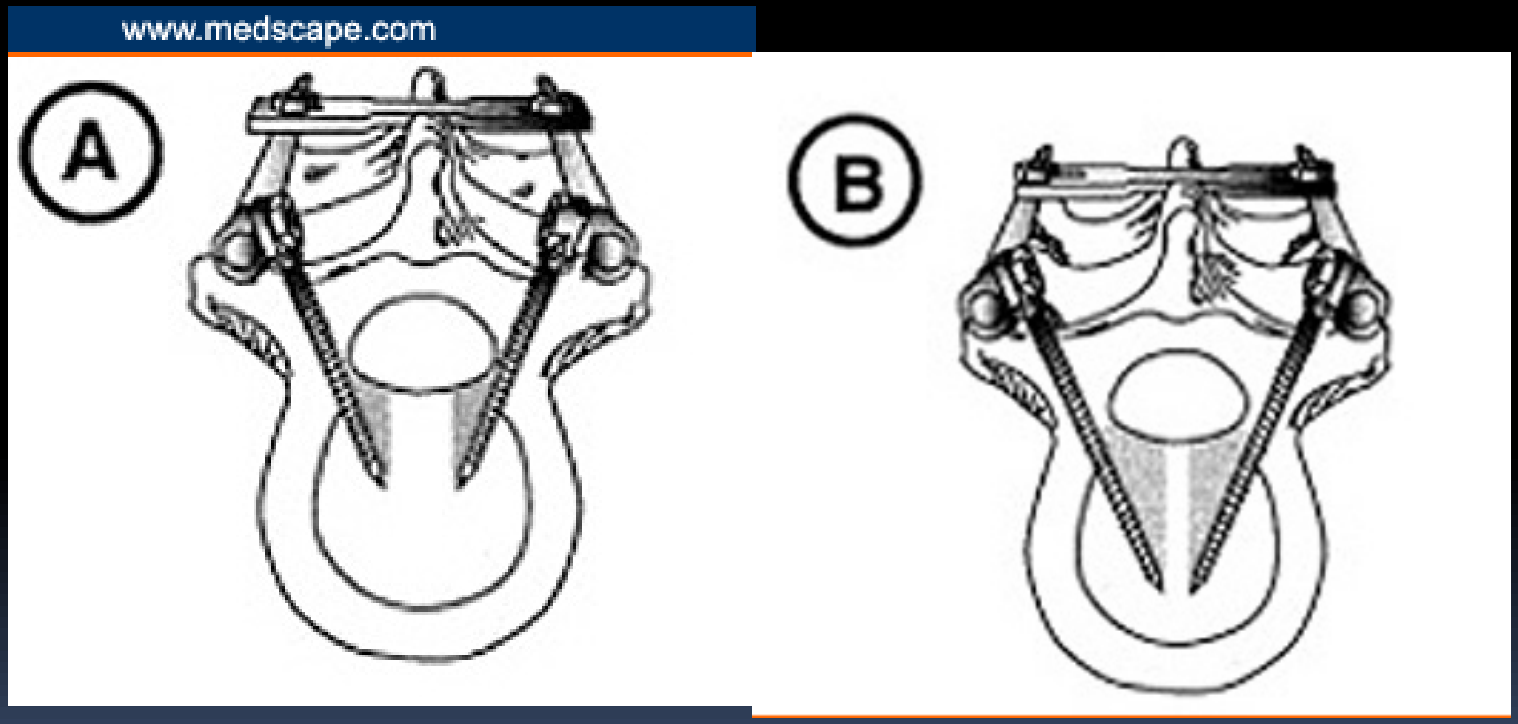
Lag

Knoringer

Types of spine screws

- Cortical screws have smaller thread and must be pre-tapped
- Cancellous screws have larger threads
- Lag screws have threaded end and smooth neck/shank
  - Pull fragments together
  - Same effect by overtapping proximal bone
- Knoringer screws are threaded on both ends, with smooth shaft in middle
  - Different pitch on two threaded ends
  - Differential advanced of threaded portions results in compression

Triangulation



Screw Fixation by Levels

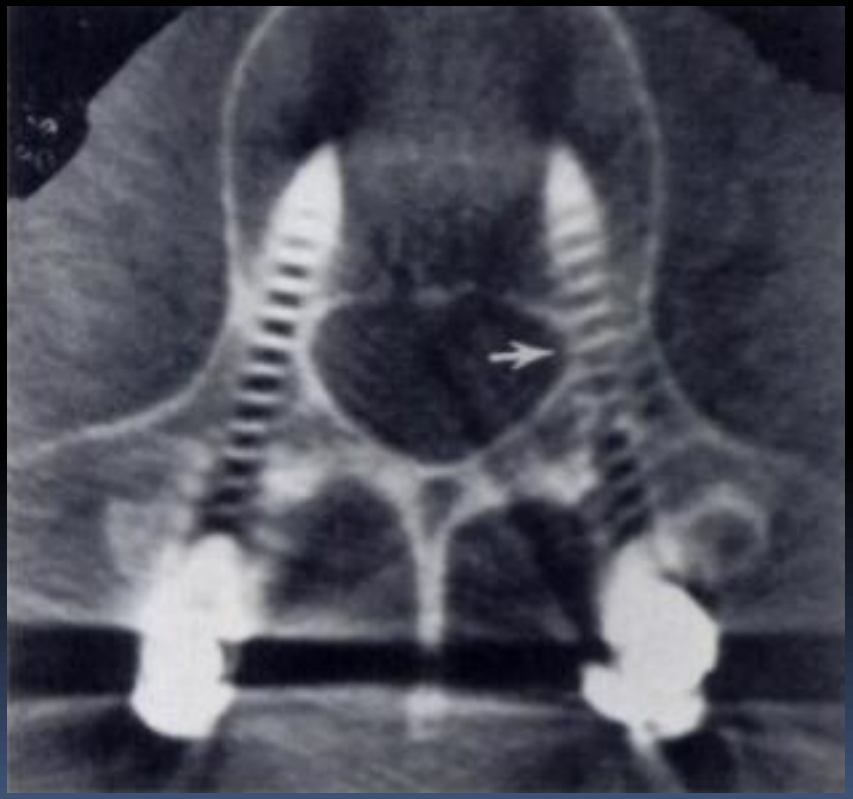
- Transcortical
  - Anterior screws at any level
- Lateral mass screws
  - C1, C3-C7
- Laminar screws
  - Cross diagonally
  - Uncommon, can be seen at any level, often C2
- Pars/Transpedicular screws
  - Definition of pars vs pedicle screw is dependent on depth of screw penetration
  - C2, entire thoracic and lumbar spine
  - C3-C7, but more often lateral mass screws at these levels
- Facet screws
  - Uncommon, and placed across facet joints
- Of note, placement of lateral mass or pedicle screws at C7 is difficult

Screw Fixation by Levels

- C1
  - Lateral masses
- C2
  - Pedicles
- C3-C6
  - Lateral masses
- C7
  - Lateral masses > Pedicles
  - Lateral masses smaller at this level than C3-C6
  - Level often skipped
- T-spine + L-spine
  - Pedicles

Screw Fixation Types

- Pedicle Screw:

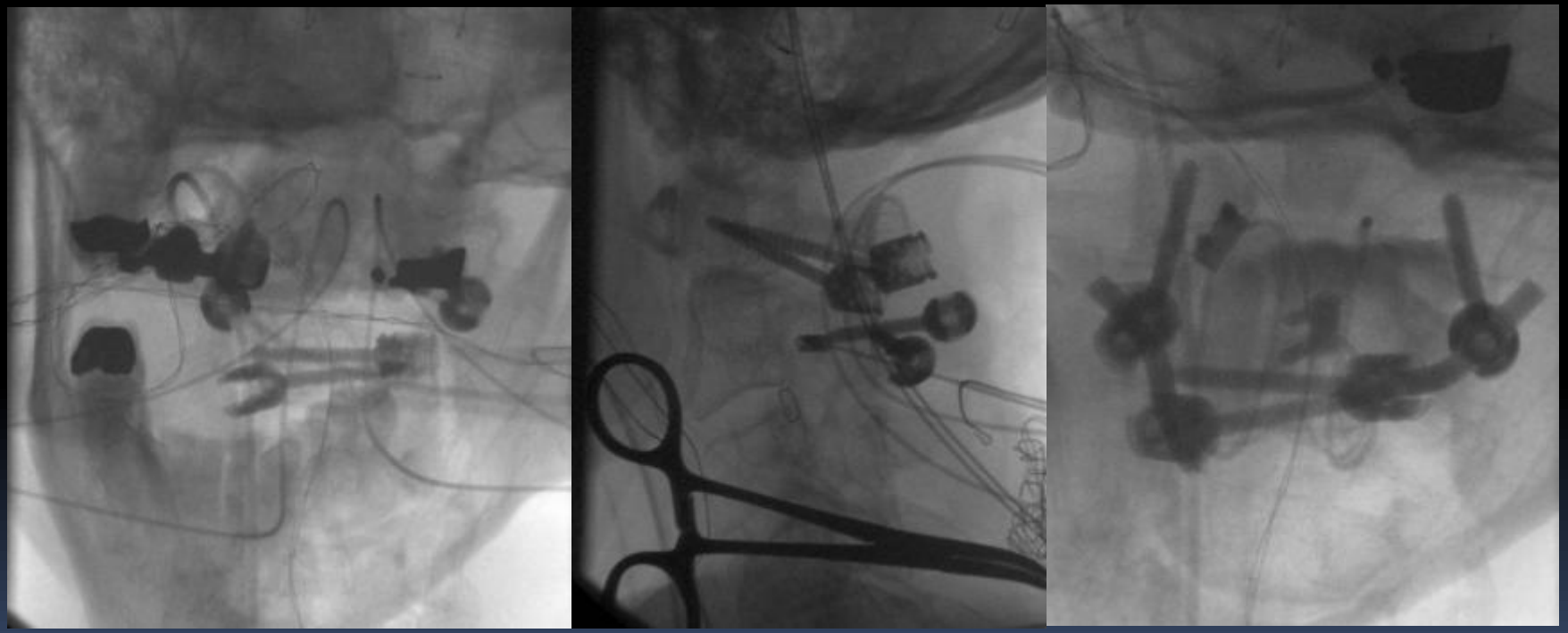


Screw Fixation Types

- Lateral Mass Screw:

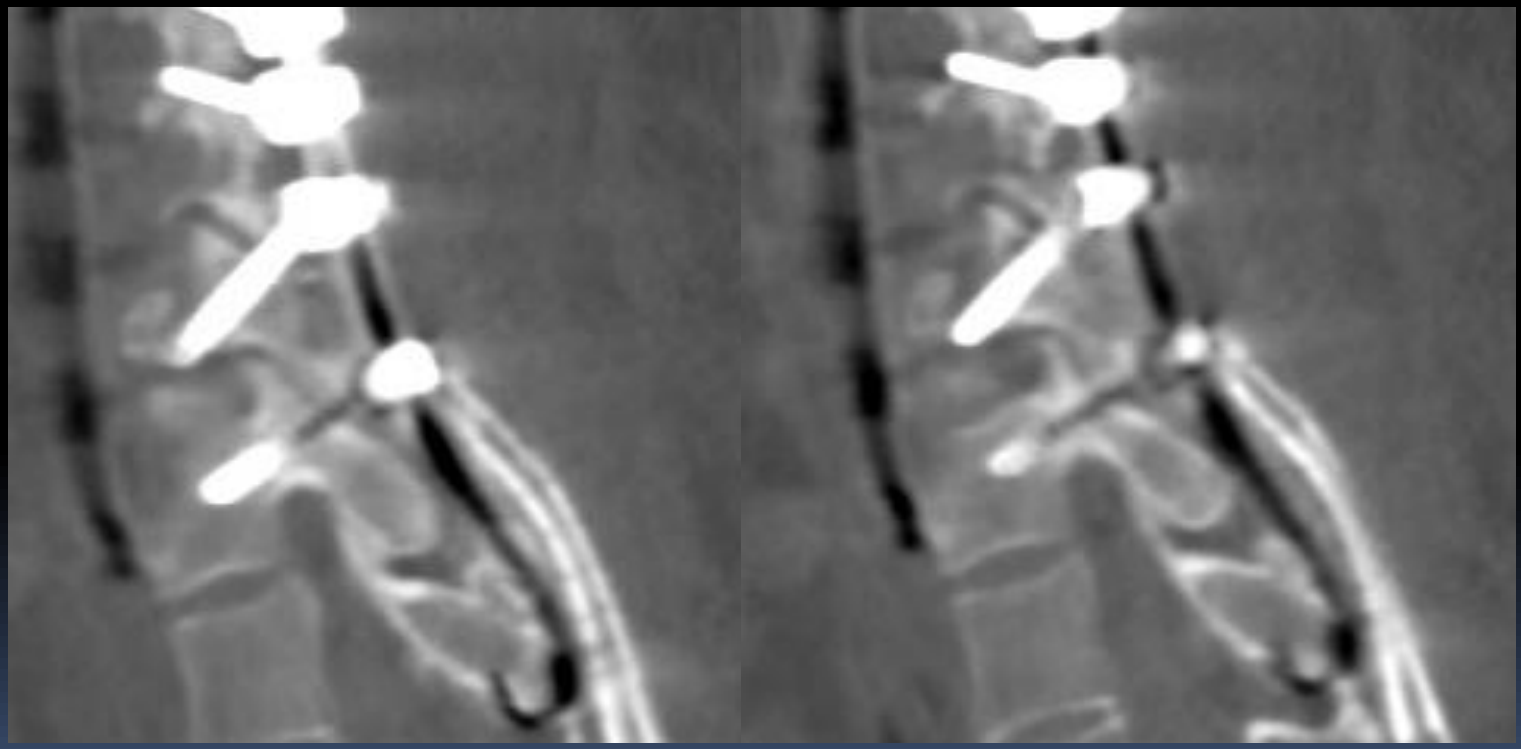
Screw Fixation Types

- Laminar Screw:



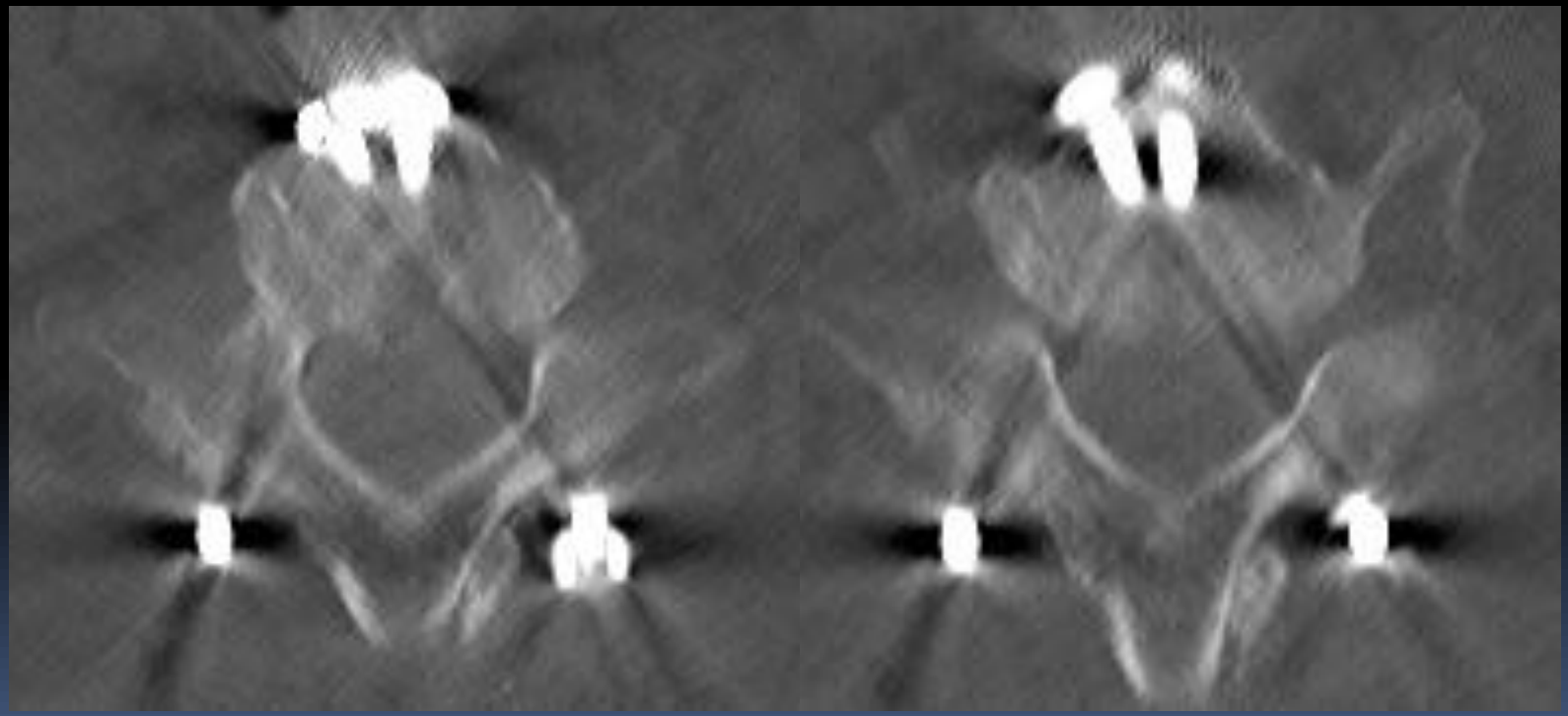
Screw Fixation Types

- Facet Screw:



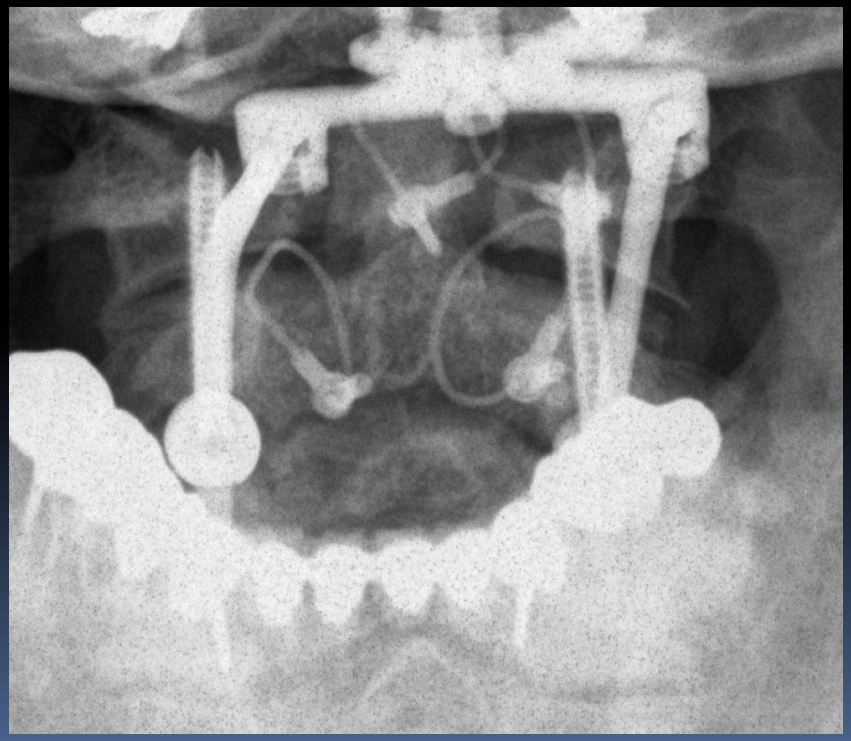
Screw Fixation Types

- Cortical Screw:

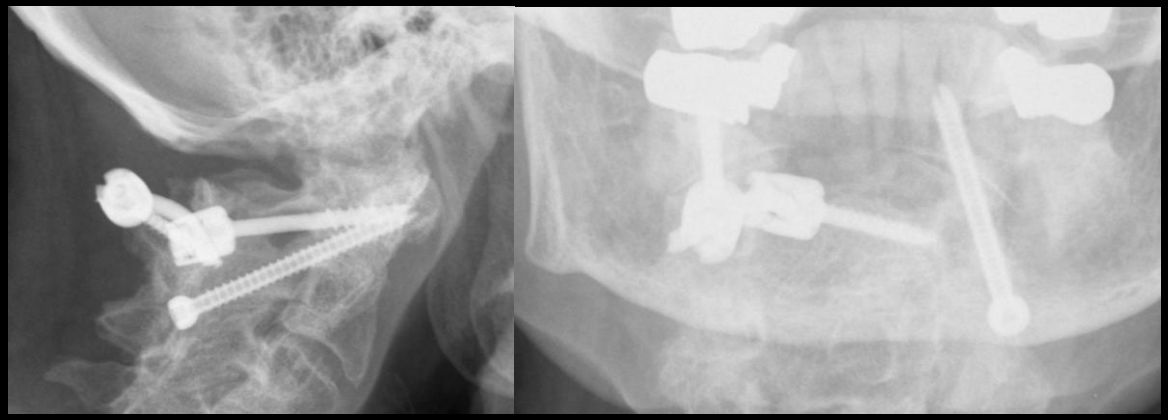


Screw Fixation Types

- Transarticular Screw:
  - Often placed from C2->C1
  - Technically difficult



Screw Fixation Types



Surgical Approaches by Levels

- Anterior approach
  - "Anterior" defined as anterior to cord
    - Includes lateral VB hardware in T+L spine
  - Increased morbidity and technical difficulty as must traverse neck, chest, or abdomen
  - Well defined landmarks exist for spine surgeons in neck
  - In chest/abdomen, often requires help of separate surgeon

Surgical Approaches by Levels

- Anterior approach
  - Preferred in C-spine because pathology is primarily discogenic
  - Can access disc directly, as opposed to attacking problem indirectly by posterior decompression
  - Lordosis an early degenerative change in C-spine, and can be corrected with bone graft

Surgical Approaches by Levels

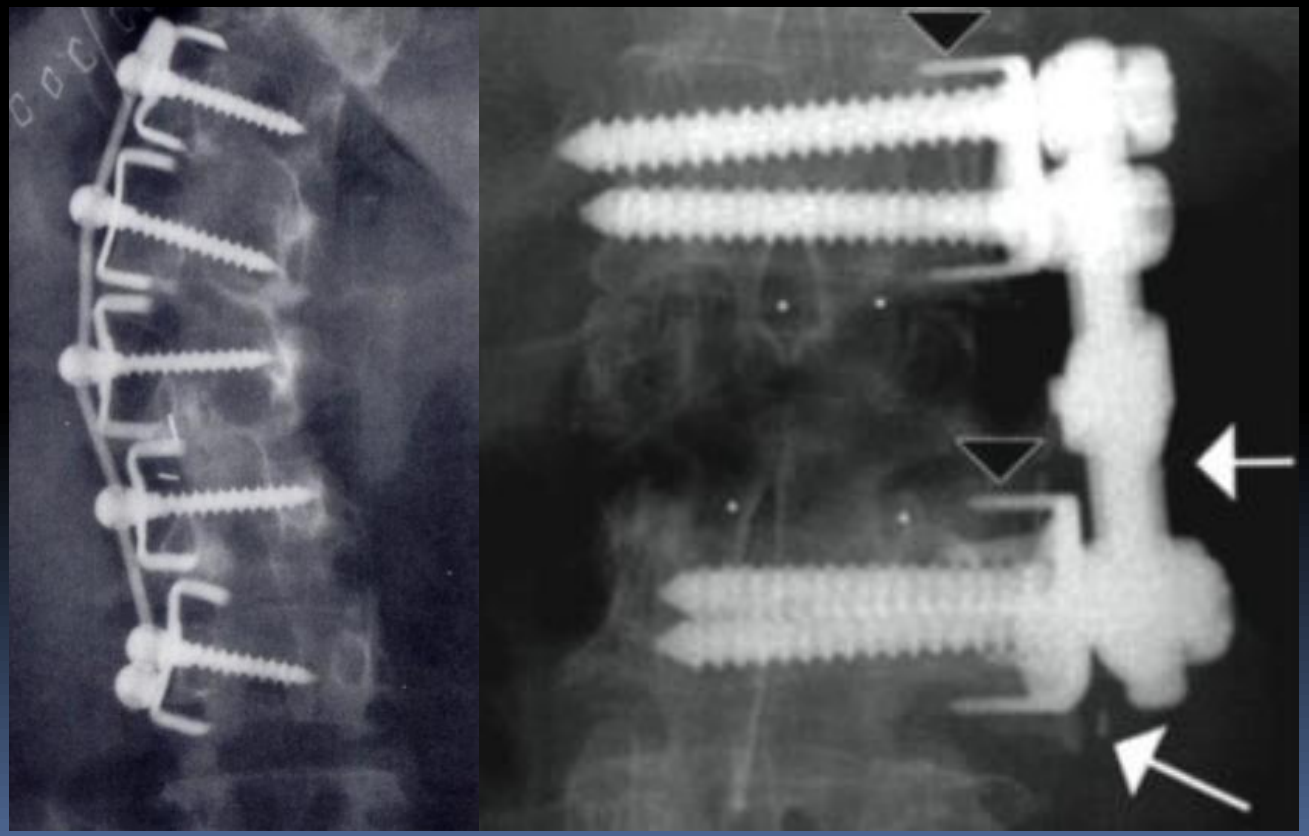
- Posterior approach
  - Preferred in thoracic and lumbar spine, as no need to traverse anterior organs
  - Of note, the spinal cord can not be moved at all, so disc can only be accessed posteriorly below cauda equina at L1-2

Anchors

- Penetrating
  - Screws
  - Staples
  - Nails
  - Spikes
- Gripping
  - Hooks
  - Wires

Anchors – Penetrating

- Staples
  - Can be placed across growth plate to decrease growth

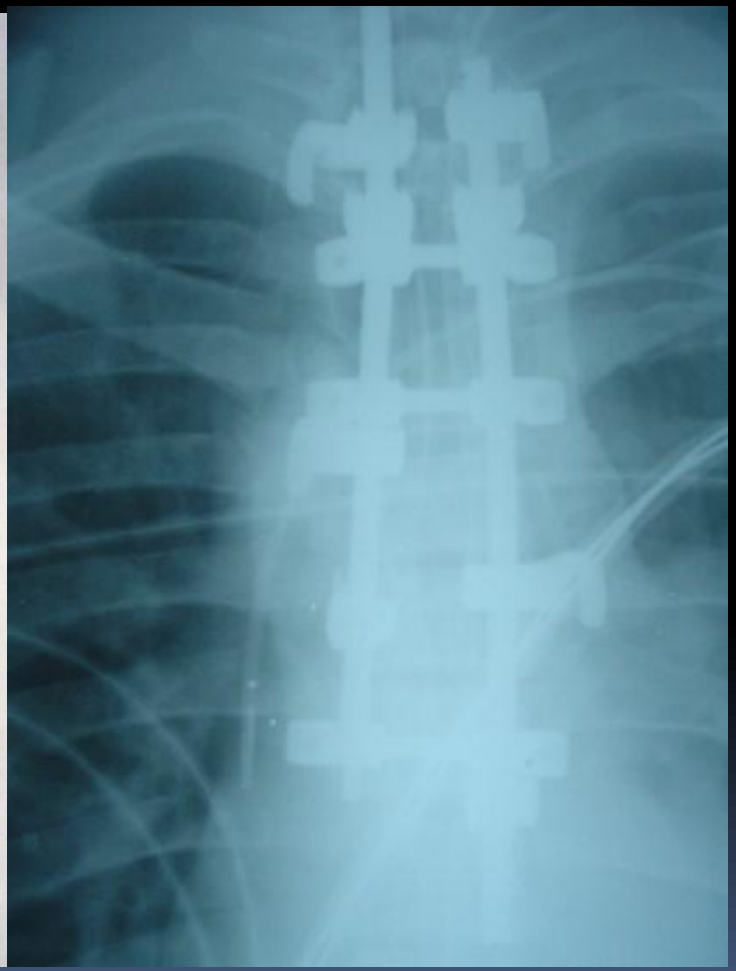


Anchors – Gripping

- Hooks
  - Usually hook around lamina
  - Can be upgoing or downgoing
    - If both types seen at one level, called claw mechanism
  - Can place transverse process or pedicle hooks
  - Better in osteopenic patients than screws

Anchors – Gripping

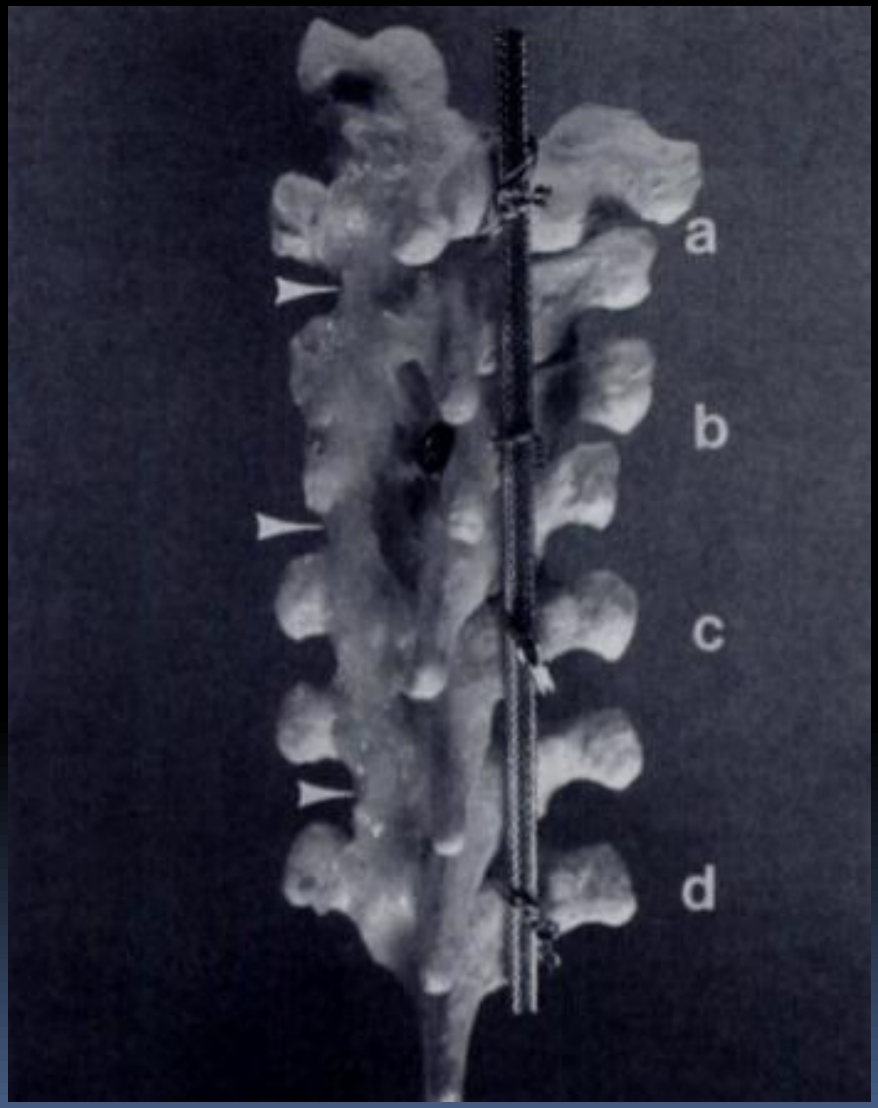
- Hooks



Anchors – Gripping

- Wires
  - Wires can directly fixate portions of the spine, or can attach to rods
  - Commonly attached to rods (Harrington, Luque, Cotrel-Debousset), Hartshill rectangles, etc
  - Very good at limiting flexion
  - Poor at limiting rotation and treating patients w/ compression of anterior thecal sac
  - Typically made of 20 gauge stainless steel
  - Primarily used in C-spine

Wires



Four common techniques to attach wire to rods:

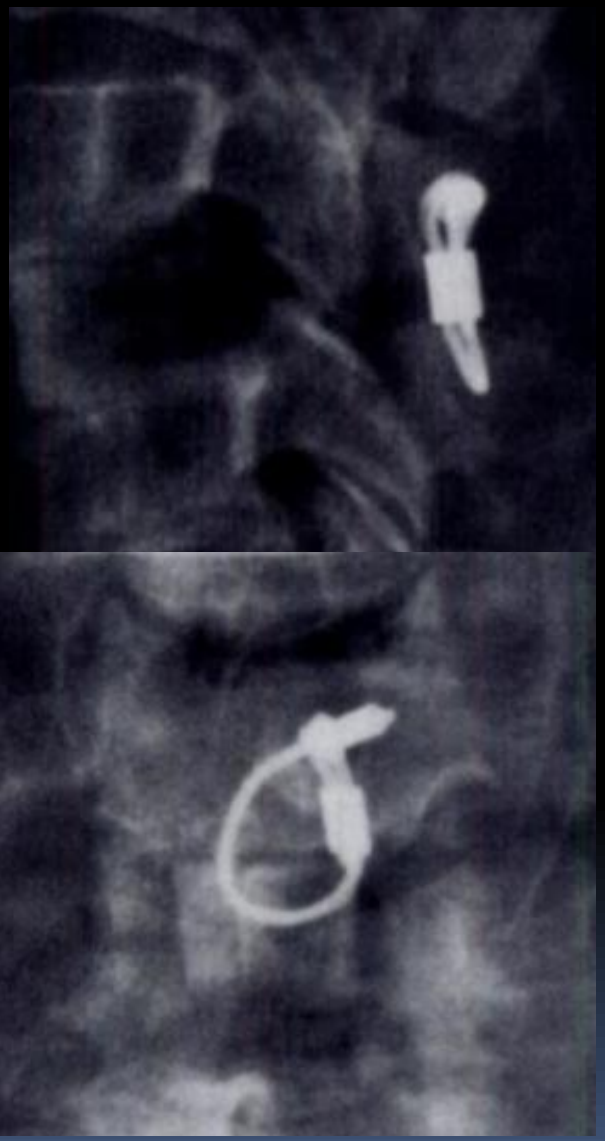
- A: Sublaminar (double strand)
- B: Interspinous
- C: Sublaminar Songer cable
- D: Subpars

Wires

- Sublaminar wires passed under lamina at each level blindly, w/ risk of possible damage to thecal sac
- Drummond system
  - Interspinous wires: passed through spinous processes and secured w/ buttons on each side of the spinous process

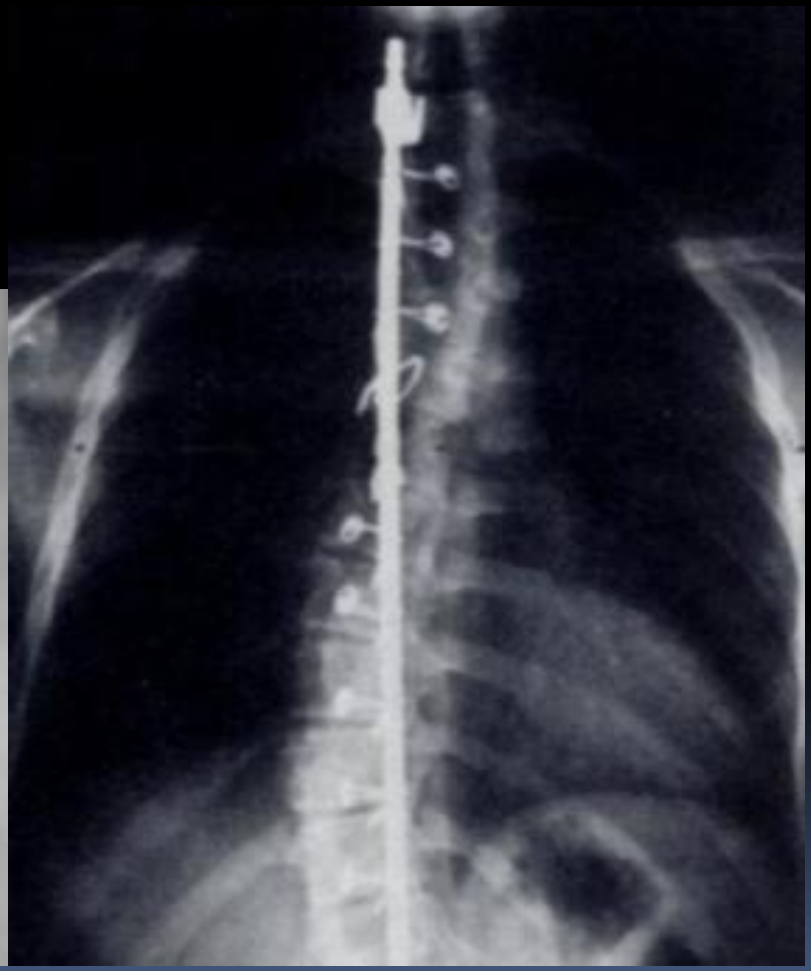
Wires

- Songer cables
  - Braided titanium or stainless steel
  - More pliable than wire
  - Held in place by metal crimp/collar



Wires

- Interspinous wires



Longitudinal Members

- Plates – 3 major types of screw-plate connectors
  - Constrained
  - Semiconstrained
  - Axially dynamic connectors
- Rods
  - Multiple different types of rods

Constrained Screw-Plate Connectors

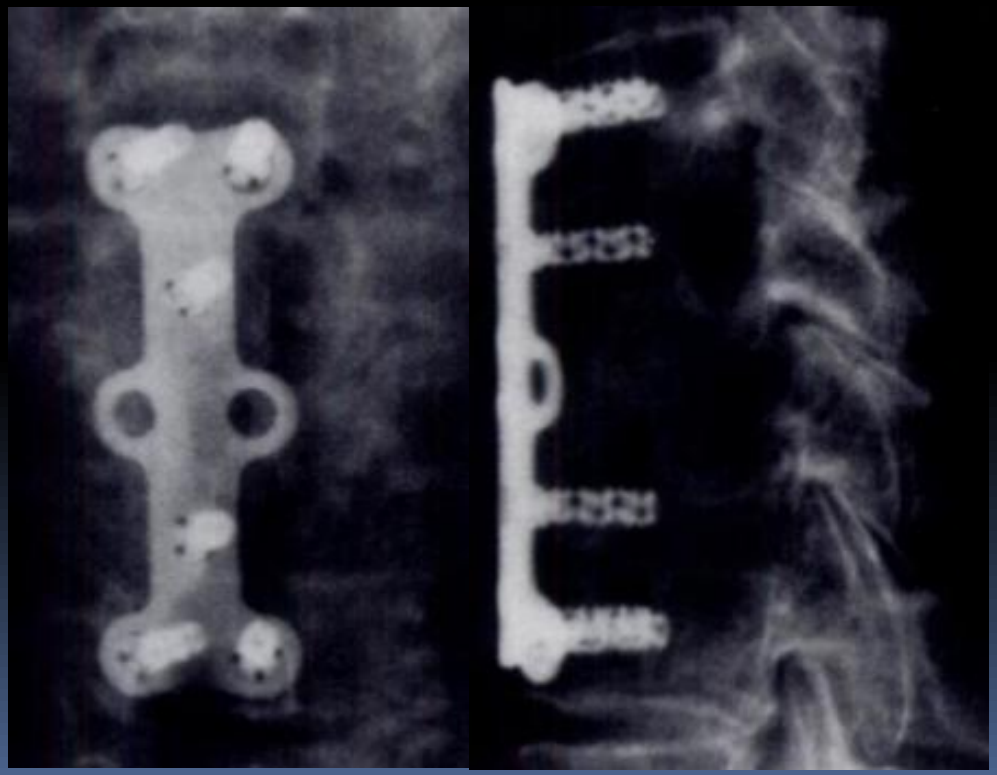
- Screw rigidly fixed to plate
- Does not permit significant subsidence
- Typically fail due to three problems
  - Construct failure
    - Implant bending, kickout, bone graft fracture
  - Implant fracture
    - Screw fx: Head if fixed core. Mid-screw if ramped.
    - Plate fx: Transverse in mid plate.
  - Stress shielding
    - Prevents fusion

Constrained Screw-Plate Connectors

- Strategies to rigidly fix screw to plate:
  - Expansion heads
  - Cam Locks
  - Screw head securing mechanisms
  - Locking plates
  - Screw with thread beneath neck to attach to plate

Constrained Screw-Plate Connectors

- Morscher Plate
  - Screw cap that locks plate and screws together
  - Screws have characteristic fenestrations

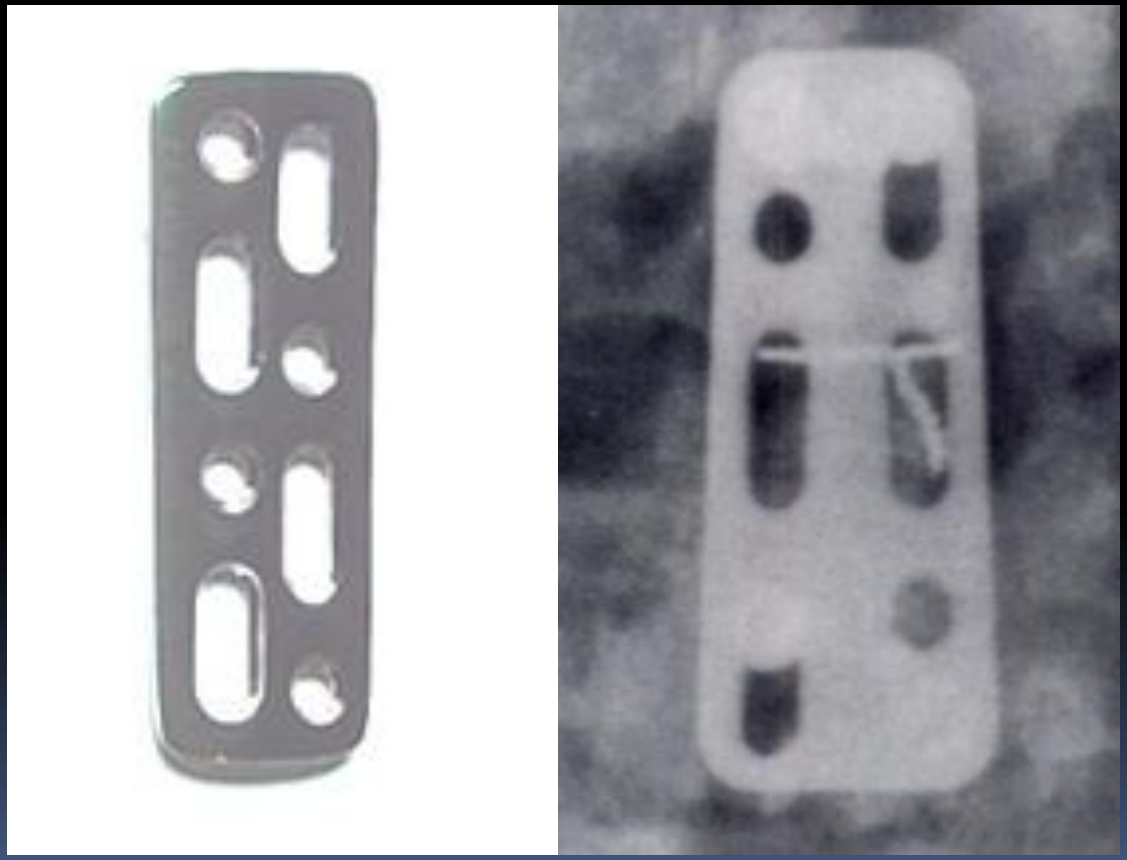


Semiconstrained Screw-Plate Connectors

- Screw used to approximate plate to bone
- Not rigidly affixed to plate
- Allow for toggling of screw in plate
- Therefore, allow for bone formation and fusion by permitting axial stress
- Examples:
  - Caspar plates
  - Dynamic compression plates
  - Lateral mass fixators

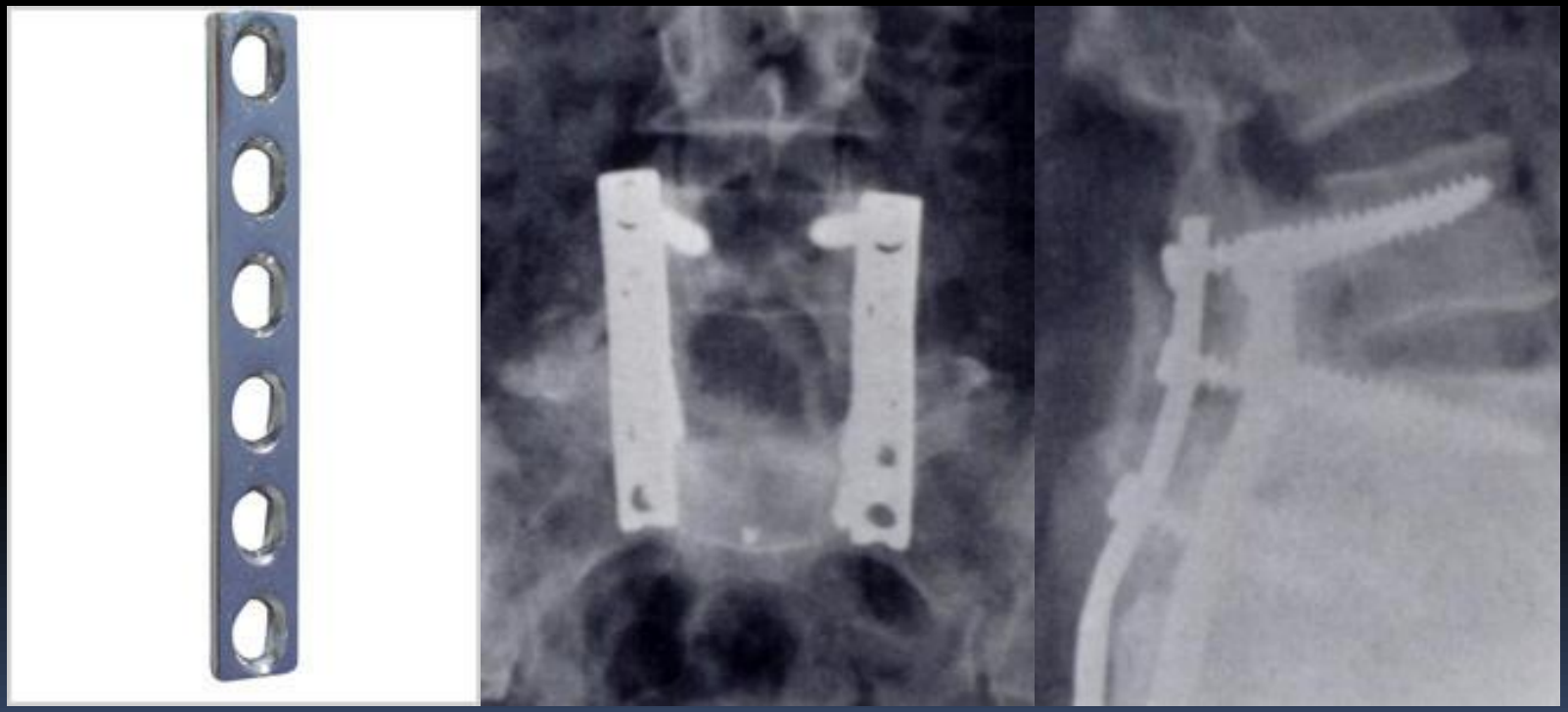
Semiconstrained Screw-Plate Connectors

- Caspar Plate



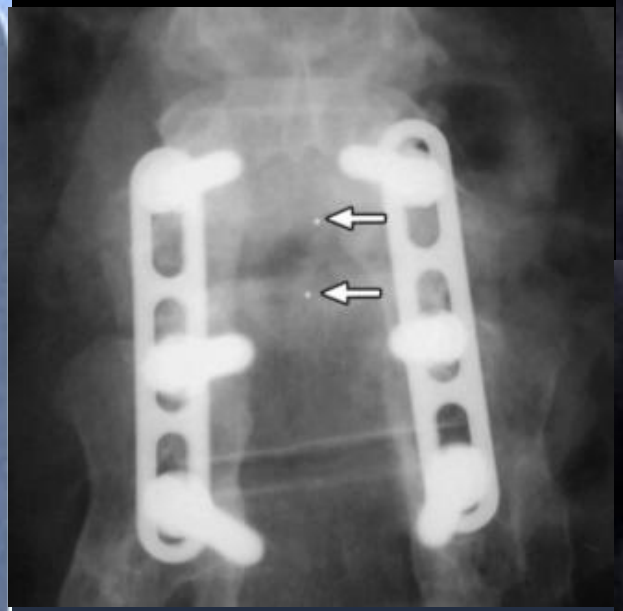
Semiconstrained Screw-Plate Connectors

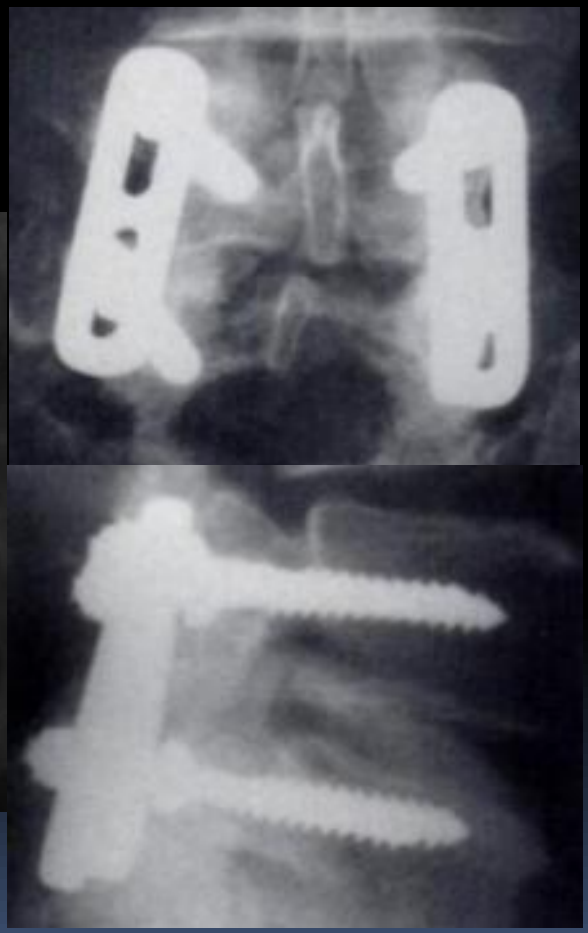
- Dynamic Compression Plates



Semiconstrained Screw-Plate Connectors

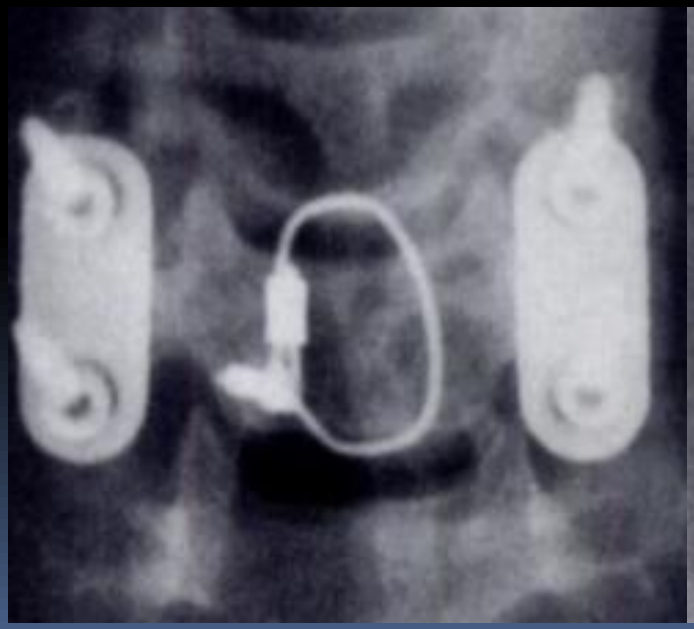
- Steffee Plates

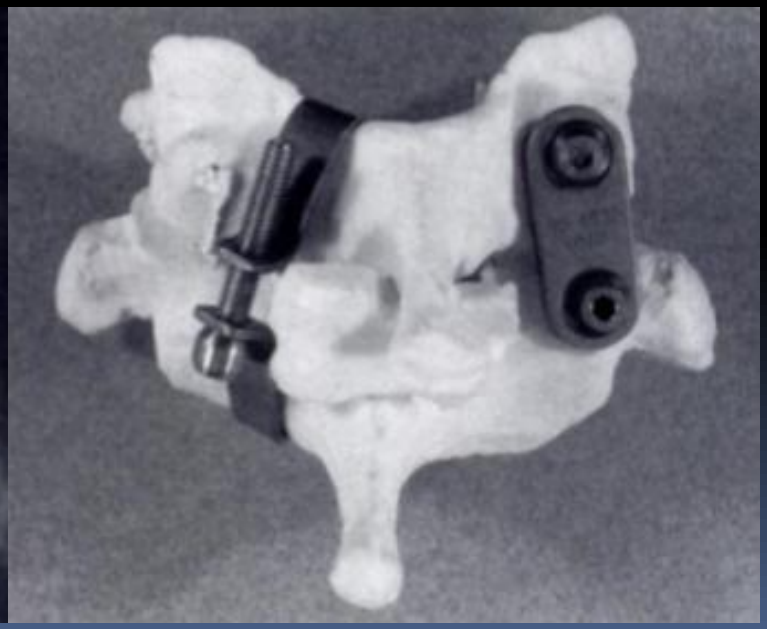




Semiconstrained Screw-Plate Connectors

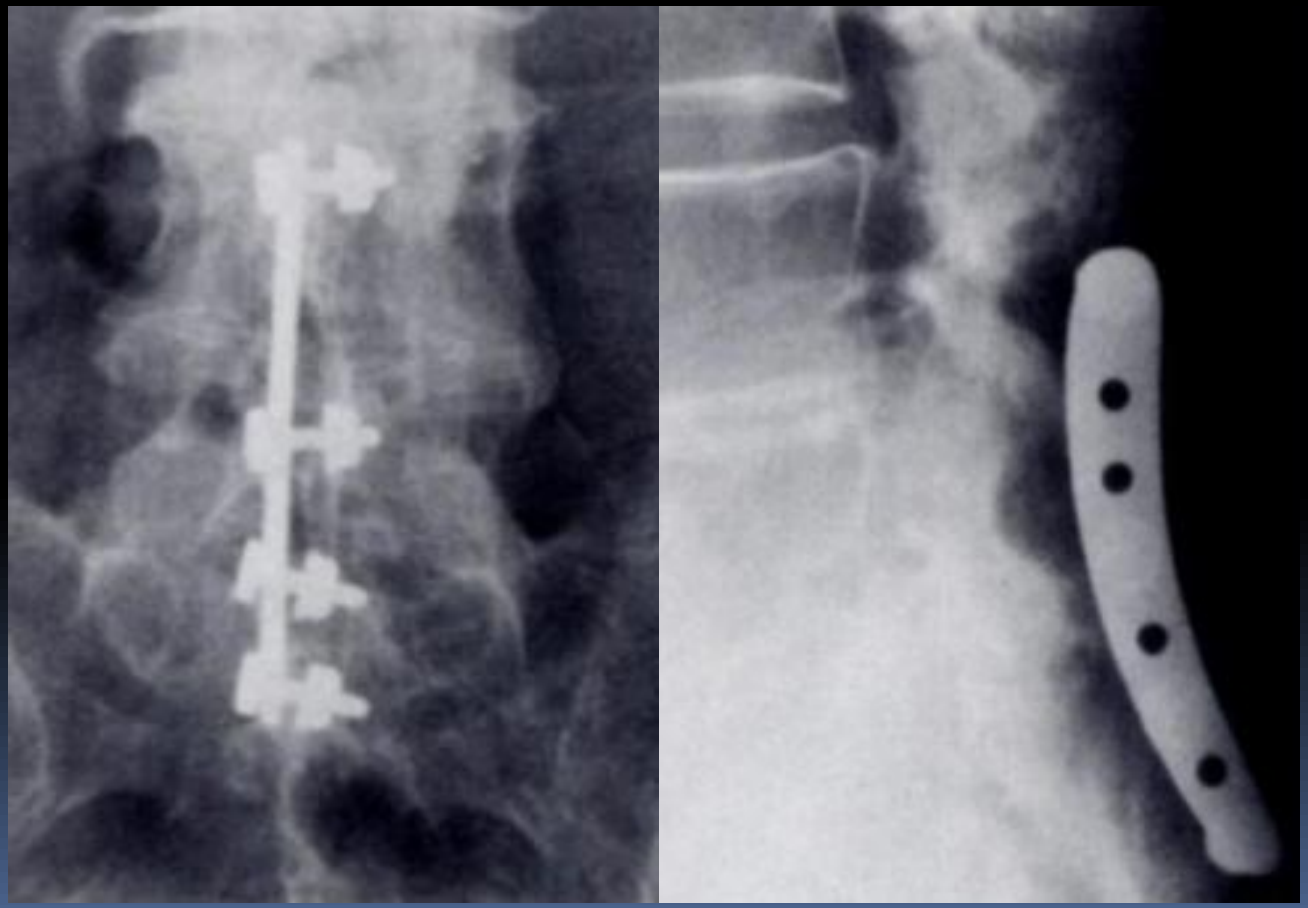
- Haid Plates
  - Made of titanium
    - Less severe artifact than stainless steel d/t its lower x-ray attenuation coefficient
  - Concave plate, fixation of lateral masses





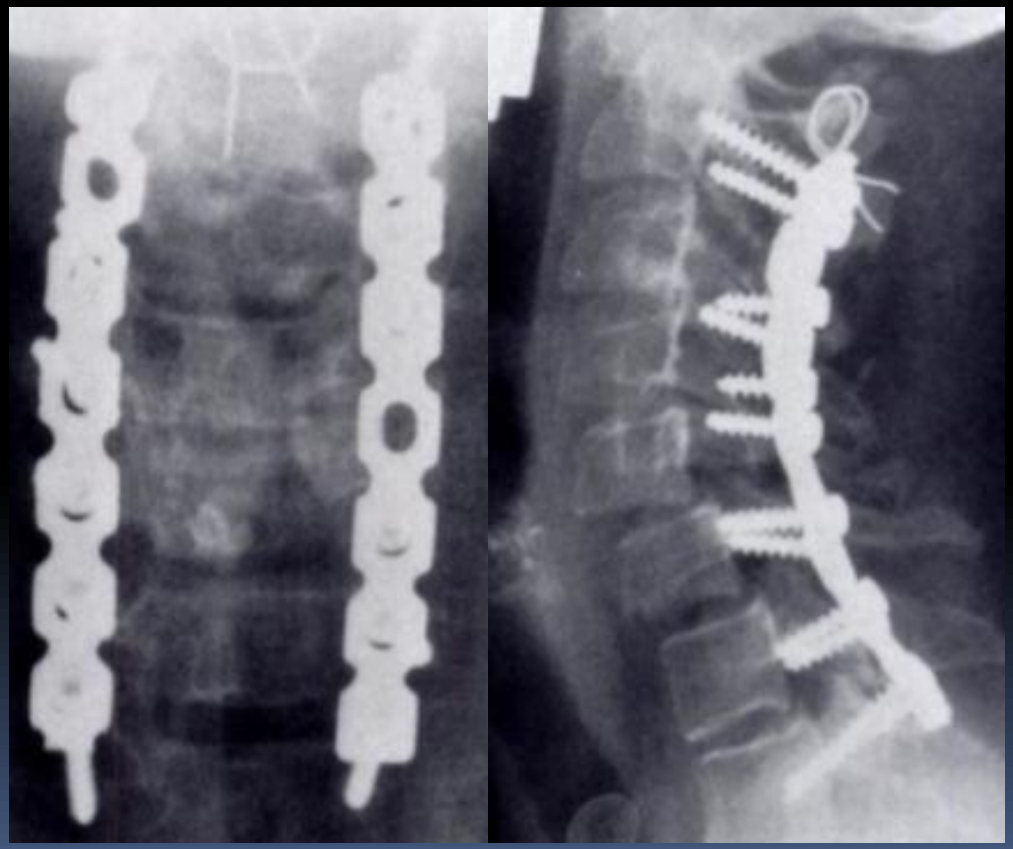
Semiconstrained Screw-Plate Connectors

- Spinous Process Plates



Semiconstrained Screw-Plate Connectors

- Malleable Reconstruction Plates



Axially Dynamic Screw-Plate Connectors

- Allow for axial deformation
- Resist toggle in coronal and sagittal planes
- Include absorbable implants and deforming implants
- Types:
  - DOC Ventral Stabilization System by Depuy-AcroMed
  - Advanced Biomechanical Concept (ABC) by Aesculap

Screw-Plate Connectors

- Radiologic distinction between different types of screw-plate connectors has not been studied in detail at this time
- Complications are different
  - Constrained more likely to result in poor bony fusion and implant fracture
  - Semiconstrained and axially dynamic more likely to result in loosening

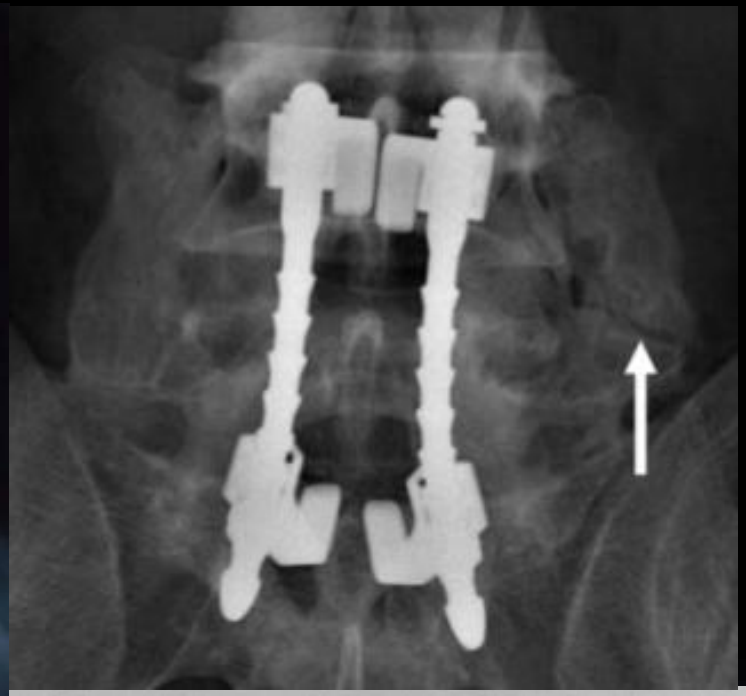
Rods

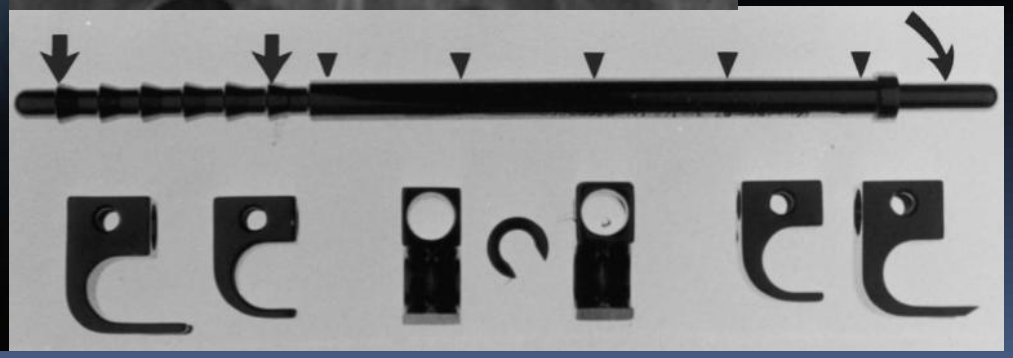
- Previously
  - Harrington
  - Knodt
  - Luque
  - Cottrell-Debousset
    - Attached with hooks or screws
  - Scottish Rite Hospital
- Current
  - Segmental Instrumentation Rods
  - Growing Rods/Telescoping Growth Rods

Rods

- Harrington
  - Attached with hooks, wires
  - Smooth rod w/ ratcheted end
  - Can be distracting or compressing
  - Typically, ratcheted end is superior w/ distracting rods
  - Device is placed, and increased distraction achieved by tightening ratcheted end
  - Typically fracture at junction of ratcheted and smooth portions
  - Rotation of rod about its round base can cause slippage of hooks

Rods – Harrington Rod

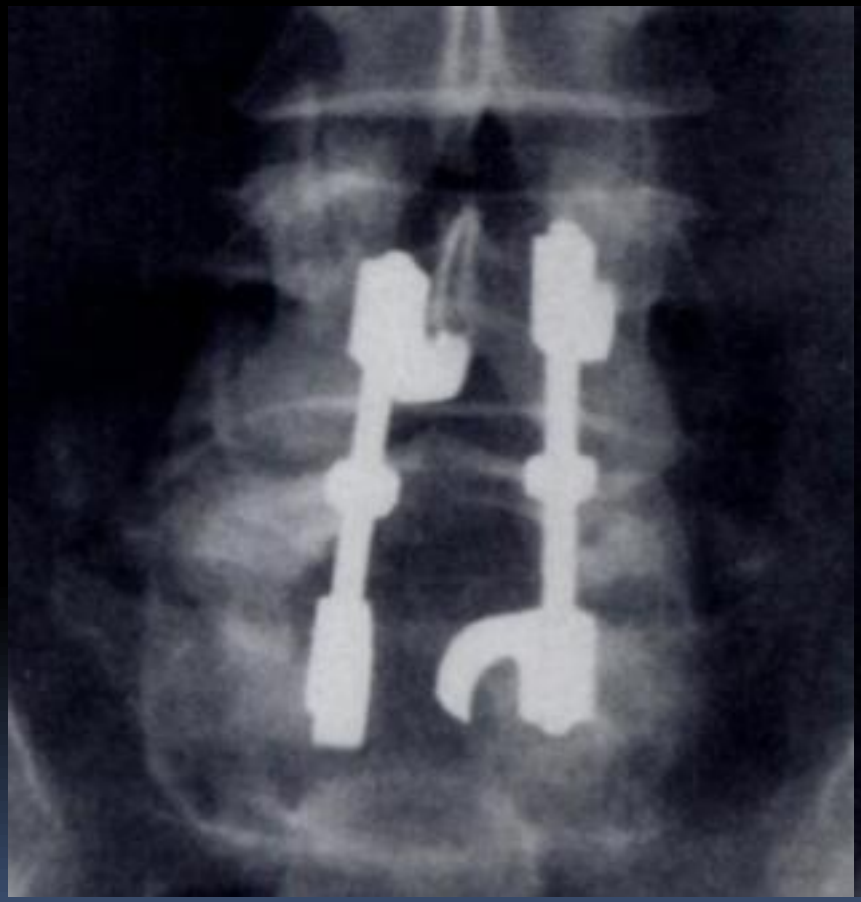


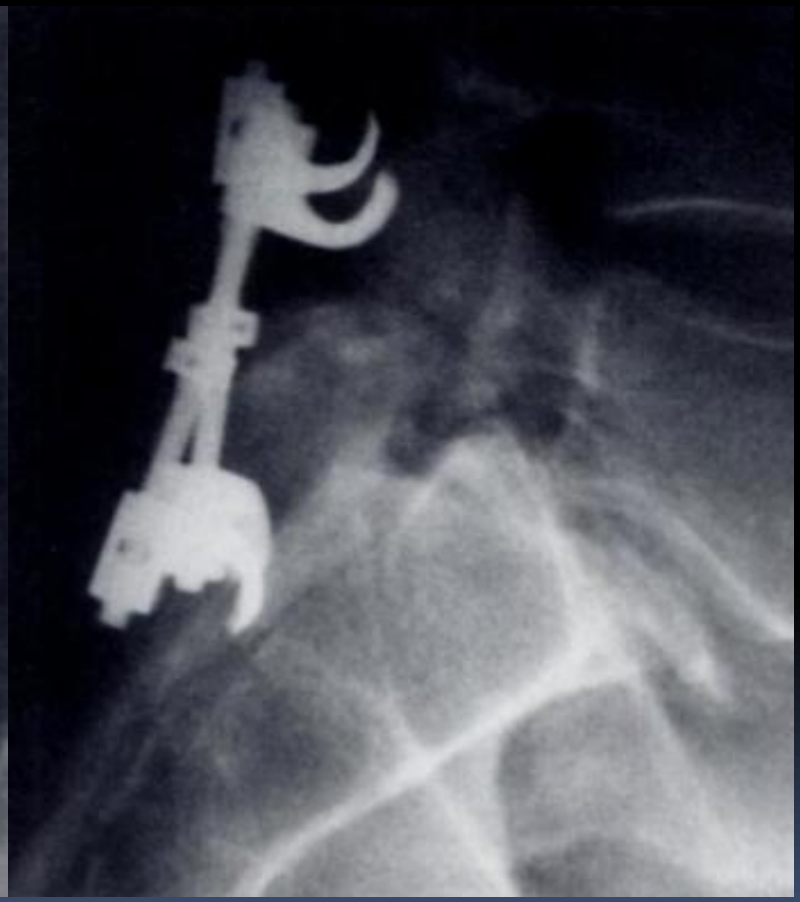


Rods

- Knodt
  - Attached to hooks
  - Threaded distraction rod w/ central fixed nut/turnbuckle (characteristic feature)
  - Two ends threaded in opposite directions
    - Result in distraction when tightened

Rods – Knodt Rod

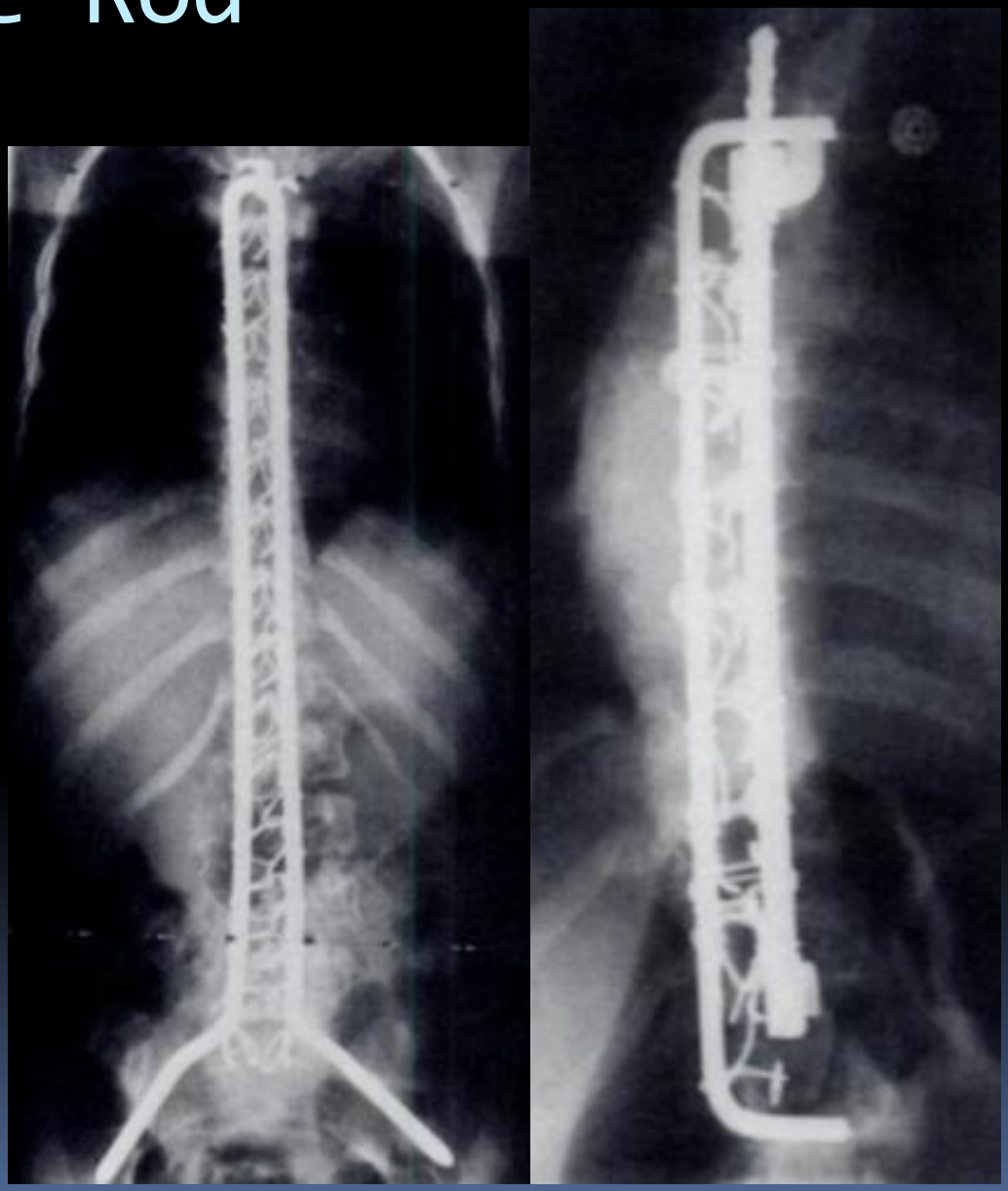




Rods

- Luque
  - Smooth rod
  - Attached with wires
  - Rotational and translational stability
  - Does not produce distraction or resist axial loading
  - Galveston technique
    - Pelvic extension of rods into iliac bones
    - Usually single rod curved back on itself superiorly

Luque Rod



Rods

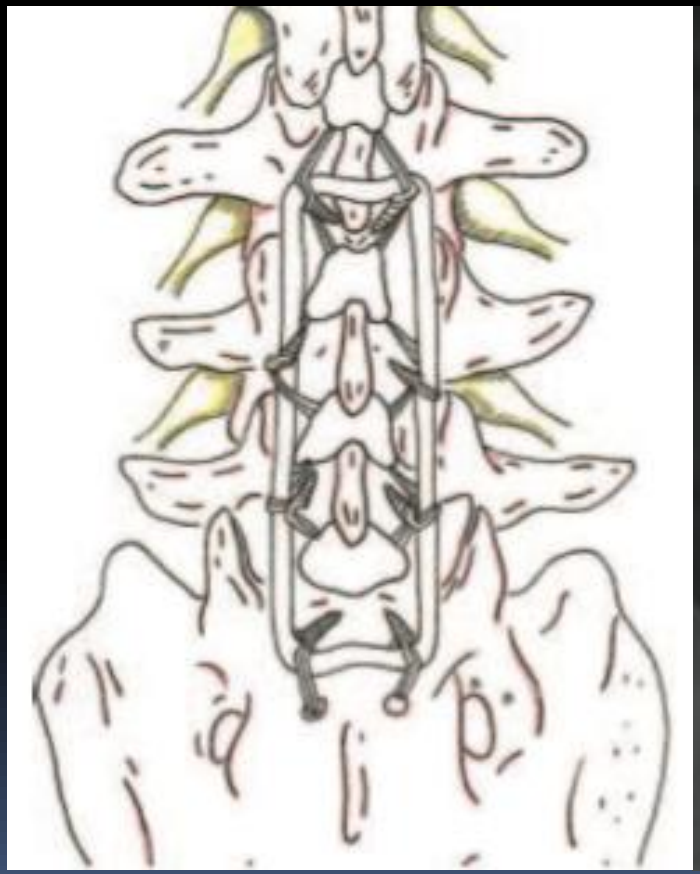
- Luque Rectangle
  - Variation of Luque rod
  - Stiffer that separate rods and more stability, especially with rotational forces
  - Drawback is lack of substantial structural support

Luque Rectangle

Rods

- Hartshill Rectangle
  - Similar appearance and function to Luque rectangle
  - Has additional bends in upper and lower ends to accommodate posterior spine anatomy

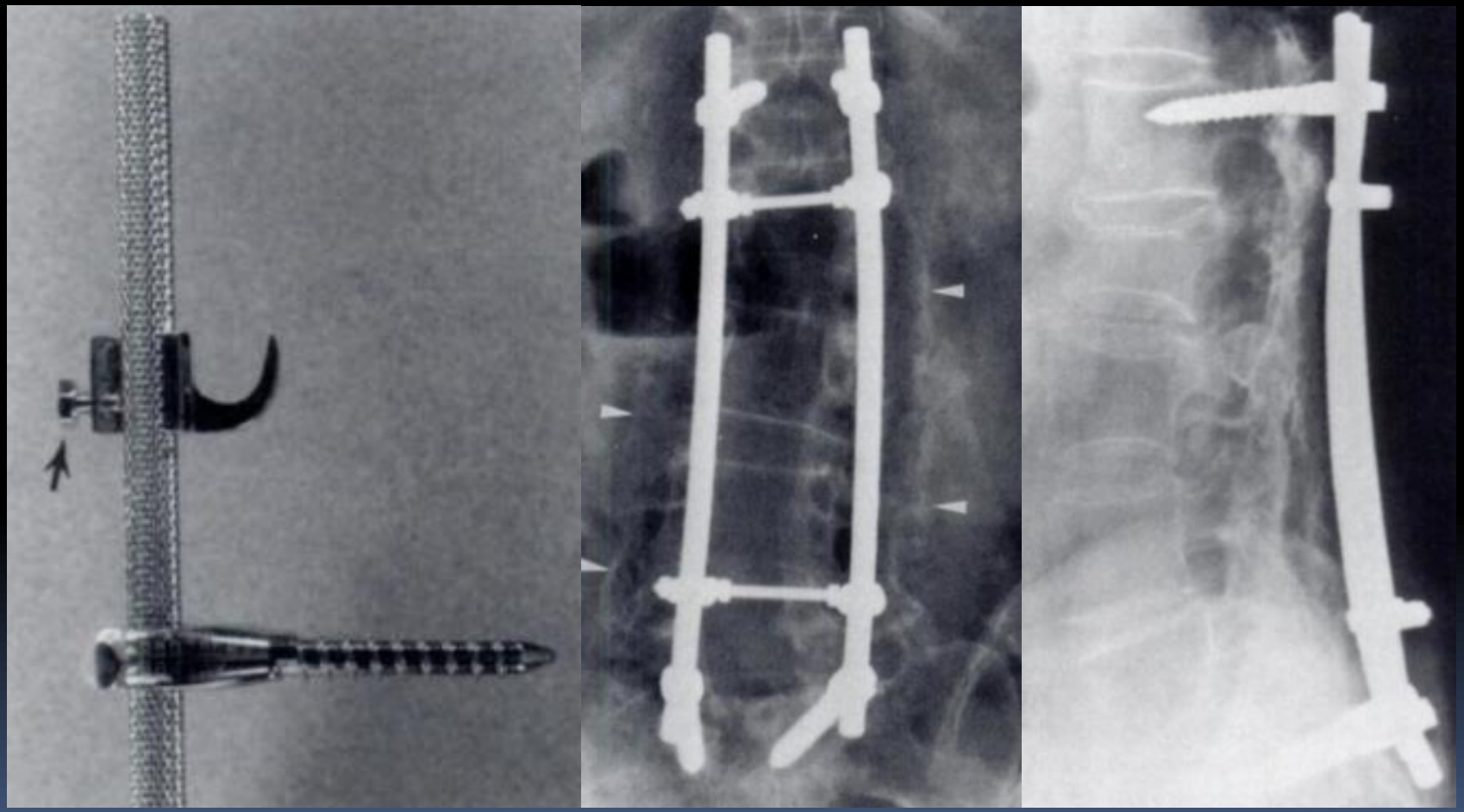
Rods – Hartshill Rectangle



Rods

- Cotrel-Debousset
  - Serrated surface
  - Attached to rods or hooks
  - Fixed screw or set screw

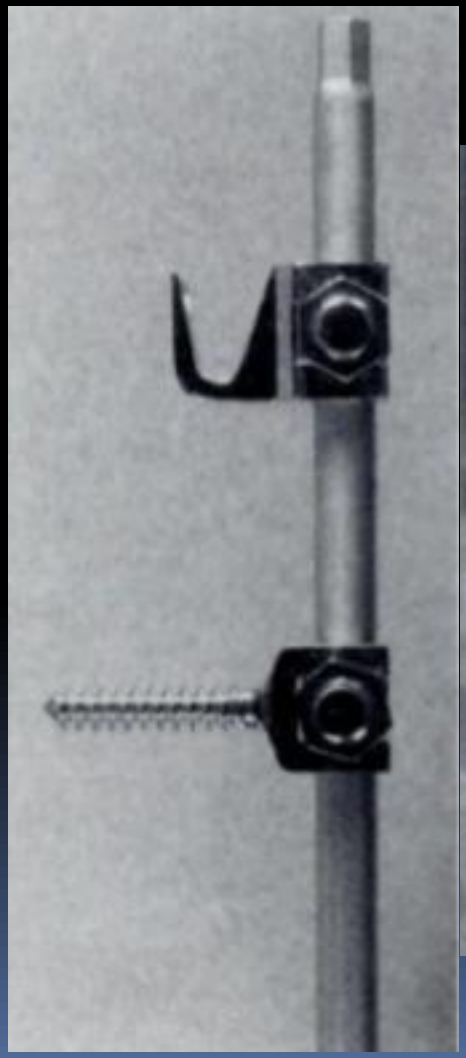
Rods – Cotrel-Debousset

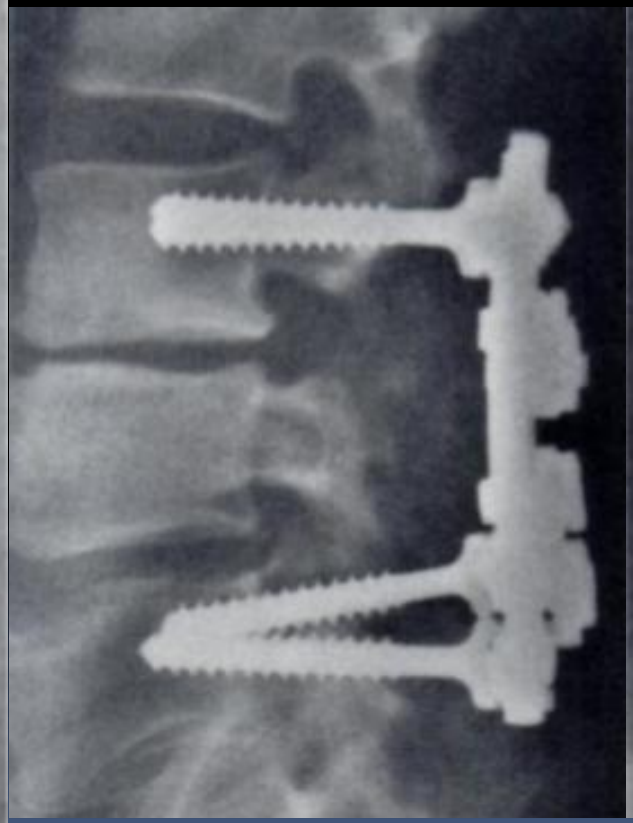


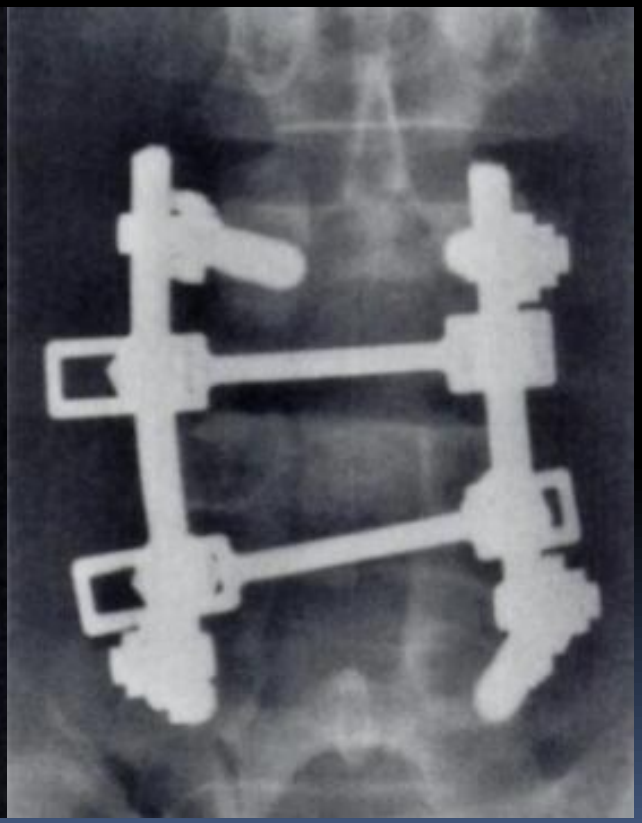
Rods

- Texas Scottish Rite Hospital Hardware
  - Nuts/bolts more stable c/w Cotrel-Debousset rods
  - Roughened surface, not serrated
  - Rods cut to desired length, leaving characteristic bevel on one end
  - Other end is hexagonal, can be torqued intra-operatively

Rods – Texas Scottish Rite



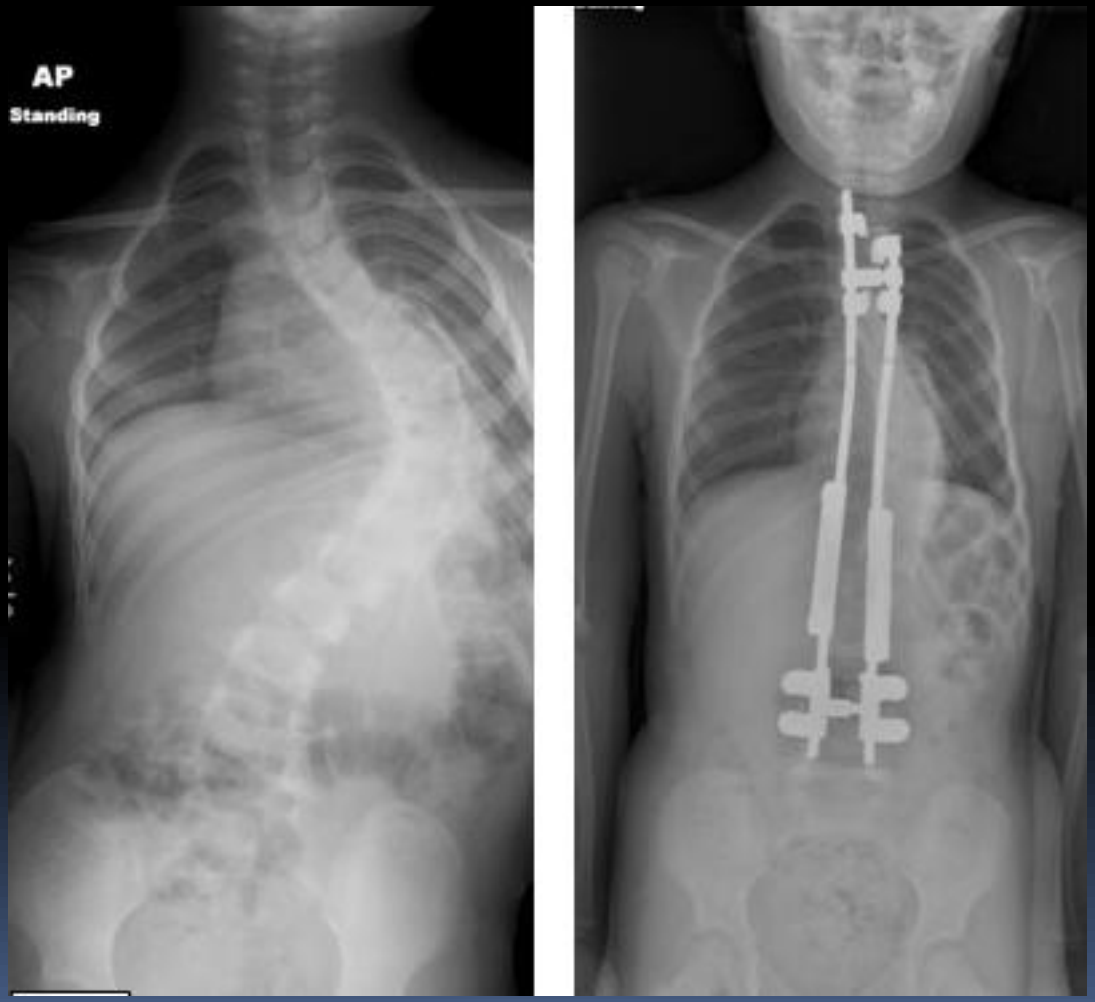




Rods

- Growing Rods
  - Fixed proximally and distally
  - Can be two distally fused vertebra and one proximal vertebra
  - Fixed with screws and/or hooks
  - Return to OR every 6 months for extension
  - Possible magnetic adjustment in future

Rods – Growing Rods



Types of Implants

- Multisegmental Fixation Implants
  - 1. Anchors
  - 2. Longitudinal members
  - 3. Cross-connectors
  - 4. Accessories
- Abutting Implants

Cross-Connectors

- Oriented perpendicular to, and adjoining, two longitudinal members
- Increase stiffness and stability
- Long constructs
  - Increase torsional stability
  - Should be placed at 1/3 and 2/3 of length of construct
- Short constructs
  - Decrease sagittal and lateral bar deformity
  - Increased pullout resistance w/ triangulated screws

Cross-Connectors

Types of Implants

- Multisegmental Fixation Implants
  - 1. Anchors
  - 2. Longitudinal members
  - 3. Cross-connectors
  - 4. Accessories
- Abutting Implants

Accessories

- Washers
- Sleeves
  - Increase resistance to rod deformation

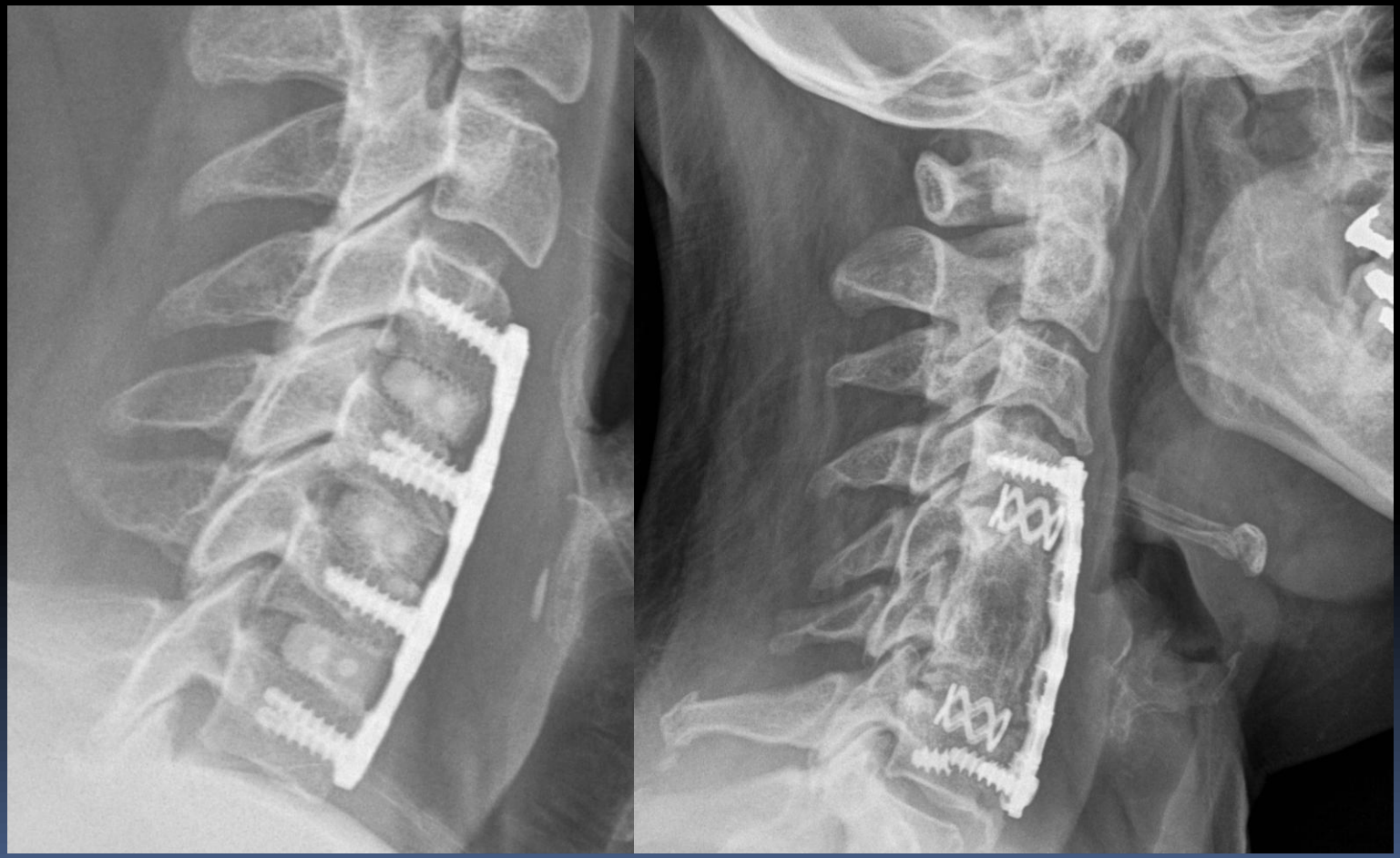
Abutting Implants

- Bone graft material
  - Often harvested from rib, fibula, tibia
    - Autograft: harvested from individual receiving the graft
    - Allograft/homograft: harvested from another individual, often cadaver

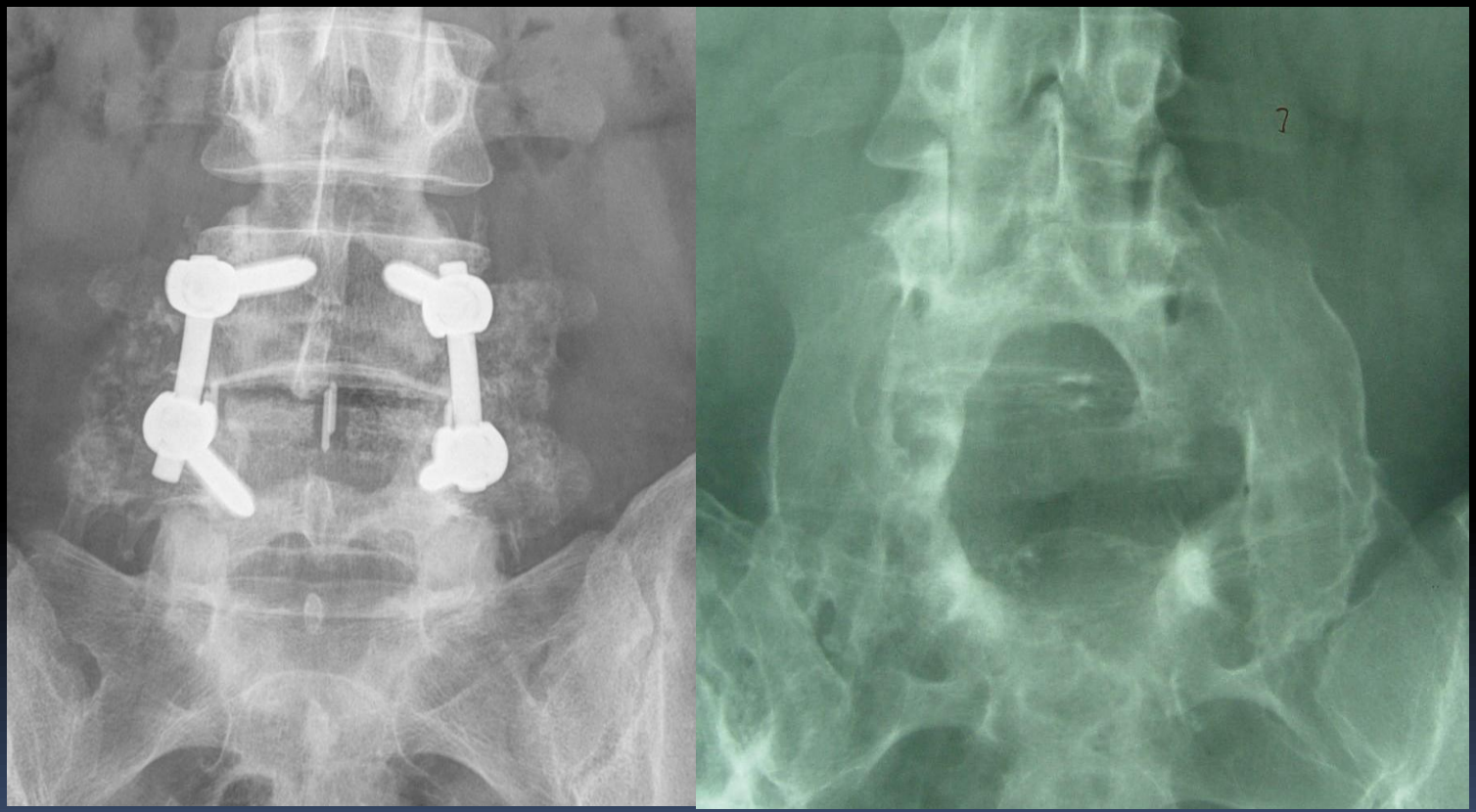
Abutting Implants

- Can place bone graft in any of 3 compartments
  - Anterior
    - Disc removed
    - Shave down to cartilage of endplates
    - Bone strut placed
  - Middle
    - Transverse processes
  - Posterior
    - Facet joints excised/taken down
    - Spinous processes
    - Laminae

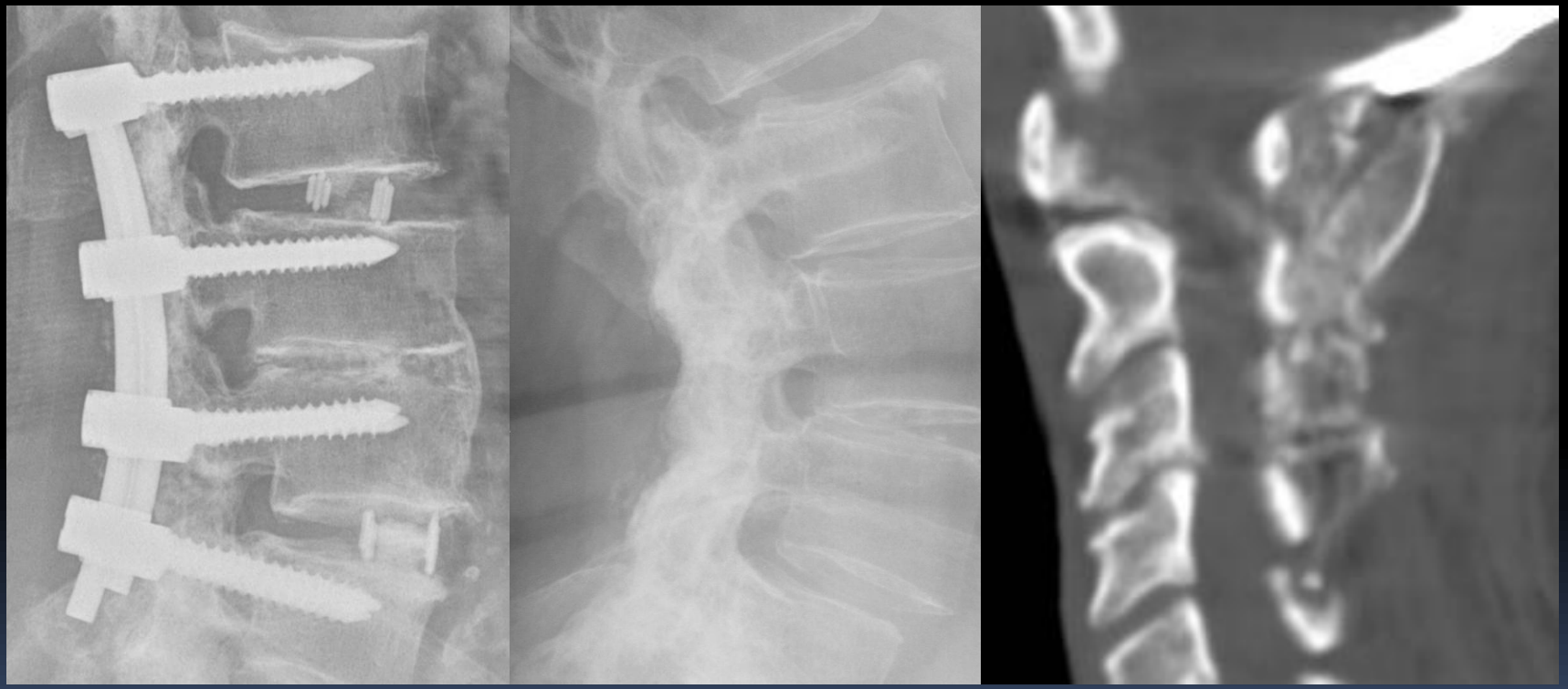
Anterior Compartment Bone Graft



Middle Compartment Bone Graft



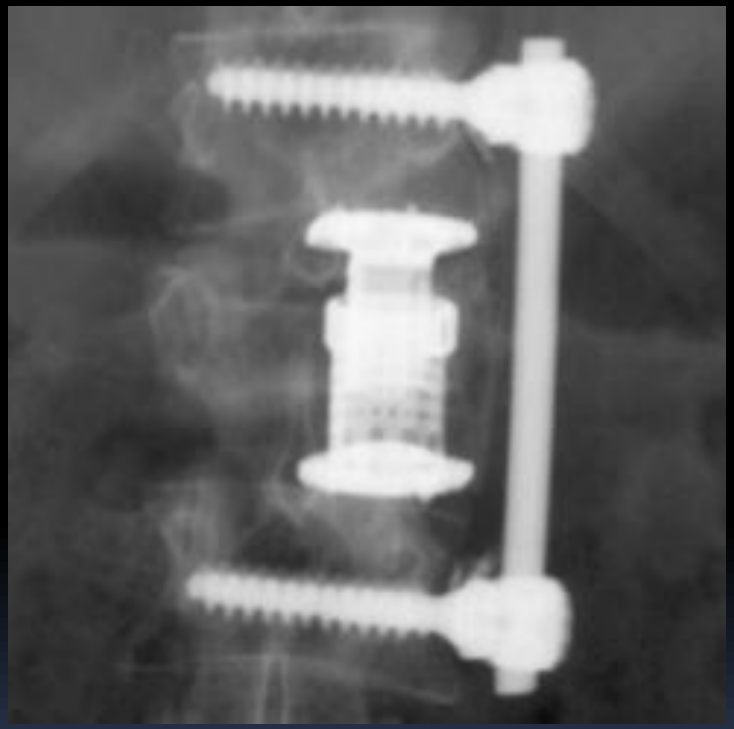
Posterior Compartment Bone Graft



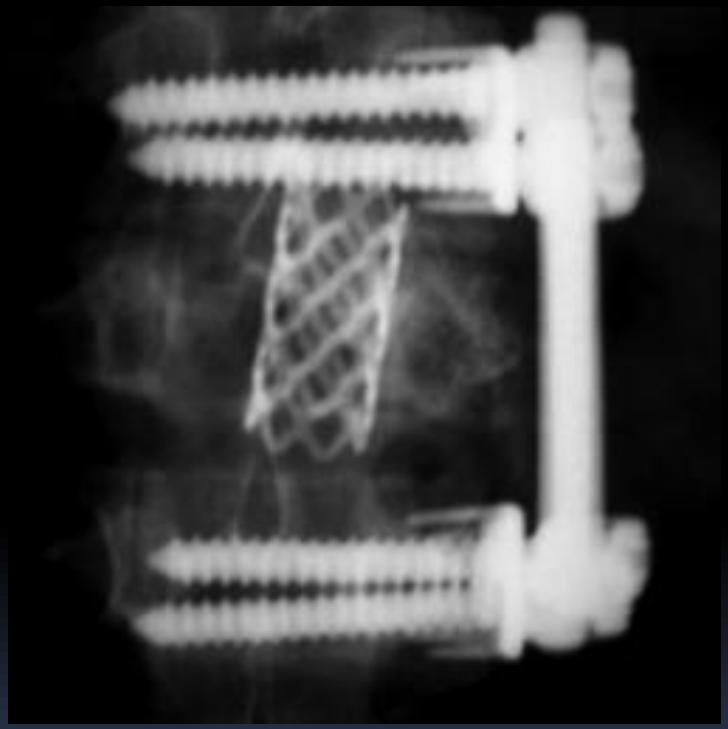
Anterior Abutting Implants

- Definitions
  - Struts
    - Any device placed b/w vertebral bodies
      - Can occur w/ or w/o corpectomy
    - Function as spacers
    - May be
      - Bone graft
      - Cage filled w/ bone
      - Inert material (metal, ceramic)
  - Cage
    - Can be made of
      - Titanium
        - Harms cage, Ray cage, Pyramesh cage, InterFix cage, lordotic LT cage
      - Carbon fiber
        - Brantigan cage
      - PEEK or PEEK/Carbon fiber mixture

Metal Cages

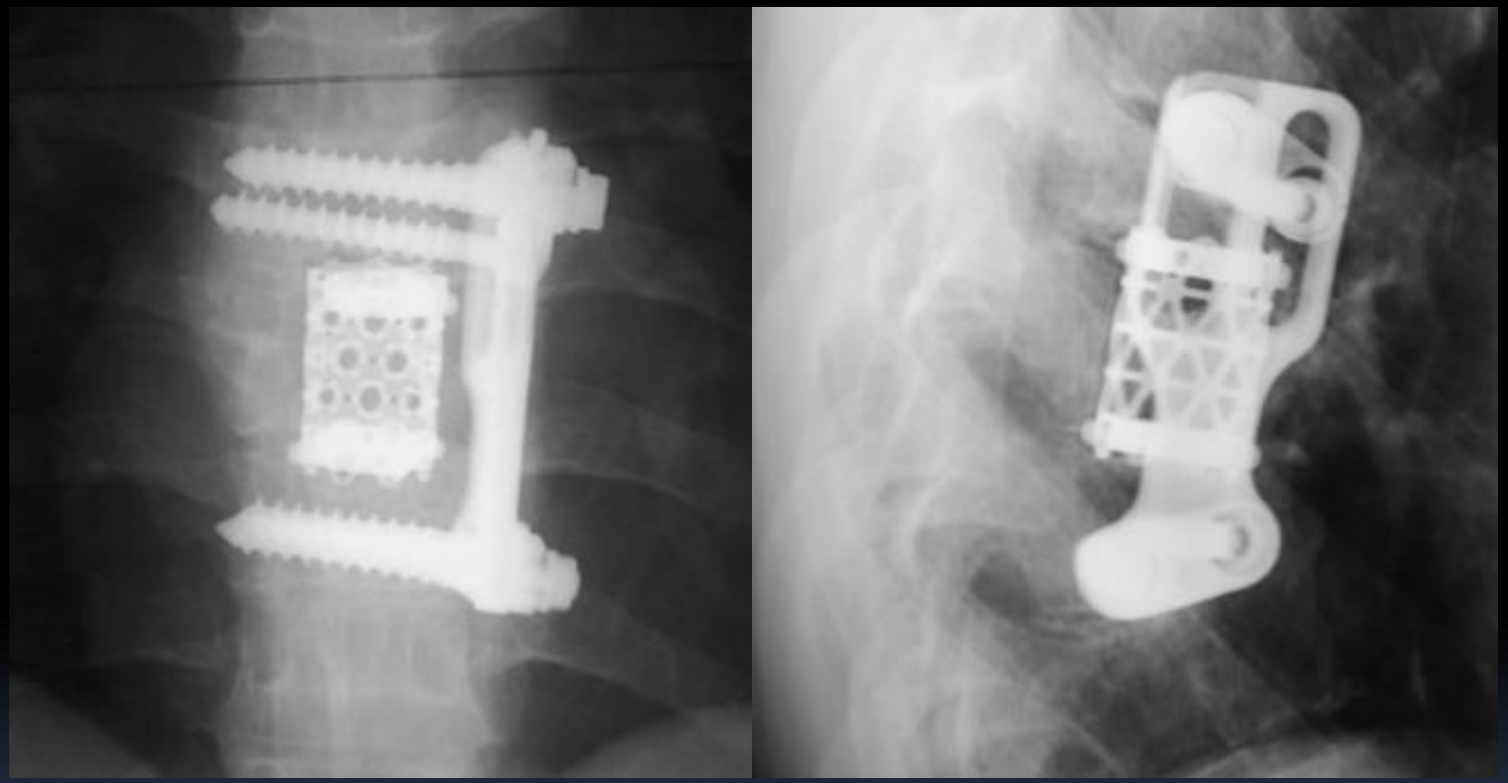


Synex Cage



Moss Cage

Metal Cages

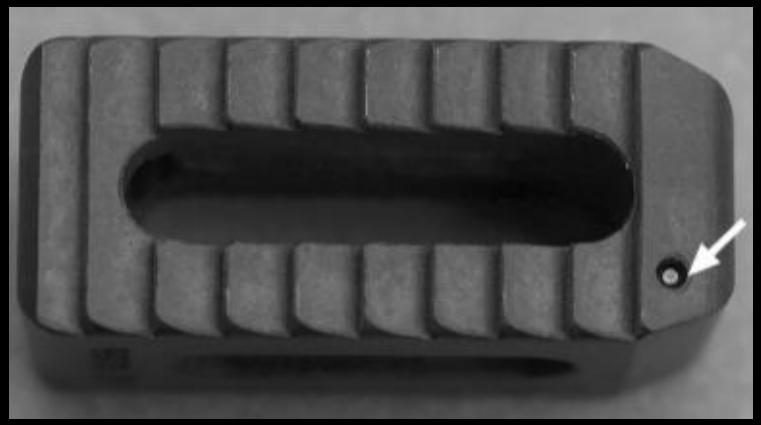


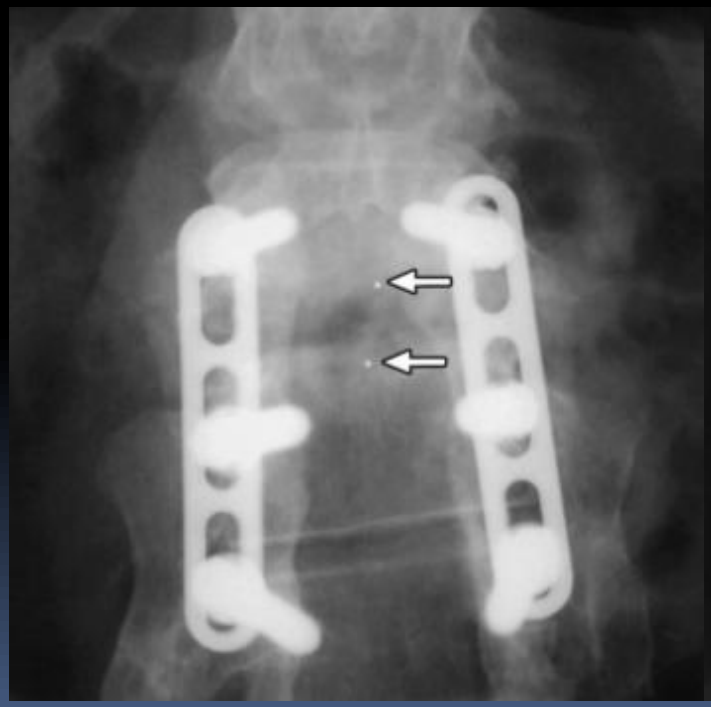
Harms Cage

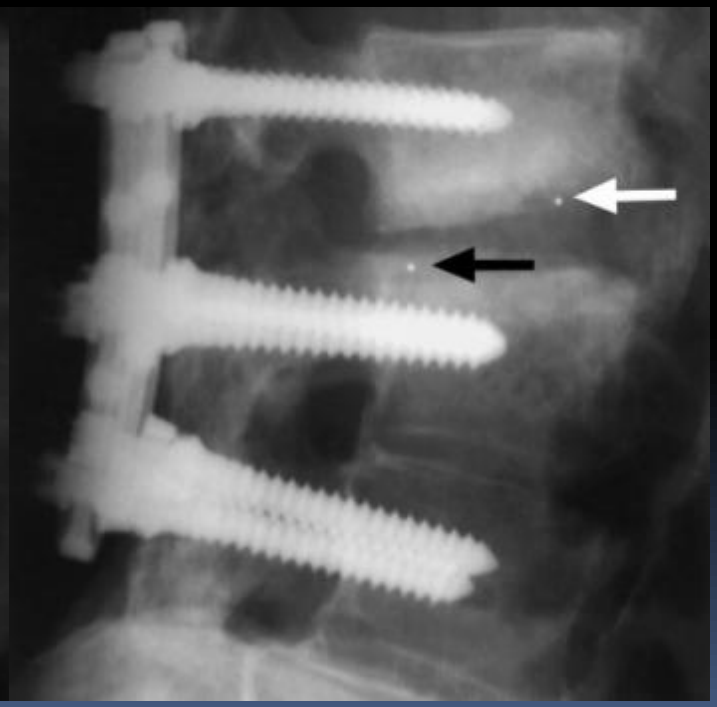
Metal Cages

Bagby & Kuslich

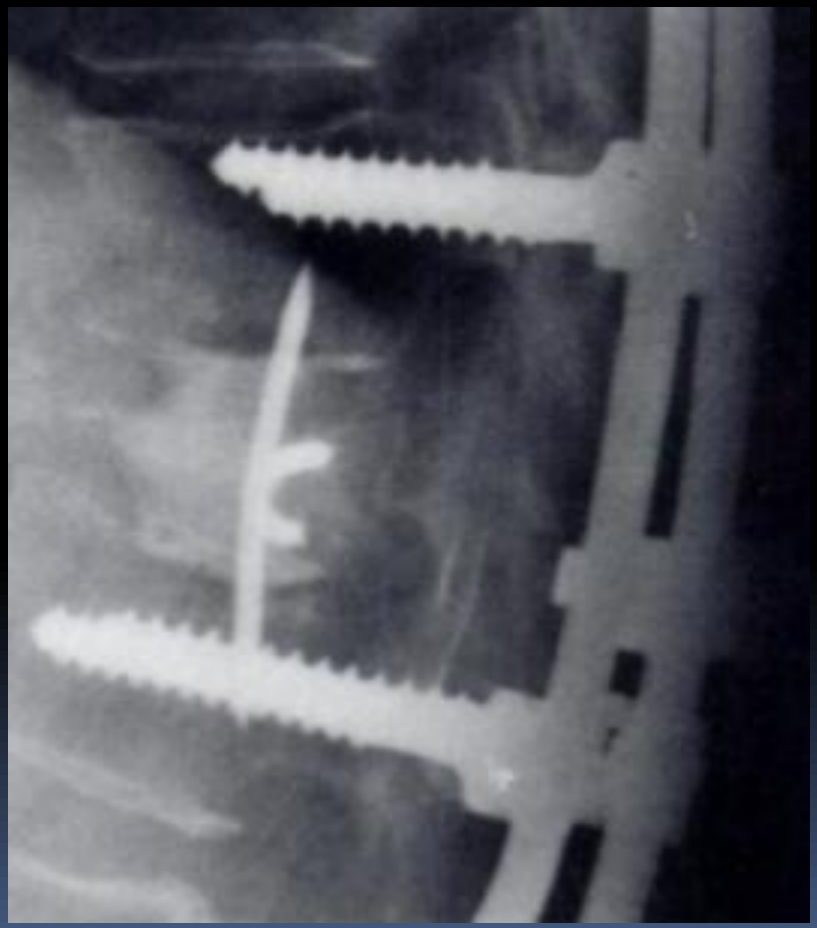
Brantigan Cage





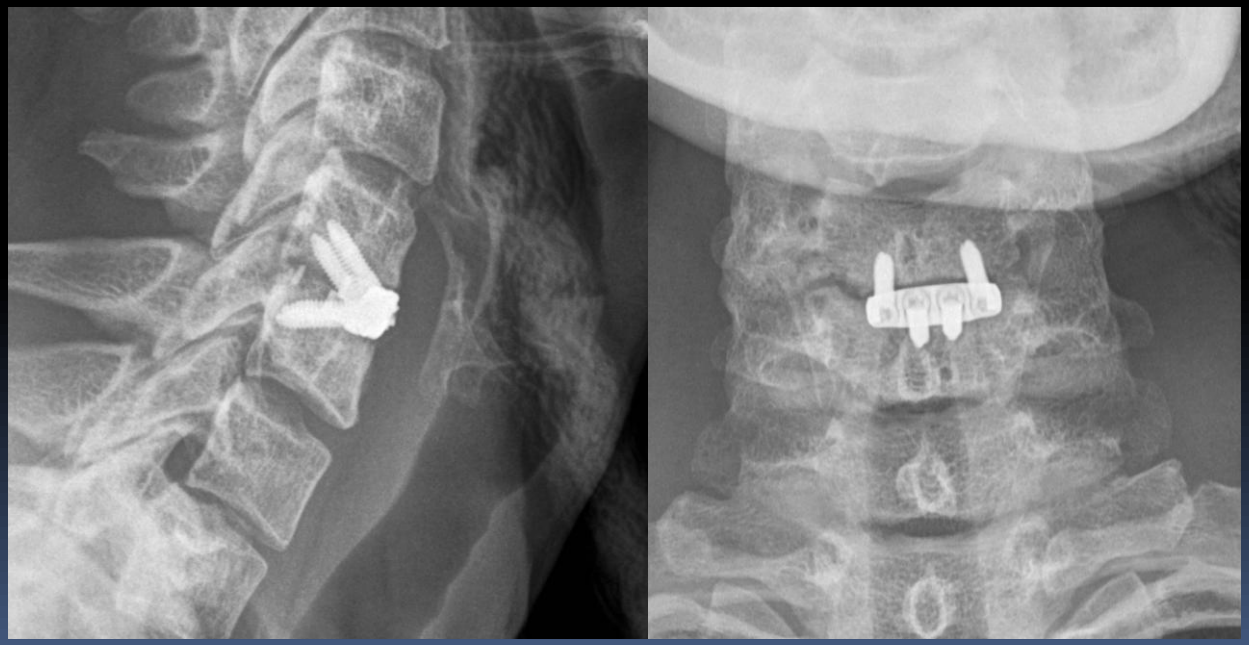


Methylmethacrylate Strut



Special Types of Hardware

- Zero profile fusion
  - Less protrusion of prosthesis reduces secondary dysphagia or impingement on vascular structures

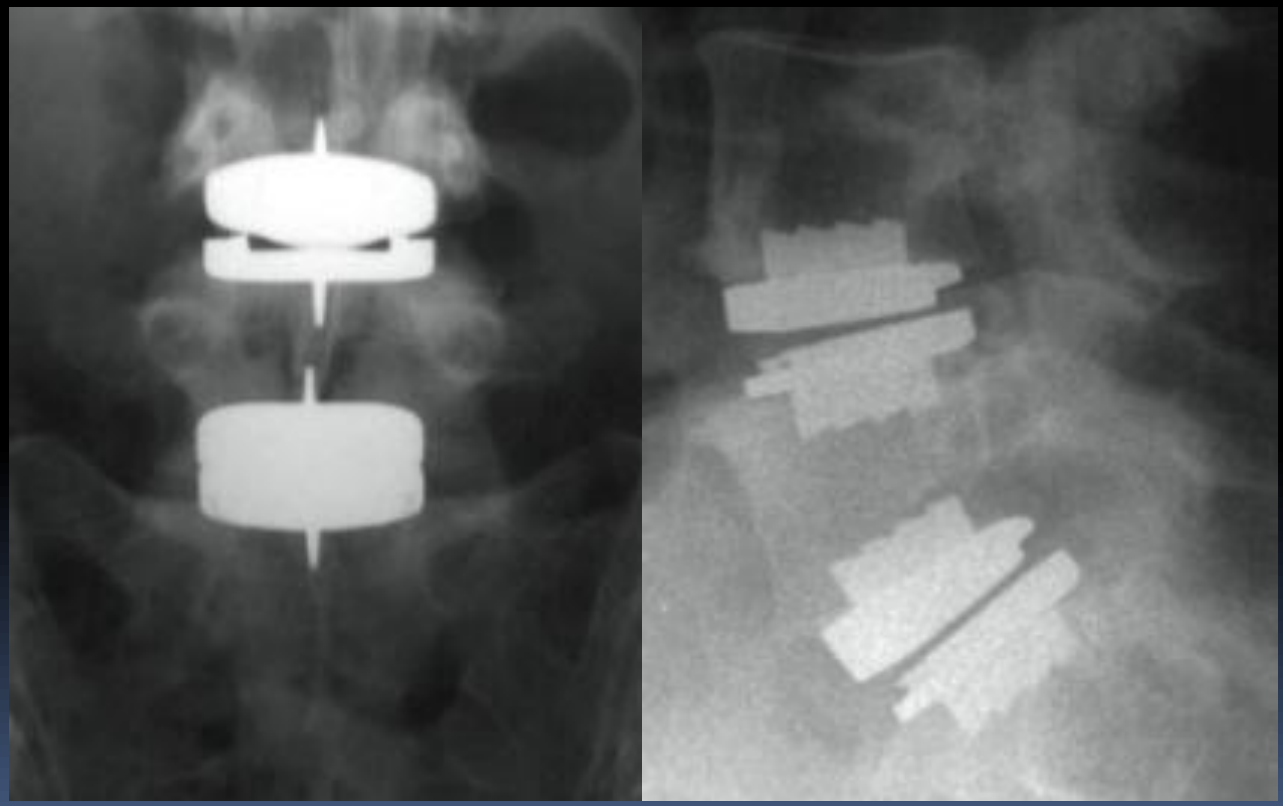


Special Types of Hardware

- Disc Replacement
  - Pain believed to be primarily from disc
  - Contraindicated in pts w/ facet joint degeneration
  - Must have at least 4 mm disc space and no endplate sclerosis
  - Two parallel metal plates w/ teeth and polyethylene core b/w plates

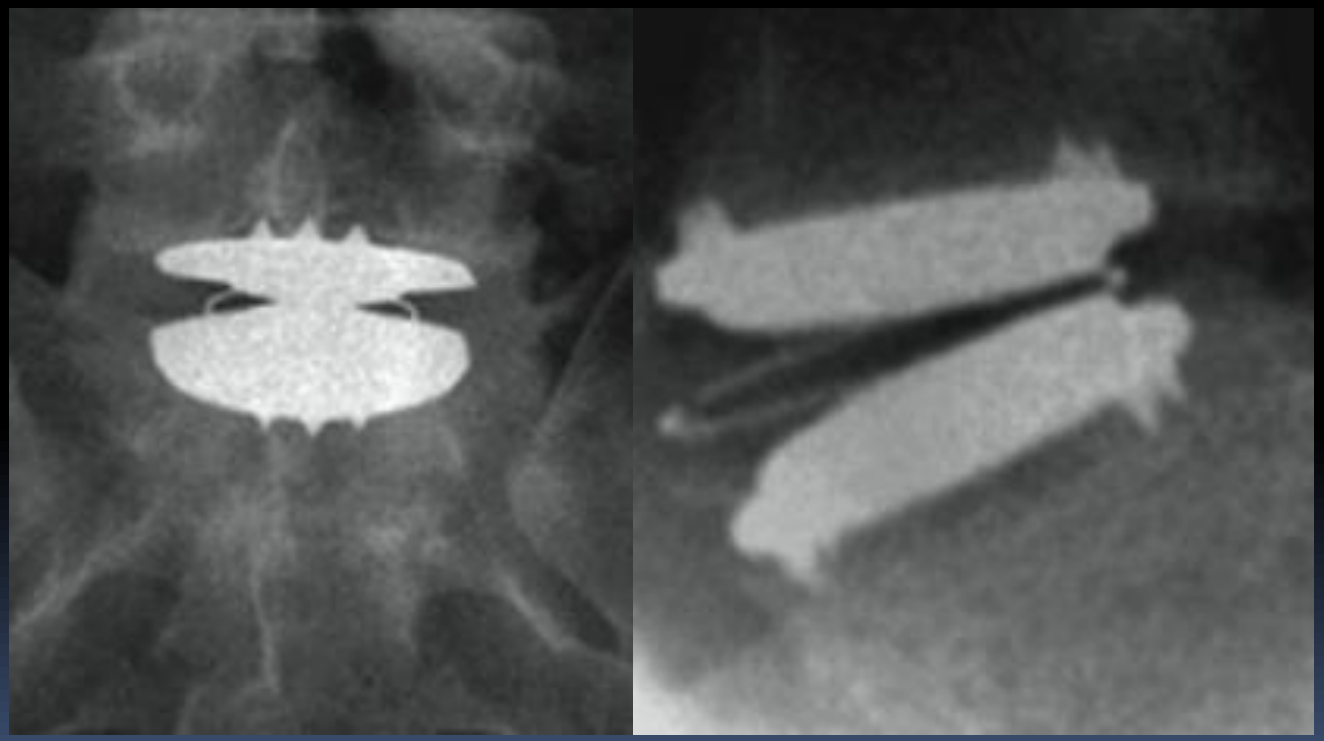
Special Types of Hardware

- Disc Replacement - ProDisc



Special Types of Hardware

- Disc Replacement - SB Charite

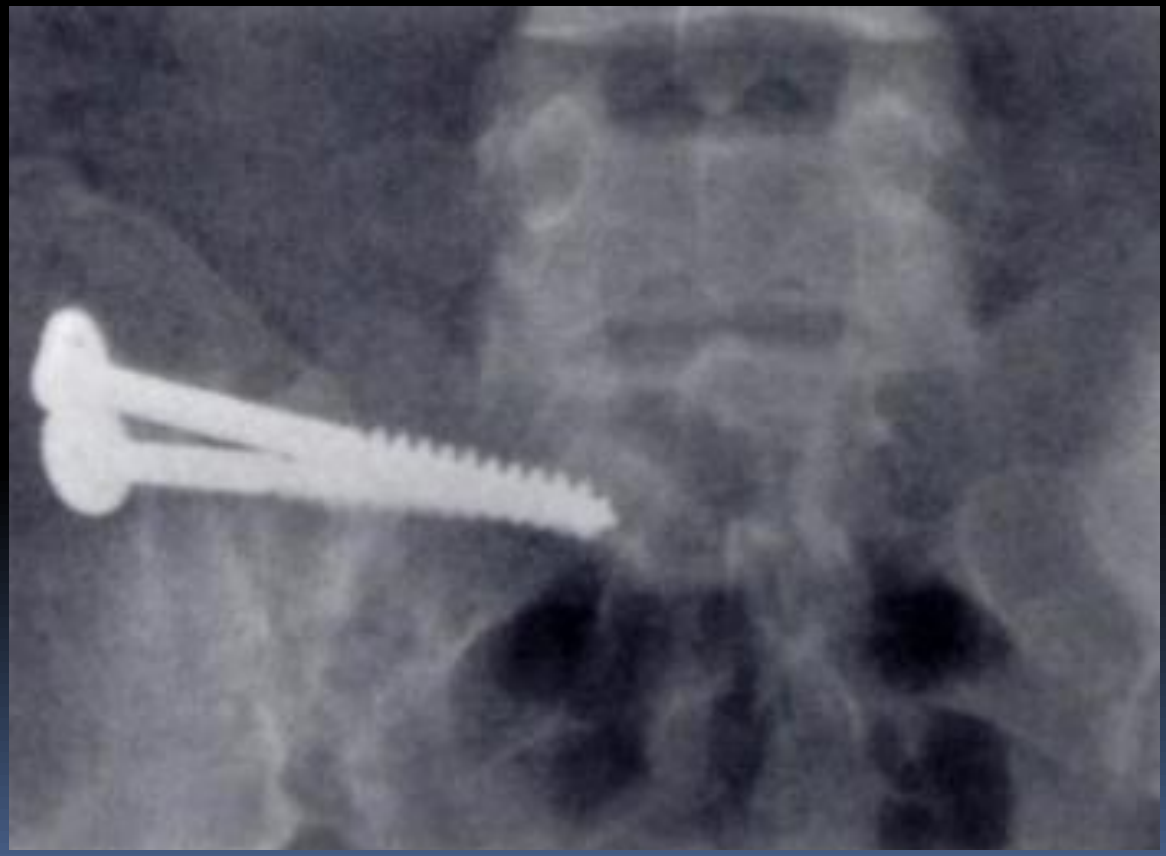


Special Types of Hardware

- SIJ fusion screws

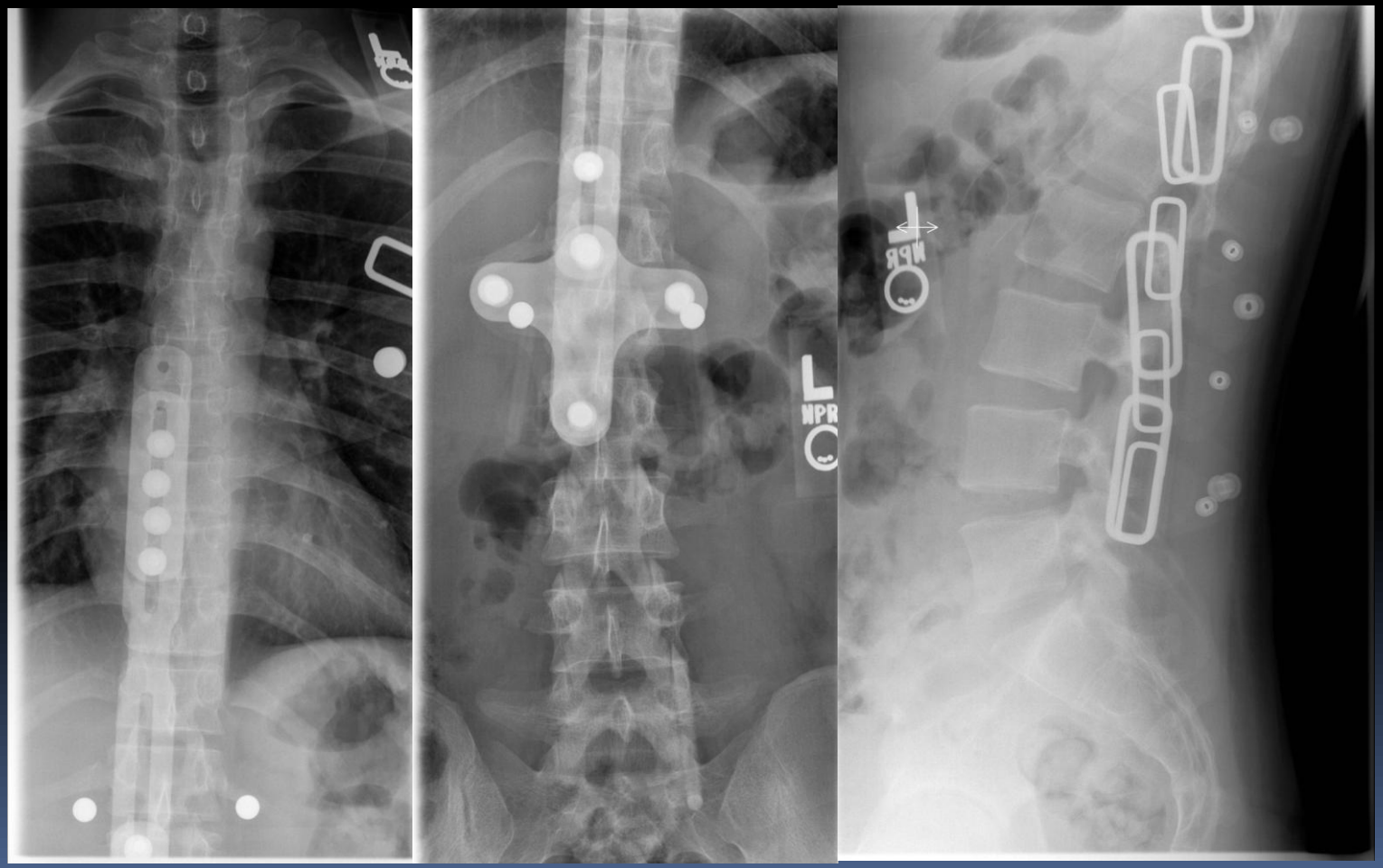
Special Types of Hardware

- SIJ fixation screws



Other Devices

- External Thoracolumbar brace/orthosis

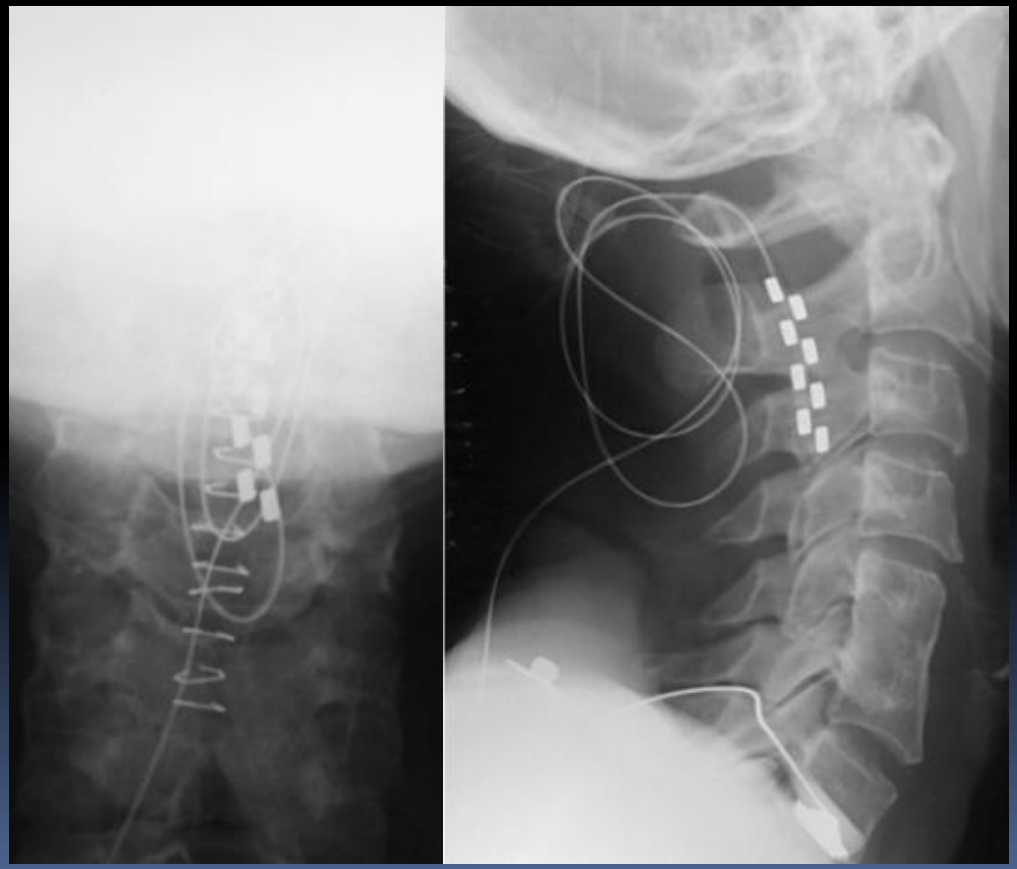


Other Devices

- Transcutaneous Electrical Neural Stimulation (TENS) Unit
  - Intended effect is pain relief through electrical stimulation of spinal canal or nerve roots
  - TENS unit is an externally placed patch like EKG leads

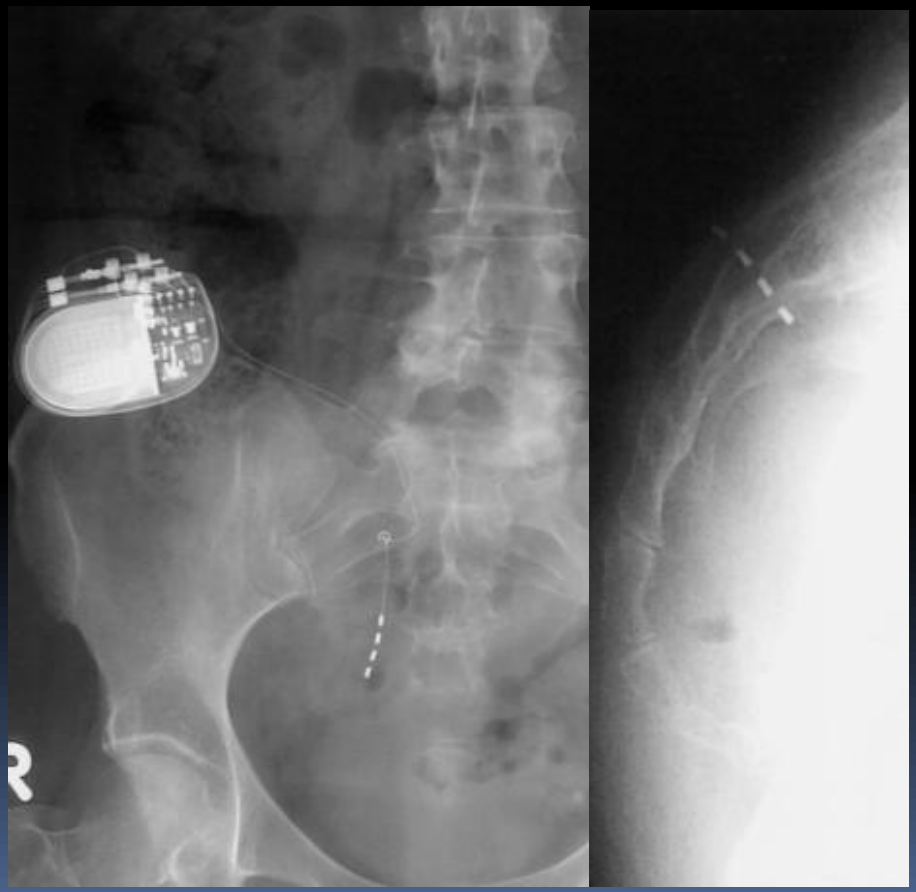
Other Devices

- Dorsal Column Stimulator (DCS) Unit
  - Terminate in epidural/subarachnoid space



Other Devices

- Sacral Nerve Stimulator
  - Bladder dysfunction



Other Devices

- Pain Pump
  - Catheter terminates in subarachnoid space

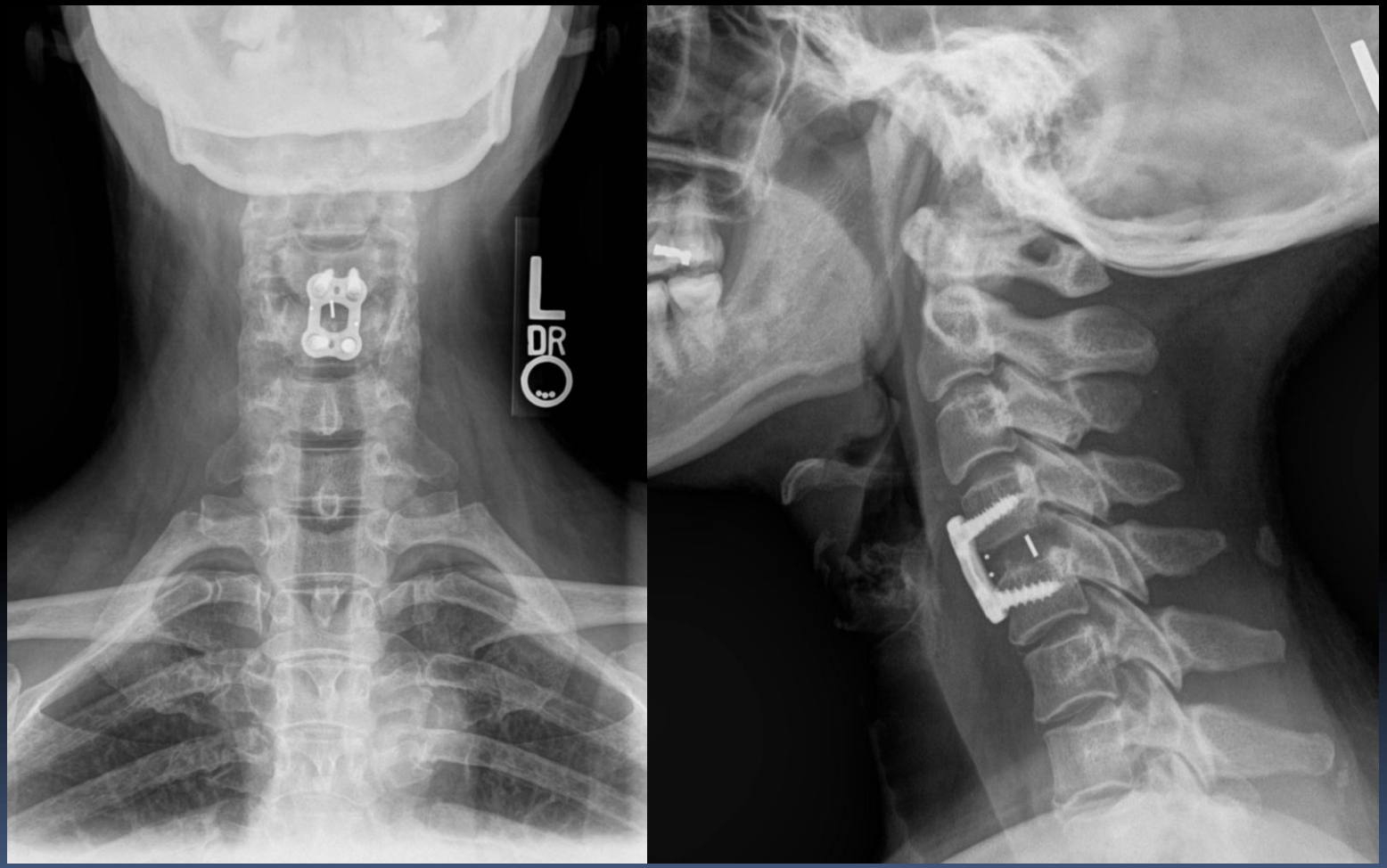
Other Devices

- Bone Stimulator
  - Increases eventual likelihood of fusion, not speed at which fusion occurs
  - After fusion, battery pack removed and electrodes left behind
  - Electrodes similar to DCS, but terminate in bone graft mass

Examples of Spine Surgeries

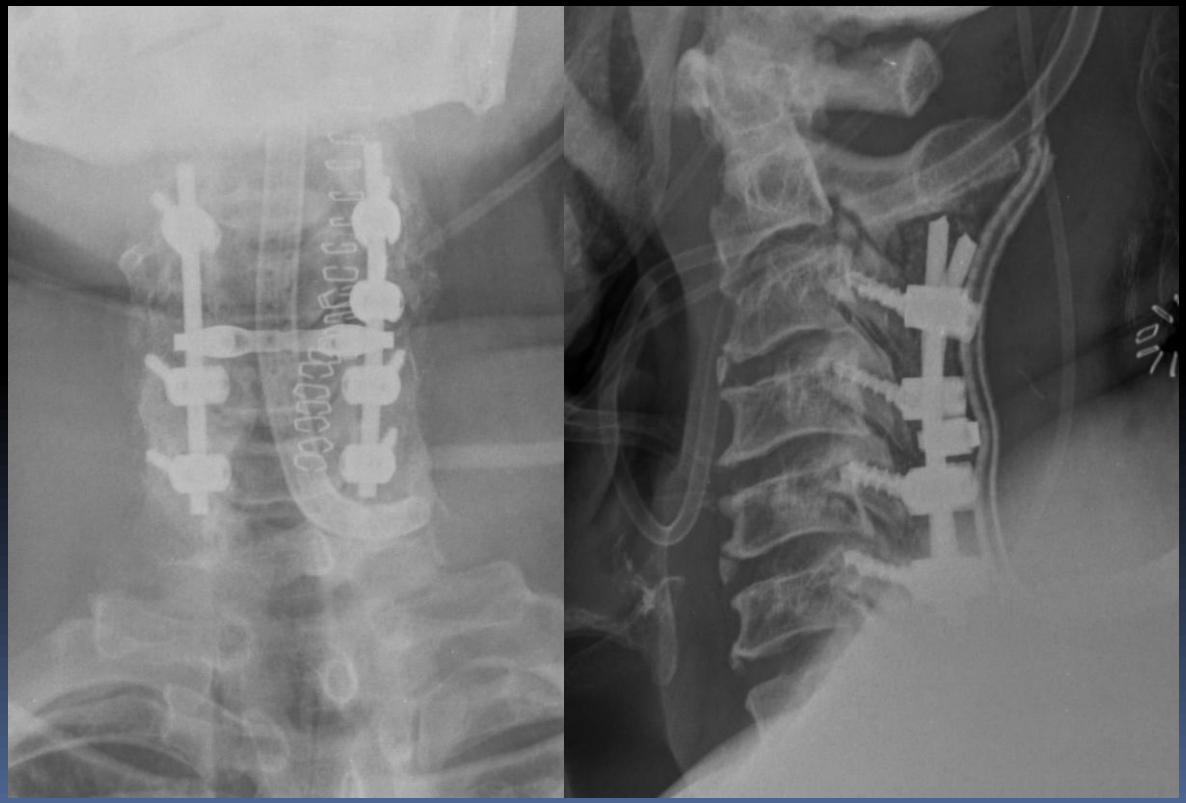
- Will now demonstrate aforementioned concepts and hardware with examples from various post-operative spine images

ACDF



Posterior Decompression and Fusion

- Combination of laminectomies and posterior fusion



Posterior Decompression and Fusion

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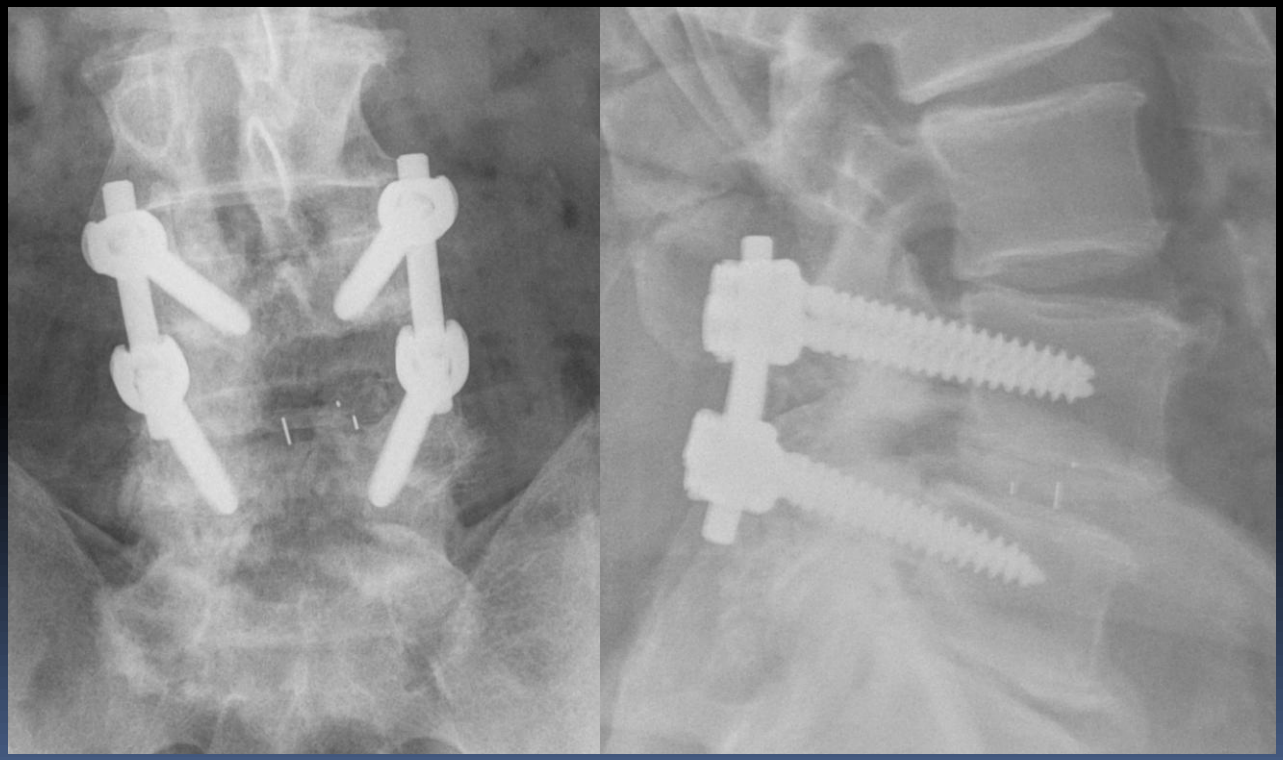
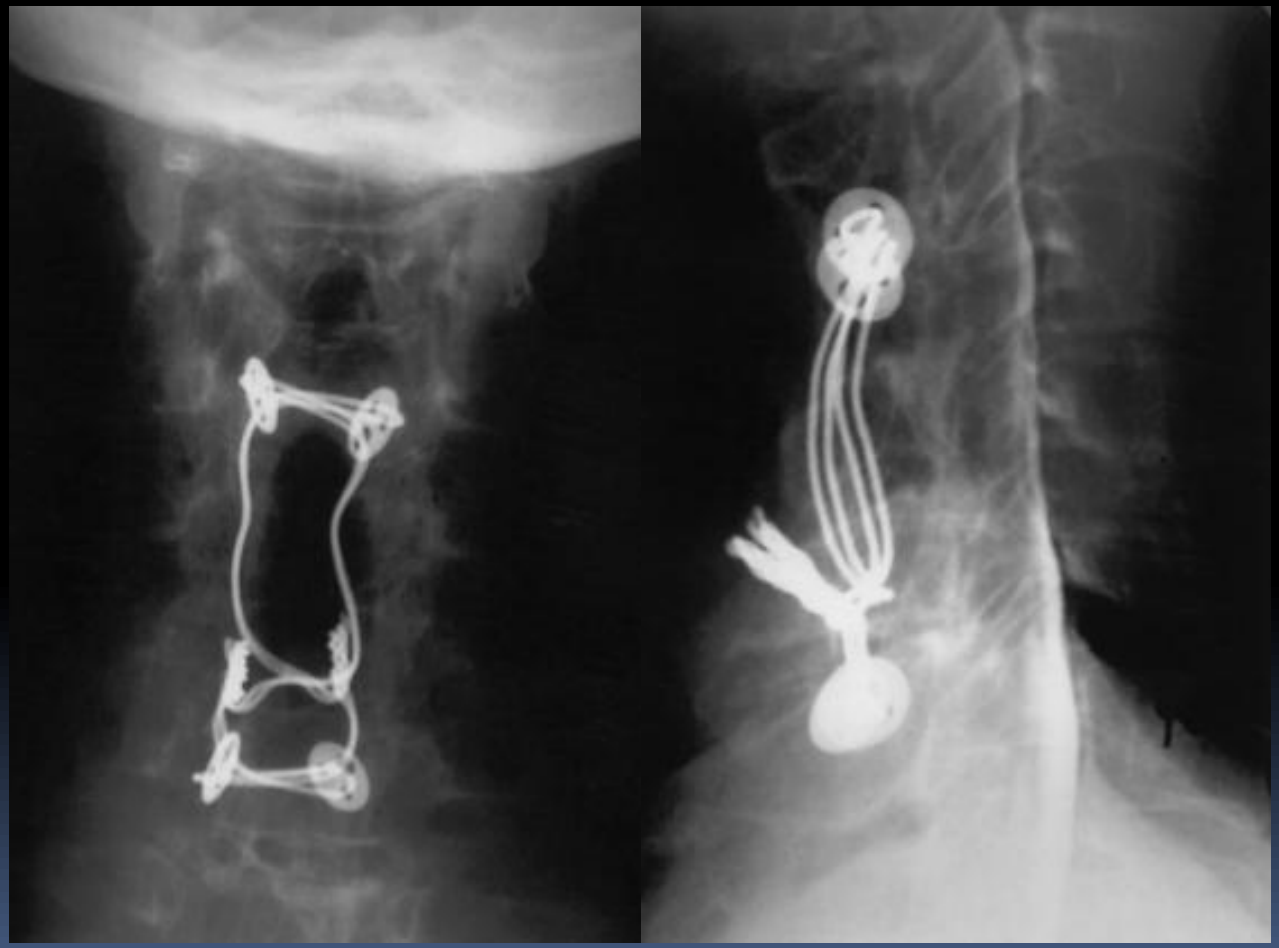
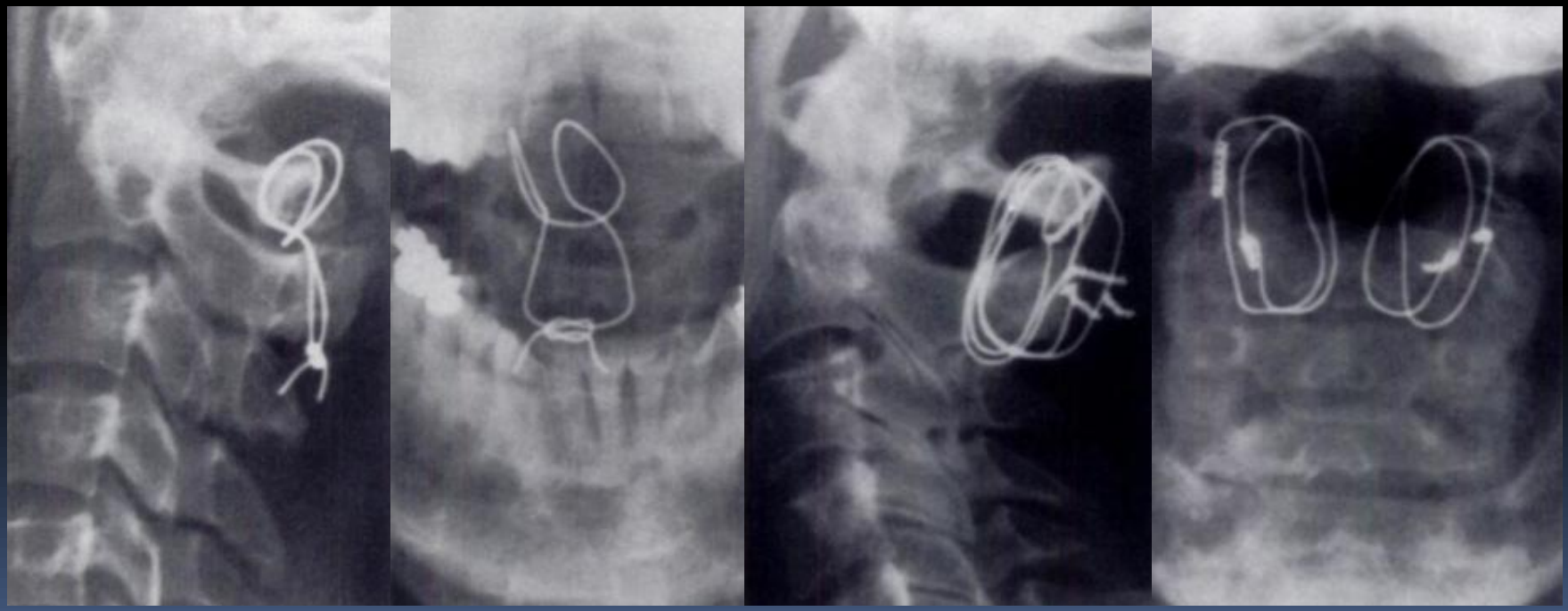


Posterior Decompression and Fusion



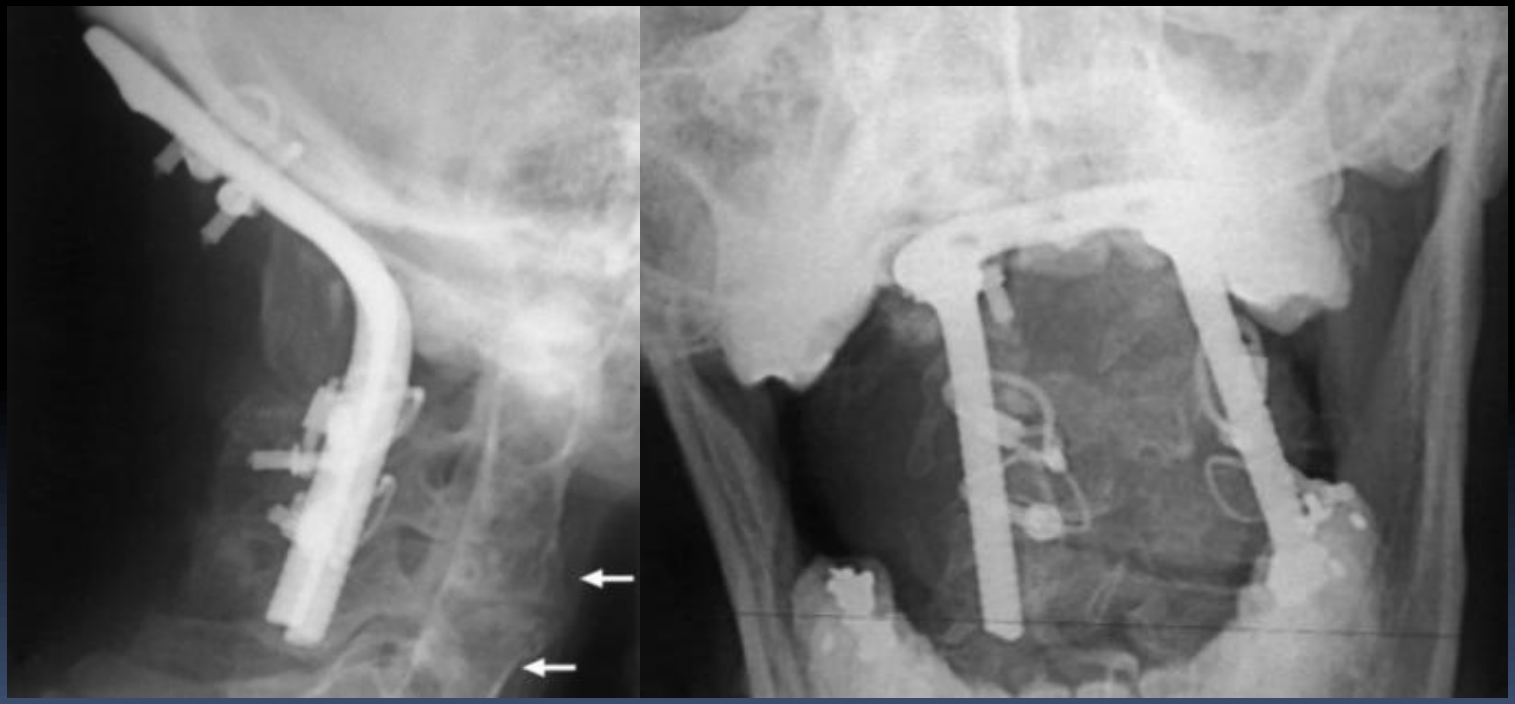
Atlantoaxial Stabilization

- Instability d/t RA
  - Prevent flexion, and rotation to lesser extent

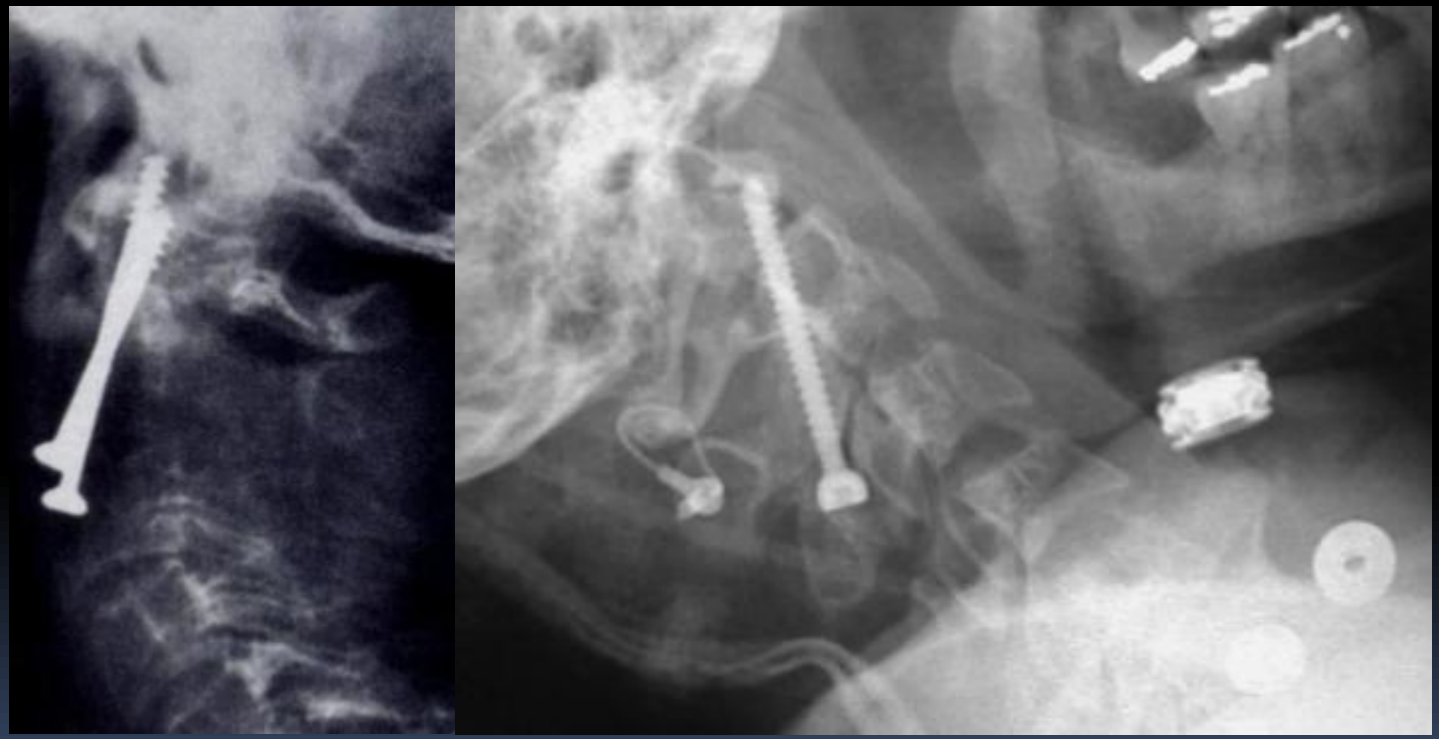


Atlantoaxial Stabilization

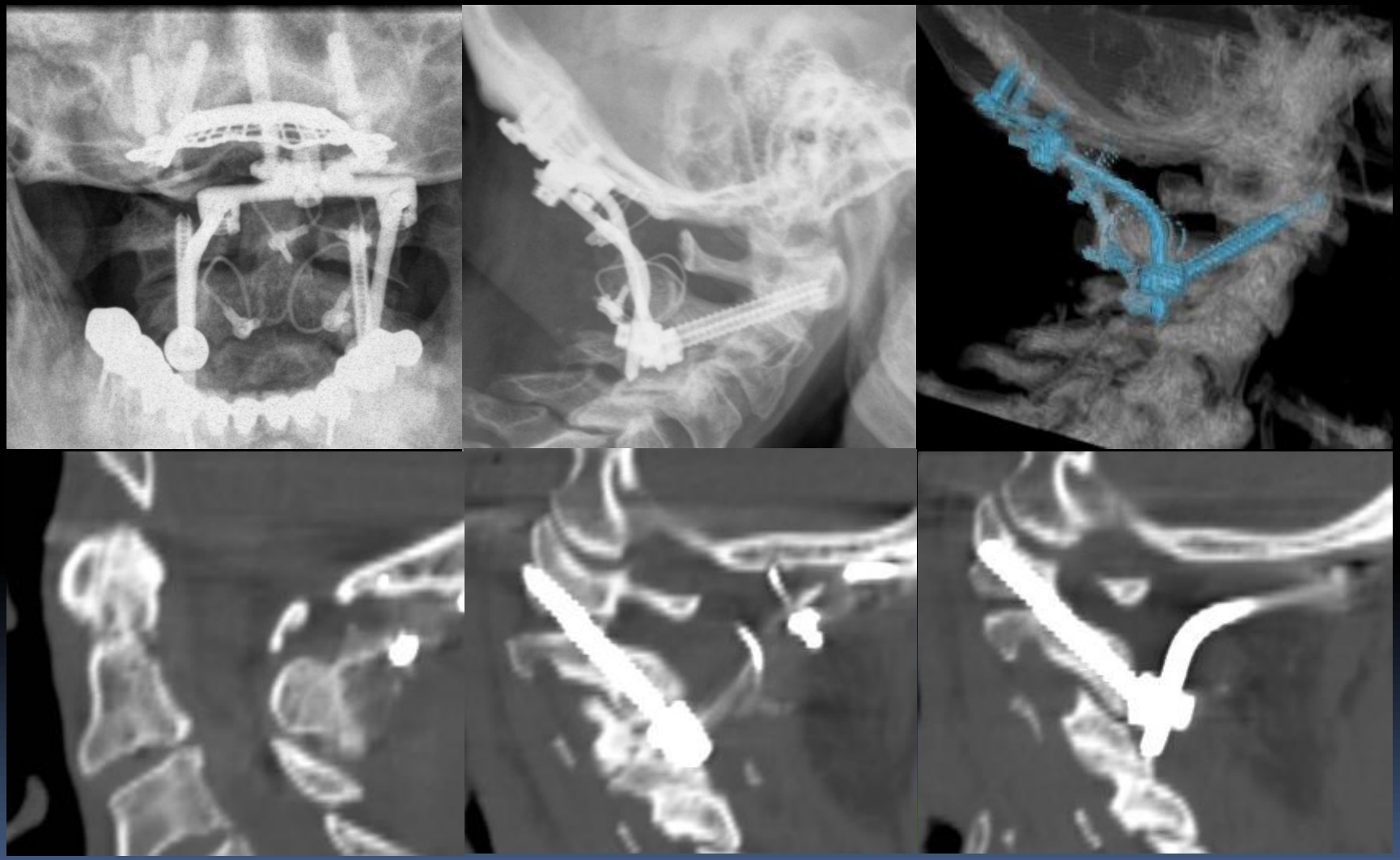
- Occipitospinal strut w/ posterior wiring
  - Incidental anterior VB ankylosis d/t RA



Dens Fracture Fixation

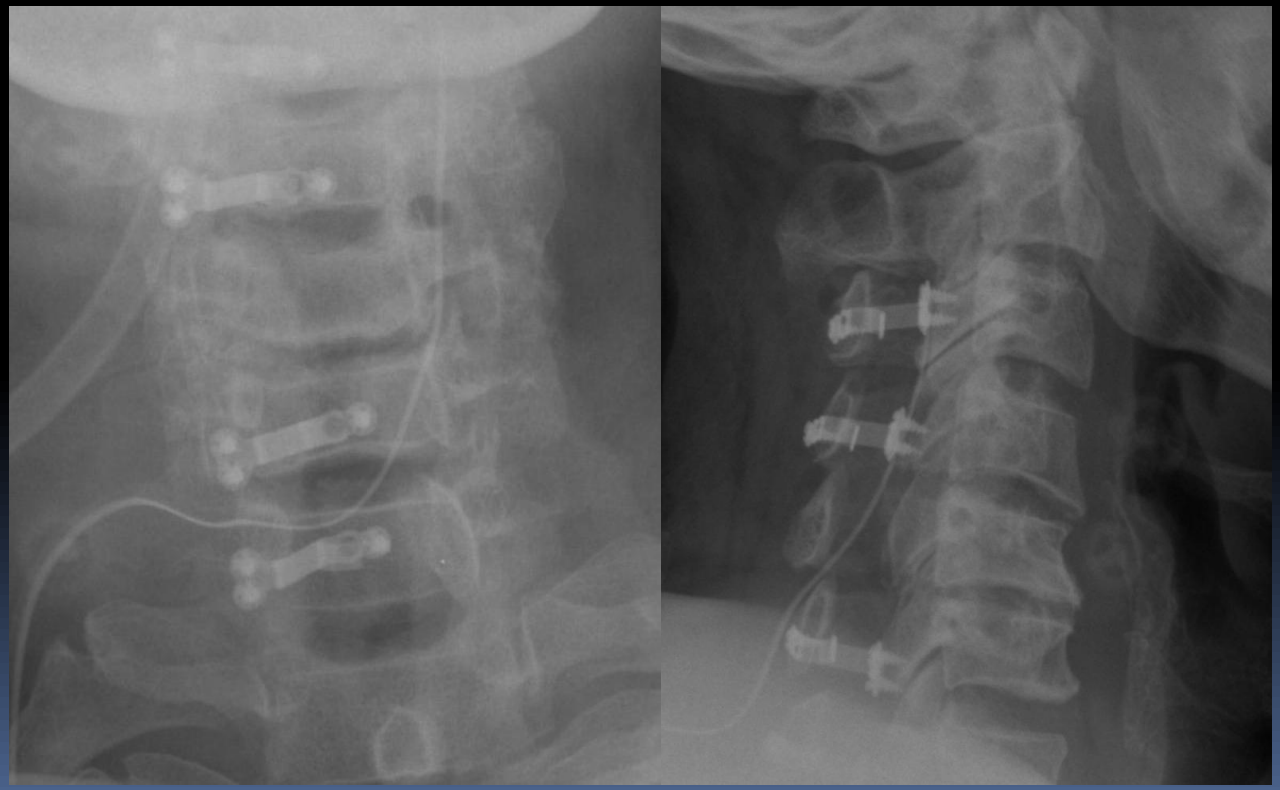


Dens Fracture Fixation



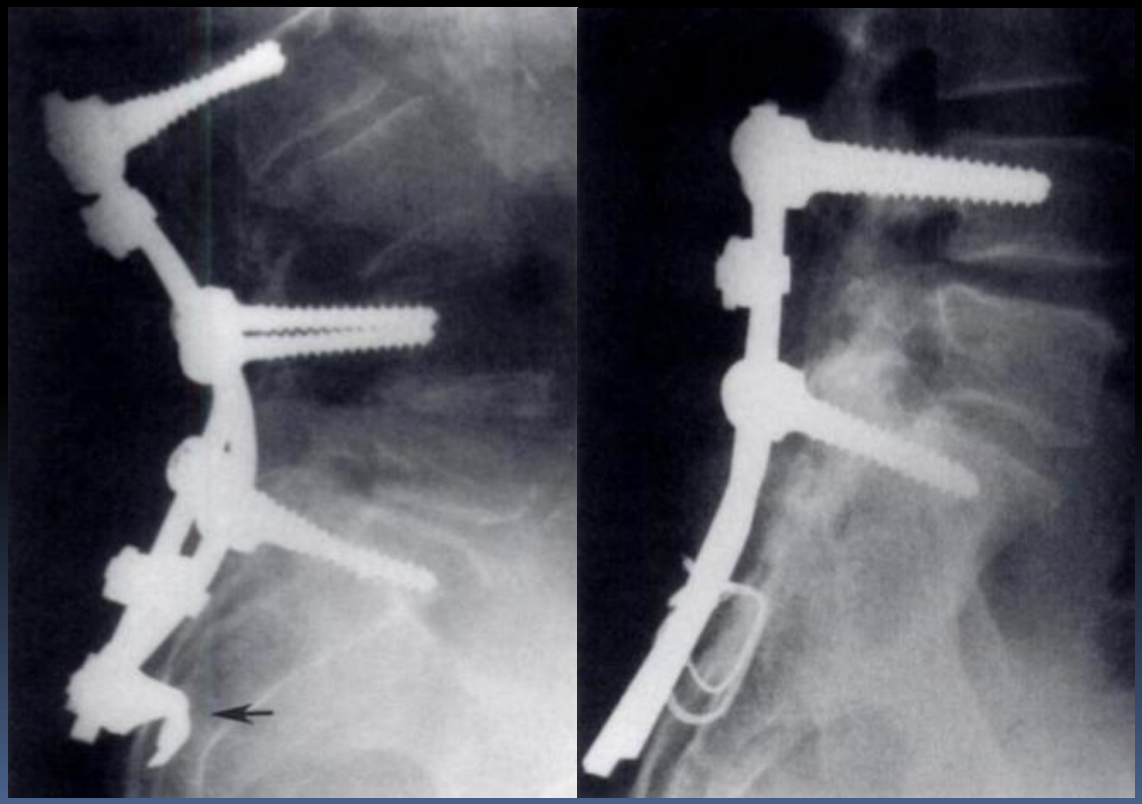
Laminoplasty

- Open door laminoplasty
  - Unilateral laminectomy and angulation of intact posterior elements



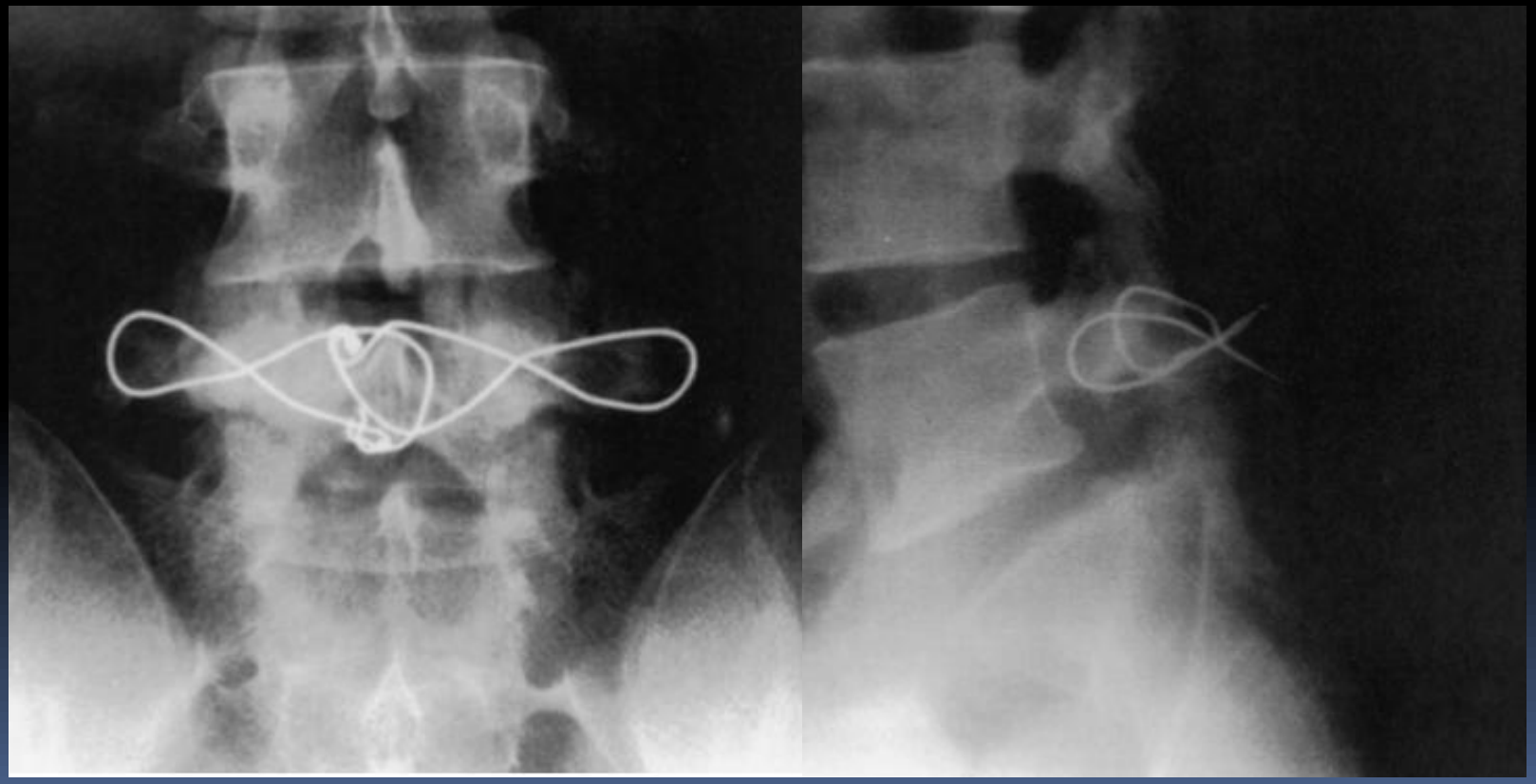
Lower Lumbosacral fixation

- Lumbosacral Spine
  - Transpedicle screws cannot be placed below S2

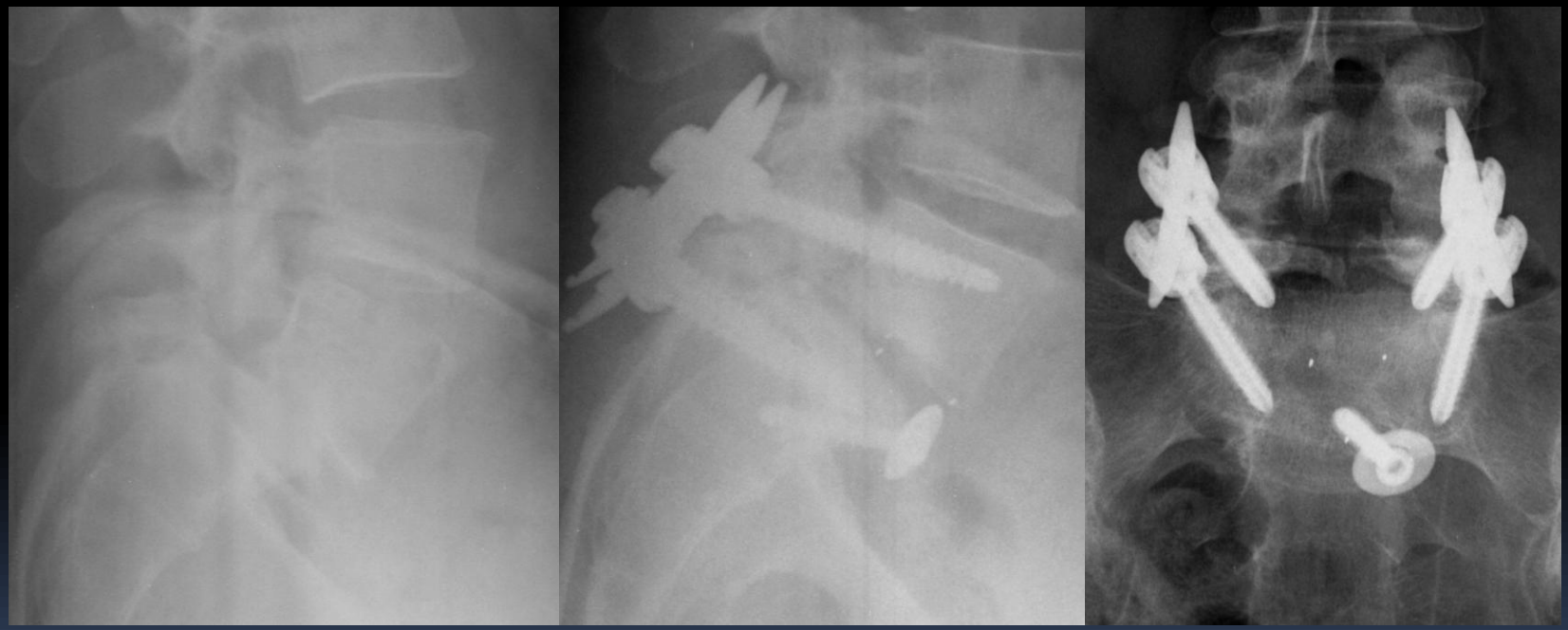


Pars Fixation

- Wiring of transverse and spinous processes w/ bone graft for pars defects

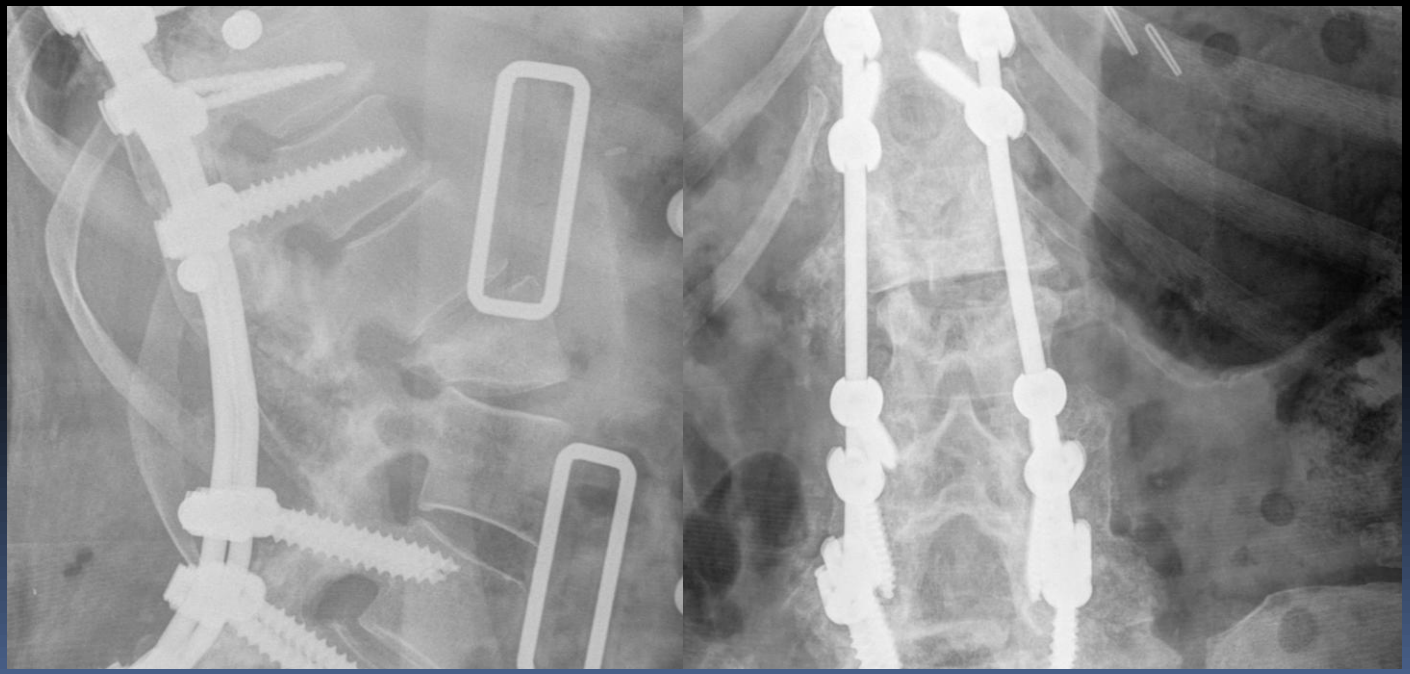


Pars Fixation



Pedicle Subtraction Osteotomy

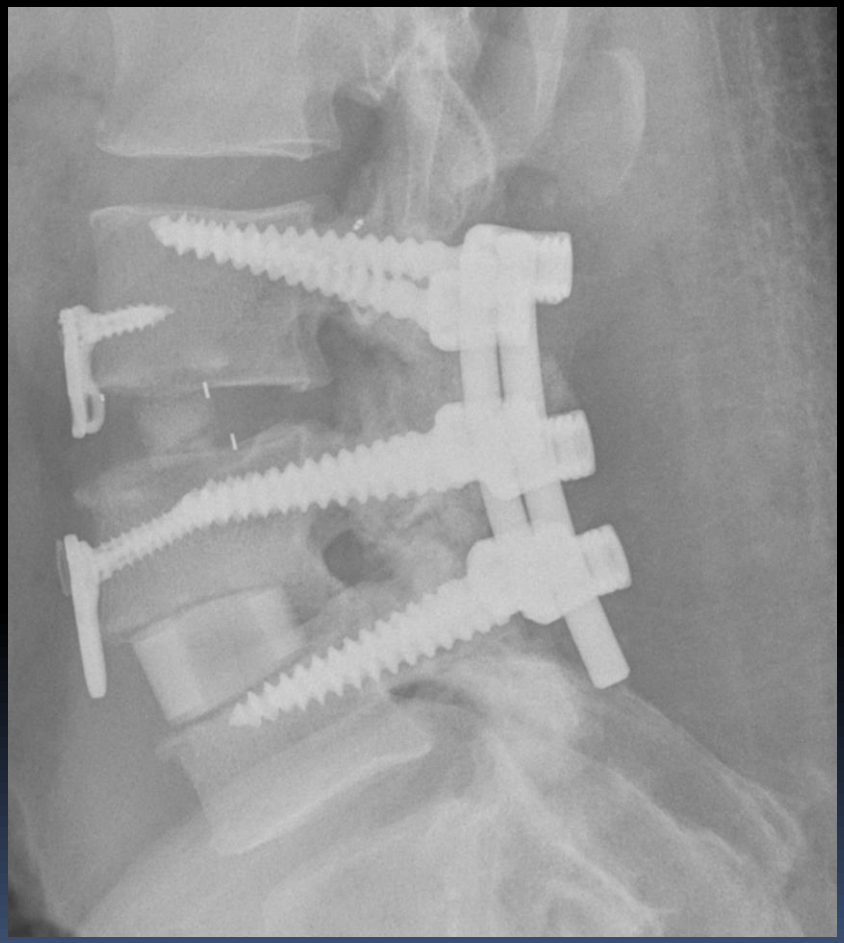
- Triangular wedge in vertebral body w/ posterior apex
  - Surgical resection of all elements posterior to pedicles



Lumbar Spine Fusion - Terminology

- Many types of anterior interbody fusions, but approaches vary
- LIF: Lumbar Interbody Fusion
  - XLIF: Lateral approach
  - PLIF: Posterior approach
    - Below L1-2, must move spinal cord
  - ALIF: Anterior
    - Below aortic bifurcation
  - TLIF: Transoforaminal
    - Below neuroforamen

Anterior Lumbar Plates

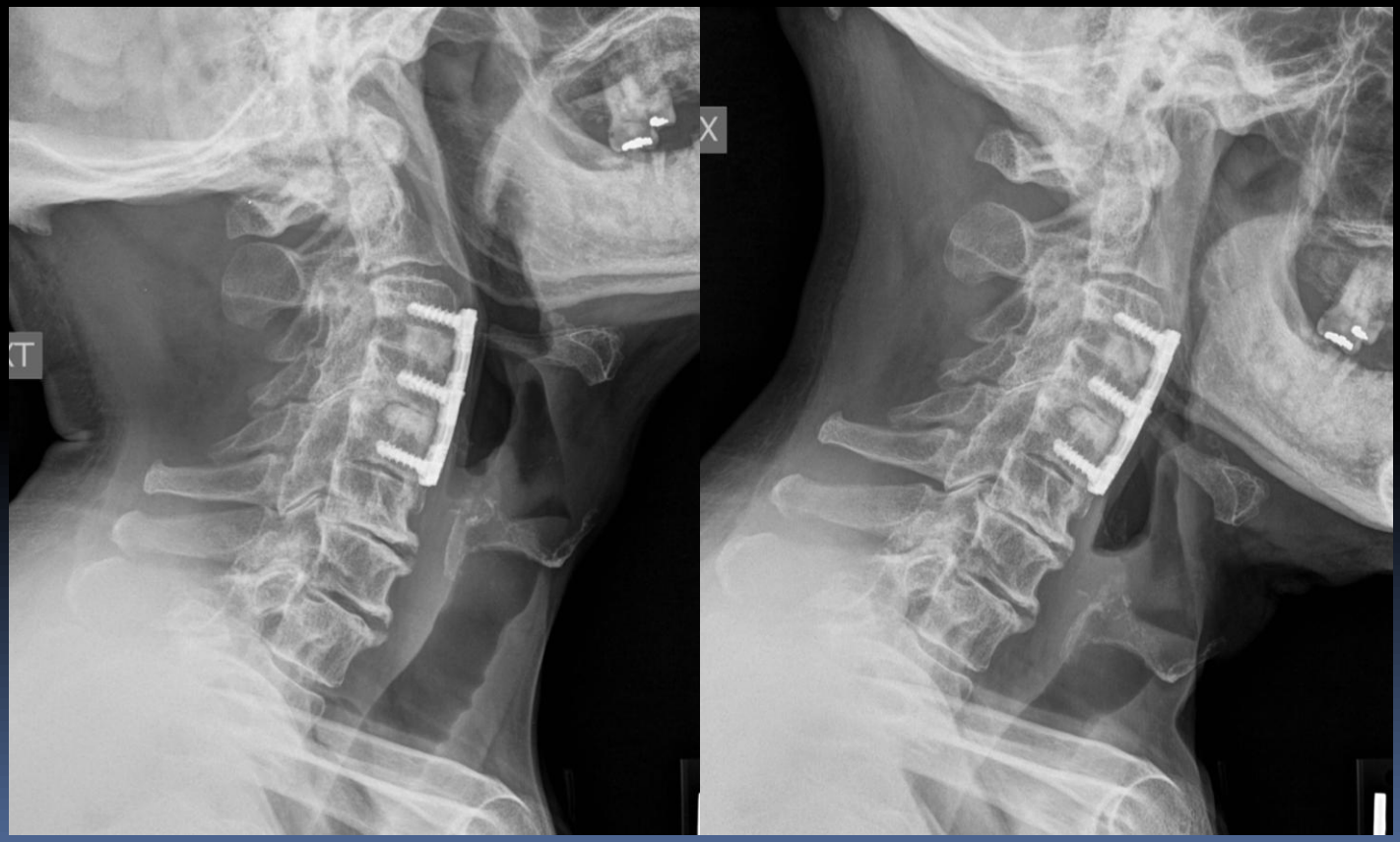


Postoperative Imaging

- Performed to:
  - Assess for osseous fusion
  - Confirm positioning and integrity of instrumentation
  - Detect suspected complications
  - Assess for new or progressive disease

Flexion-Extension Radiographs

- Can assess for instability/motion even in the absence of definite bone graft fusion



Complications

- Operative/Peri-operative
- Implant
- Bone Graft
- Long Term

Complications: Operative/Peri-operative

- Improper level/location
  - Critical role for radiologist to recognize intended surgical location prior to surgery
  - Hardware encroaches on important structures
- Nonphysiologic reconstruction
  - Flat back sx
- Hematoma
- Infection
- Dural tear, pseudomeningocele
- Vascular injury

Complications: Implant

- Instability/poor purchase
- Loosening
- Infection
- Fracture
  - Implant or bone
- Migration/Dislodgement
- Poor inter-implant contact
- Overdistraction

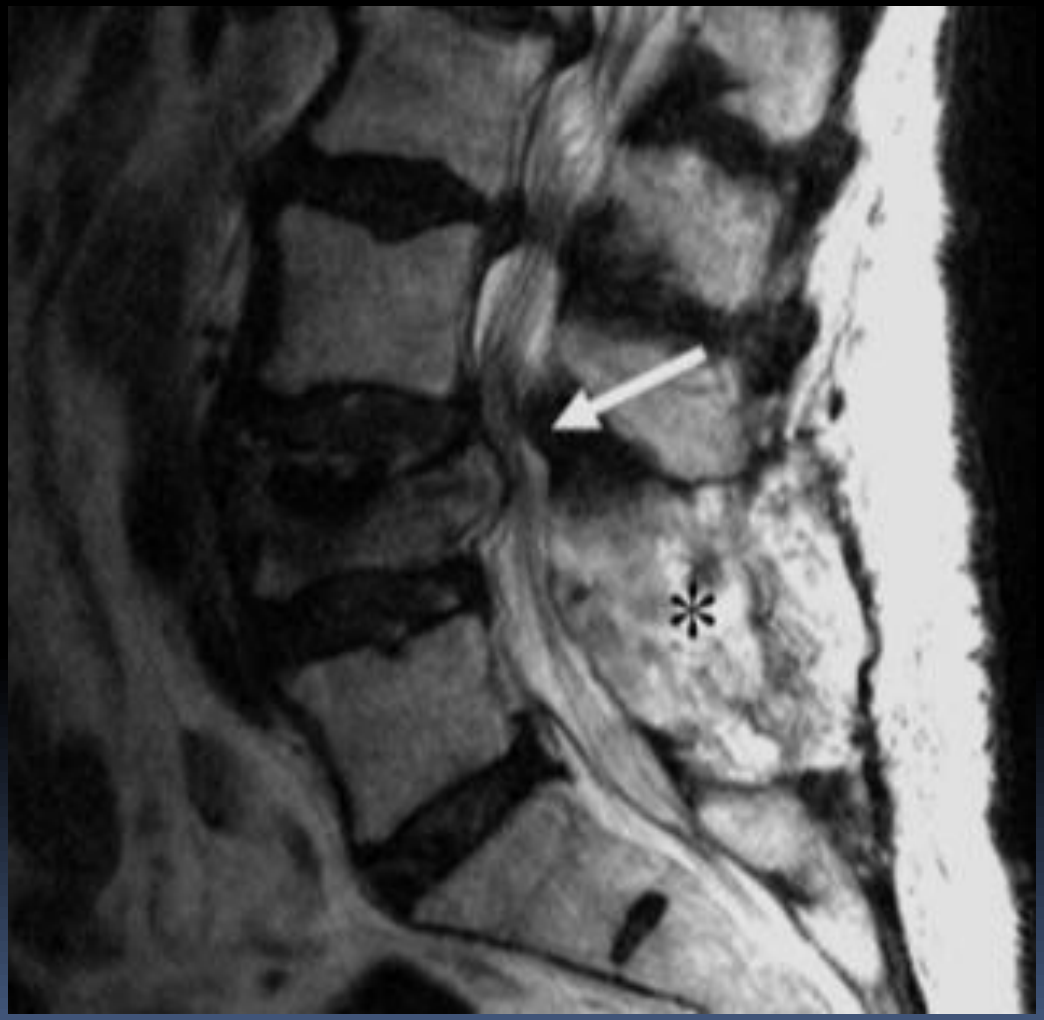
Complications: Bone Graft

- Failure of fusion
  - Can have fusion, fibrous union, or pseudoarthrosis (no bony fusion)
  - Fibrous union and pseudoarthrosis both considered failure
  - Should have signs of bridging bone by 6-9 months
- Poor graft location
  - Migration, incorrect placement, fusion mass encroaching on spinal canal or nerve roots
- Harvest site complications
  - Pelvic fx, infection, hematoma, and nerve, ureter, or SIJ injury

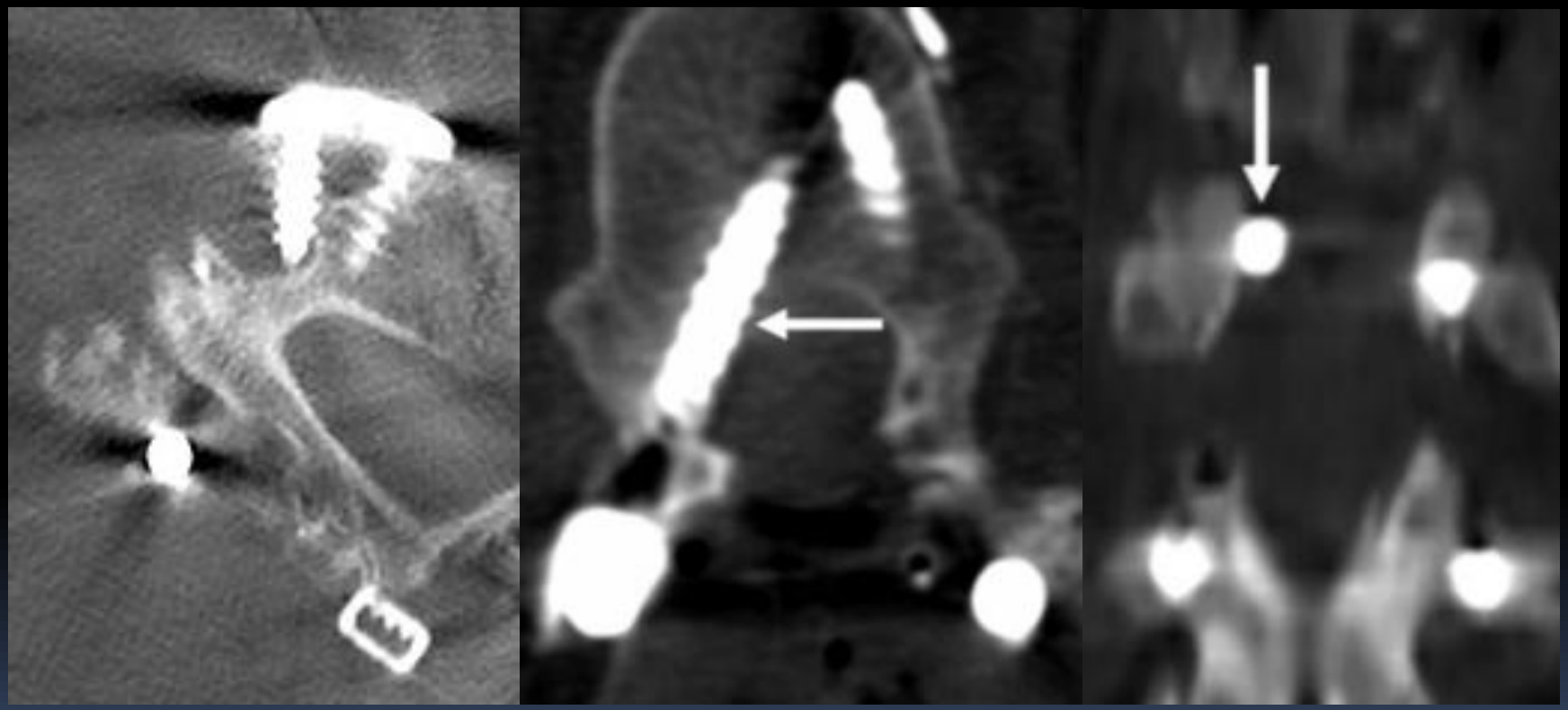
Complications: Long-term

- Adjacent instability/degeneration
  - Fixation/fusion causes problems at adjacent spinal levels
- Infection
- Fracture of fusion mass
- Arachnoiditis

Improper Level



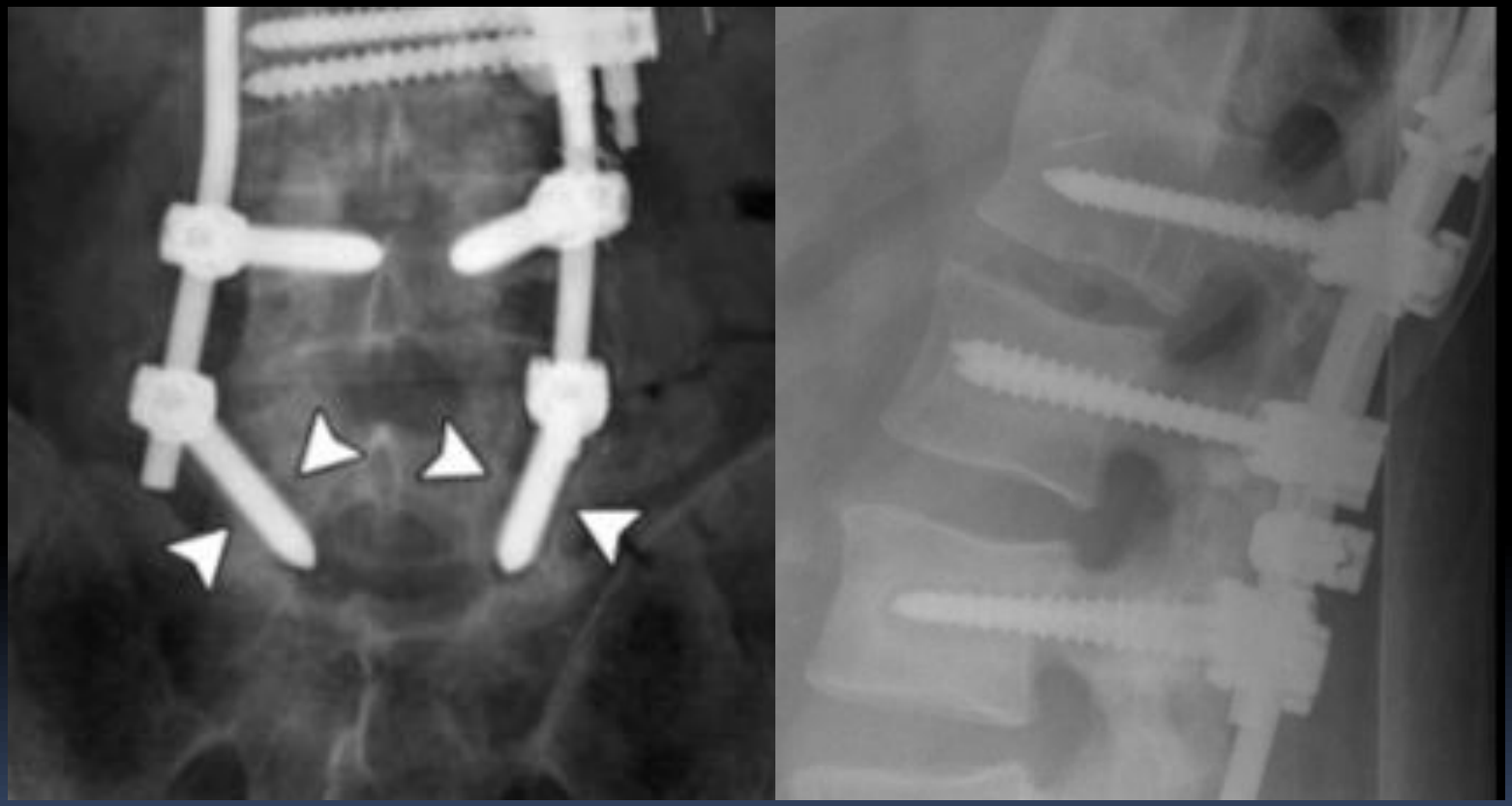
Improper Location



Hematoma

Infection

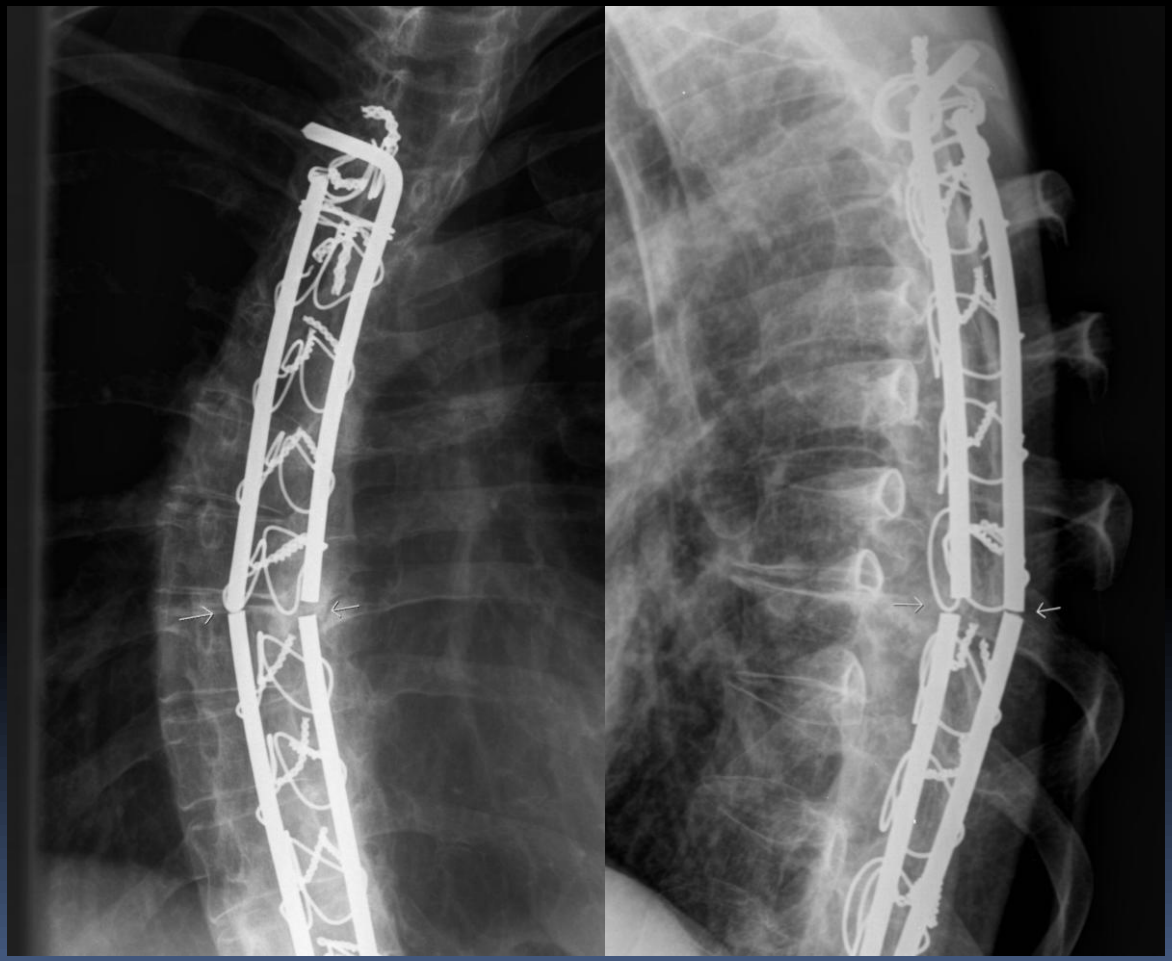
Implant Loosening



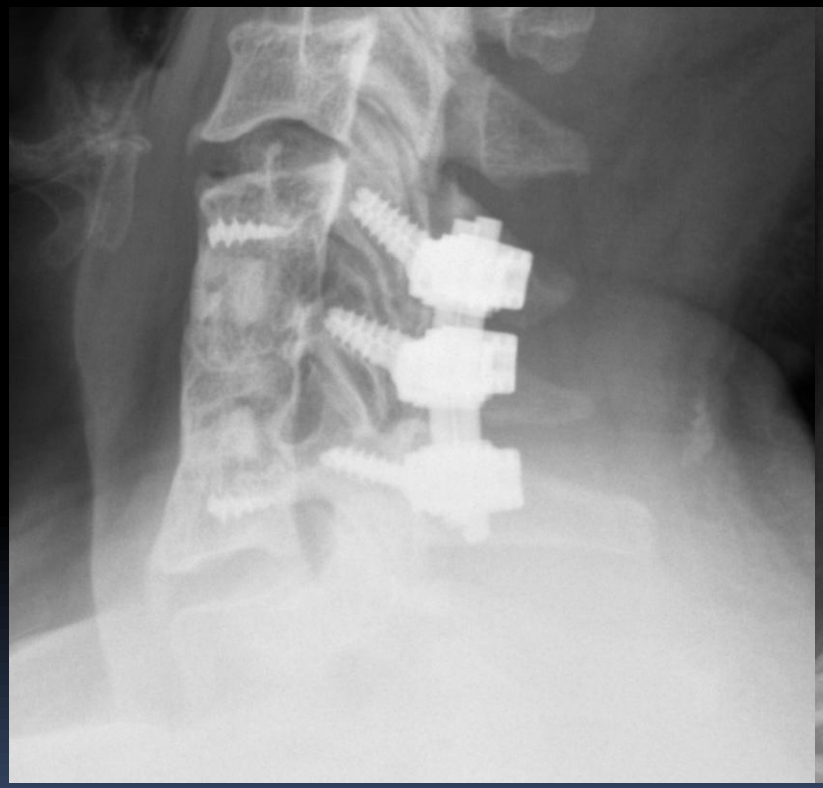
Peri-Implant Infection

Implant Fracture

Implant Fracture



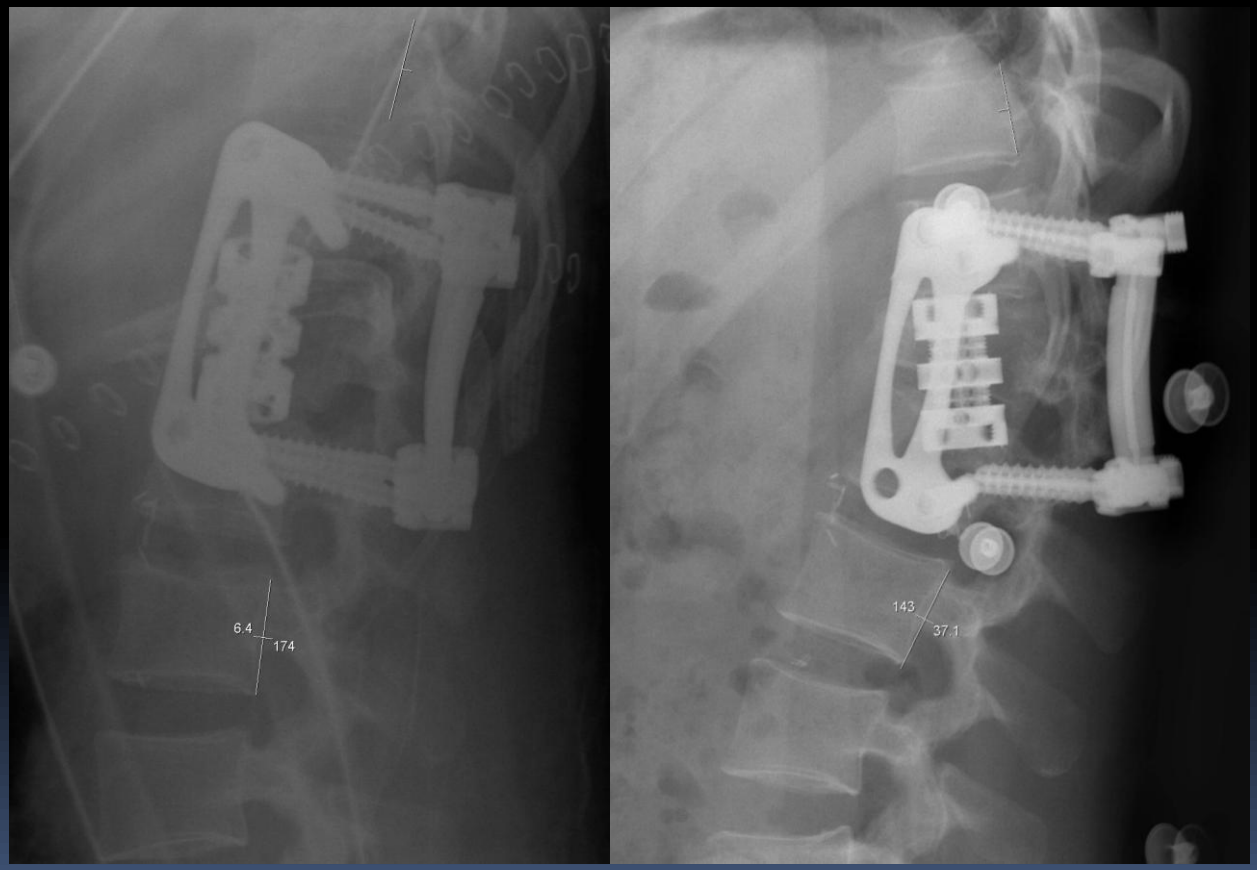
Remotely Fractured Screws



Implant Migration

Implant Dislodgement

Implant Dislodgement

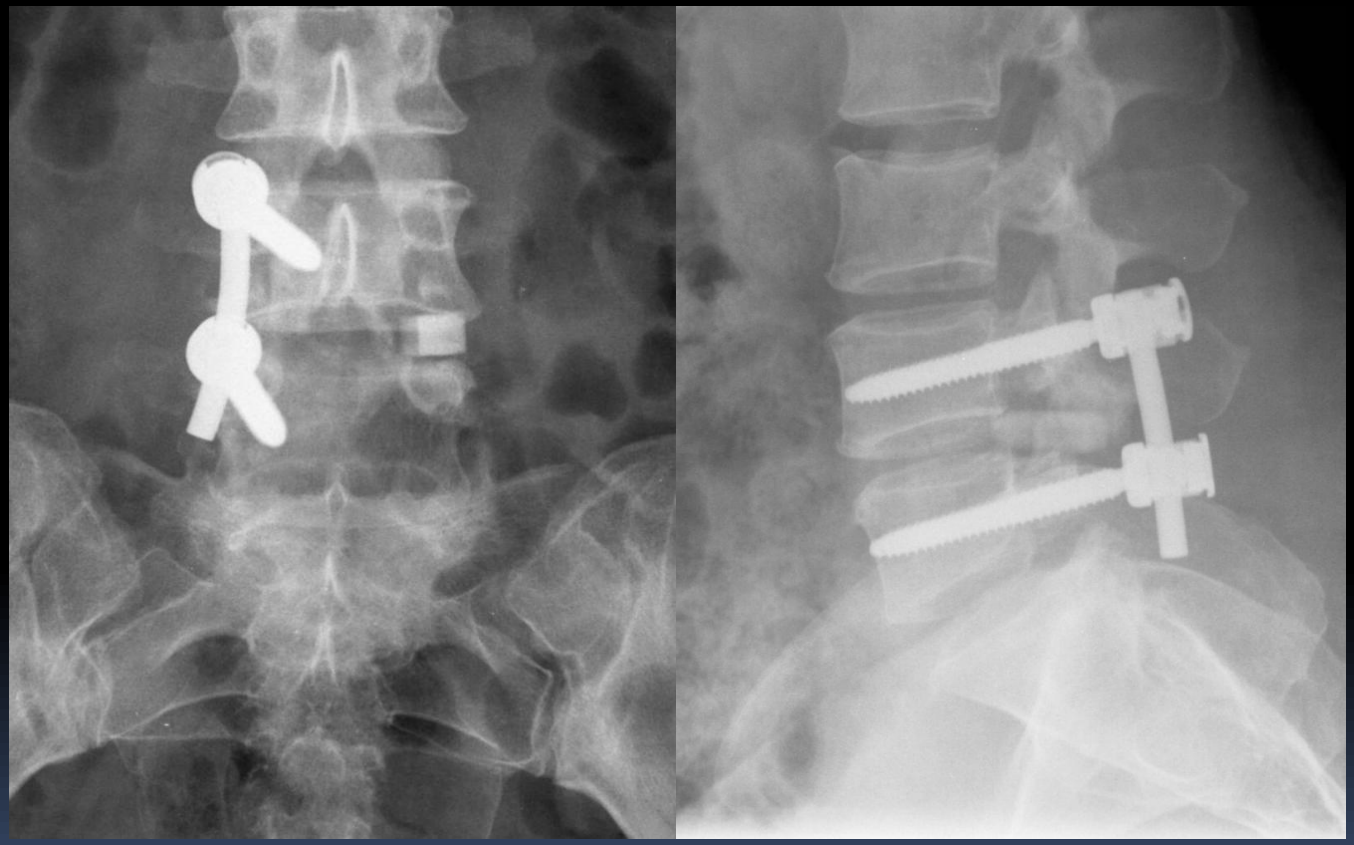


Pseudarthrosis

Criteria for Bridging Osseous Fusion (Young)

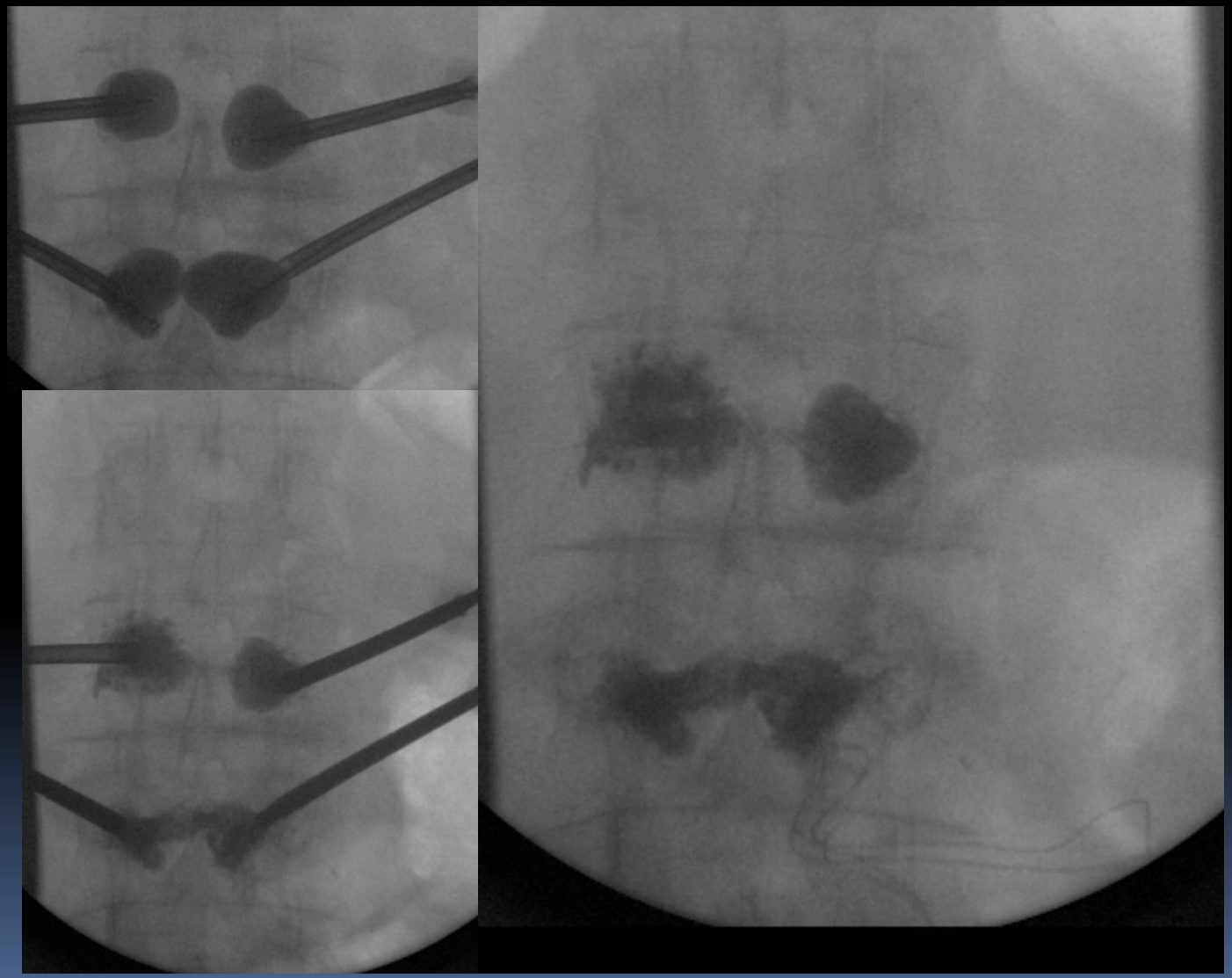
- 1: No lucency around implant
- 2: No fx of device, graft, or vertebra
- 3: No sclerotic changes in graft or adj vertebra
- 4: Visible bone formation in/about graft
- 5: Minimal loss of disc height
- 6: <3 degrees of intersegmental position change on flexion/extension views
- * Lower rate of pseudoarthrosis w/ posterior than anterior fusion

Poor Graft Location - Extrusion



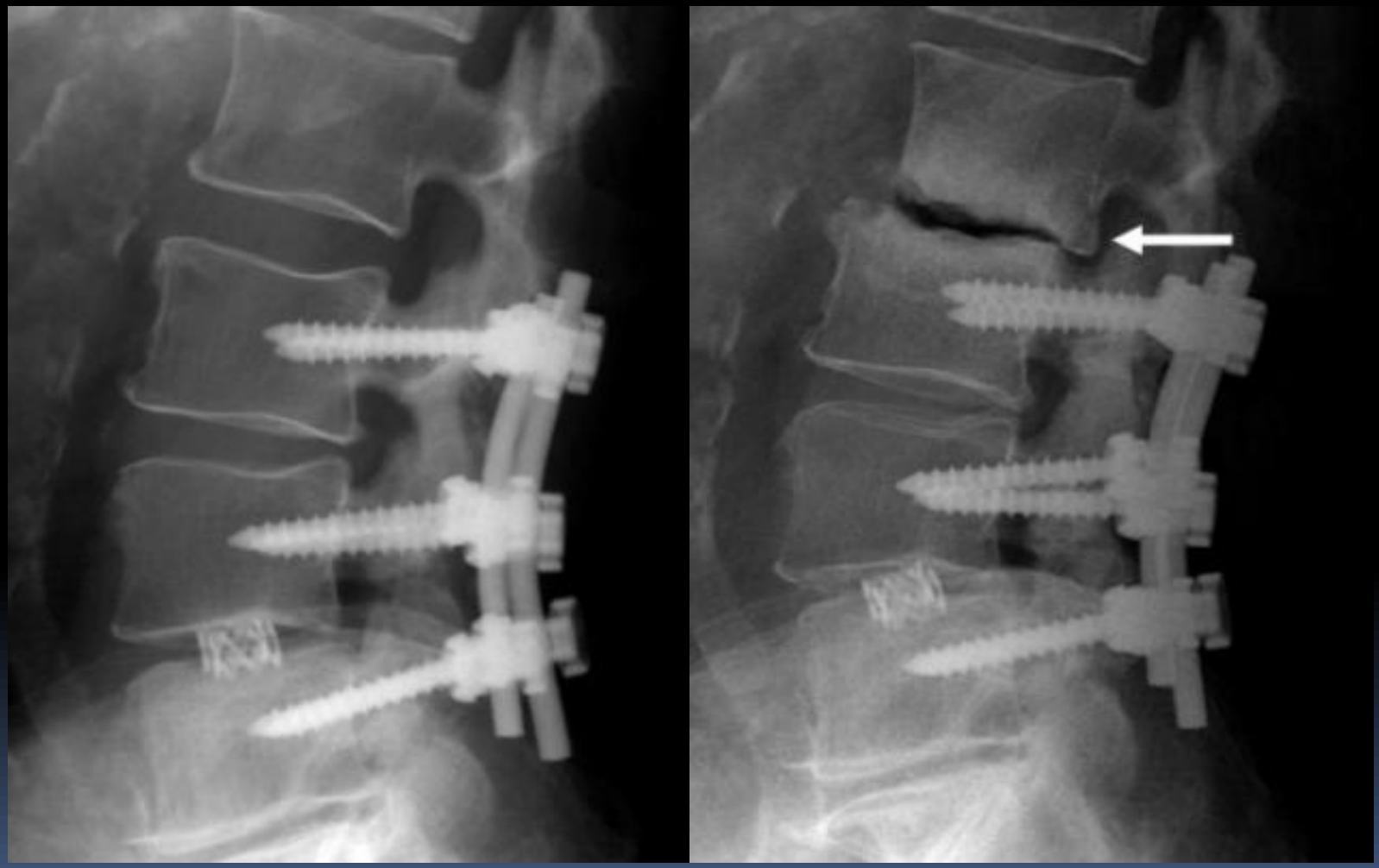
Poor Graft Location - Extrusion

Poor Cement Placement - Kyphoplasty



Adjacent Degenerative Changes

Adjacent Degenerative Changes



Adjacent Instability

- Marked ligamentous instability

Fractured Fusion Mass

Arachnoiditis

References

- Foster MR. A functional classification of spinal instrumentation. Spine J. 2005 Nov-Dec; 5(6): 682-94.
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