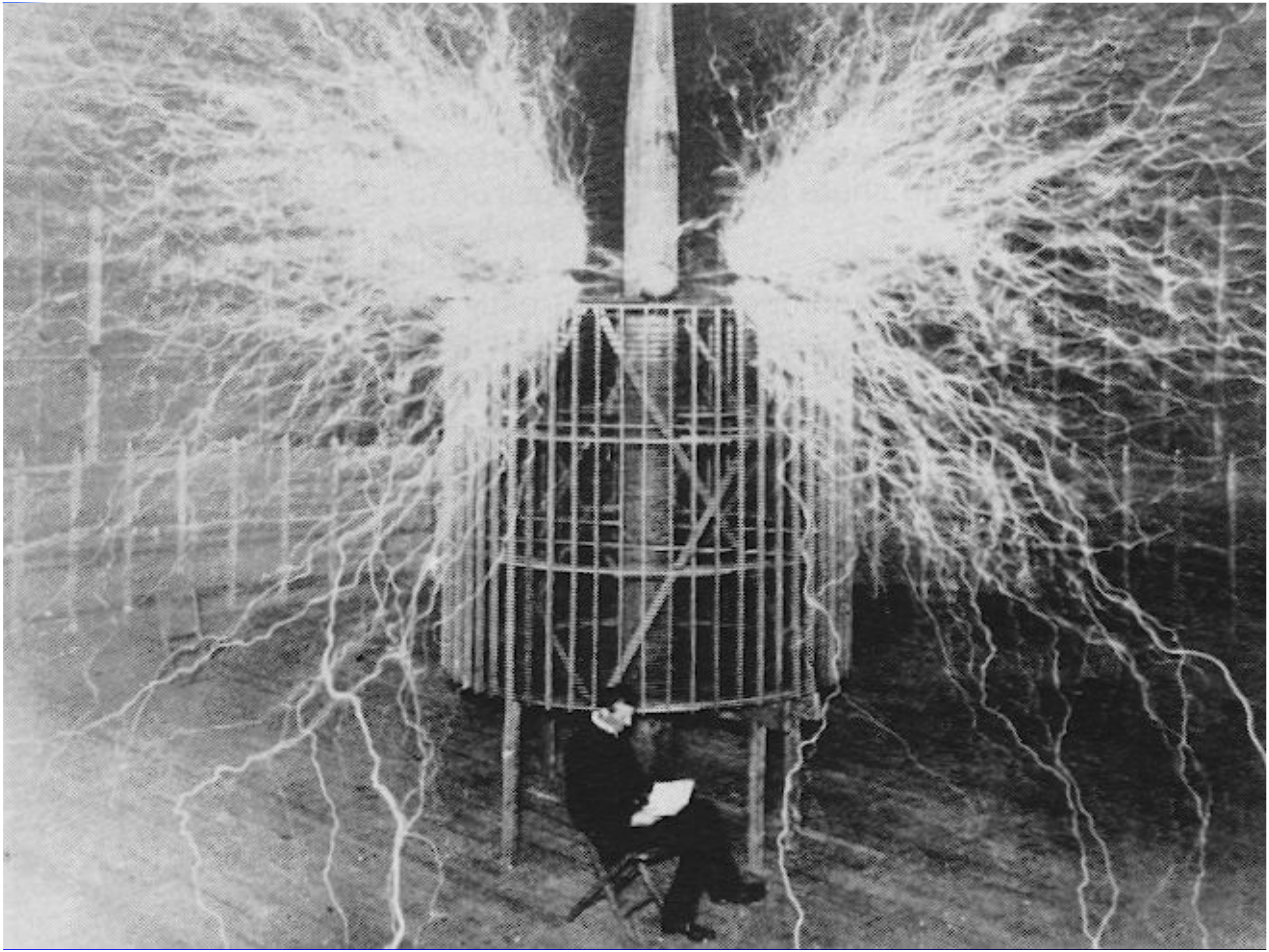

MRI Update in Spinal Trauma and Spinal Cord Injury

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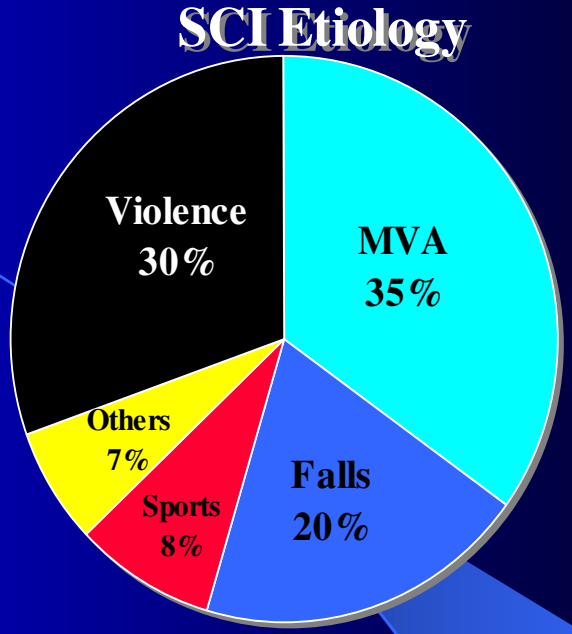
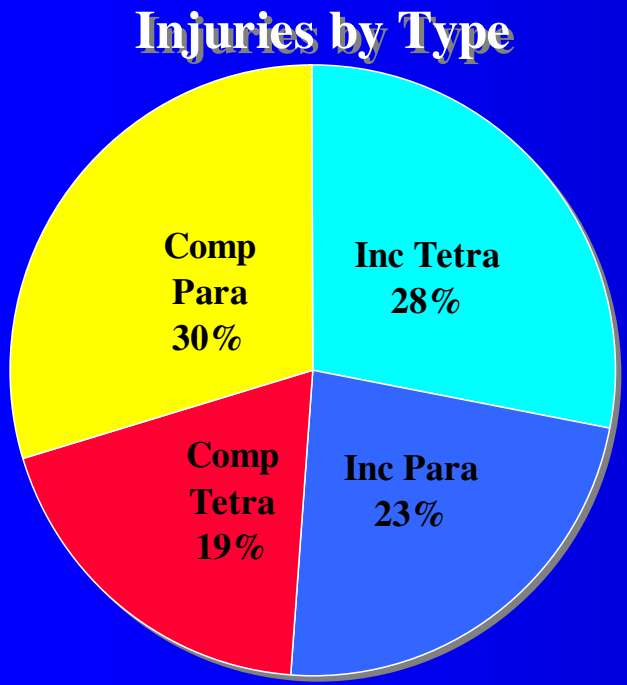
Philadelphia, Pennsylvania

Web Syllabus

- There is an *e*-syllabus for this course.
- Appears on the web at the URL shown in the program.
- http://www.neuro.tju.edu/spine617
- http://www.neuro.tju.edu/rsnaspine

Scope of the Problem





- Despite increased public awareness and safety programs, SCI remains a significant problem.
- Incidence: 11,000 per year.
- Prevalence: 200,000 - 250,000.
- Mean age: 31.2 years.
  - 56% occur in 16 - 30 yr olds.
  - Second peak in 60-70 range.
- 82% males
  - whites > AA > hispanics
- Peaks in Summer and Weekends

Imaging Algorithm for Spine Trauma

- Imaging algorithms vary by institution and within institutions depending upon:
  - Clinical protocols & criteria are instituted.
  - How many different specialties “control” spinal injury.
  - “Judgement” of individual physicians.
  - Litigenous climate.

Imaging Modalities

- Plain Radiography (CR)
- ~~Multiplanar Tomography~~
- ~~Myelography~~
- Computed Tomography (CT)
- Magnetic Resonance Imaging (MRI)

Imaging Algorithm for Spine Trauma

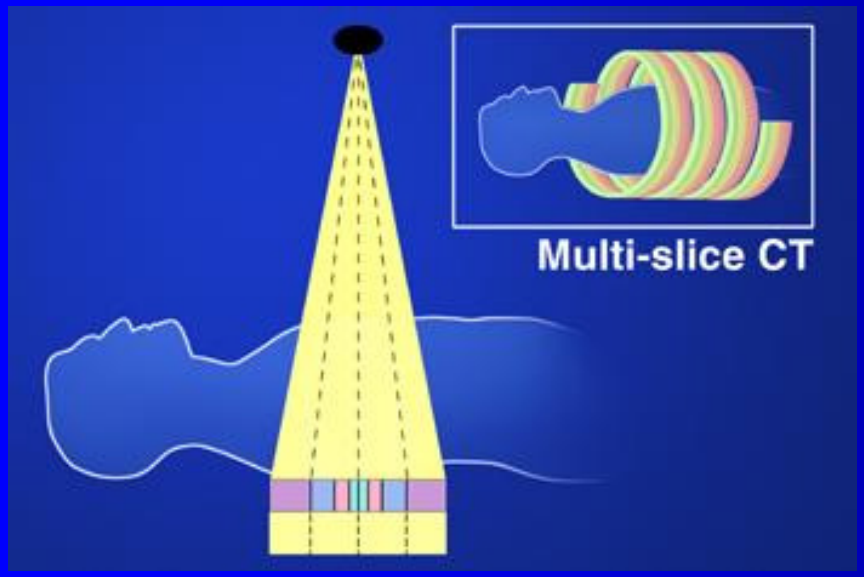
- Radiographs or Send Home
  - Significant? Trauma
  - Impaired sensorium
- CT
  - Equivocal or positive radiographs, normal radiographs with severe pain.
- MRI
  - Neurologic deficit (myelopathy is significant).
  - Impaired sensorium, difficult to elicit neurologic exam.

What Has Changed?

- Proliferation of Multidetector CT scanners.
- Maturation of Magnetic Resonance Imaging as a clinical tool.
- New MRI techniques which have yet to reach the clinical domain.
- Increased dependency on imaging for patient management and treatment.
- Development of powerful, inexpensive post-processing workstations.

Multi-Detector Computed Tomography

Single vs Multidetector CT



Images courtesy of www.ctisus.org

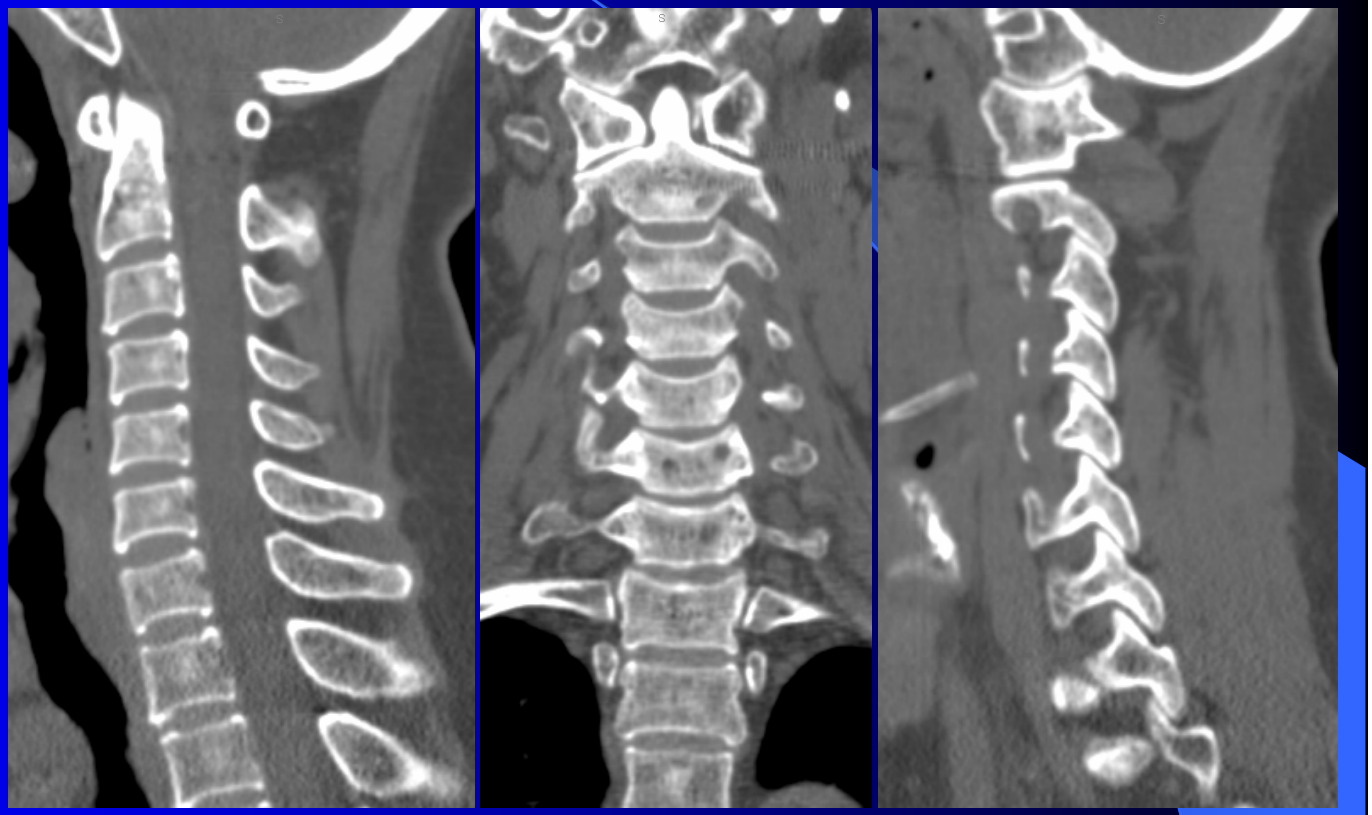
- Multi-detector or multi-slice CT expands spiral CT technology by acquiring image data from multiple slices/locations at once.
- Permits much greater coverage in shorter period of time.
- Analysis of datasets with new 3D workstations.

Multidetector CT

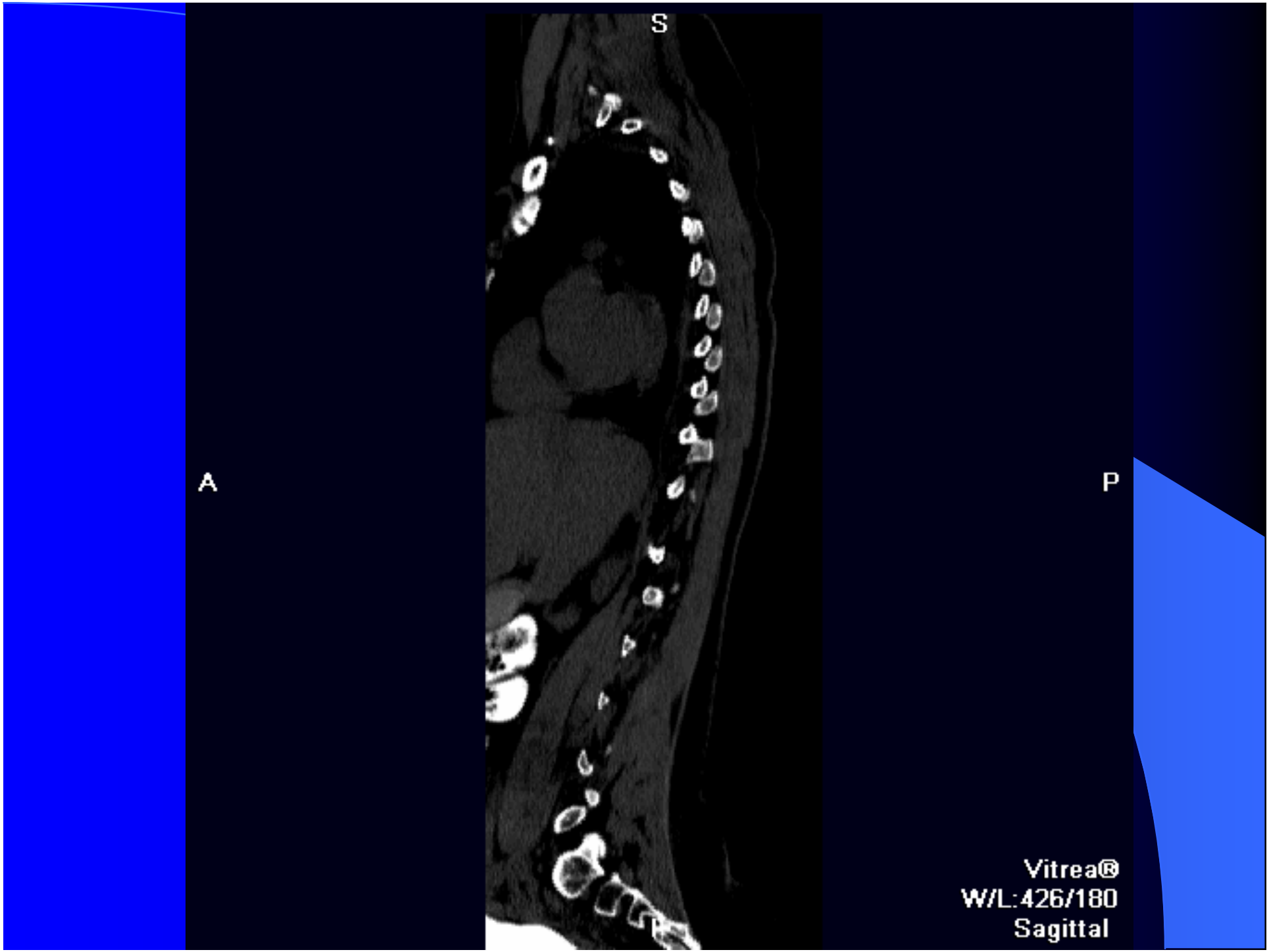
- Single detector CT tradeoff in slice resolution versus coverage.
- Multi-detector provides both high slice resolution and coverage.
- Typical scan now contains hundreds of images.
- Analysis of datasets with new 3D workstations.
- Old Paradigm:
  - Focus on axial dataset; MPR secondary.
- New Paradigm:
  - Focus on MPR dataset; review source data secondarily.

Multidetector CT

2D Sagittal Reformats from a Single Detector CT



2D Multiplanar reformatted images from a 16 detector CT axial dataset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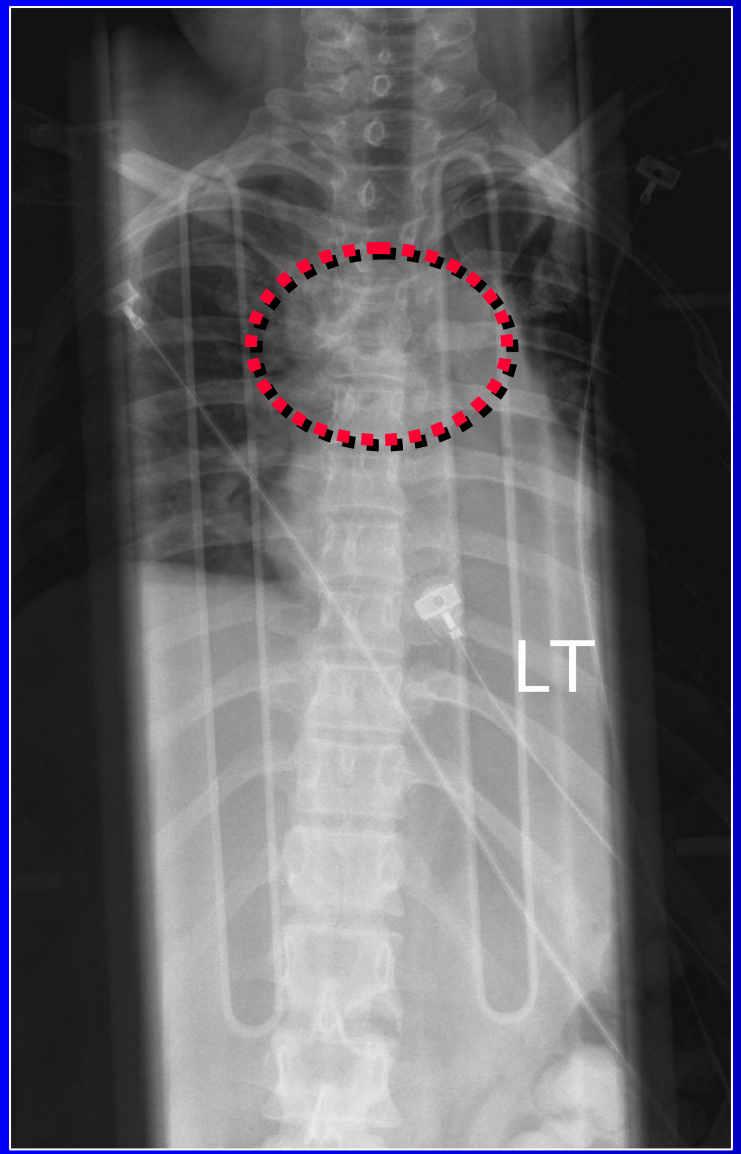
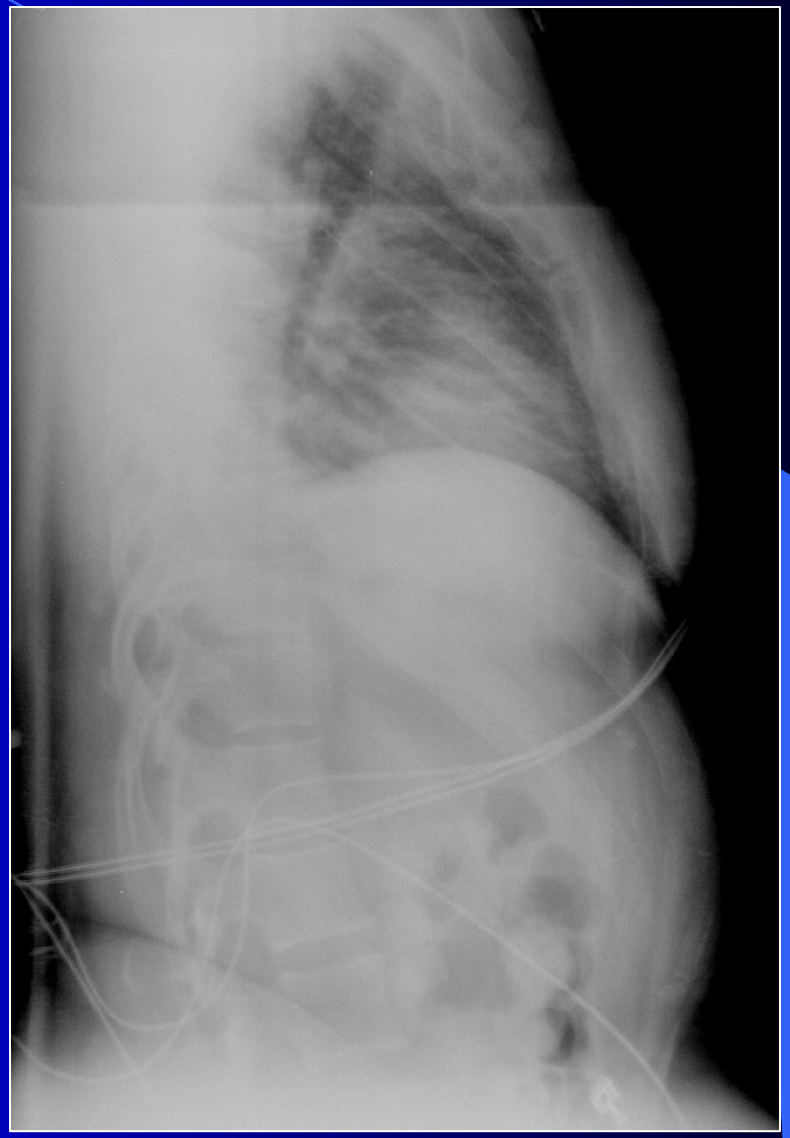
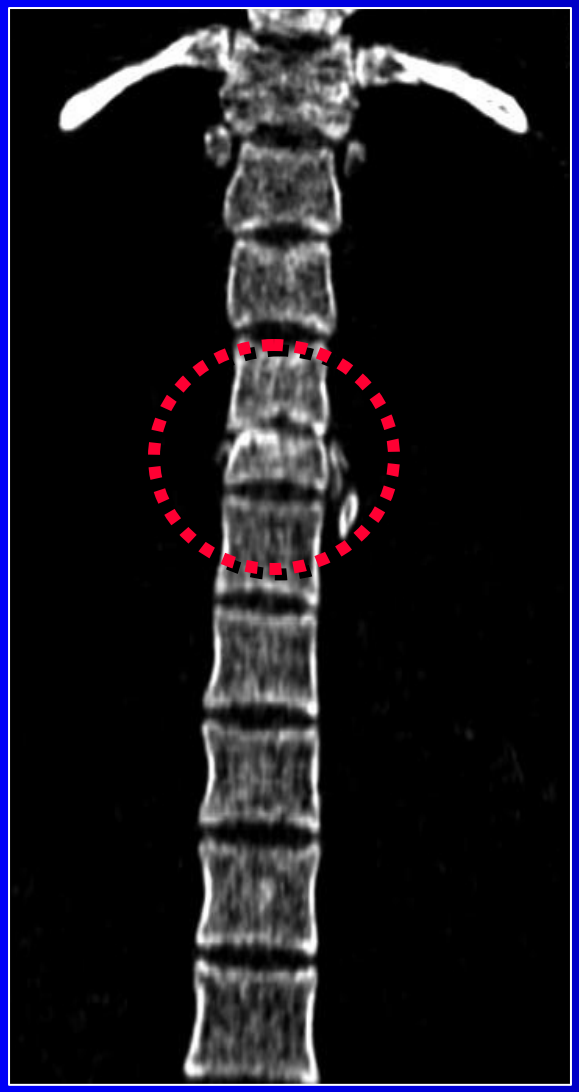
Sagittal

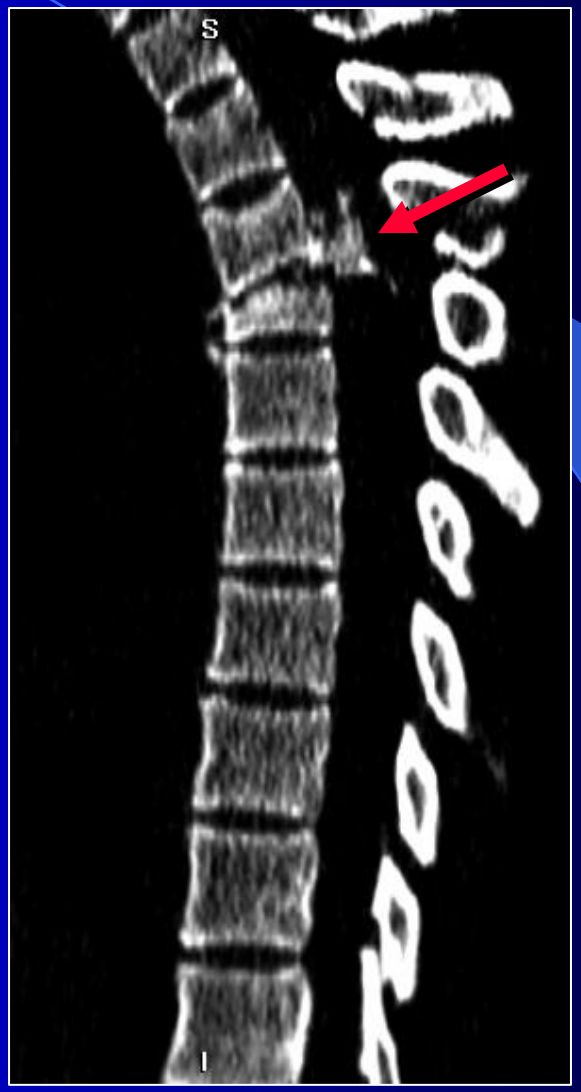
T5 Burst Fracture



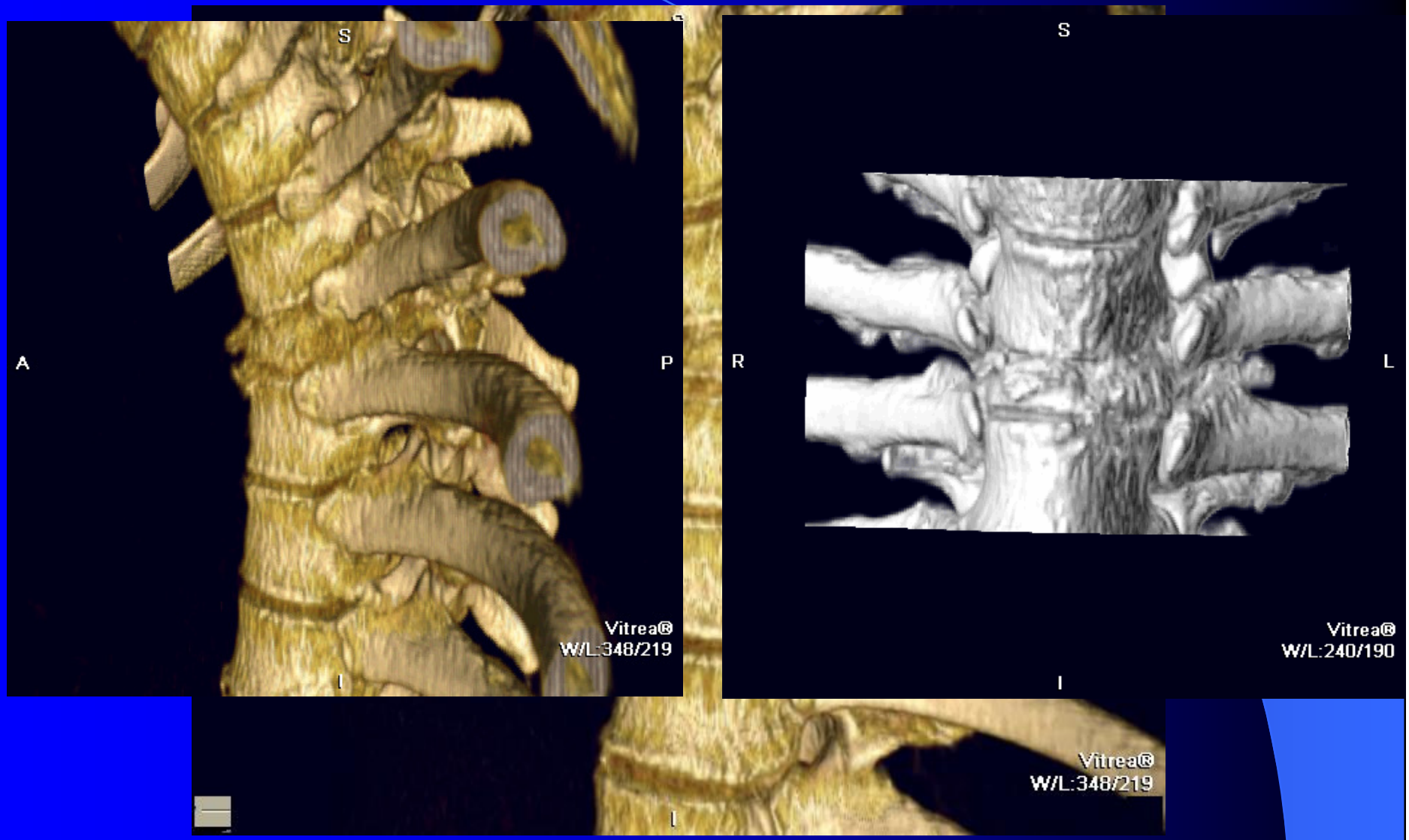


2D Multiplanar/Curved Reformation

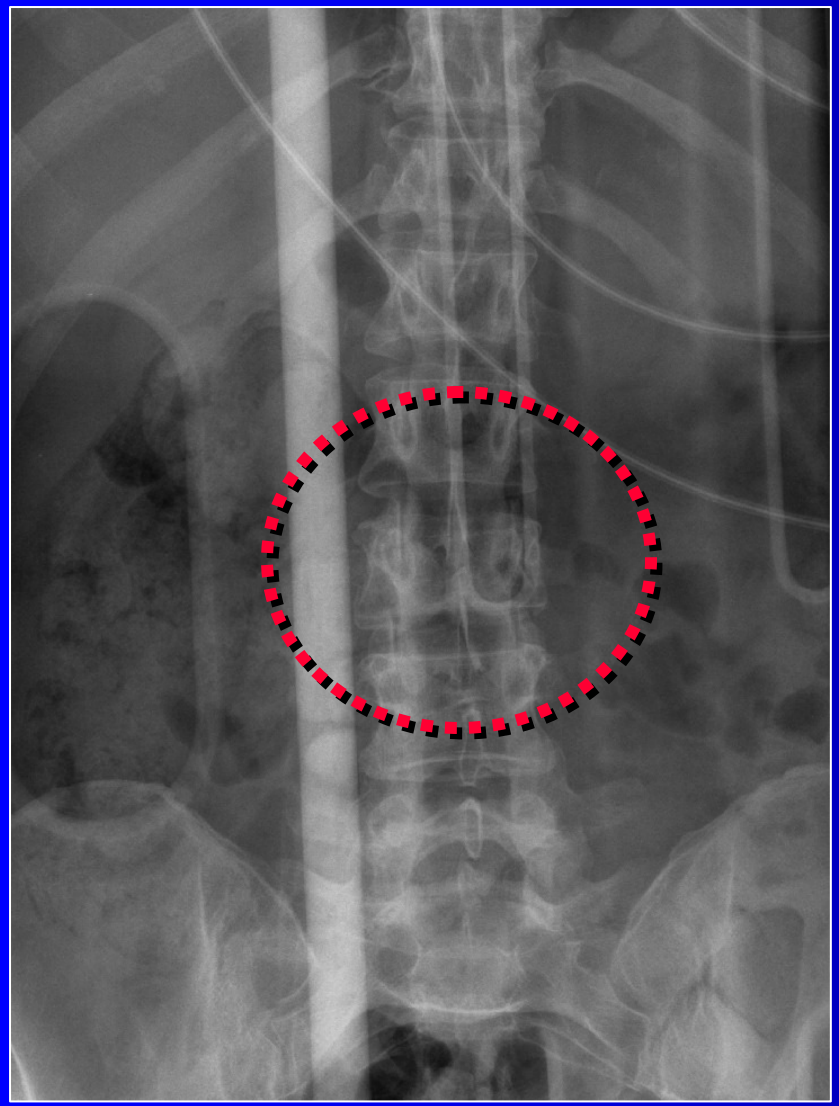


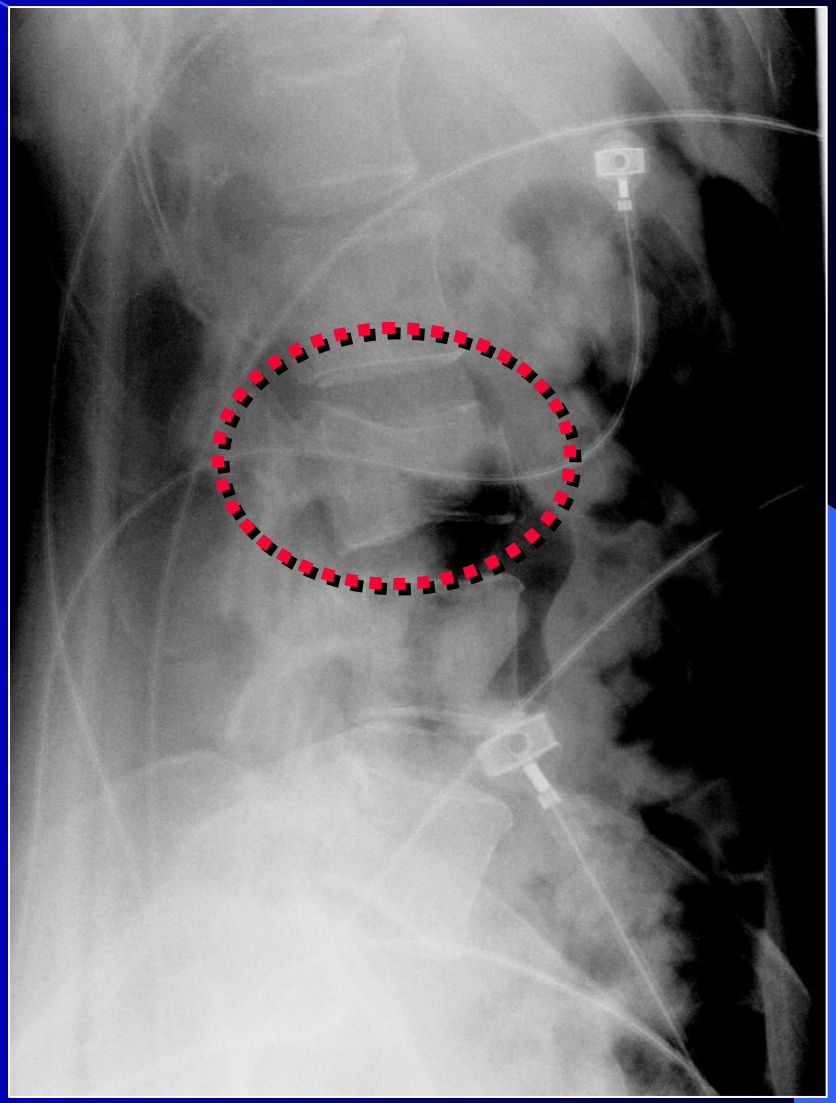


3D Surface Rendering



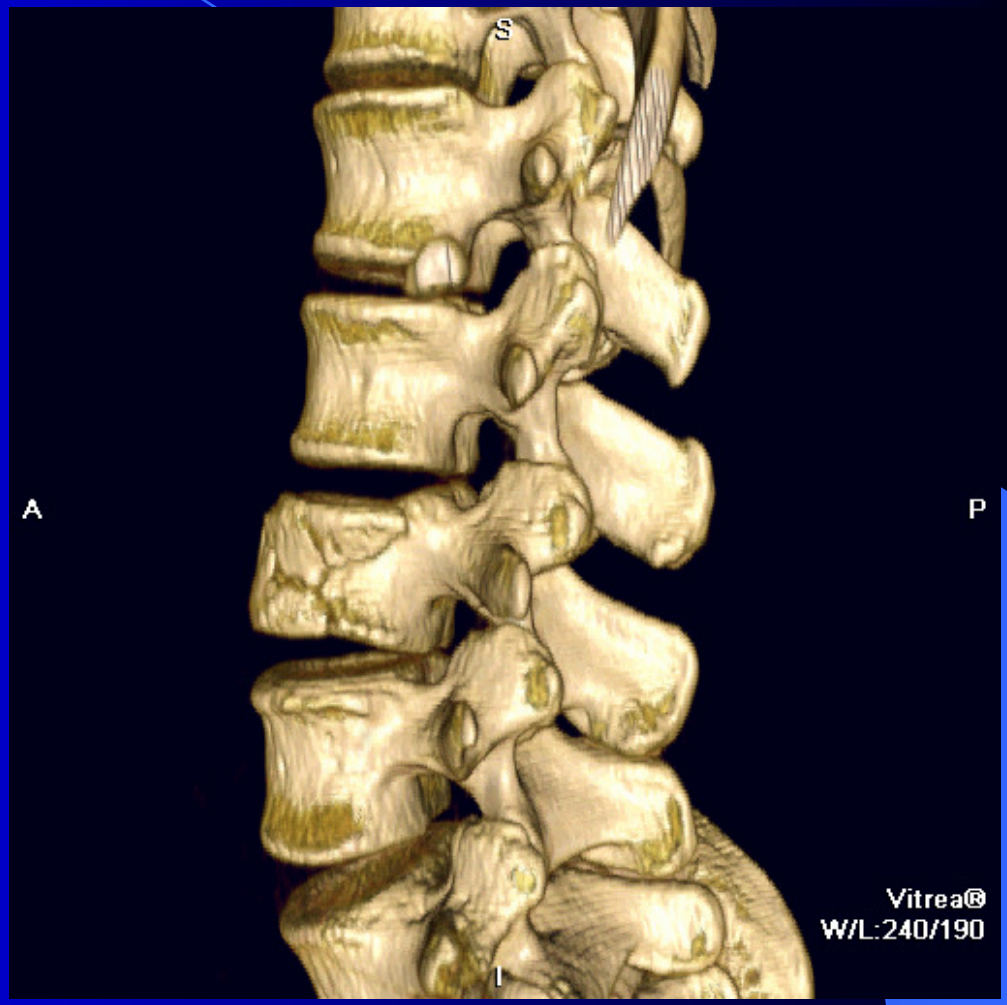
L3 Burst Fracture





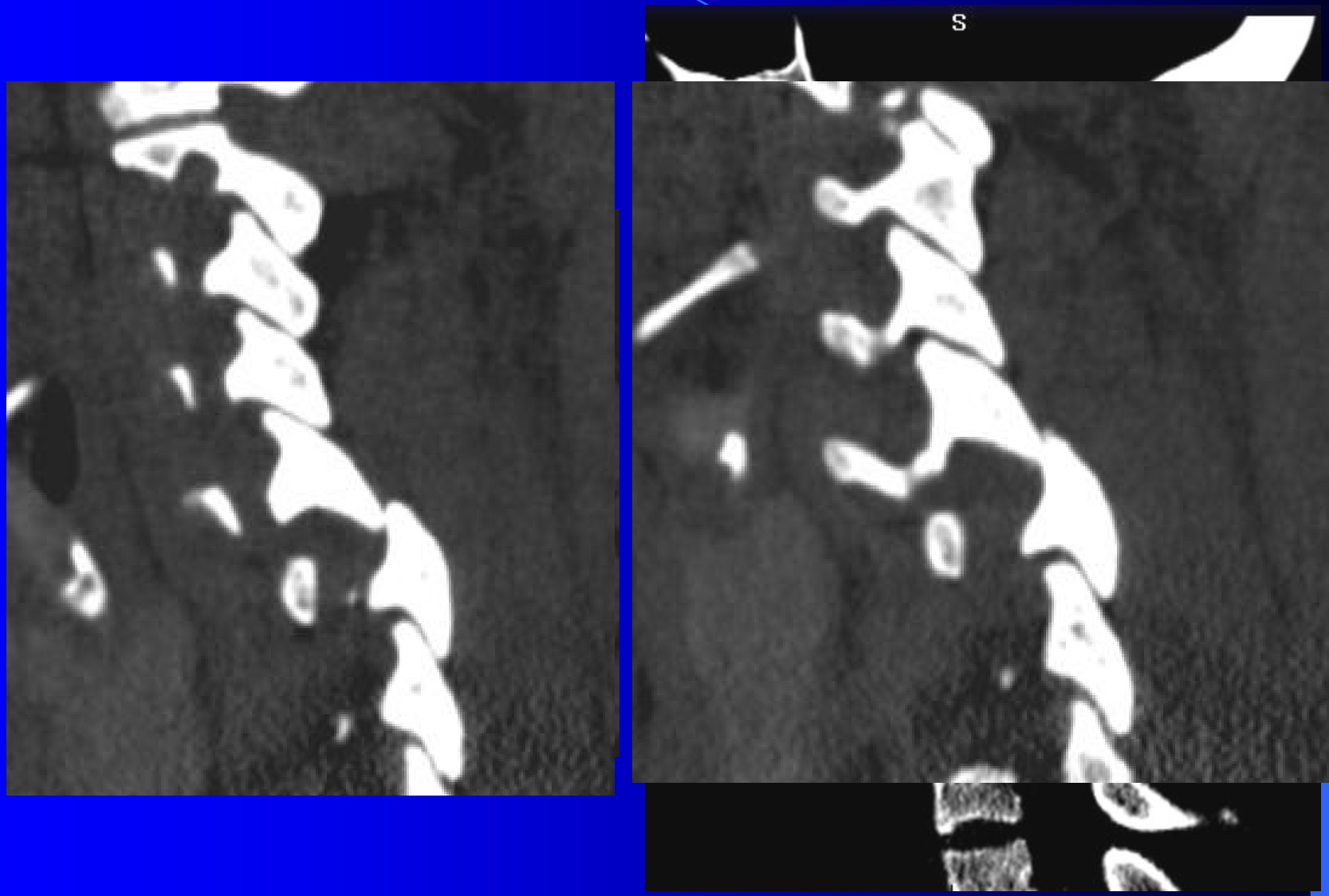
2D Multiplanar Reformation

3D Surface Rendering

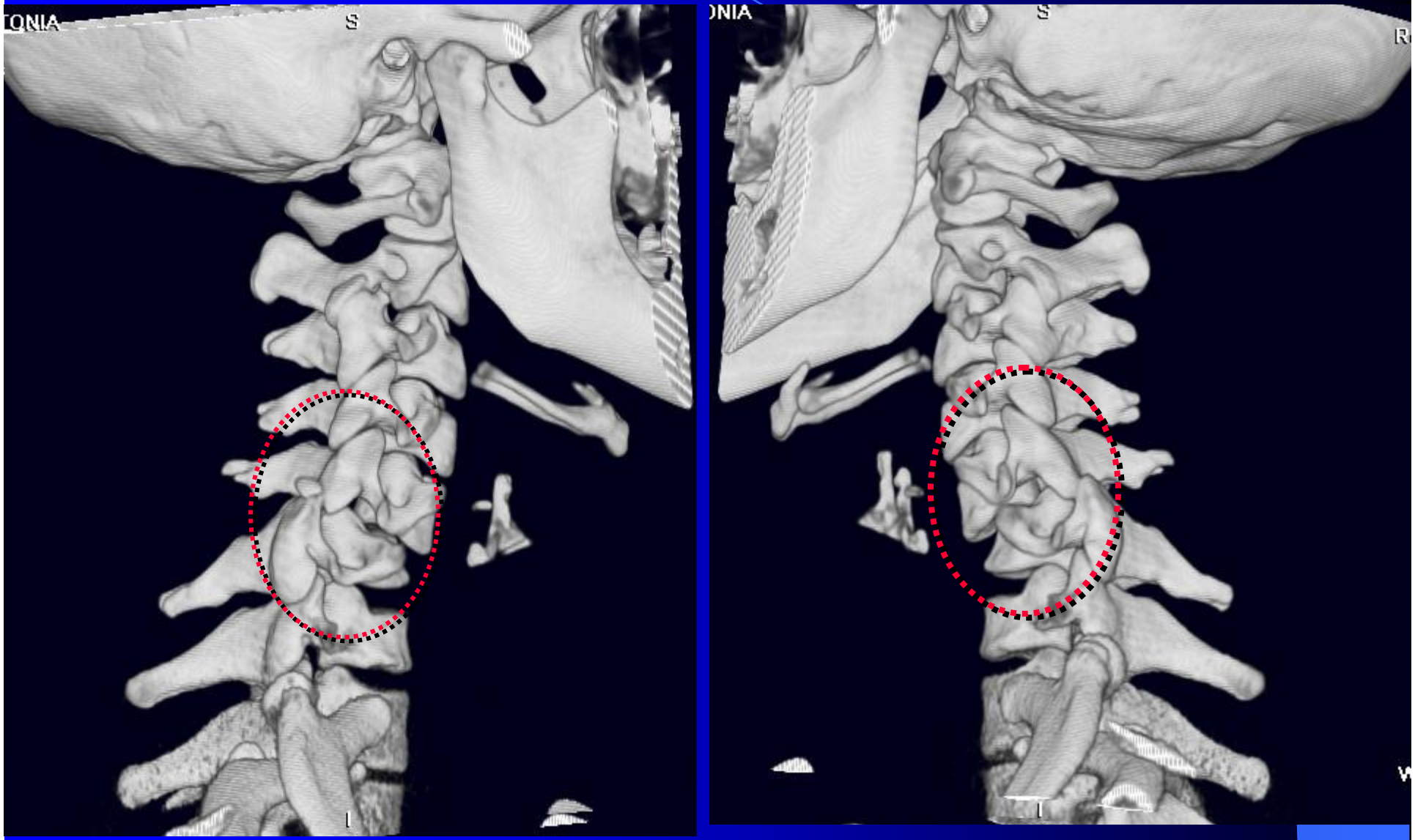


Cranial-Cervical Dislocation

BID



BID Surface Rendering

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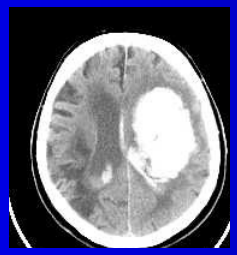
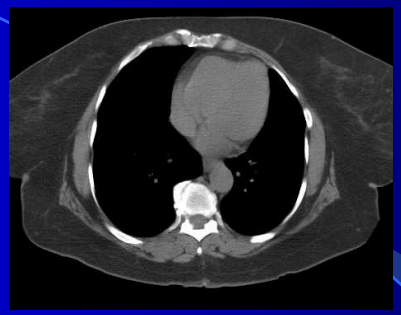
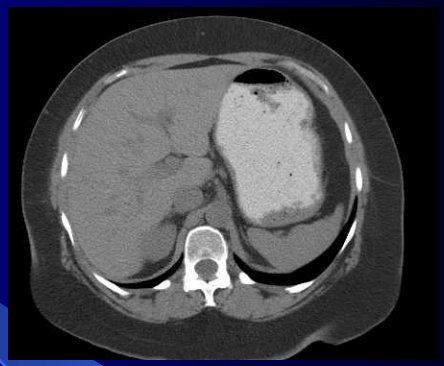
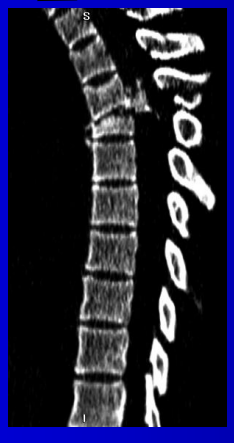
Replace Radiography with MDCT?

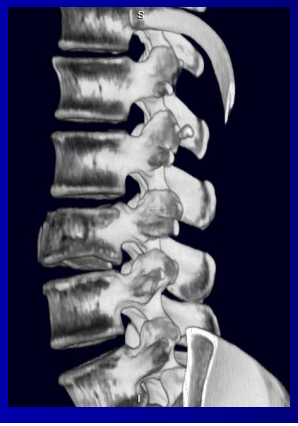
Digital dataset of whole body



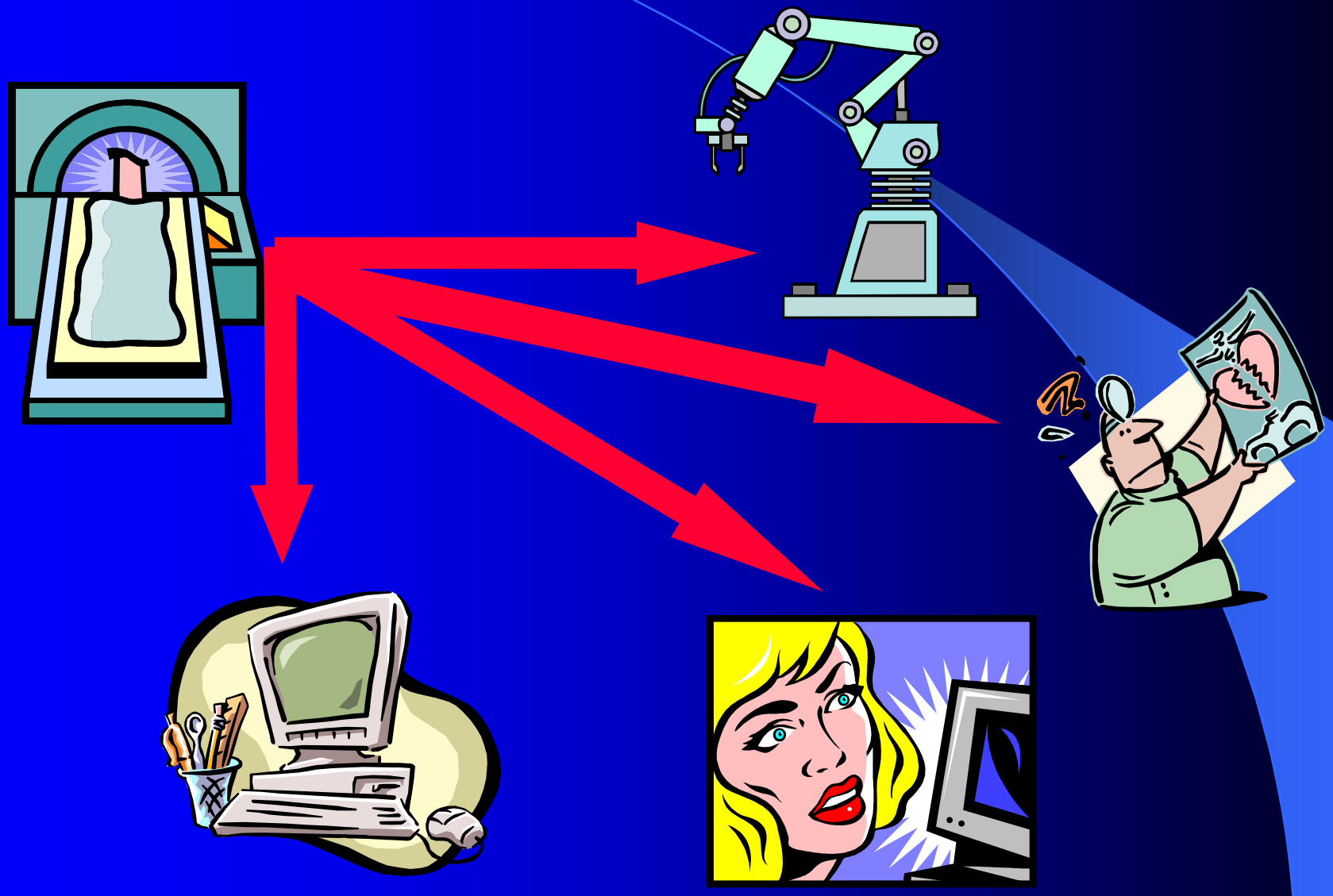








Radiology Informatics

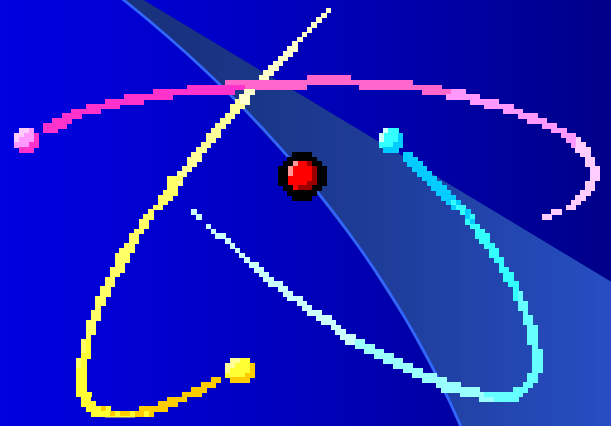


Expectation of instantaneous delivery of images and results

Too Much Data to Handle

- Soft copy interpretation essential!!
- TRIP^{tm} = Transforming the Radiology Interpretation Process
- Discovery of innovative solutions to the problem of information/image data overload.
- Use of decision support tools, CAD.
- Improved man-machine interfaces.

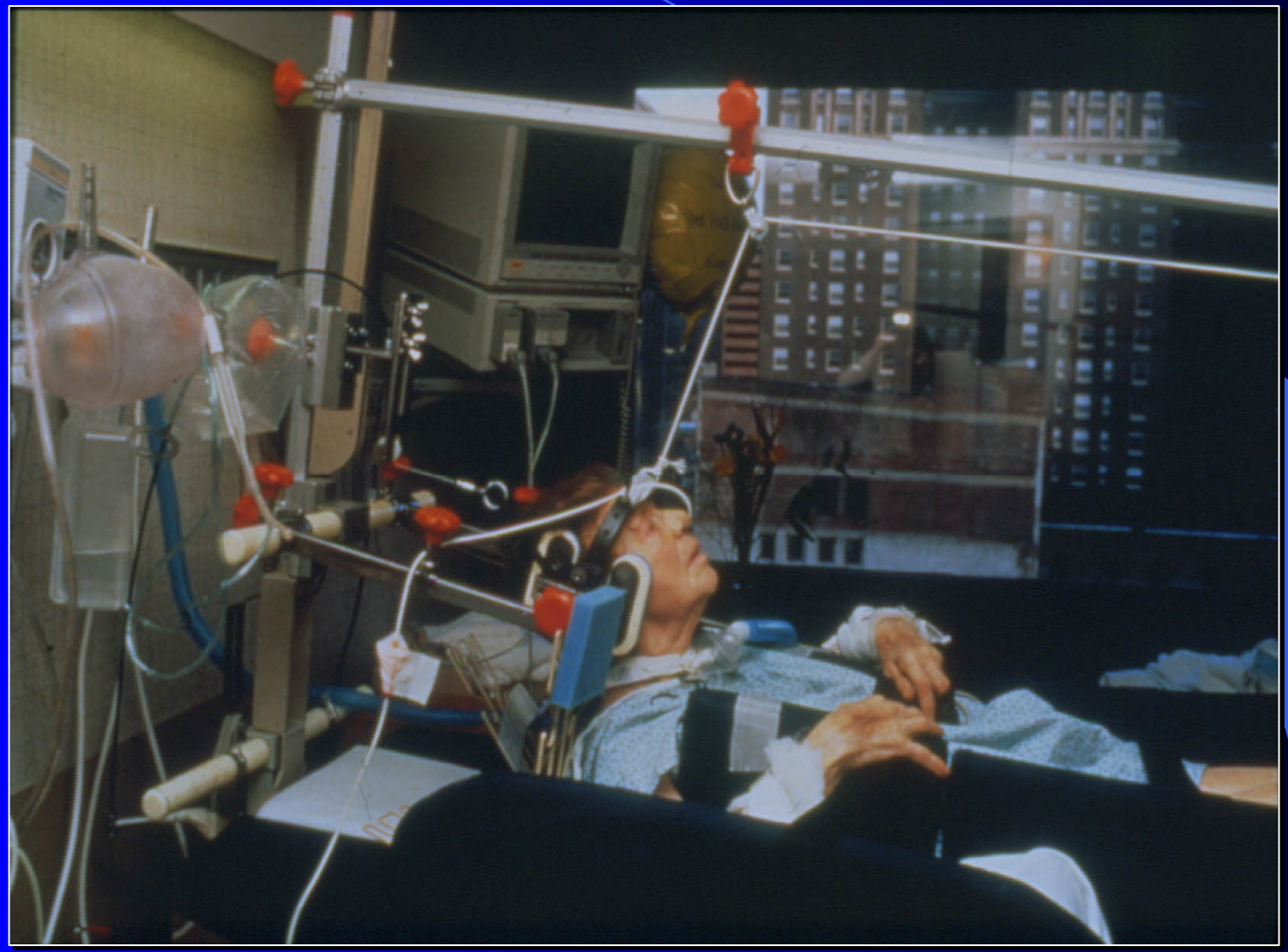
Magnetic Resonance Imaging



Why Use MRI in Spinal Injury?

- Offers most comprehensive eval of spinal injury and SCI.
- Depicts **soft-tissue component** of the injury.
- At many centers, the clinical evaluation is not complete without a MRI study.
- MRI has changed the clinical focus from the spine to the spinal cord.
- Not supplanted radiographs and CT.
- MRI has replaced myelo and CTM.
- MRI is warranted in the acute period for any patient with a persistent neurologic deficit after trauma.
  - SCIWORA

MRI Challenges



MRI Challenges

Imaging Objectives

- Good sagittal imaging with dedicated surface coils is mandatory.
- All studies:
  - Sagittal T1
  - Sagittal T2 + FS
  - Axial T2
- Cervical:
  - Sagittal GRE
  - Sagittal PD
  - Axial GRE
  - Axial 2DTOF MRA
- No role for gadolinium

How is MRI used as a clinical tool?

- Open versus closed reduction of injury.
  - MRI prior to or after reduction?
  - Herniated disc or epidural clot compressing cord.
- Timing of surgery *(controversial!)*
  - Early versus late decompression and fusion.
  - Incomplete/Complete motor injury.
- Type of surgery
  - Anterior and/or posterior fusion.
  - Integrity of ligaments, discs, anterior, middle and posterior columns
- MRI assessment plays significant role in determining or confirming the surgical formula.
- Prognosis?

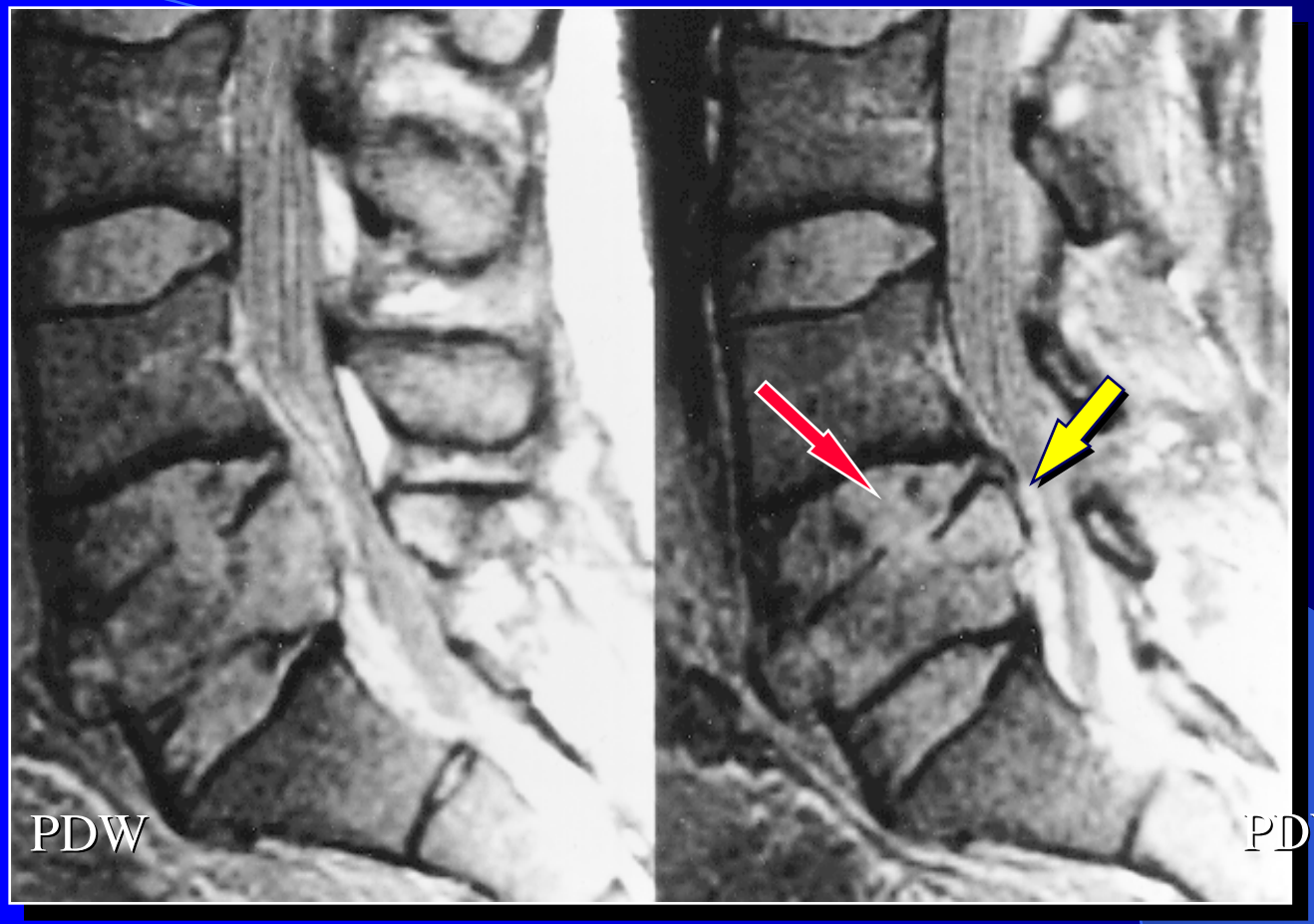
Characterization of Spinal Injury with MRI

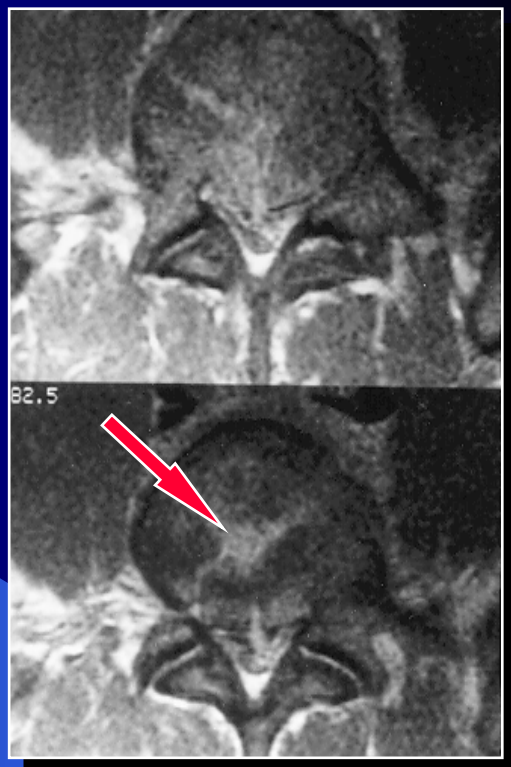
Spectrum of injuries depicted with MRI subdivided into:

- *Fractures*
- *Disc Injury or Herniation*
- *Ligament Disruption, Strain*
- *Extradural Fluid (Hematoma)*
- *Vascular Injury*
- *Spinal Cord Injury*

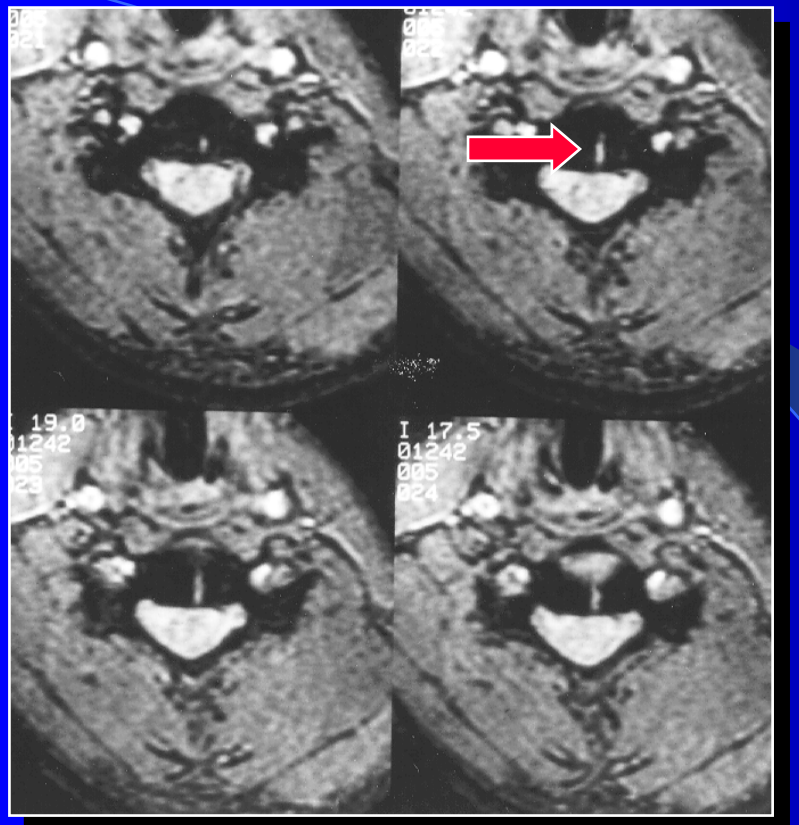
MRI & Vertebral Fractures

L5 Axial Loading Injury

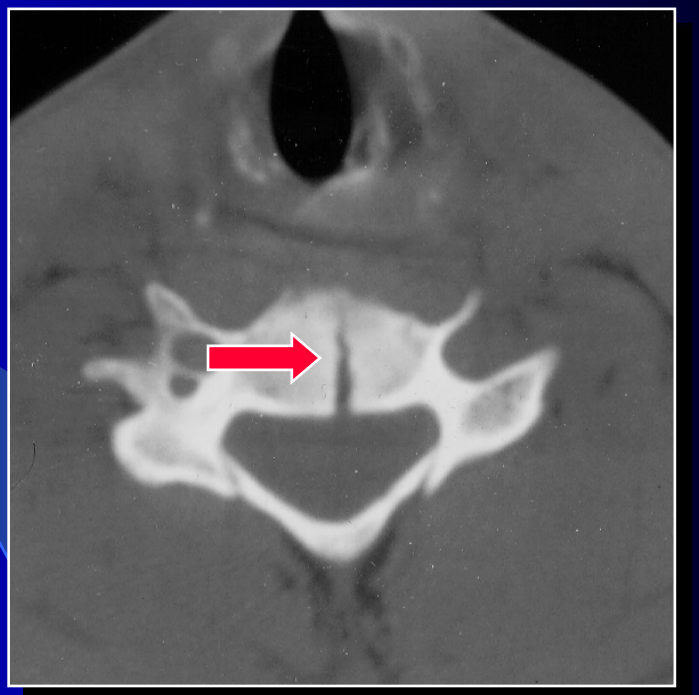




MR/CT Comparison of Vertebral Fractures

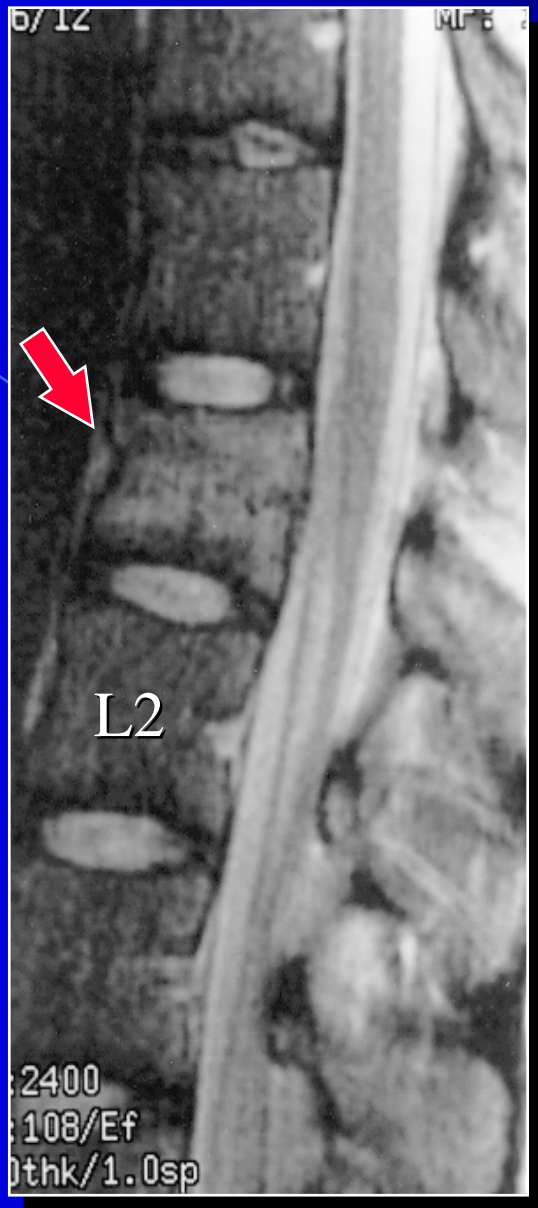


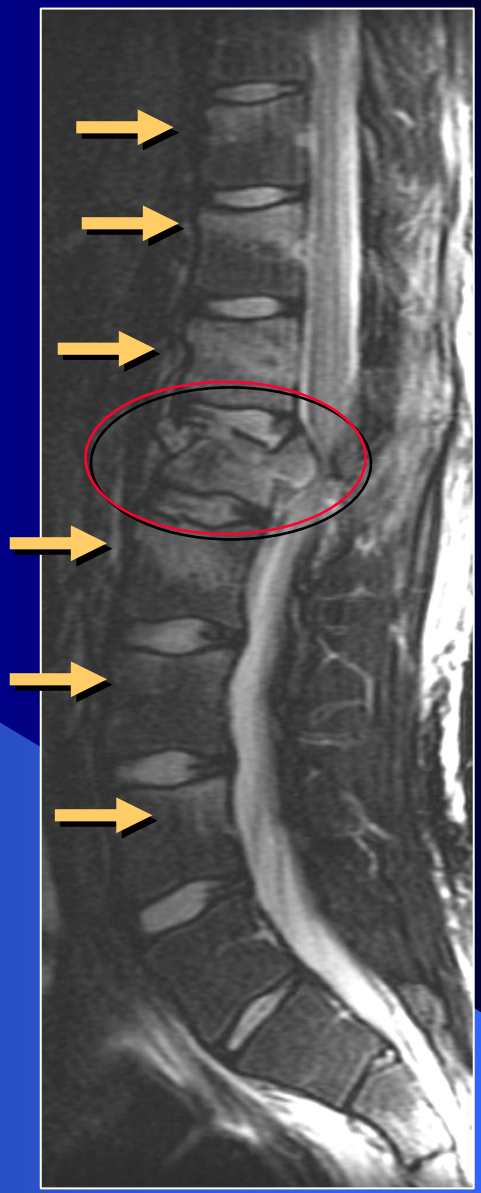
3DFT GRE



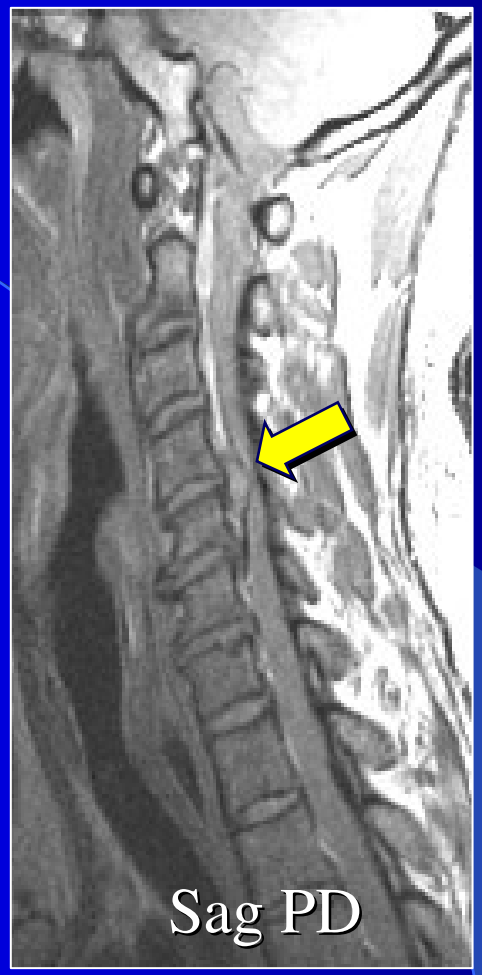
CT

Fracture Induced Marrow Changes





Large Cervical Disc Herniation

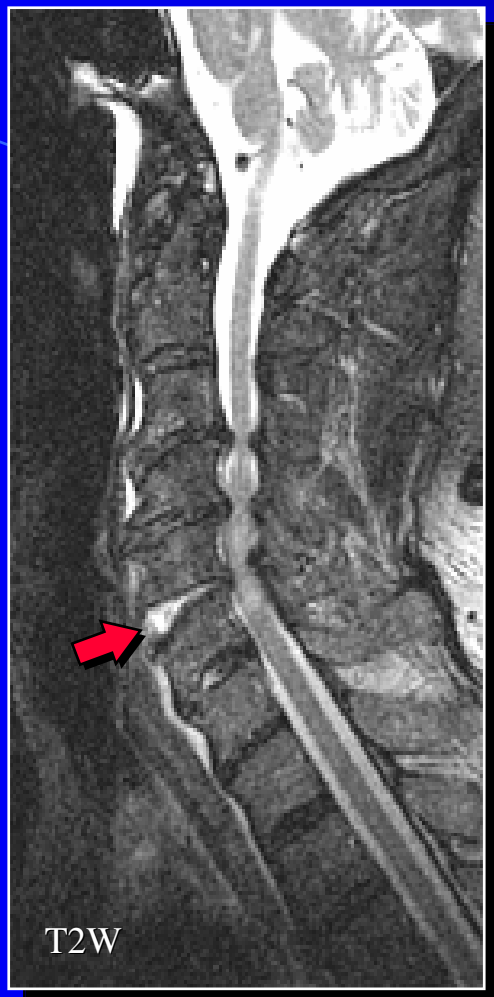


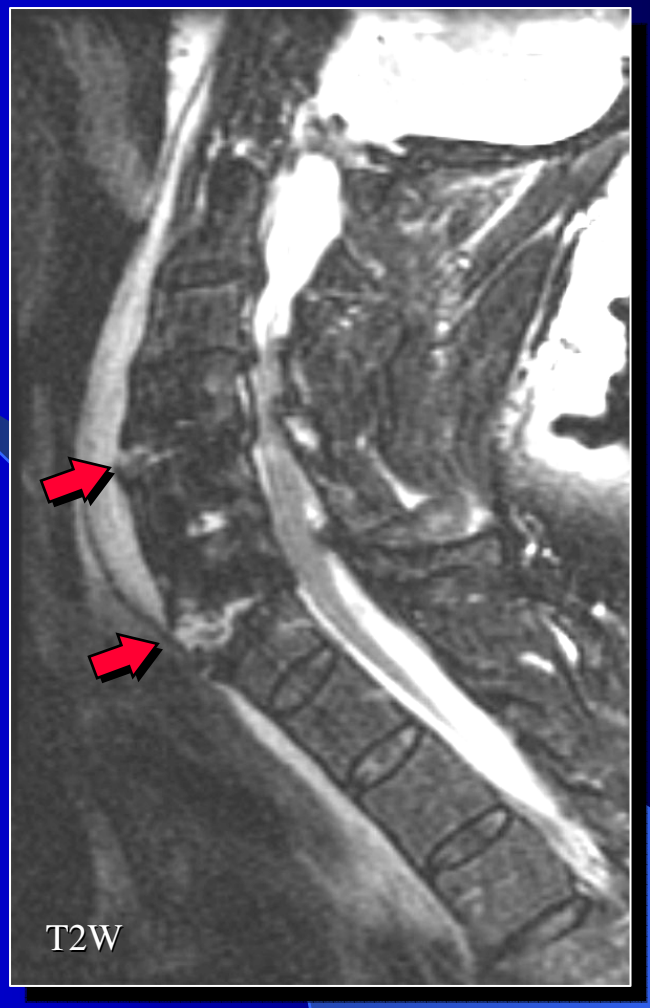
Large Cervical Disc Herniation

Axial GRE

Axial GRE

Extension-Type Injury



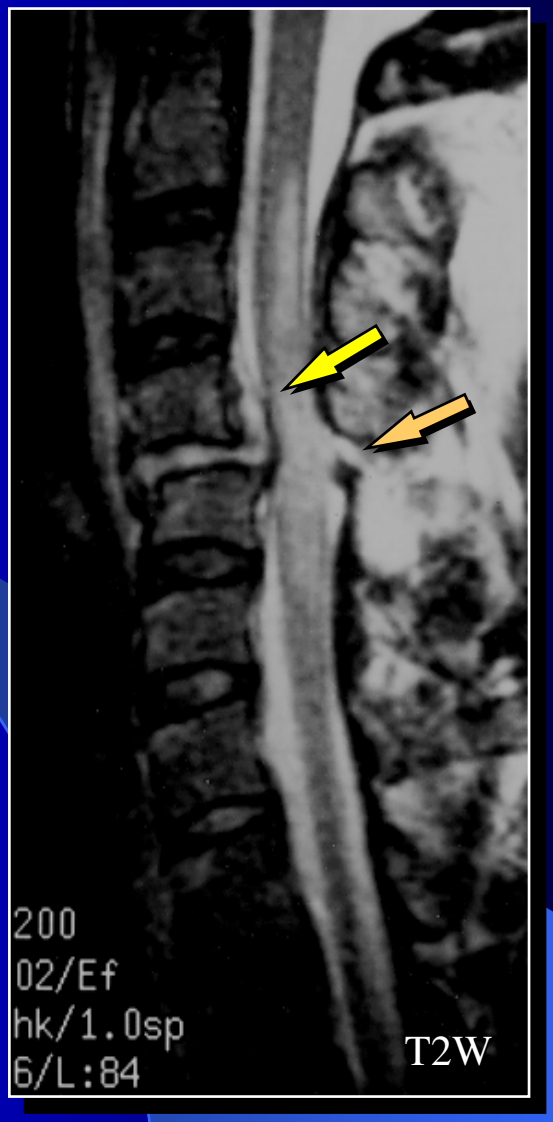


Fractures & Ligament Injury

Extension-Teardrop Fracture of C2

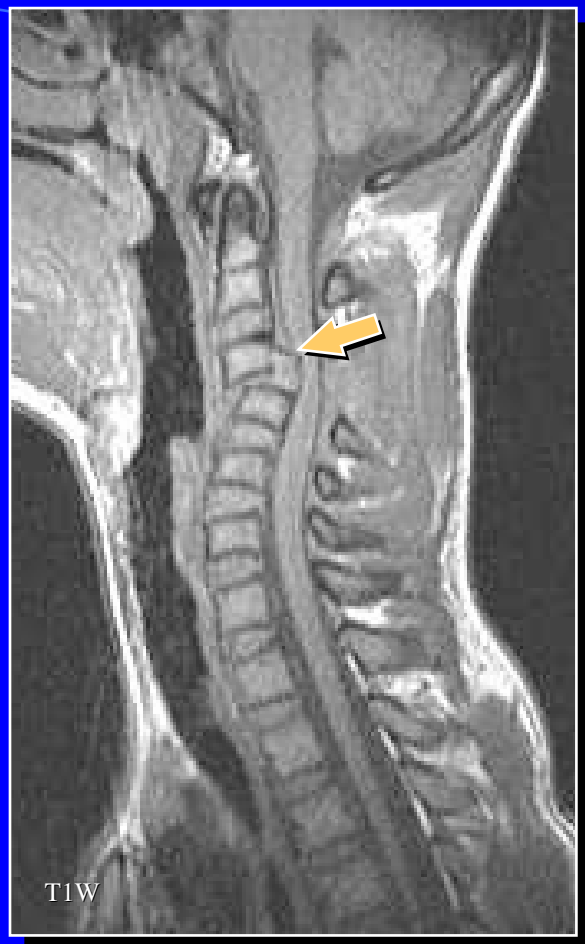
T2W (2000/80/2 NEX)

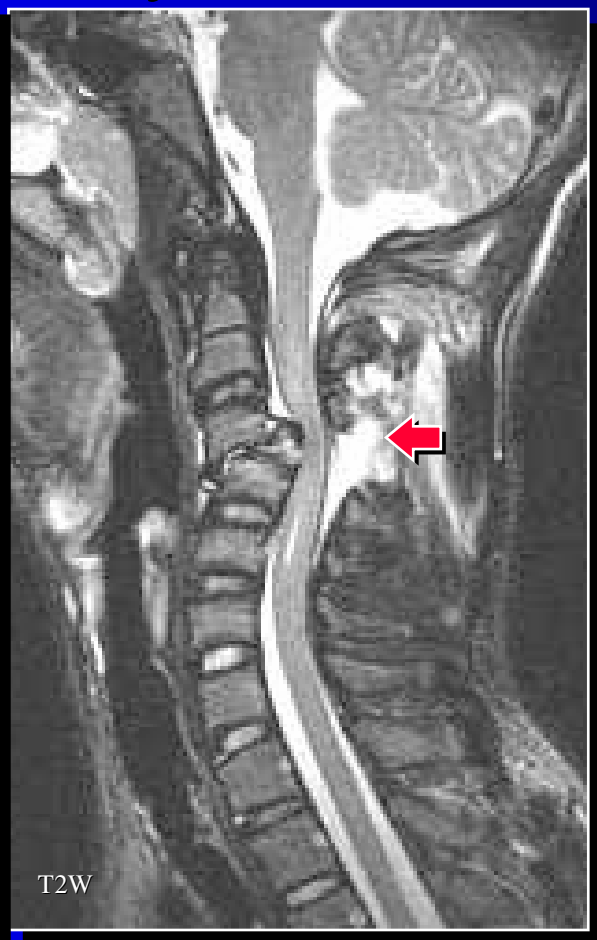
Hyperflexion Type Injuries



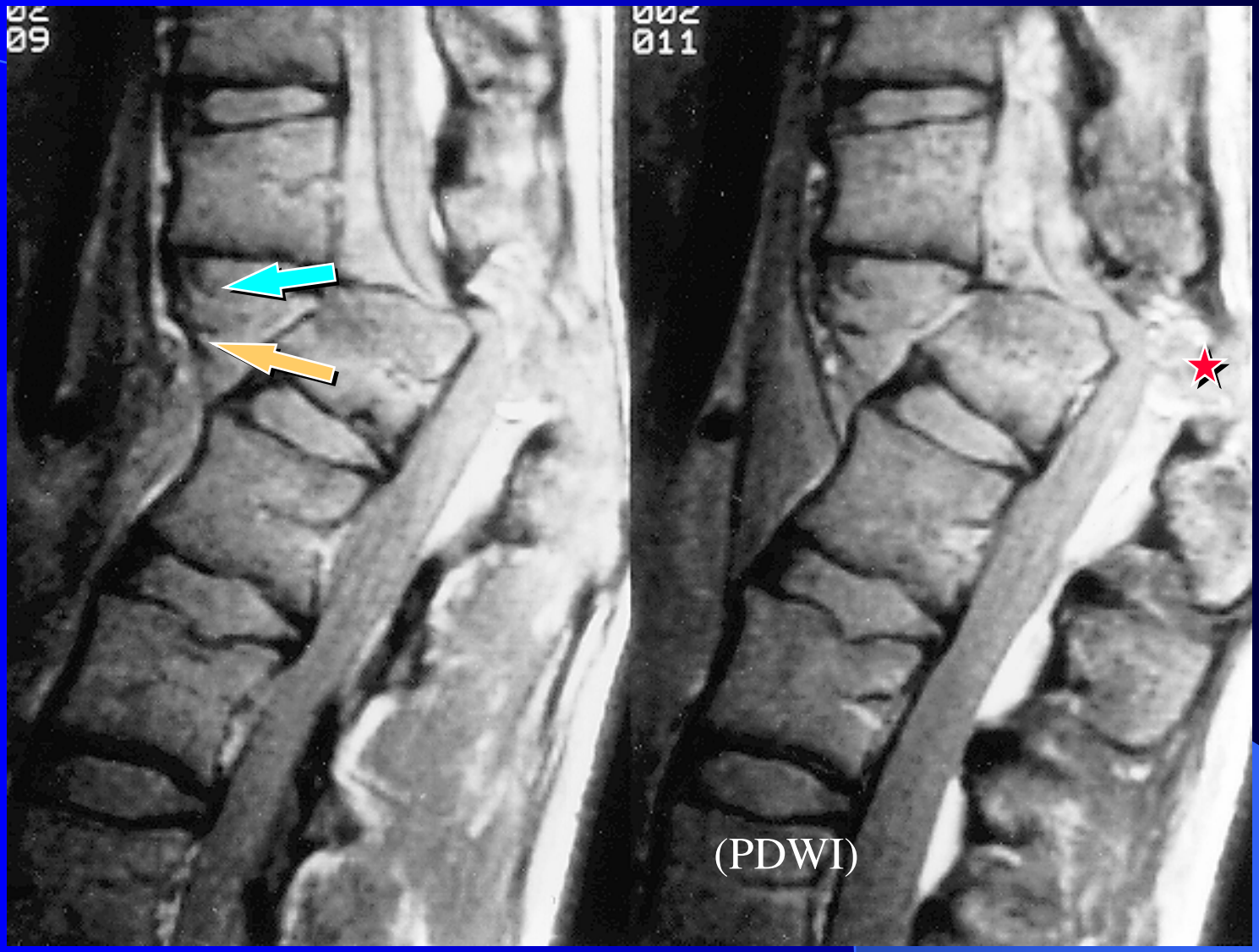
Flexion-distraction Type Injury

15 y/o wrestler



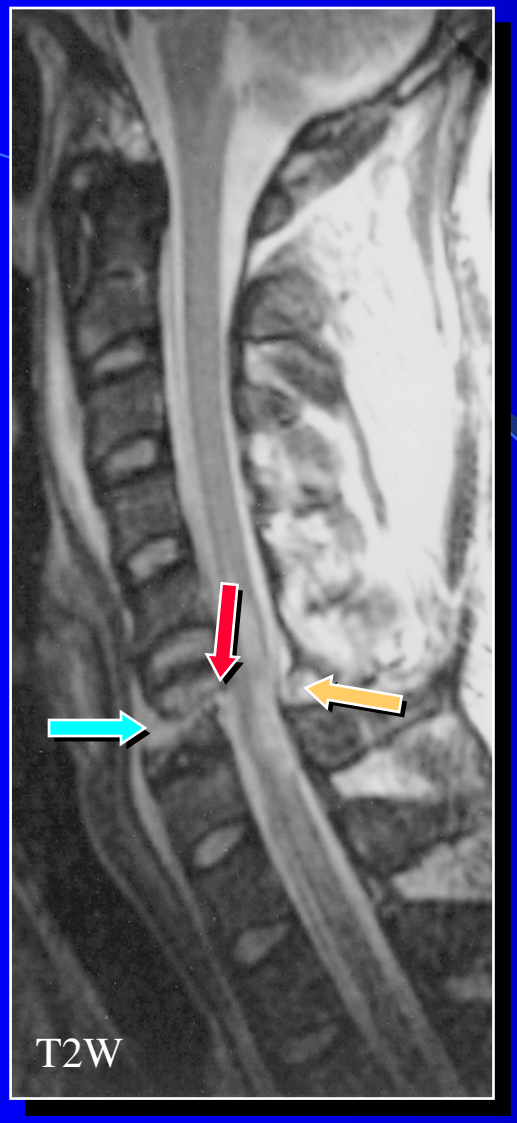


Ligament Disruption
T12-L1 Fracture Dislocation



Injury to ALL and LF

3 Column Ligamentous Disruption



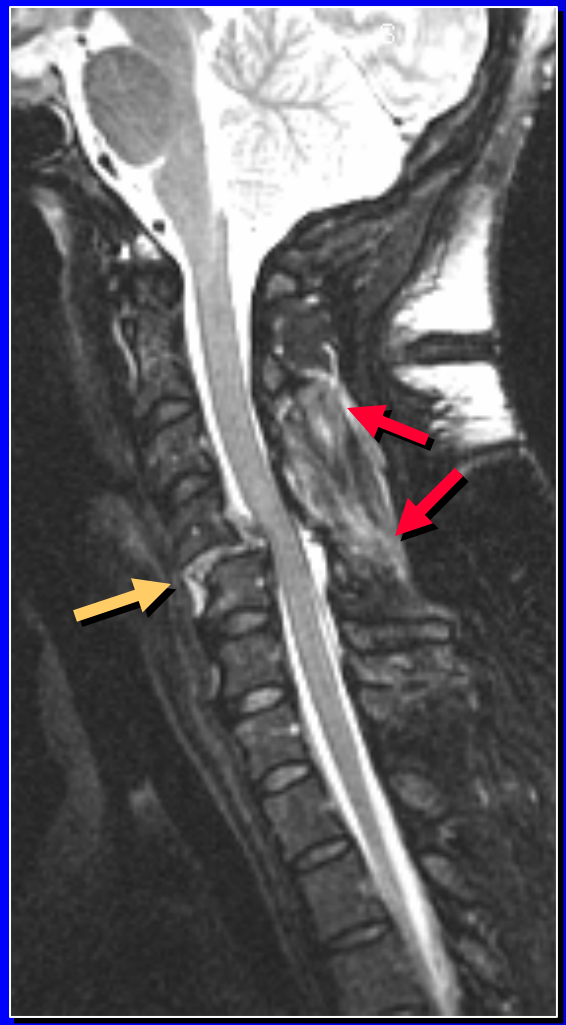
How Well Does MR Predict Ligamentous Damage?

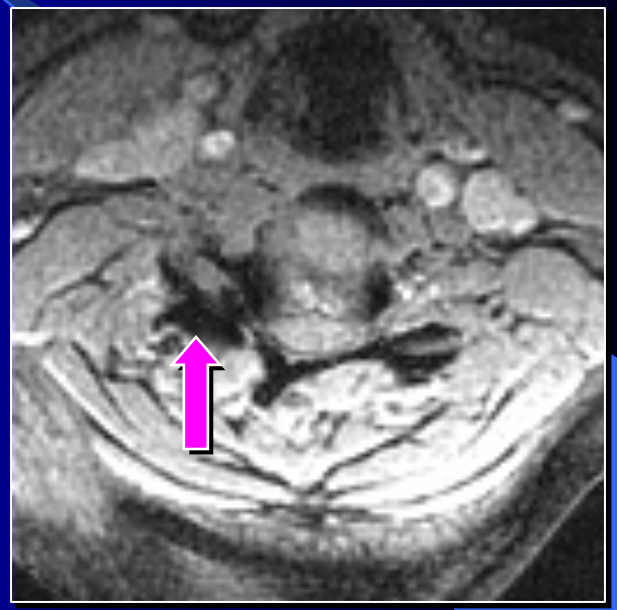
Detection of PLC Injury

	Sens %	Spec %	Pos PV %	Neg PV %	Accuracy %
Palpation	52.0	66.7	92.9	14.3	53.6
Radiograph	66.7	66.7	95.2	16.7	66.7
MRI SSL	92.9	80.0	96.3	67.6	90.9
MRI ISL	100	75.0	96.7	100	97.0
MRI LF	85.7	88.5	66.7	95.8	87.9

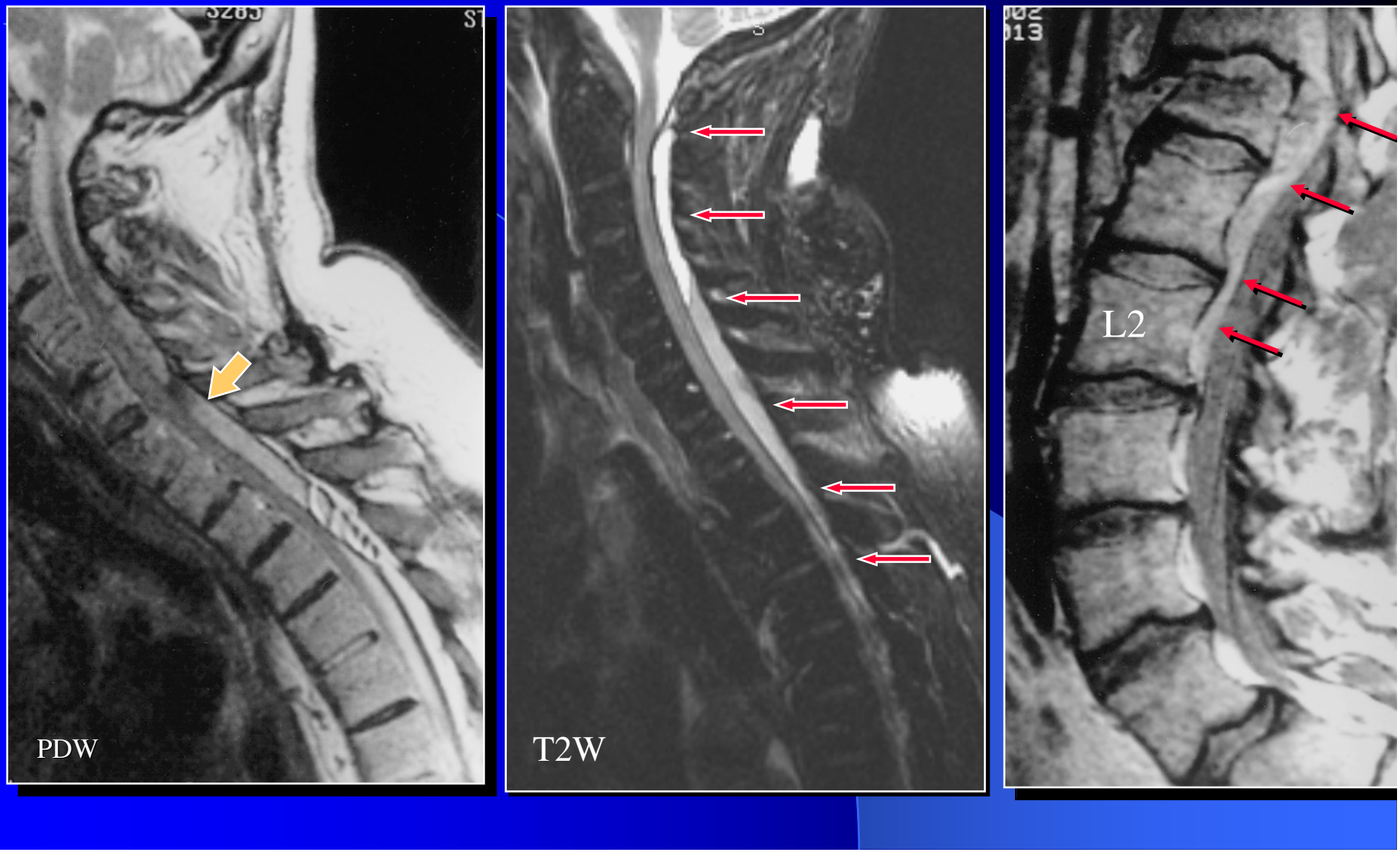
Lee HM etal. Spine 2000

Unilateral Facet Dislocation C4-5



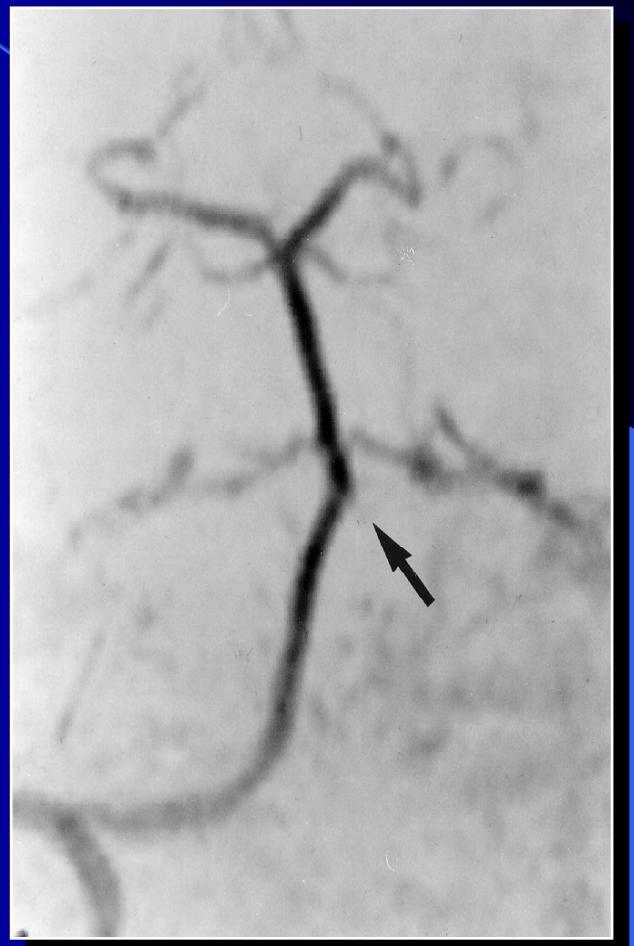


Epidural Hematoma



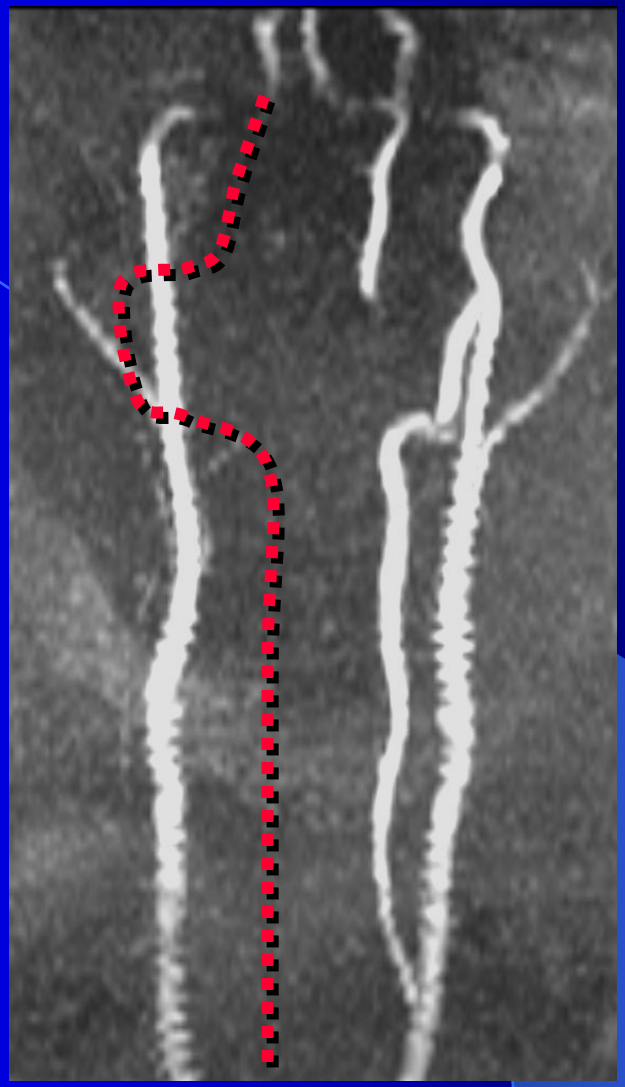
Traumatic Occlusion of the Vertebral Artery

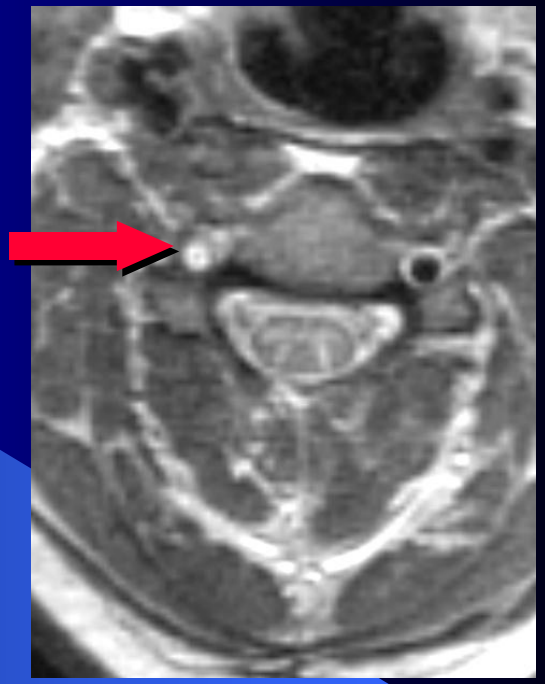
2DTOF MIP



2DTOF MIP

Traumatic Occlusion of RVA

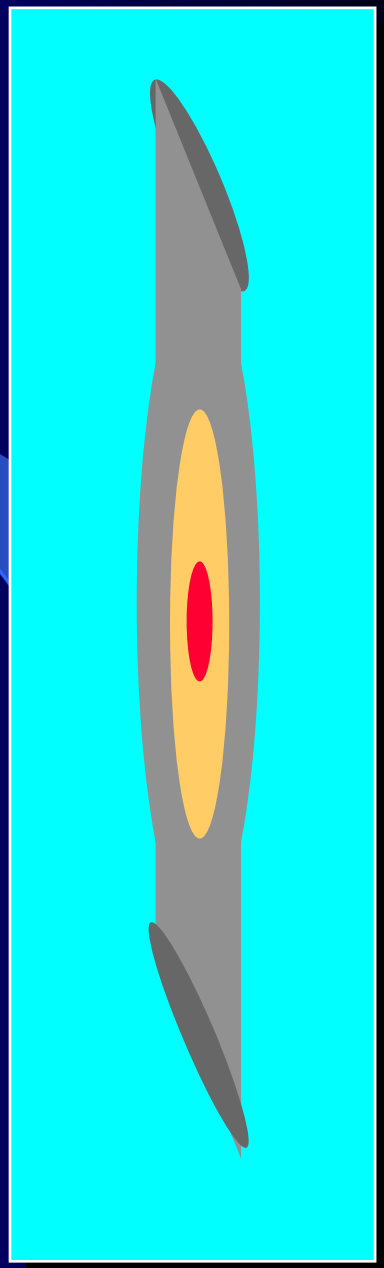




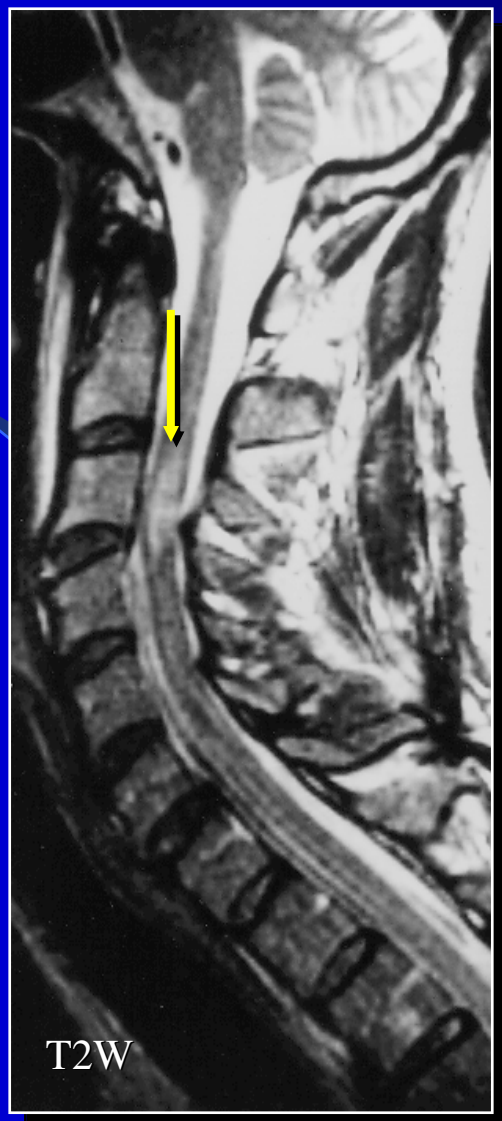
MRI of Spinal Cord Injury

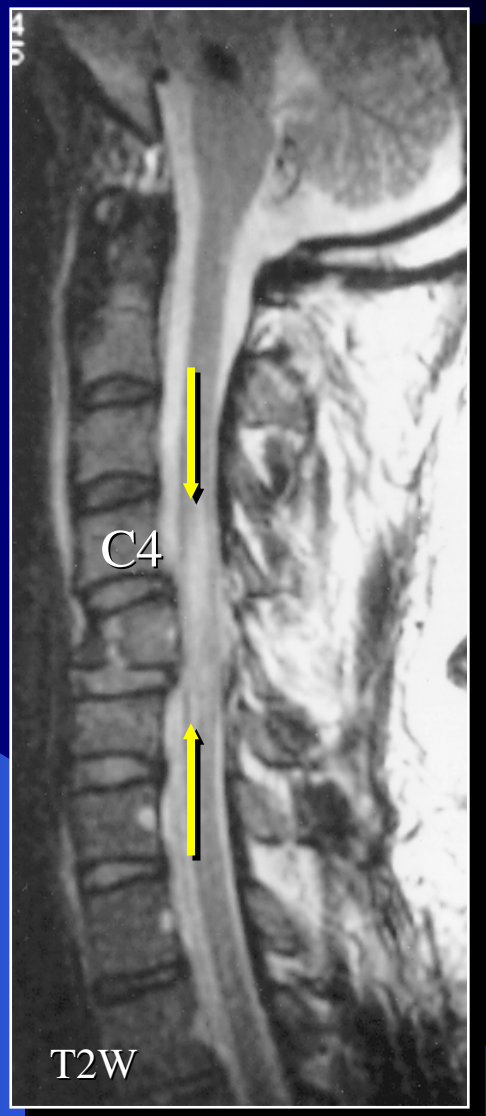
MRI Findings of SCI

- Features of SCI on MRI include:
  - **Spinal Cord Swelling**
  - **Spinal Cord Edema**
  - **Spinal Cord Hemorrhage**
- Edema length prop to neurologic deficit and prognosis.
- Heme associated with most severe injuries and predicts poor neurologic recovery.
- Heme location correlates with NLI.

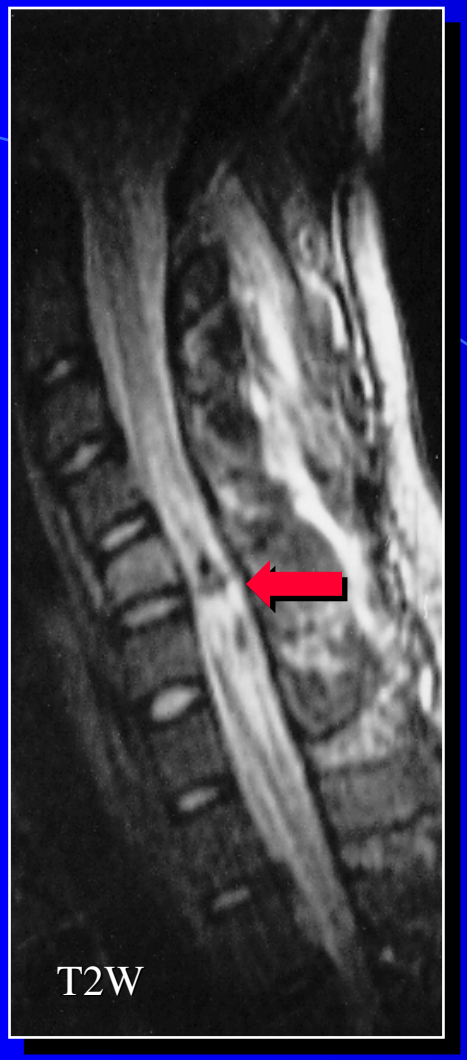


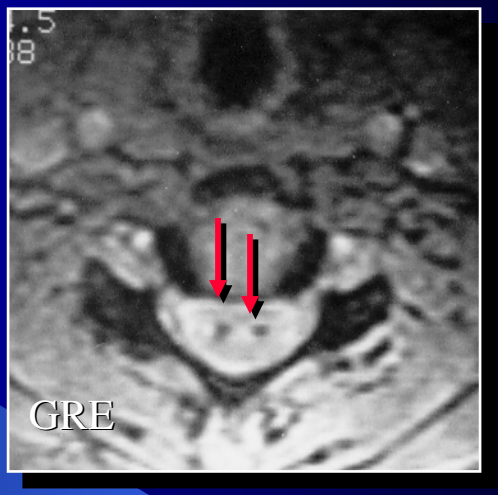
Spinal Cord Edema



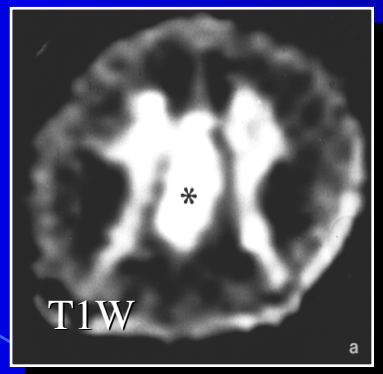


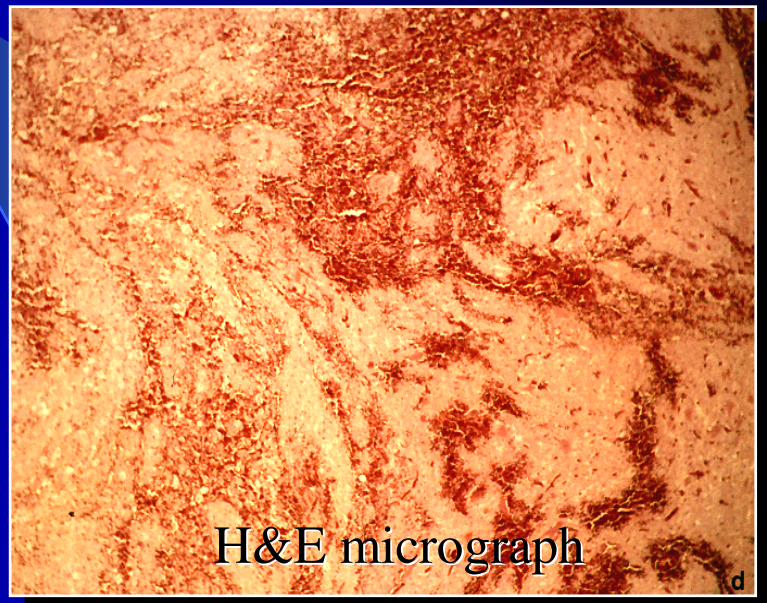
Acute Hemorrhagic SCI





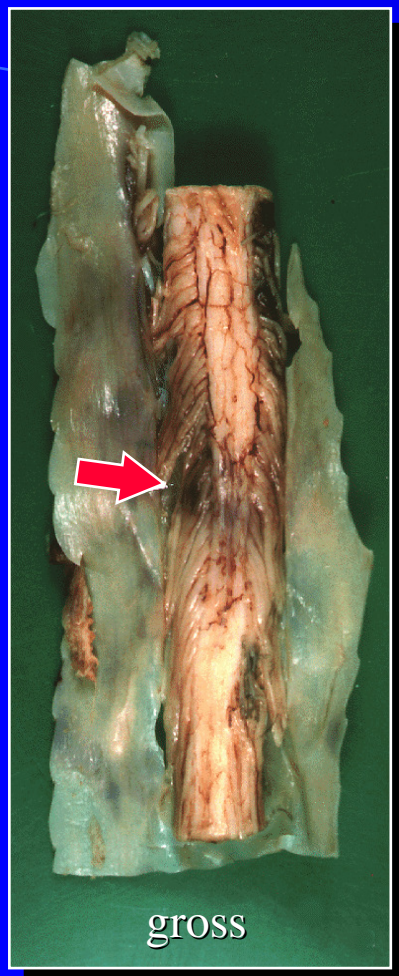
Hemorrhagic Cord Injury

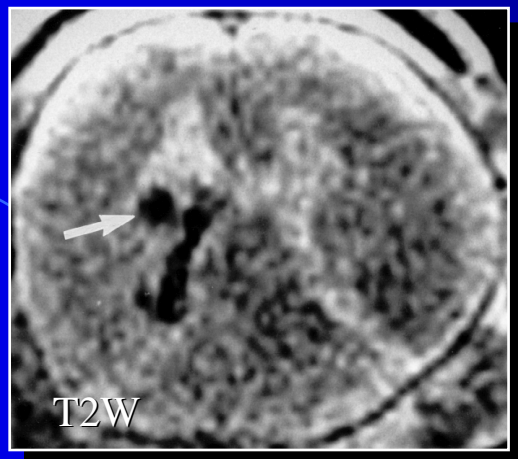


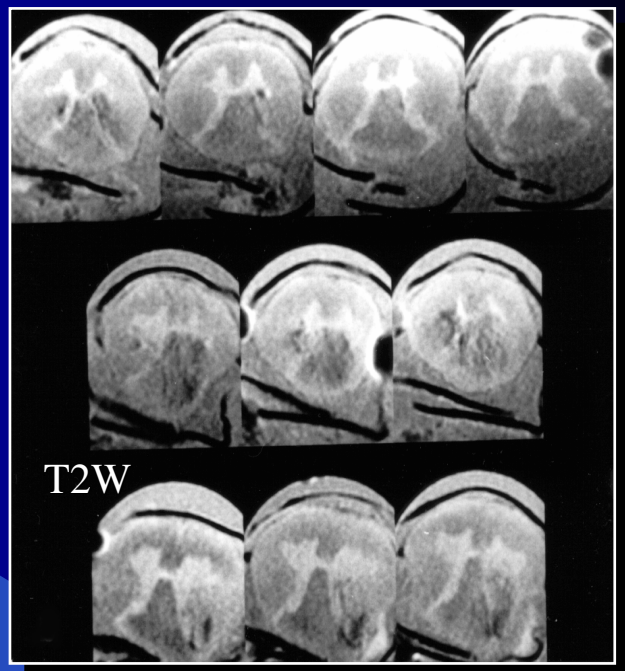


Hemorrhagic SCI

s/p C6-7 subluxation, ASIA B

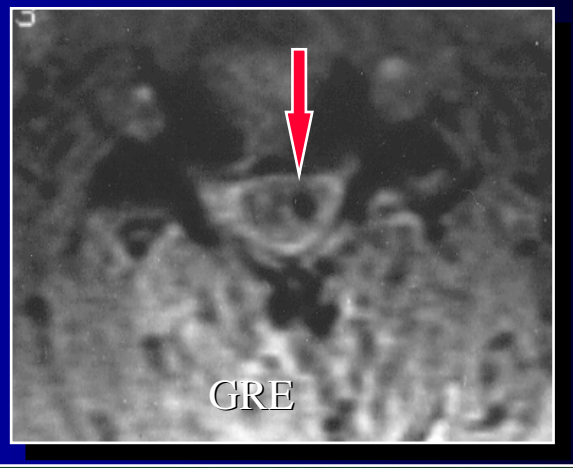






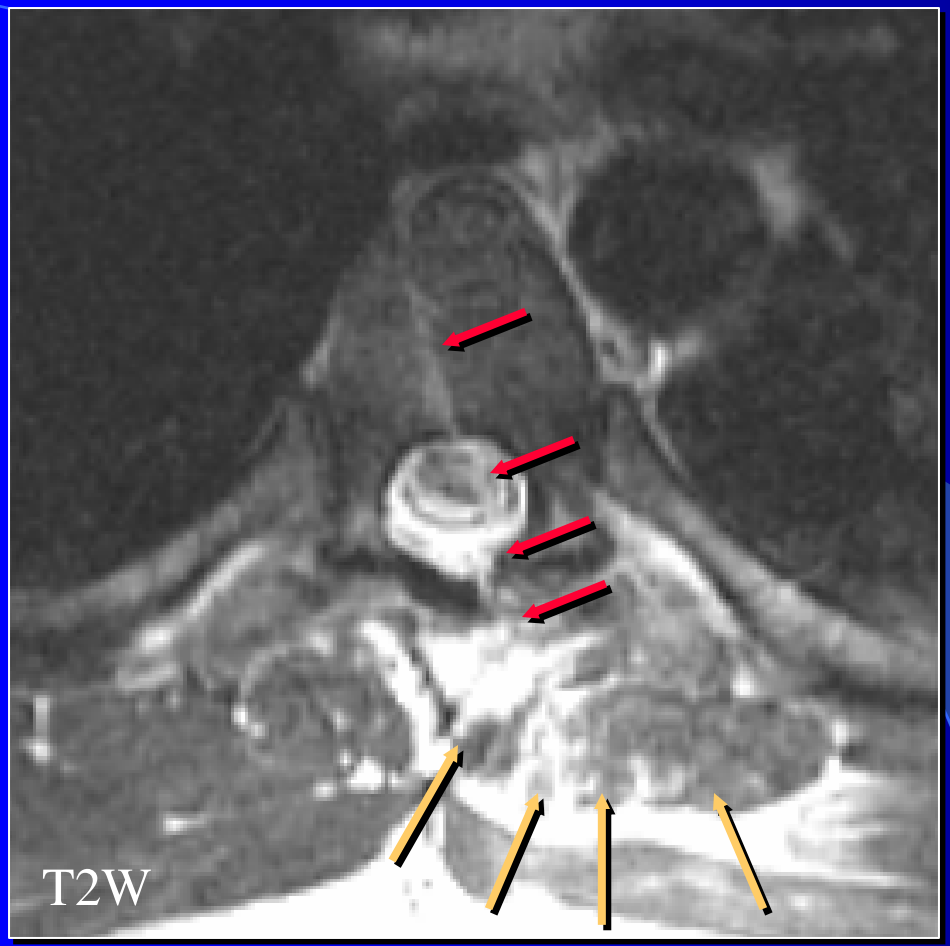
Brown-Sequard Syndrome

s/p stab wound with screwdriver

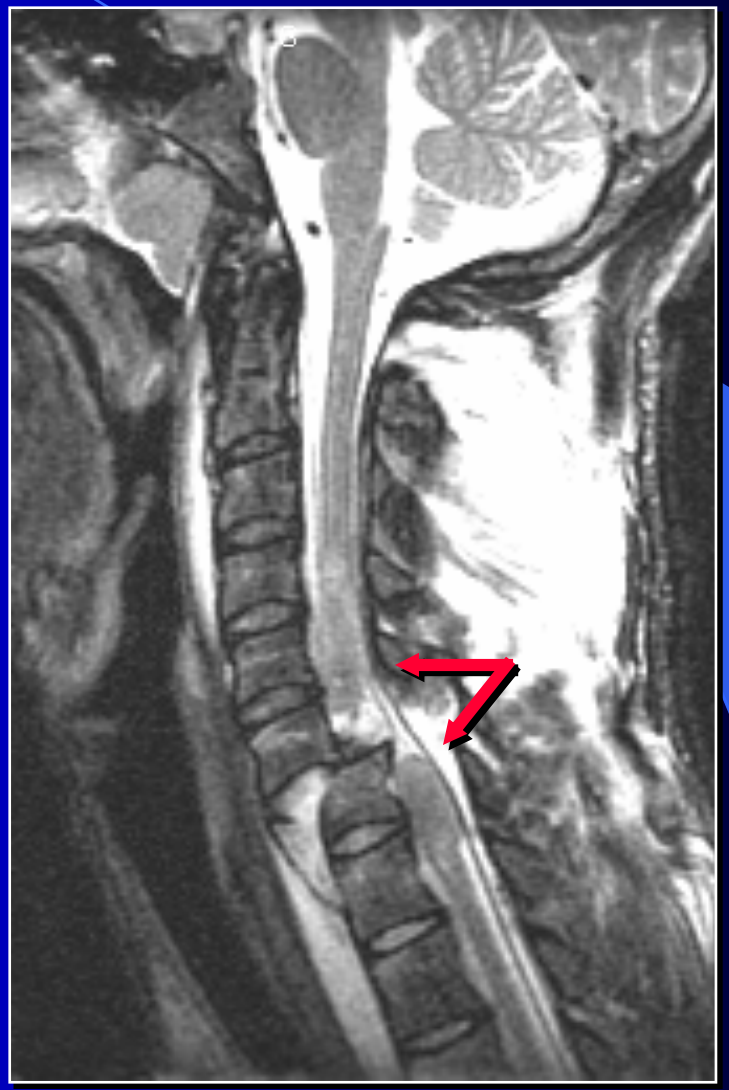


Brown-Sequard Syndrome

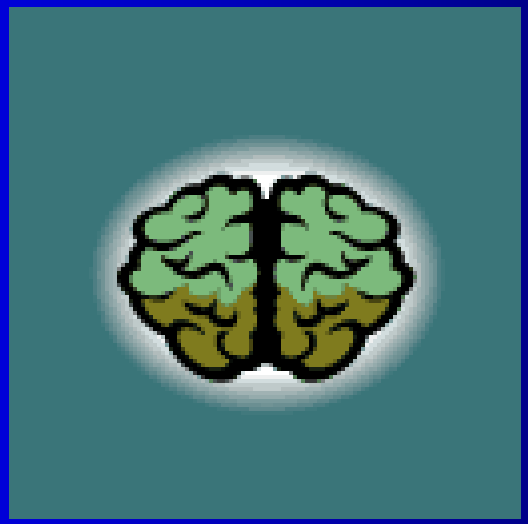
s/p stab wound



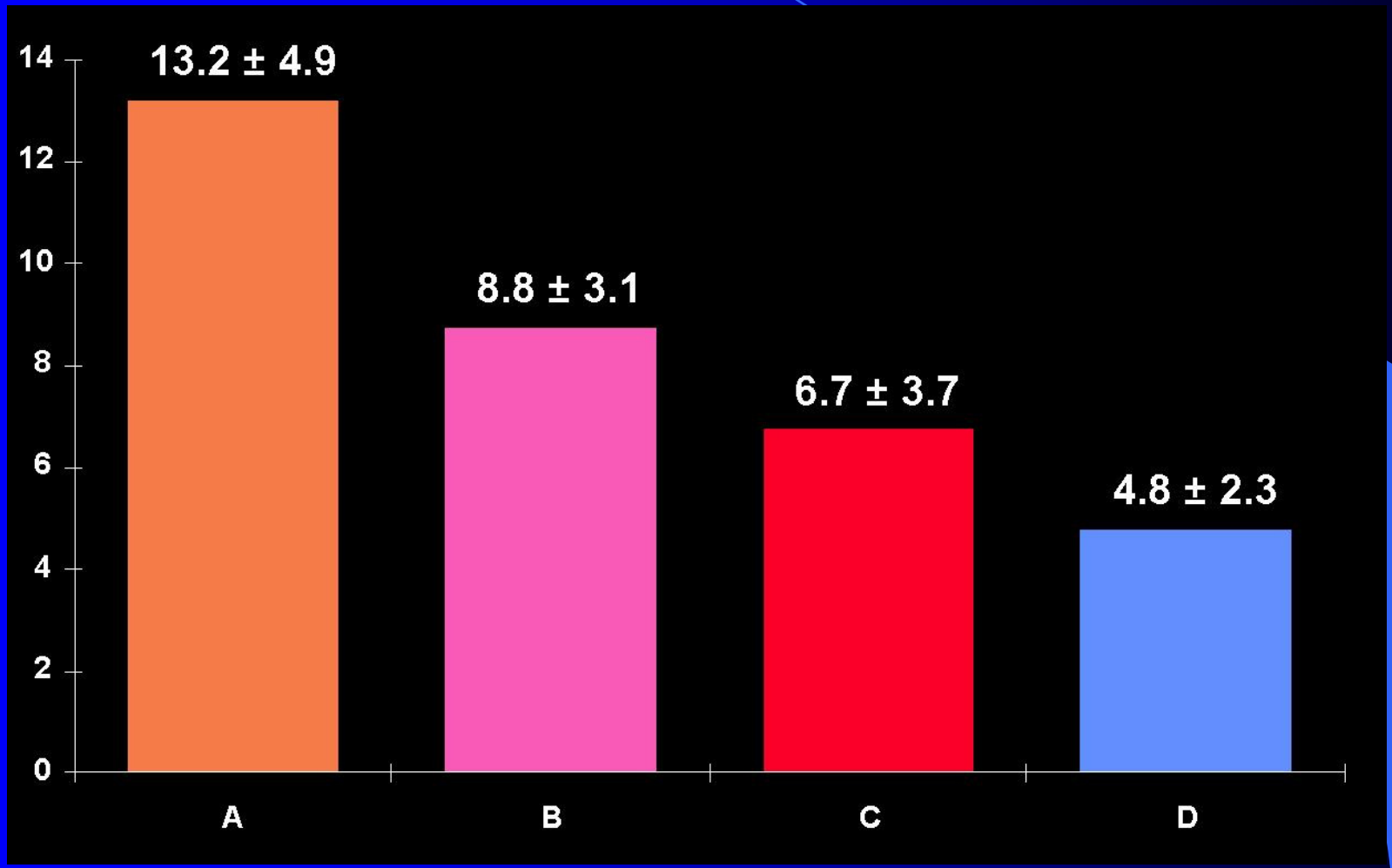
BID & Cord Transection



Correlating MR Parameters with Neurologic Deficit in SCI

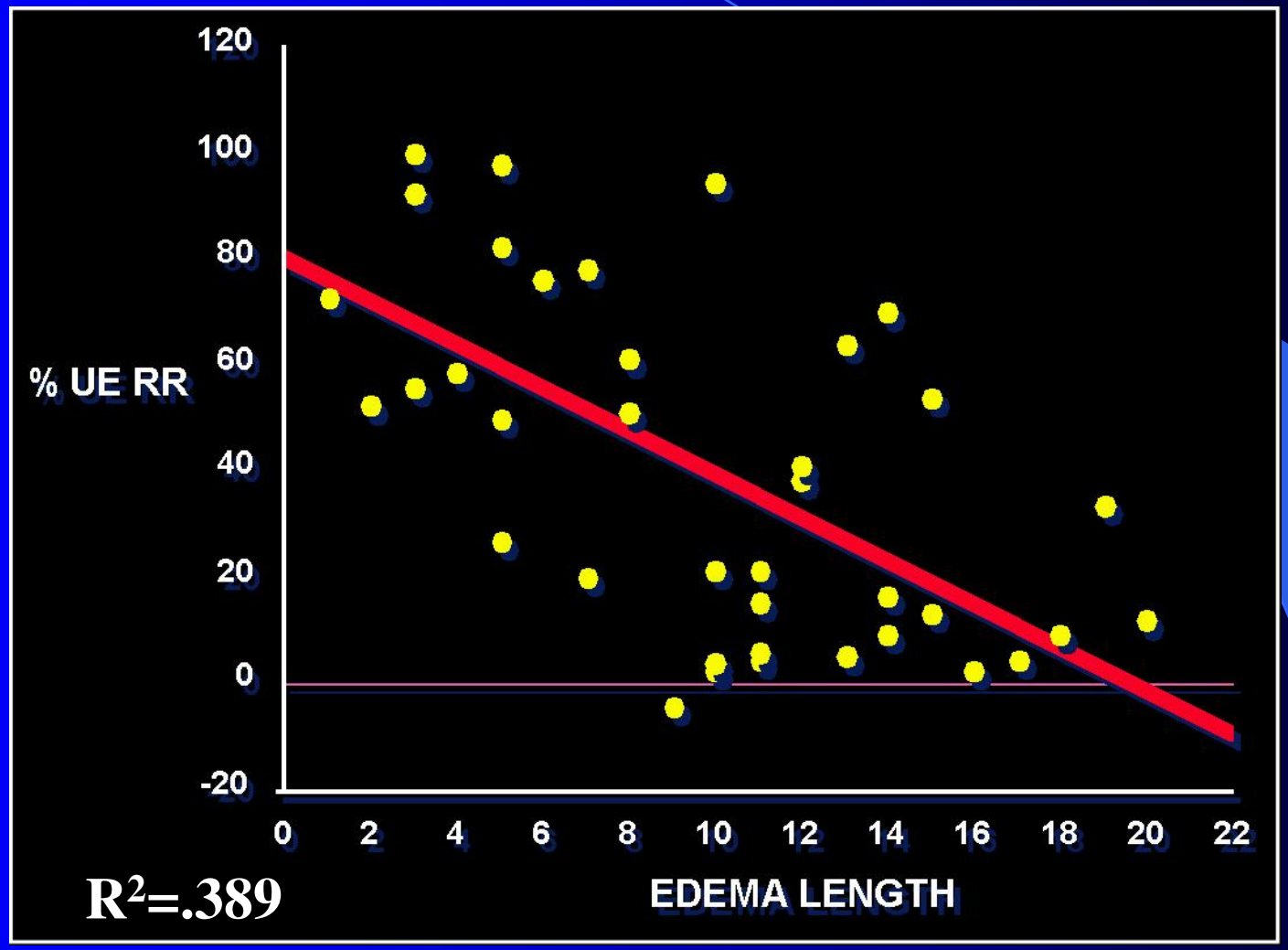


Mean Edema Length (units) by ASIA Grade

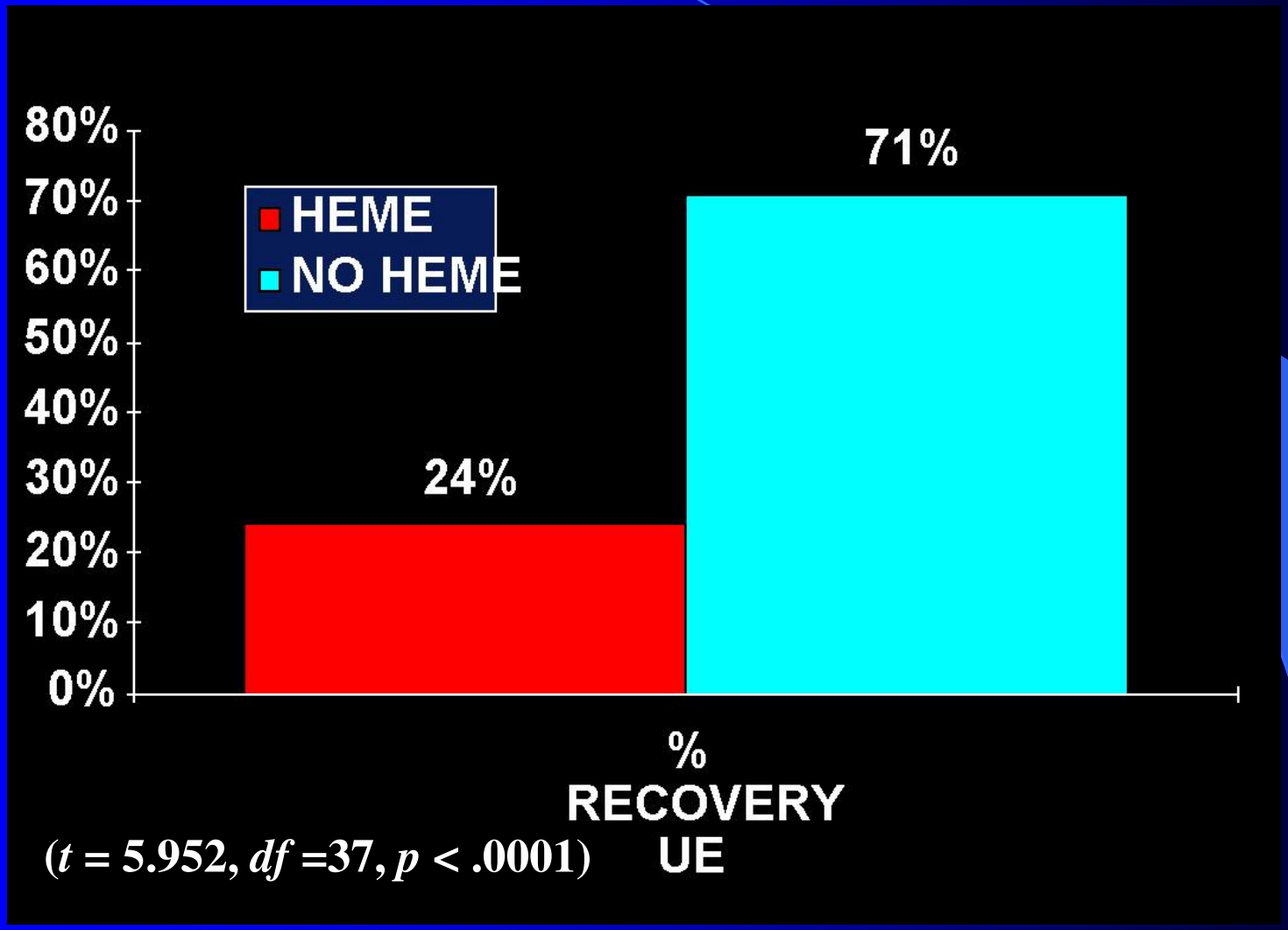


(ANOVA: A>B,C,D & B>D)

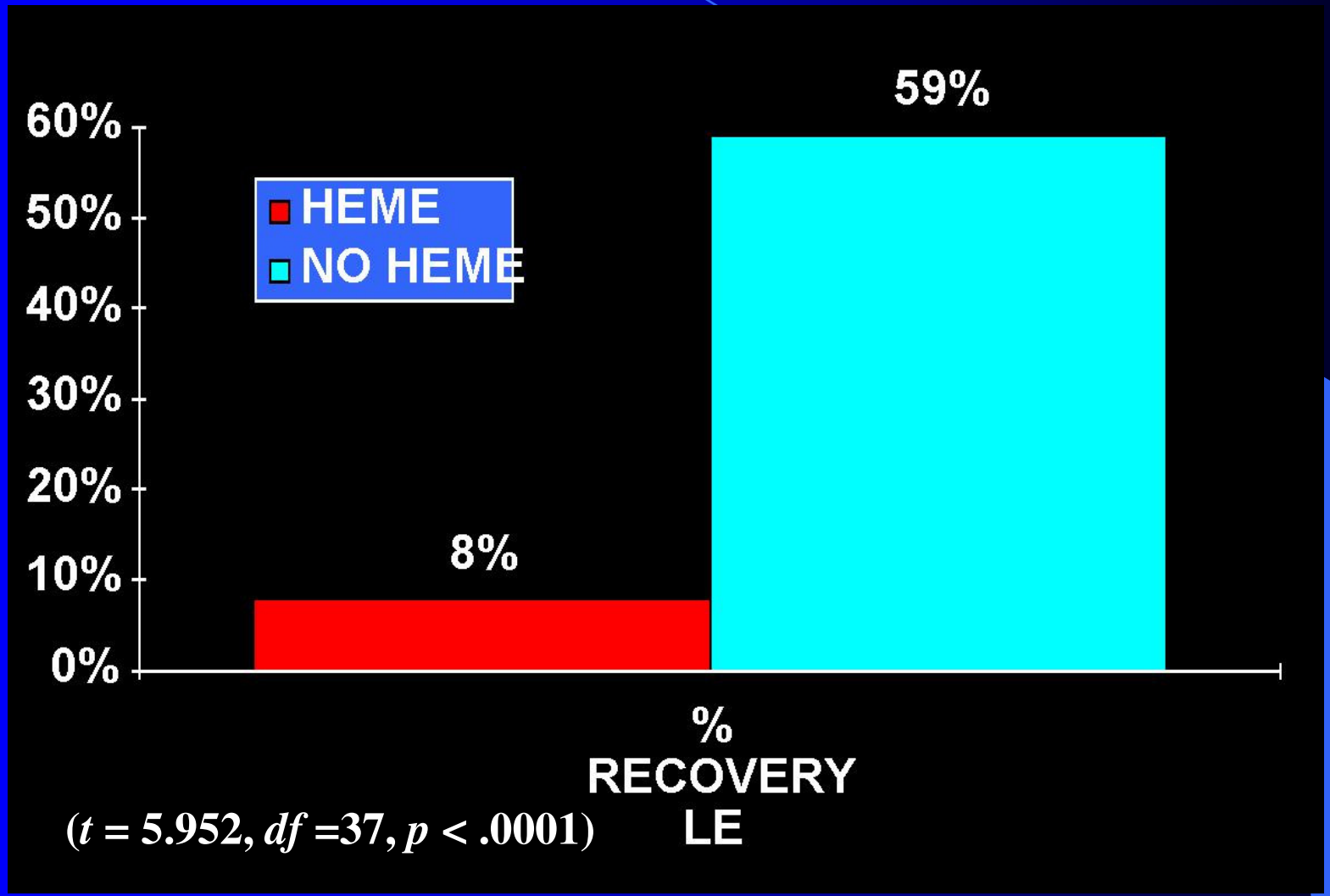
Correlation Between Edema Length and UE %RR.



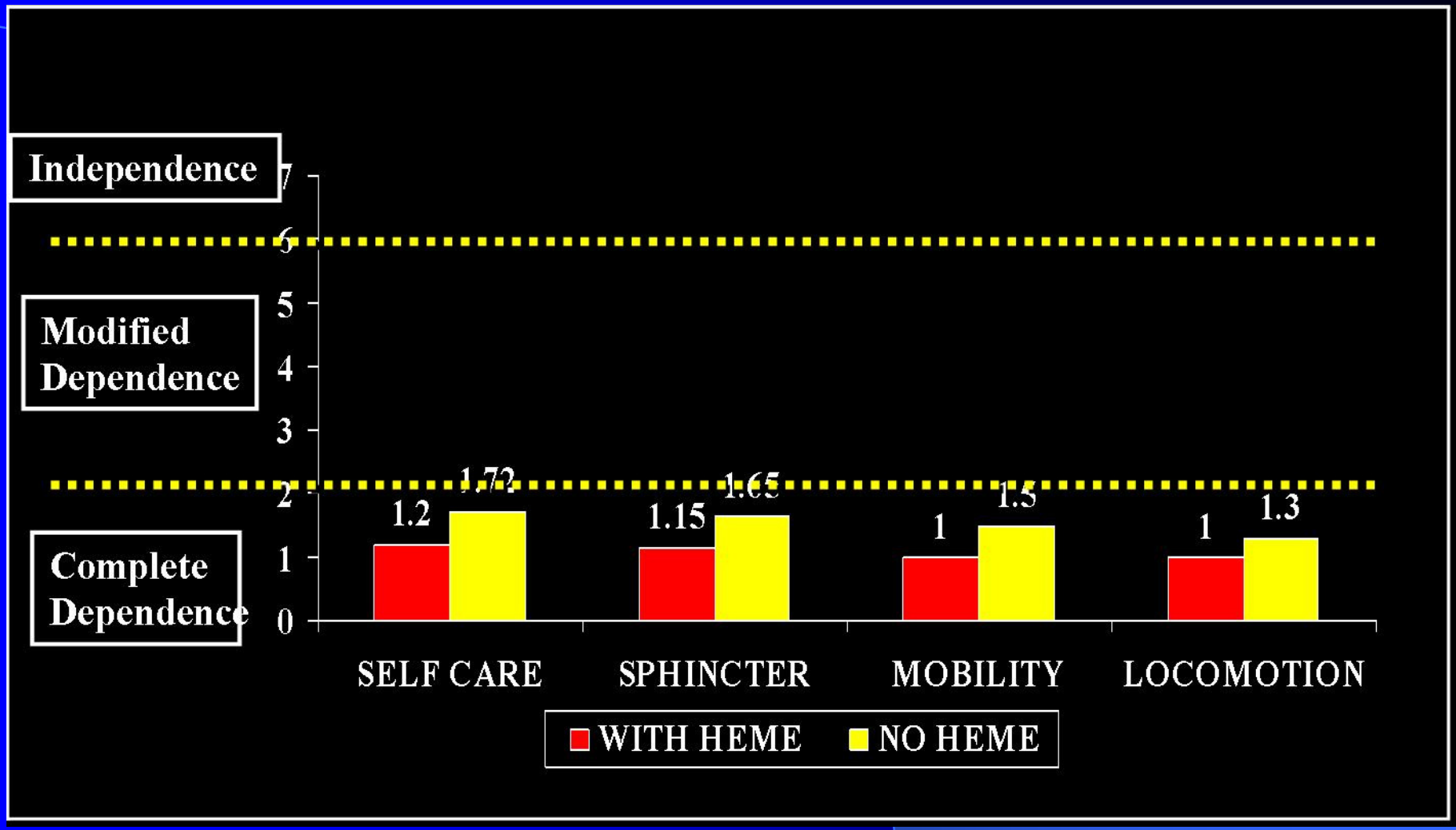
Effect of Spinal Cord Heme on UE Motor Recovery at 12 mos.



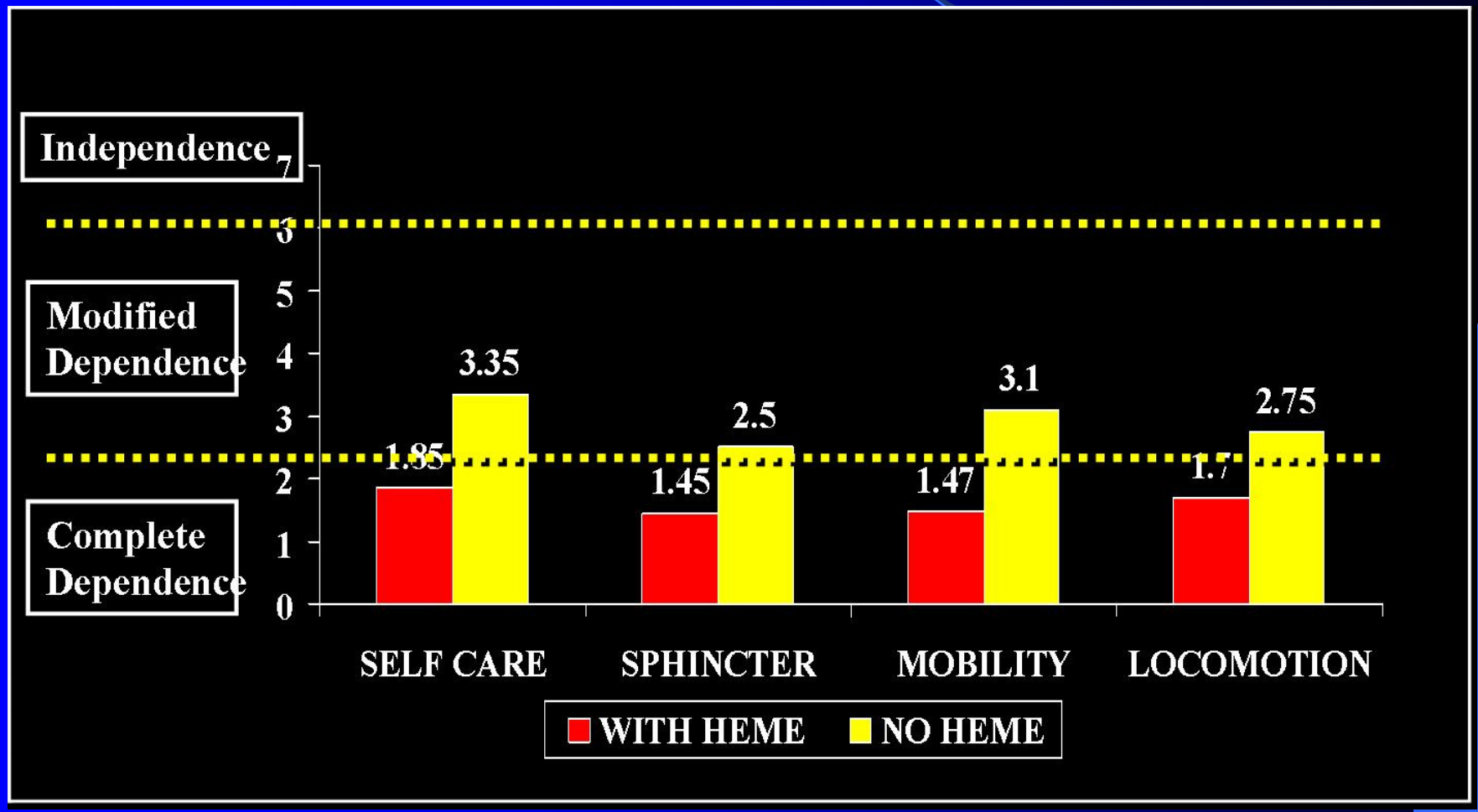
Effect of Spinal Cord Heme on LE Motor Recovery at 12 mos.



Relationship of Spinal Cord Hemorrhage to Mean Admission FIM Subscales

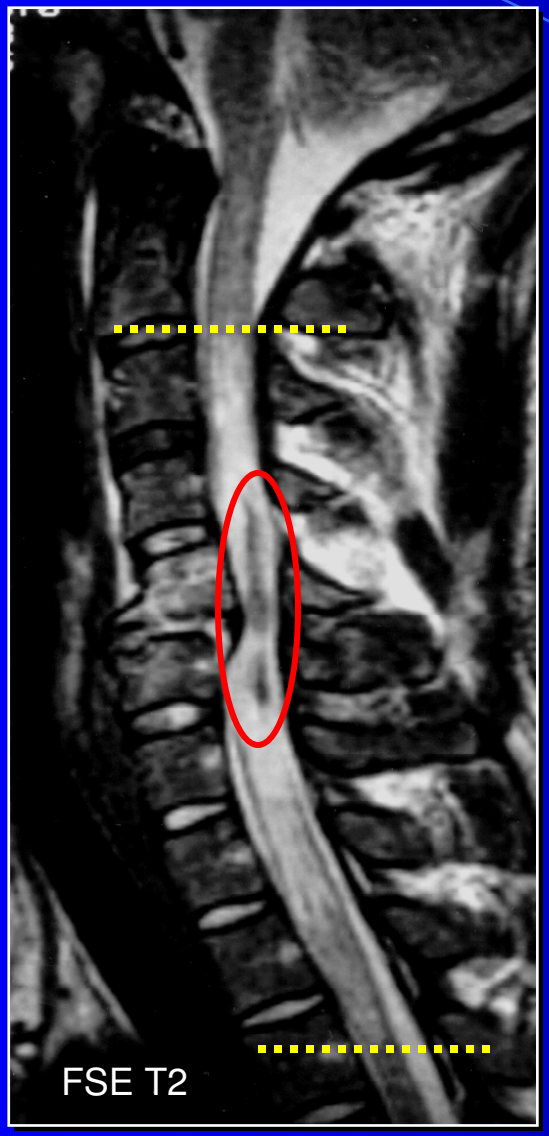


Relationship of Spinal Cord Hemorrhage to Mean Discharge FIM Subscales

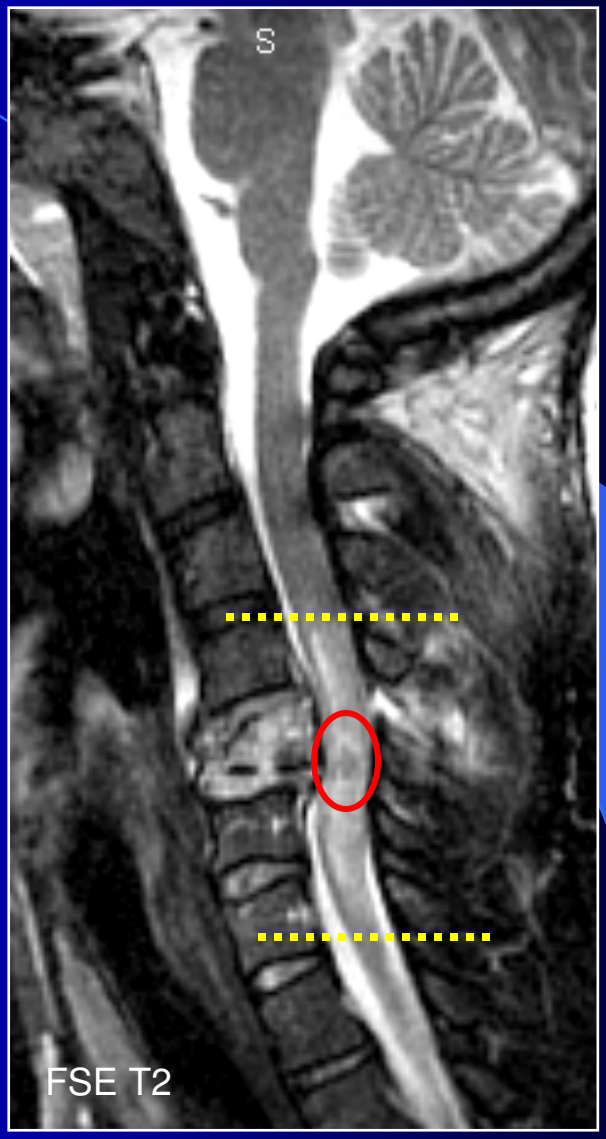


Effects of Steroids on SCI

MRI Comparison



20M C5 ASIA A (-) MPS



29F C5 ASIA A (+) MPS

Results
Presence of Hemorrhage

Steroids	(+) Heme	(-) Heme
(+) MPS	54%	46%
(-) MPS	85%	15%

($p = 0.0007$)

Results
Mean Total Lesion Length*

	(-) MPS		(+) MPS	p
C4-6	10.4	>	8.6	0.031
C4	10.2	<	11.1	0.44
C5	11.2	>	7.1	0.007
C6	10.9	>	7.0	0.027

(* Arbitrary units)

Results
Mean Hemorrhage Length*

	(-) MPS		(+) MPS	p
C4-6	2.7	>	1.4	0.076
C4	2.6	>	2.0	0.619
C5	2.8	>	1.0	0.149
C6	2.9	>	1.0	0.189

(*Arbitrary units)

Evolution of Spinal Cord Injury

18 y/o C5 ASIA A

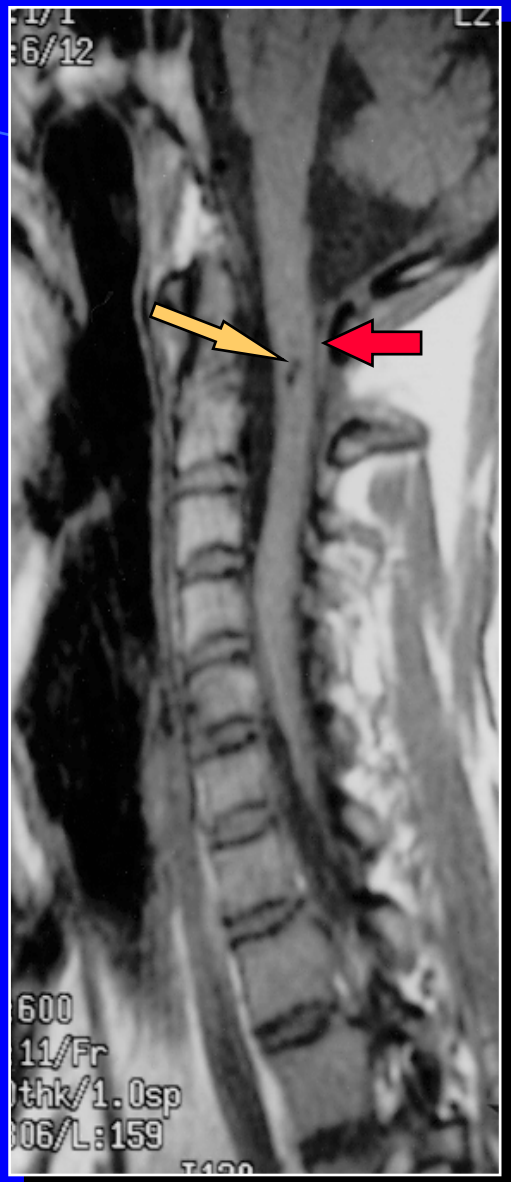
Initial

2 months post injury

Chronic Changes following SCI

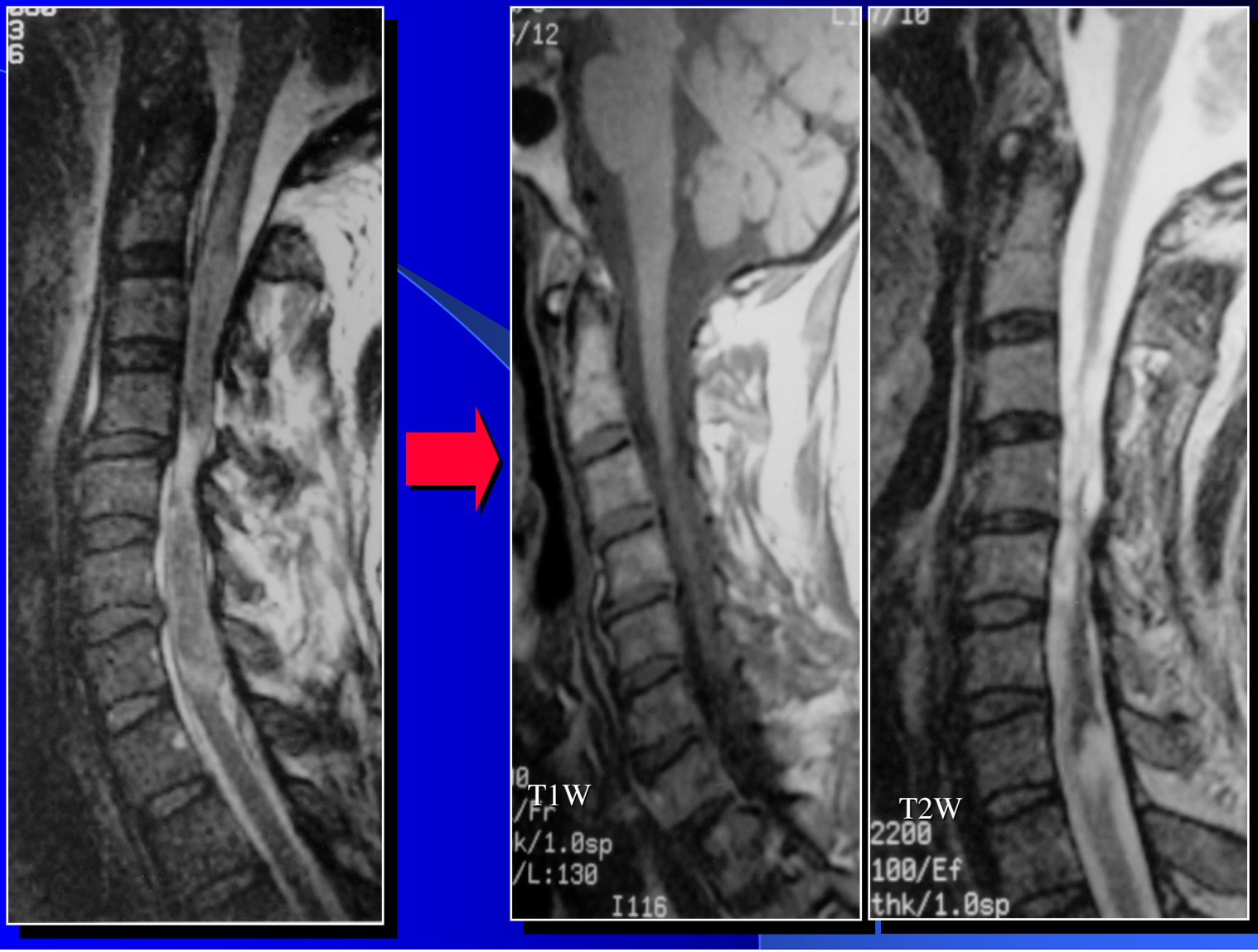
Chronic Changes after SCI

tethering, adhesions & cyst



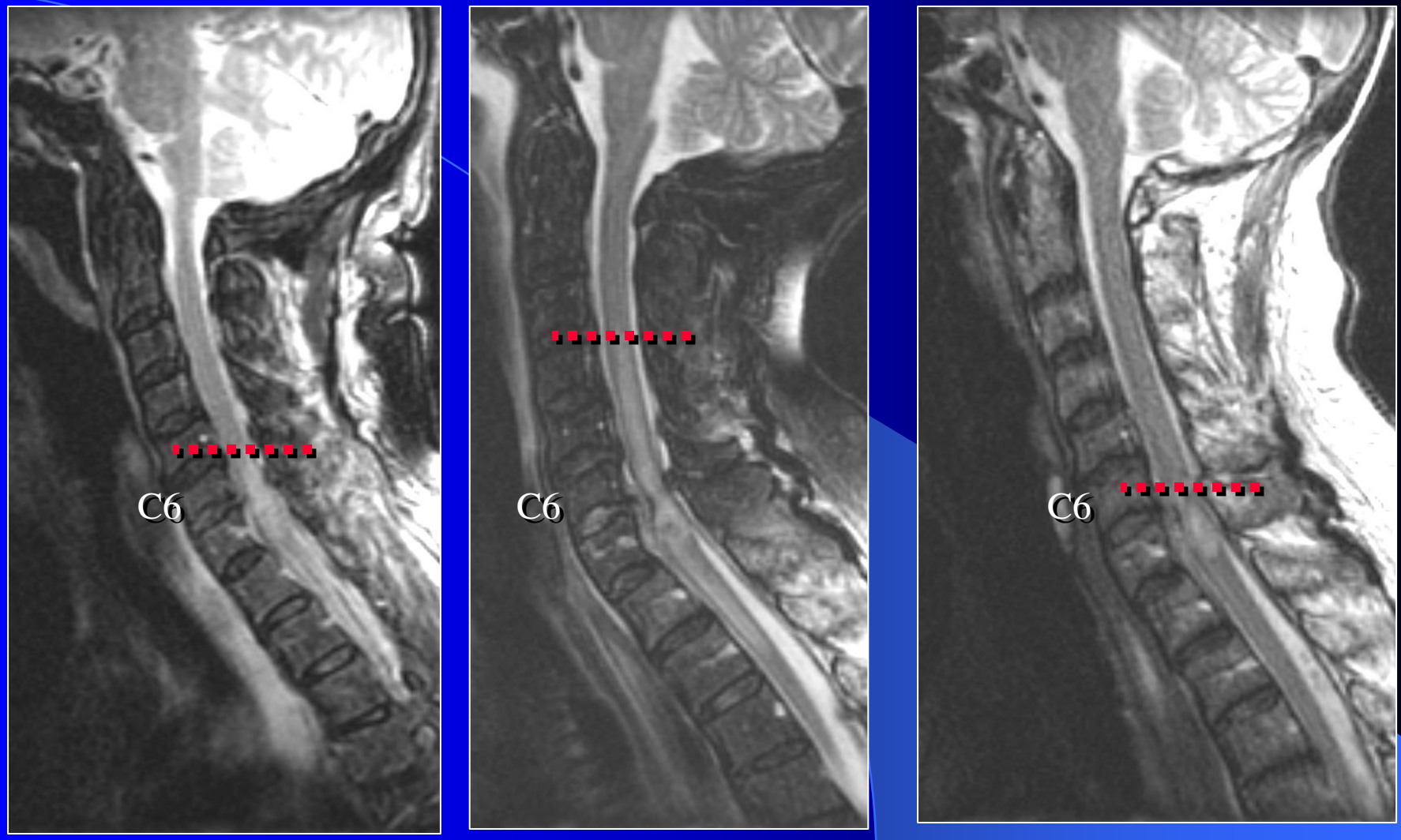
Atrophy & Myelomalacia

10 mos. after crush injury



Deterioration at 10 days

C5 level ascending to C3



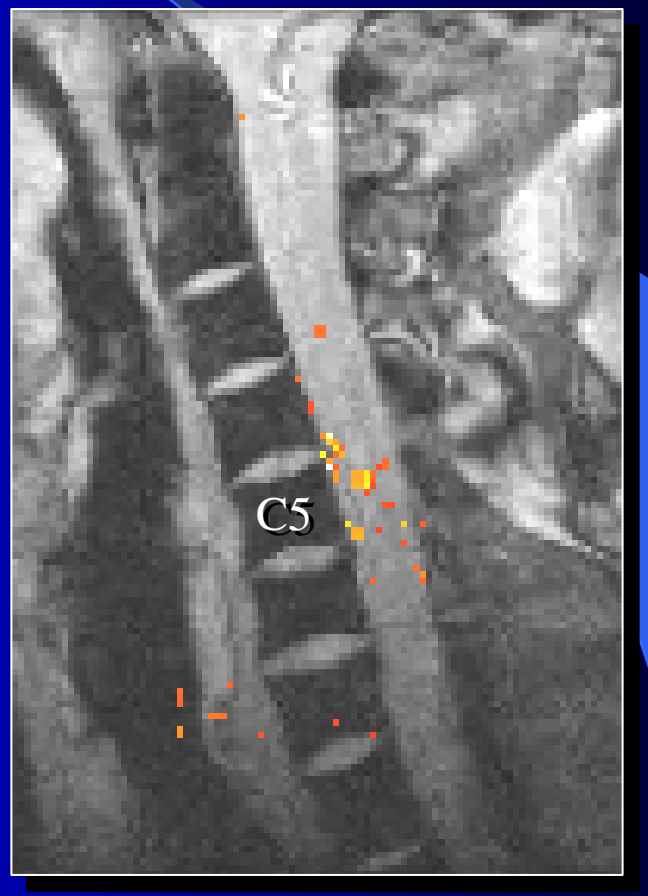

The Future???

Future of MRI & SCI

- Future developments in imaging of SCI parallel progress in functional imaging.
- Diffusion, perfusion MRS and BOLD imaging of spinal cord will improve our precision in assessing spinal cord function.
- MRI will also prove invaluable in evaluating viability of transplants.

fMRI Signal Generated by Biceps Contraction

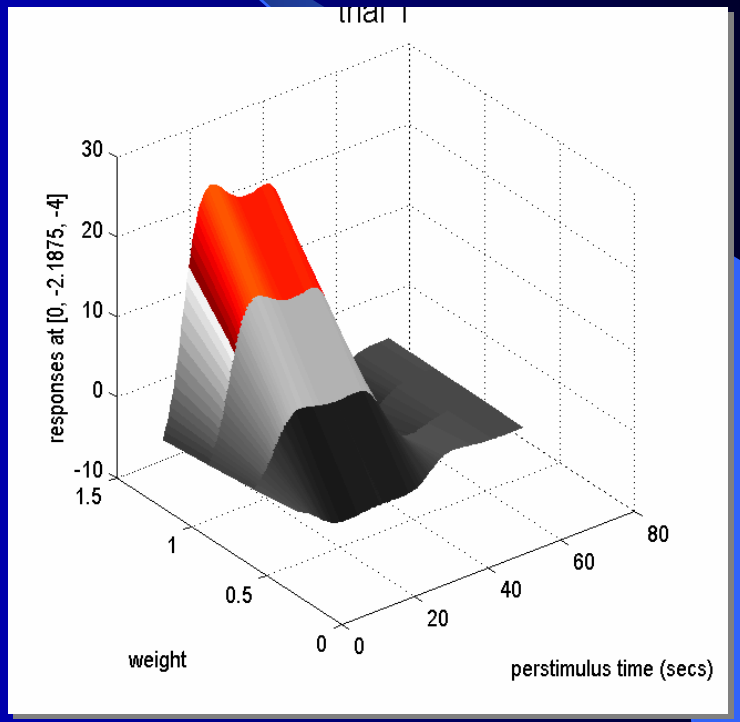
- Exploits subtle changes in blood O_2 levels detectable on MRI.
- Currently used to study brain cortical activation.
- BOLD signal has been successfully elicited from human spinal cords.
- Future application in understanding cord function & plasticity in recovery.



Madi et al. AJNR 2001

Activation & Deactivation During Isometric Contraction

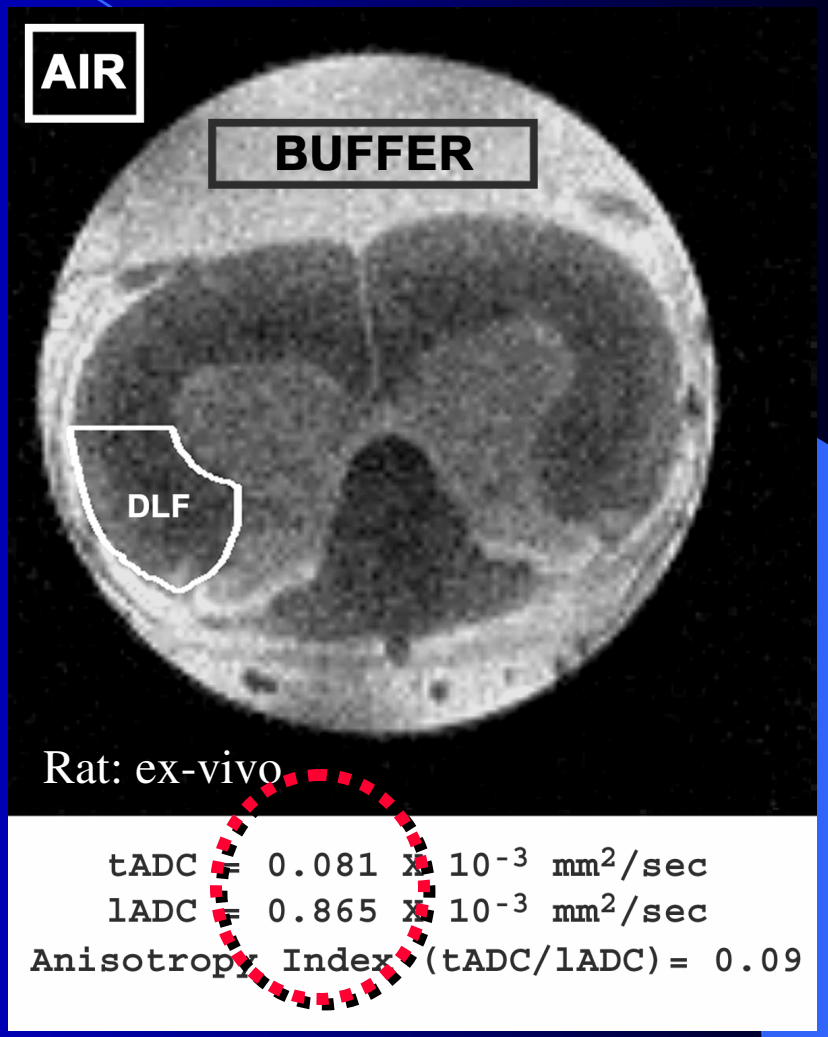
Madi etal AJNR 2001



Isometric Contractions

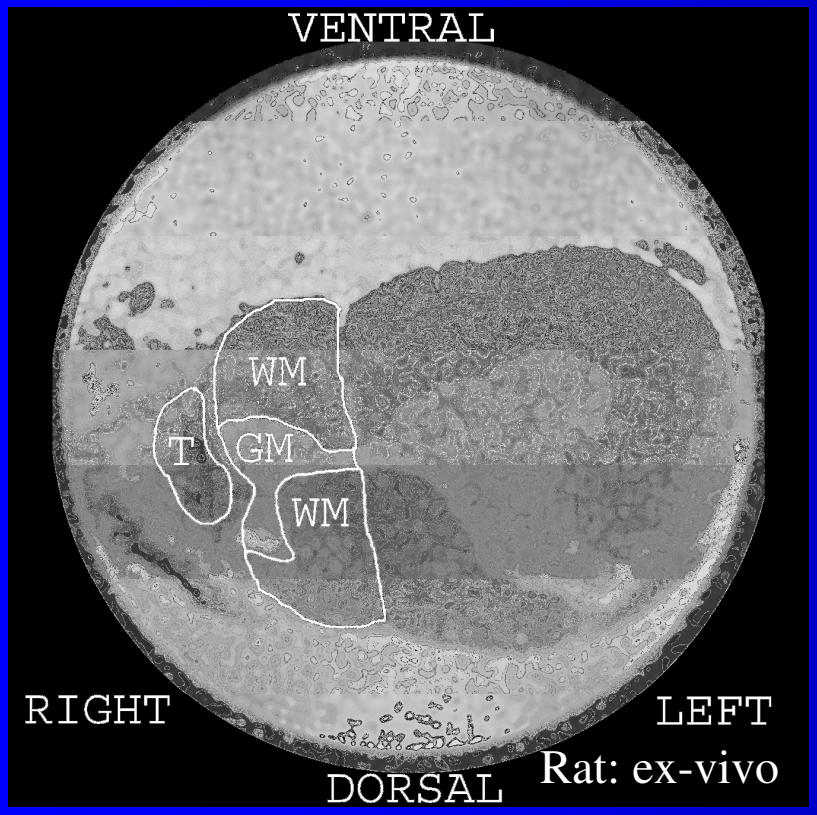
Diffusion Characteristics of Normal Spinal Cord

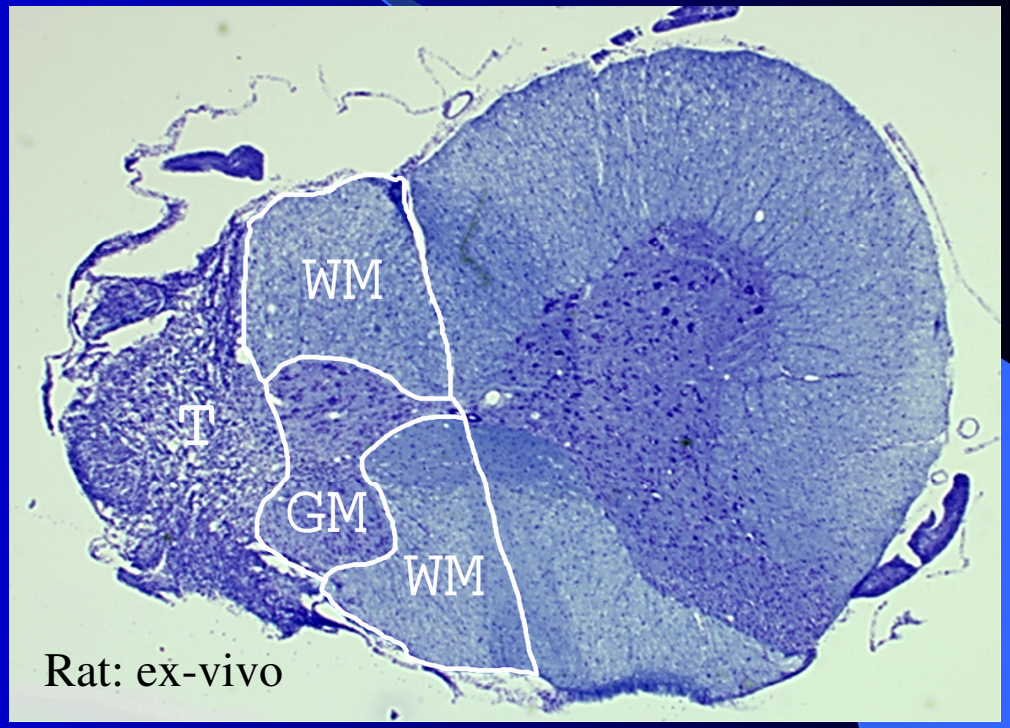
- Routinely used to diagnose infarction and to map fiber tracts in brain.
- Diffusion correlates with integrity of myelin sheath & neuronal function.
- SC consists of ordered bundles of myelinated fibers.
- Free diffusion of water is “unrestricted” along axis of normal neurons.



Courtesy of Eric D. Schwartz, MD, Hospital of the University of Pennsylvania

Transplant and Histology

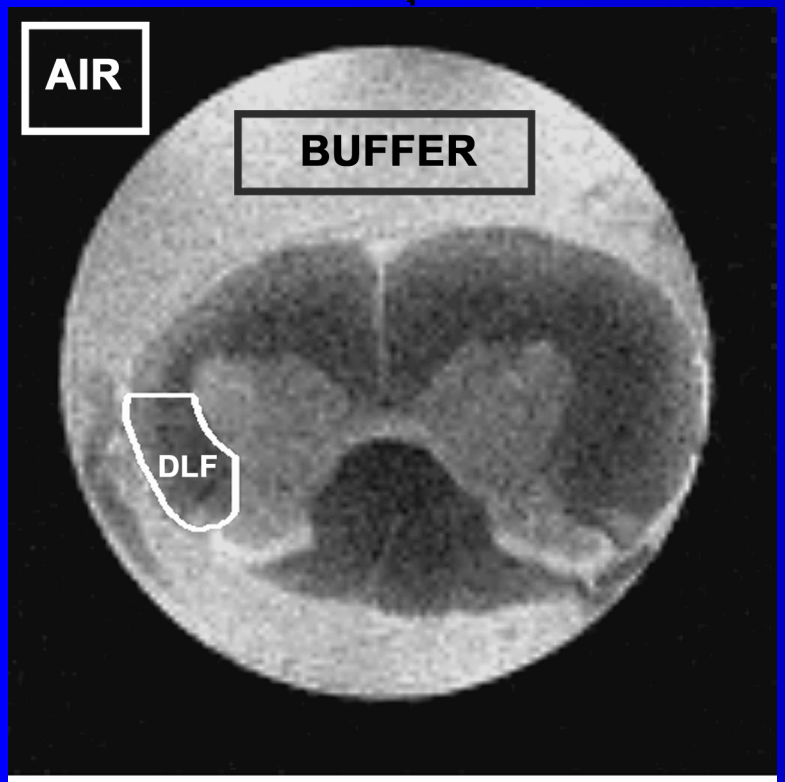




Courtesy of Eric D. Schwartz, MD, Hospital of the University of Pennsylvania

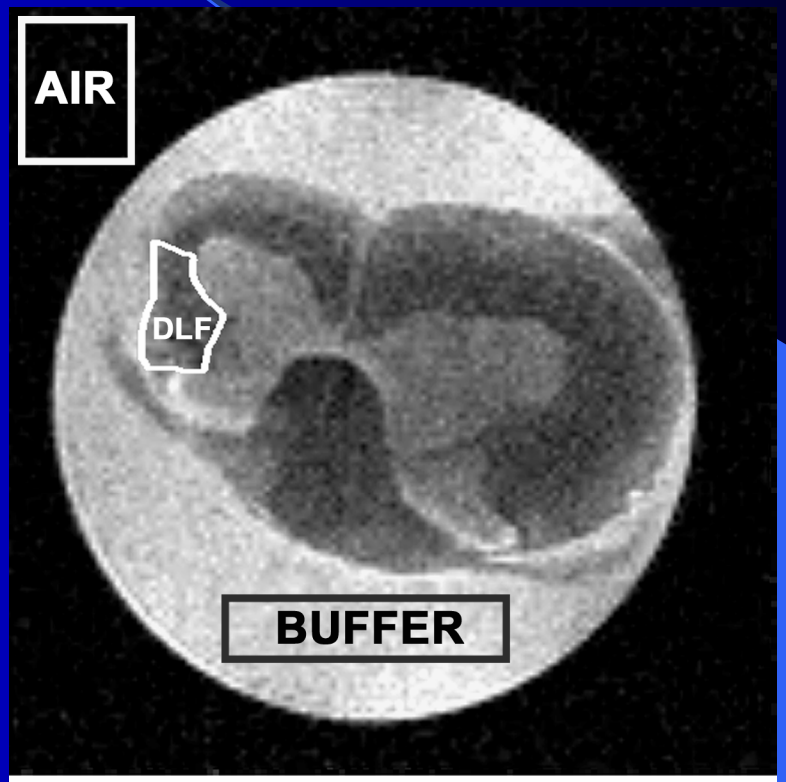
Diffusion Characteristics of Spinal Cord Transplants

1 mm rostral to Fb-BDNF transplant



tADC = 0.191 X 10^{-3} mm^2/sec
lADC = 0.649 X 10^{-3} mm^2/sec
Anisotropy Index (tADC/lADC)= 0.29

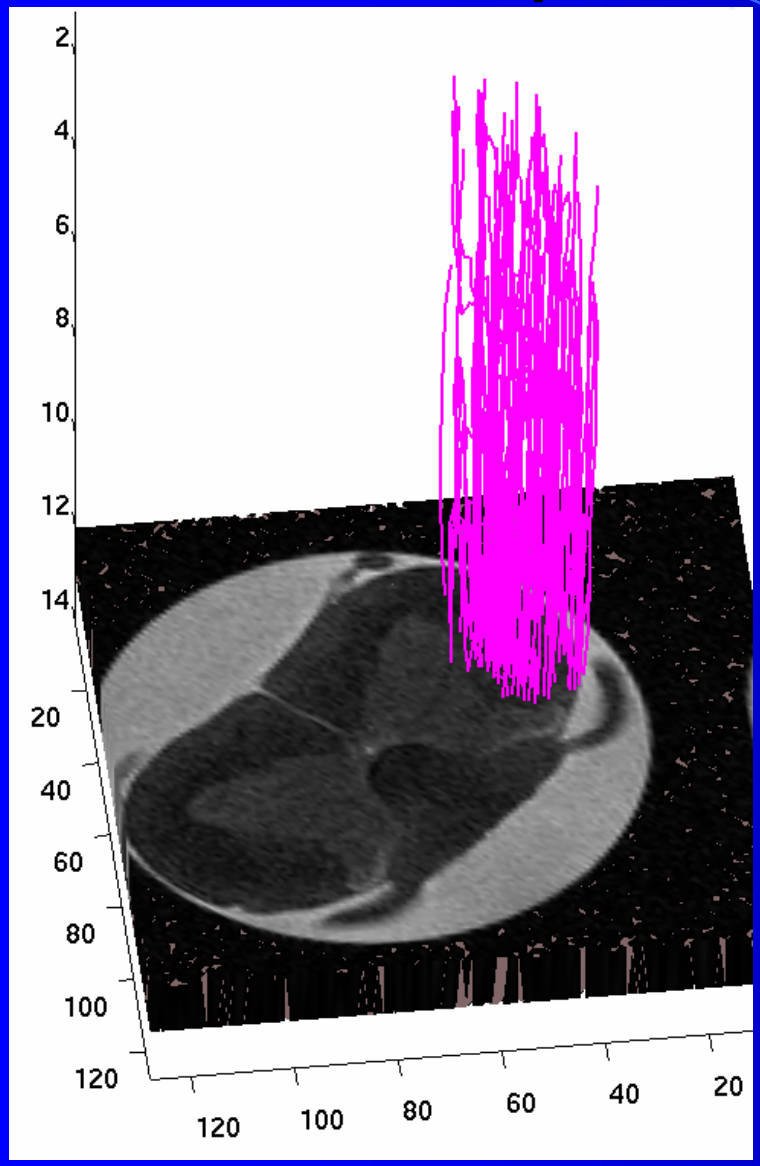
1 mm rostral to Fb-UM transplant

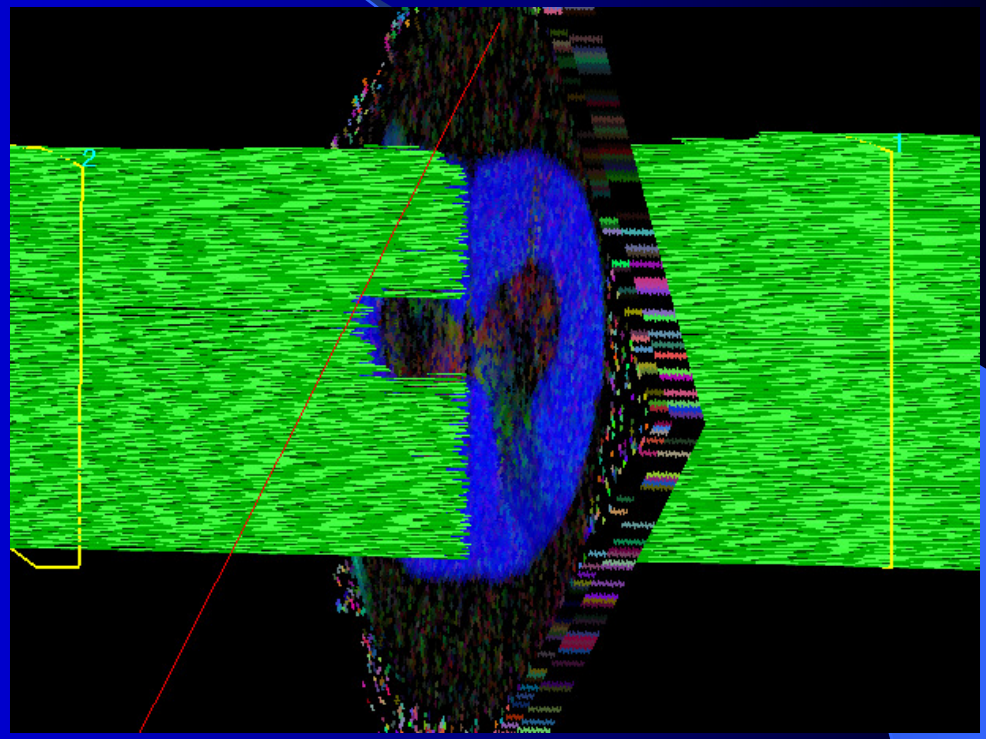


tADC = 0.224 X 10^{-3} mm^2/sec
lADC = 0.586 X 10^{-3} mm^2/sec
Anisotropy Index (tADC/lADC)= 0.38

Courtesy of Eric D. Schwartz, MD, Hospital of the University of Pennsylvania

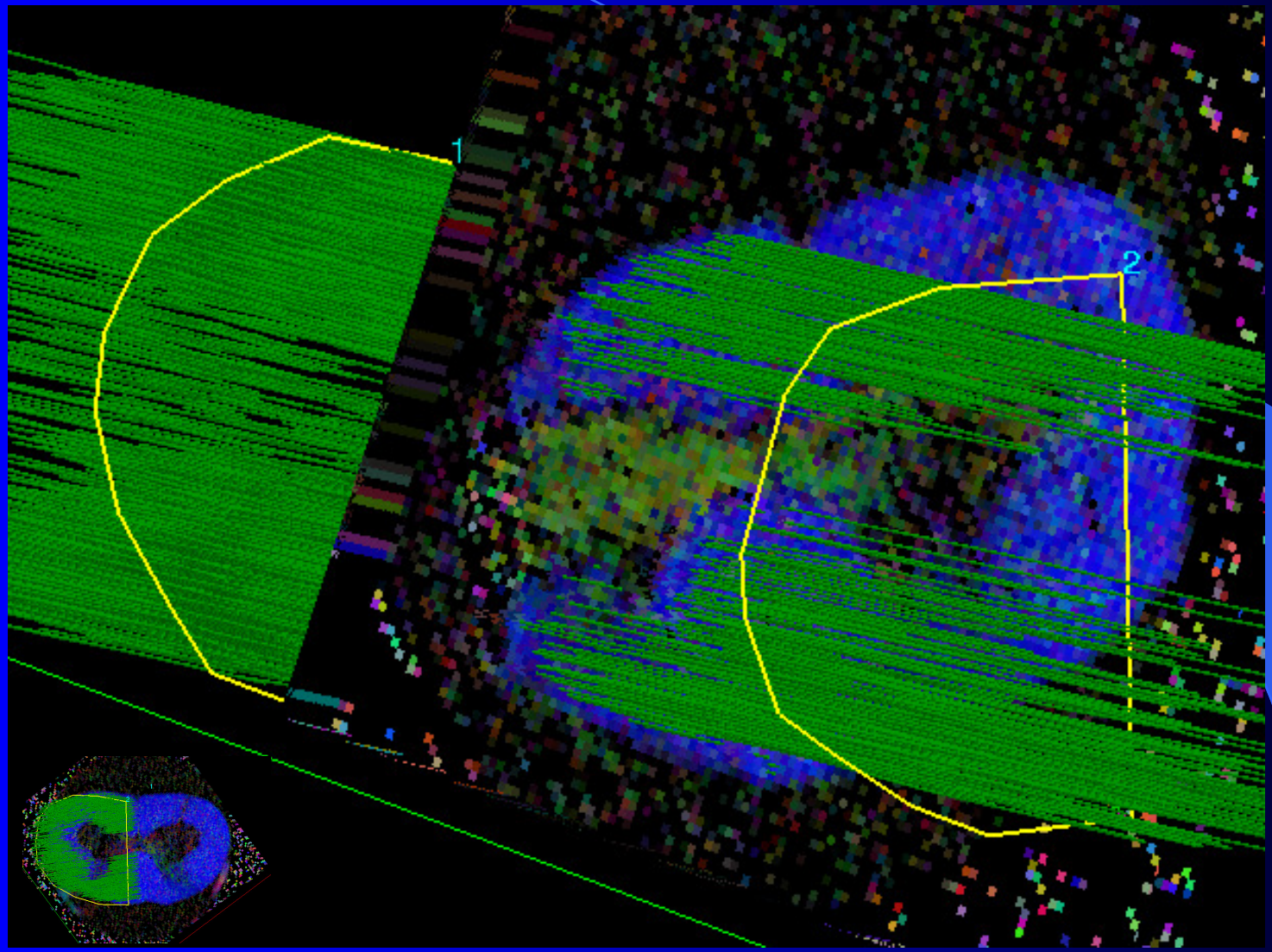
DTI and Spinal Cord Fiber Tracking in Normal





Courtesy of Eric D. Schwartz, MD, Hospital of the University of Pennsylvania

DTI and Spinal Cord Fiber Tracking at 9.4T



Courtesy of Eric D. Schwartz, MD, Hospital of the University of Pennsylvania

Controversies!

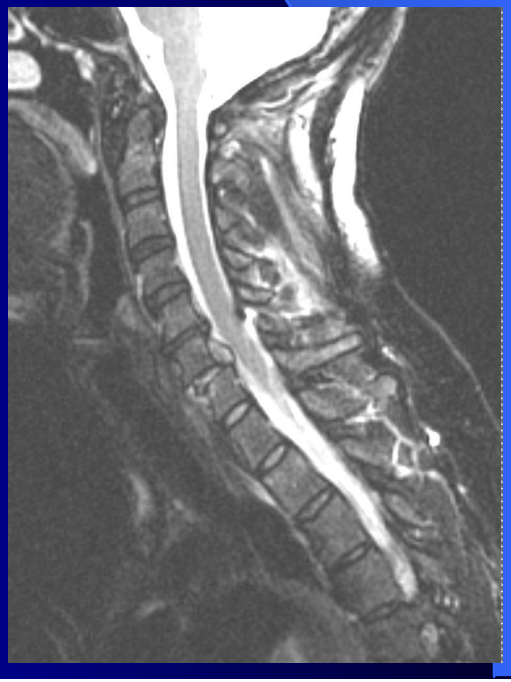
- Too much data to handle!!!
- Replacing radiography with CT.
- When is CT or MRI appropriate?
- Assessing stability.
  - C1-2 instability (“crooked dens”).
  - r/o lig injury w/o fracture.
  - Use of MRI as alternative to flexion/extension.

Assessing Instability

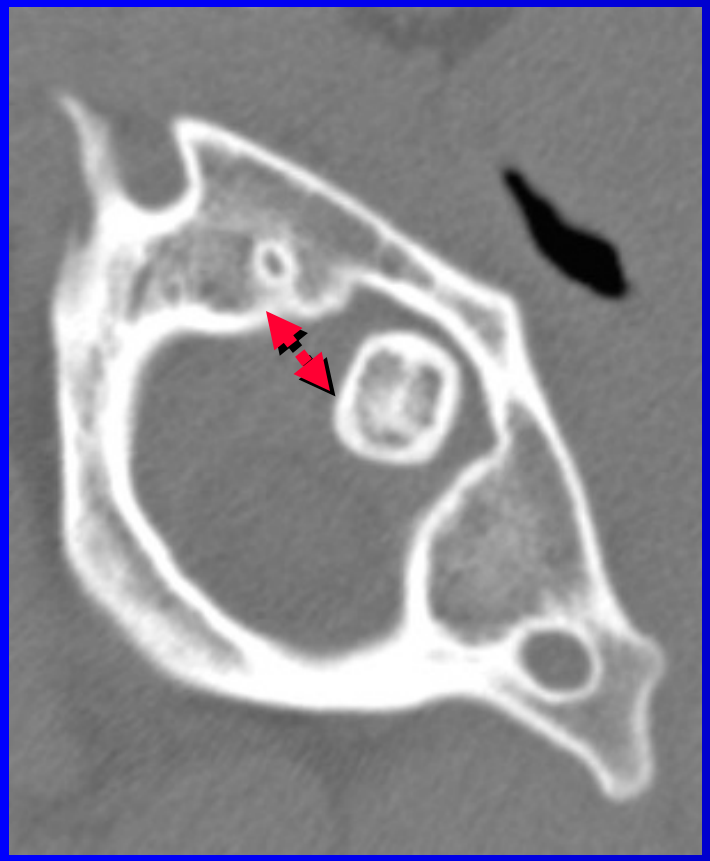
- Scenario: Cervical sprain
  - No fx, no neurologic deficit
  - residual pain, motion limitation
- Rx Option #1
  - Meds & home in soft collar.
  - Follow-up outpt flex/ex views.
- Rx Option #2
  - Get emergent MRI to assess integrity of ligaments.
- Has MRI been validated to determine mechanical stability?

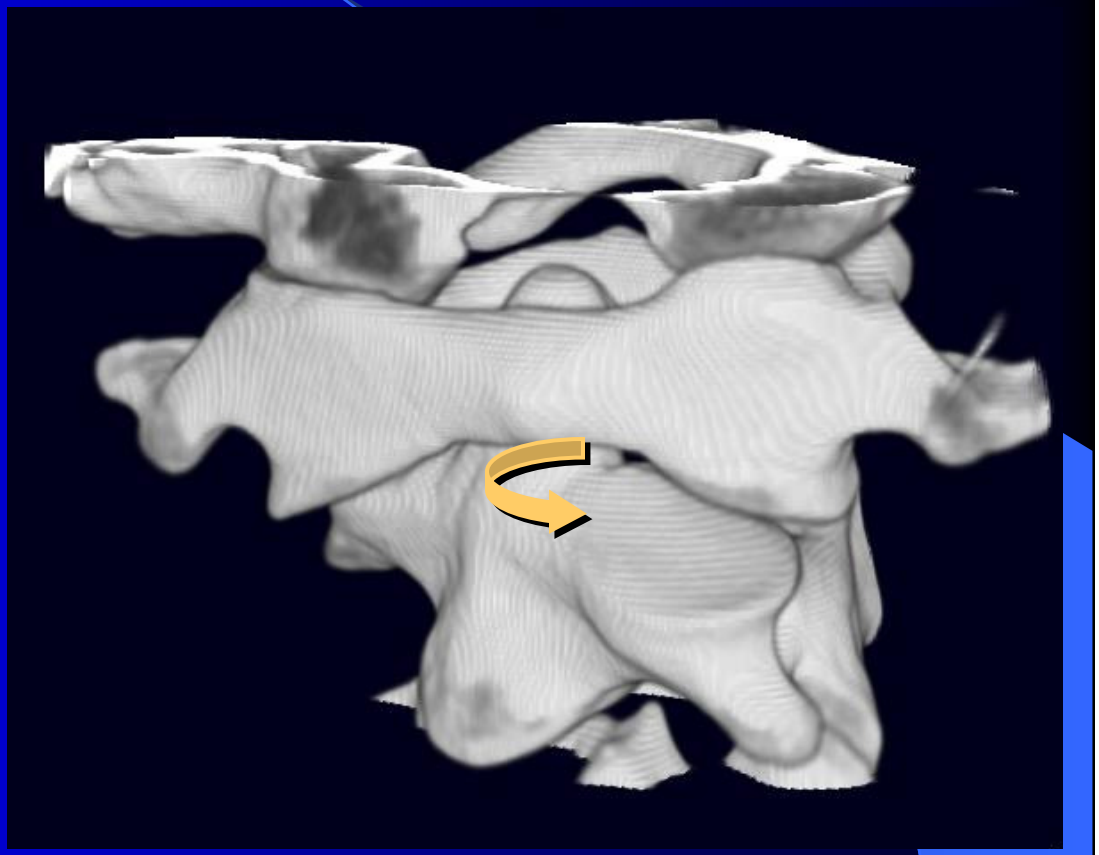
Ext

Flex



Tilted Dens Scenario





Tilted Dens Scenario

Are the ligaments truly intact or is the MRI insensitive?

Question?

- We rely on MRI to determine if it's:
  - Safe to discharge patients
  - For obtunded or unreliable pt:
    - Safe to allow a patient to move (stability).
    - Safe to discharge pt.
    - To confirm or refute neurologic examination.

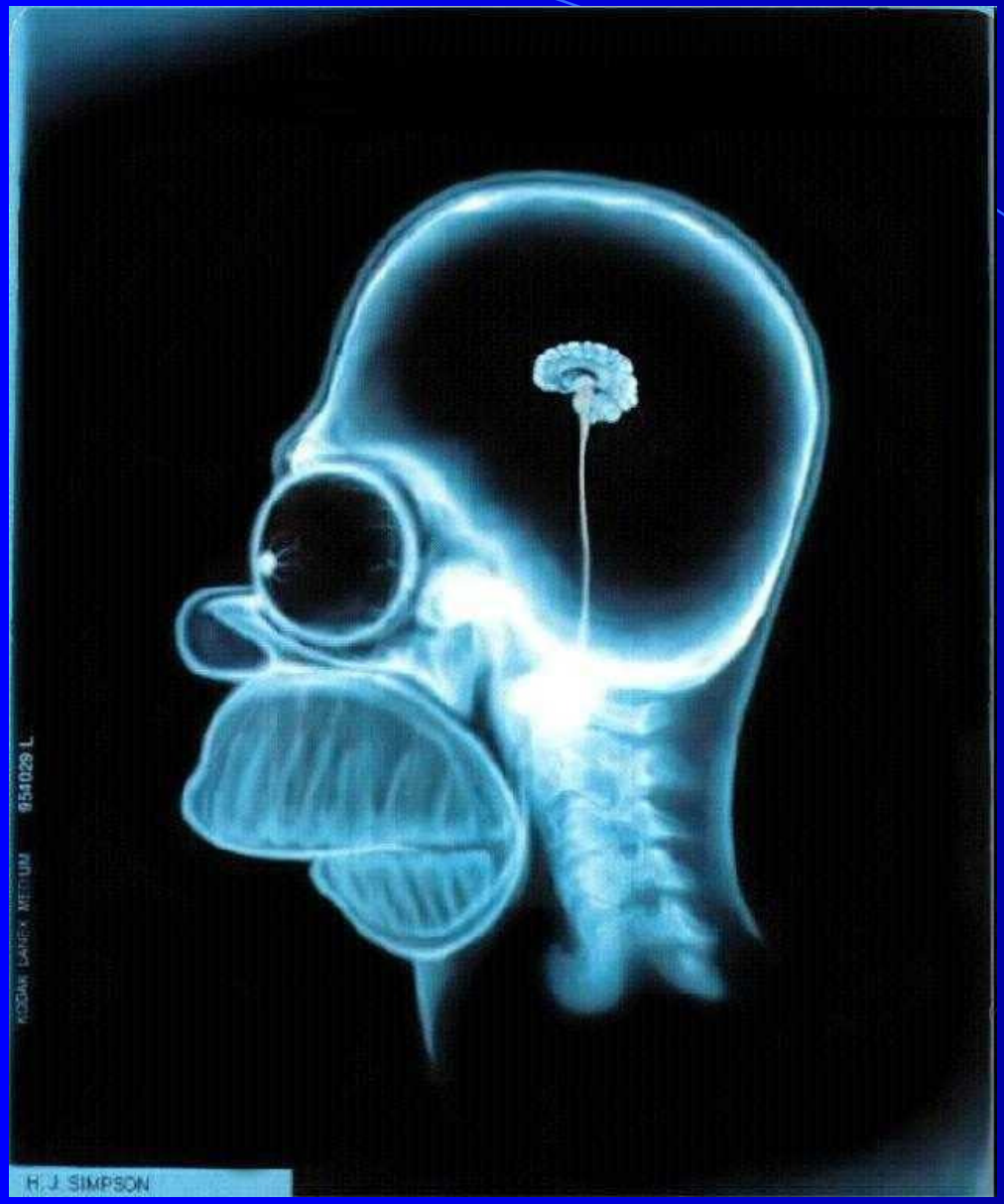
We enjoy a false sense of comfort that MRI shows all these essential features with a high degree of reliability, yet many aspects have not been validated.

Summary

- Radiography and CT are primary diagnostic modalities in initial eval. of SCI.
- MDCT improves our accuracy to detect and characterize fractures.
- MRI is *required* in all spinal injured patients with a persistent neurologic deficit.

Summary

- MRI improves the prognostic capabilities of clinical examination.
- MRI is study of choice for eval of chronic SCI.
- New MRI techniques may provide new parameters to assess restoration of function following therapy.
- New workflow paradigms are needed to accommodate to data overload.



Thanks to the Regional Spinal Cord Injury Center of the Delaware Valley.

John F. Ditunno, MD
Anthony S. Burns, MD
Eric D. Schwartz, MD


Thank You!