

Respecting and restoring the sagittal profile in spinal surgery

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ABMU Health Board



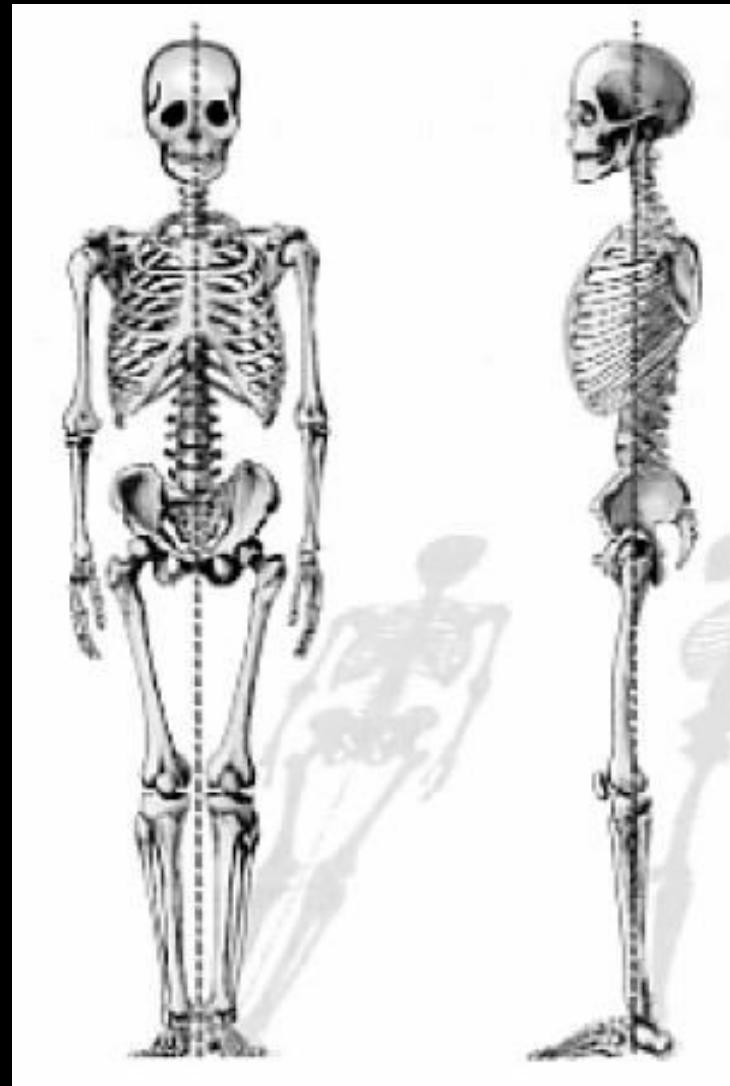
Outline

Why this fuss about the sagittal profile?

- ¤ The sagittal parameters
- ¤ Pathology
- ¤ Surgical restoration
- ¤ Clinical evidence

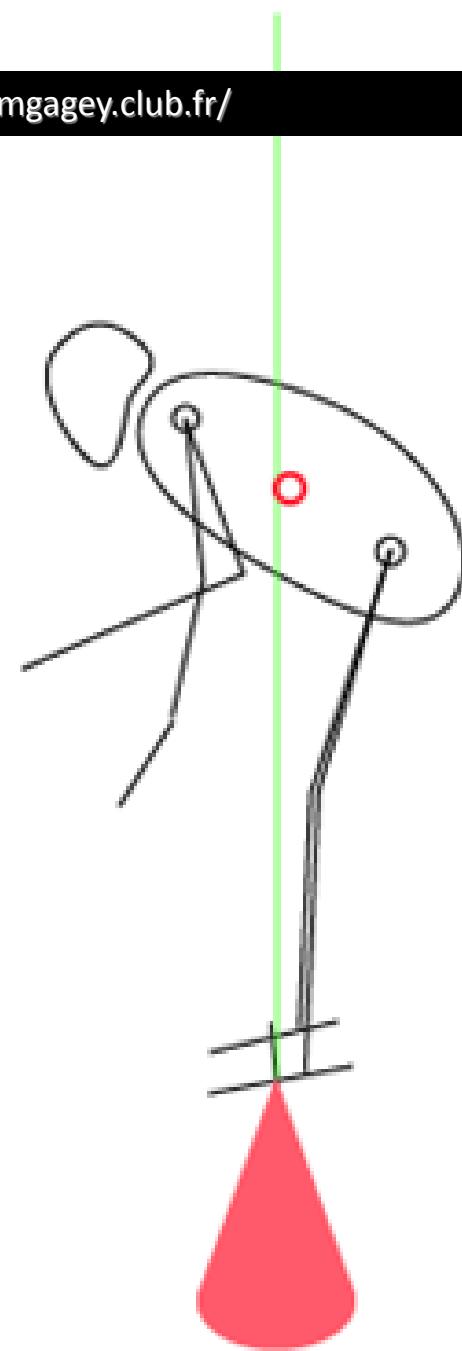
Sagittal : Plane dividing right & left halves

Balance: Head over heels!





<http://pmgagay.club.fr/>



Alignment

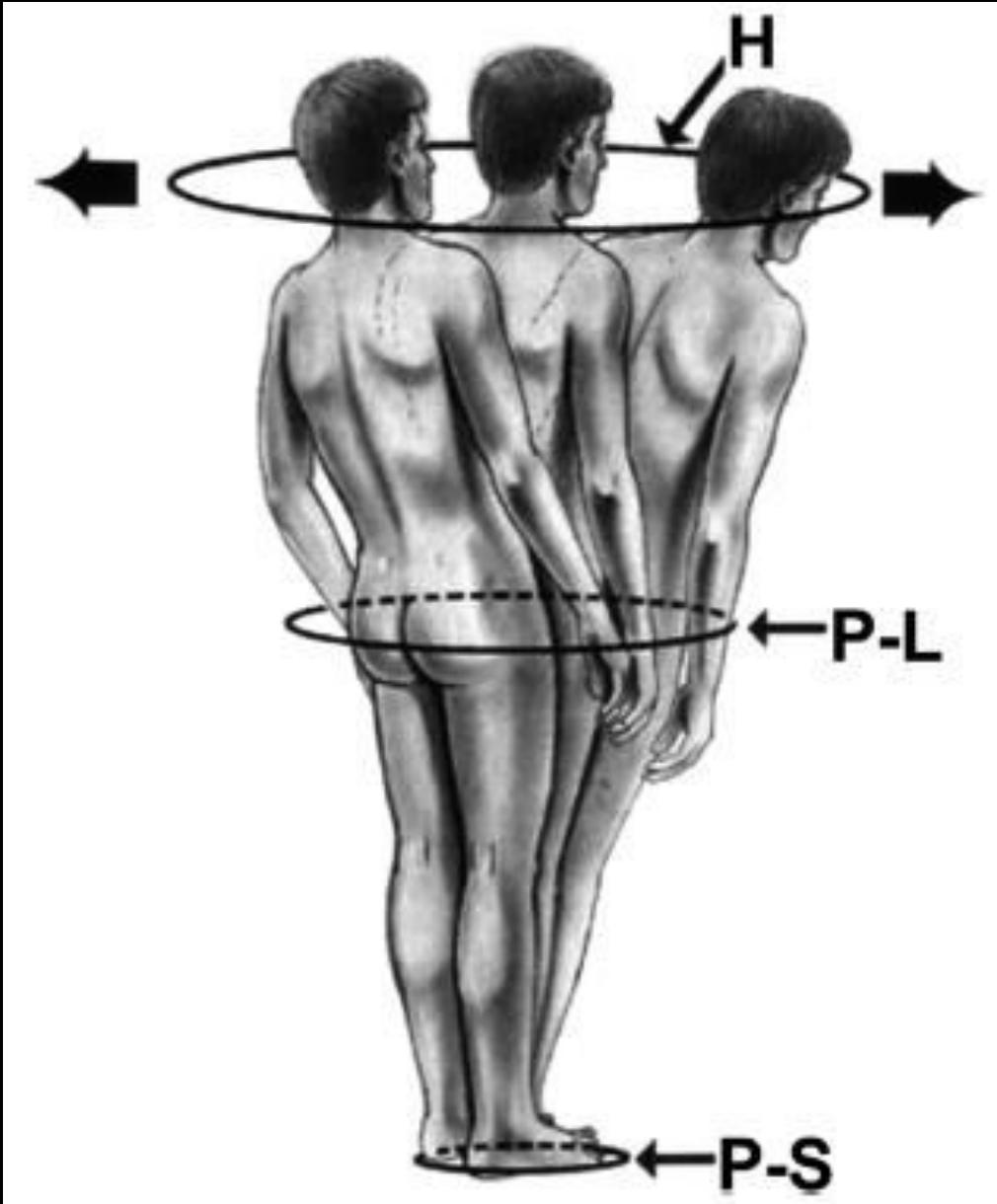
Balance



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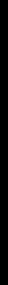
Cone of economy

J. Dubousset

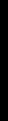


Sagittal Plane Alignment...

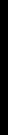
... More Than Just the Spine



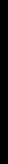
Thoracic kyphosis



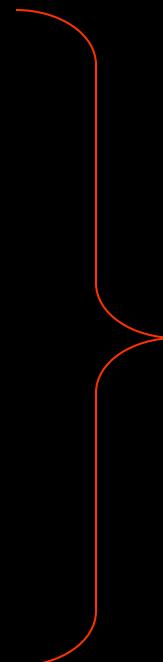
Lumbar lordosis



Pelvic morphology/
version



Lower extremity



Global
Alignment

Sagittal pelvic morphology

- ¤ Influences standing balance
- ¤ Normal gait

Jackson Spine 2000

Legaye Rachis 1993; ESJ 1998

Vaz ESJ 2002



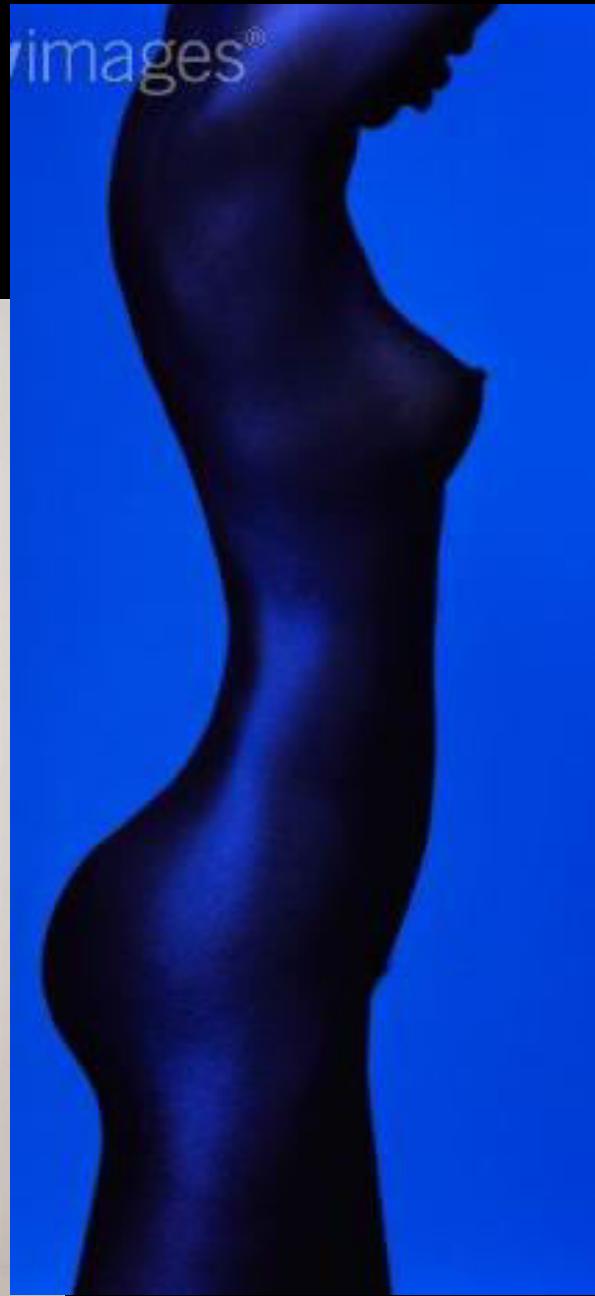
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Measuring sagittal balance

- ¤ Spinal parameters:
 - ø Thoracic kyphosis
 - ø Lumbar lordosis

- ¤ Pelvic parameters:
 - ø Pelvic incidence
 - ø Pelvic tilt
 - ø Sacral slope

- ¤ Global:
 - ø Gravity line
 - ø Sagittal vertical axis
 - ø T9 sagittal offset
 - ø T1 sagittal offset



Thoracic kyphosis:

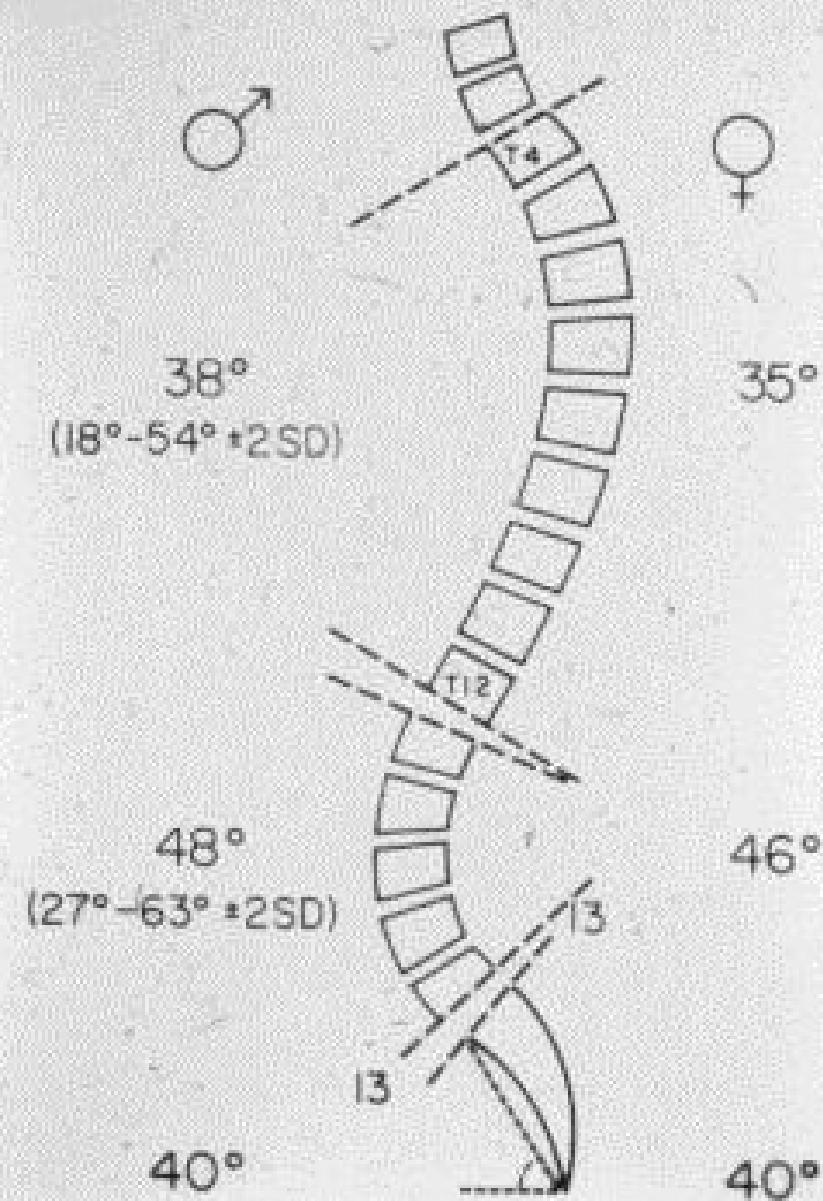
$38^\circ \pm 18$

Lumbar lordosis:

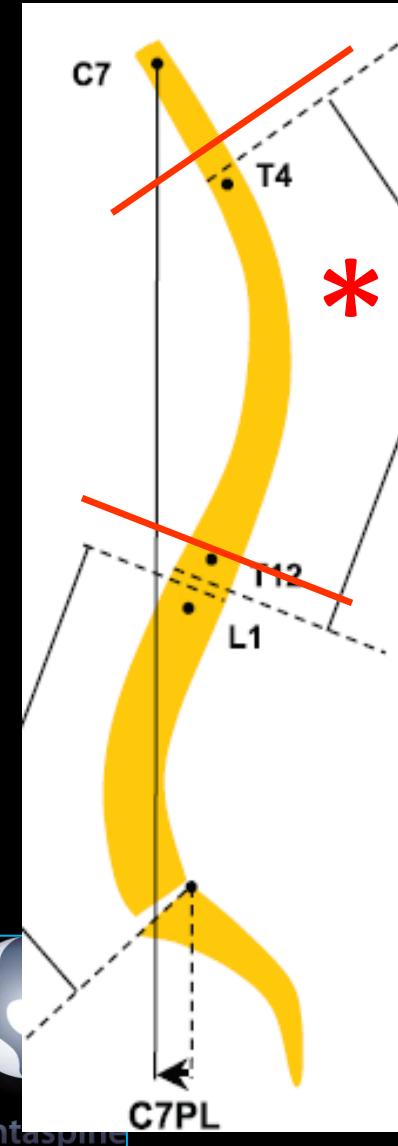
$48^\circ \pm 18$



Dran, G. 1979 (Lyon)



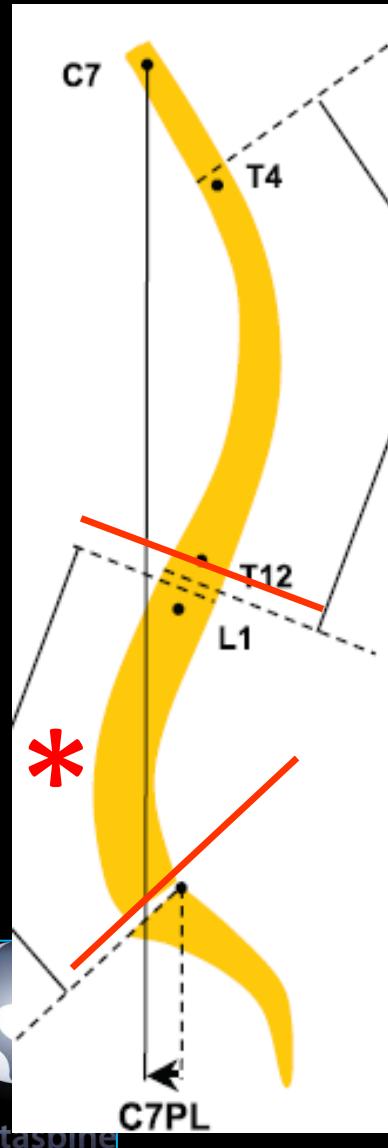
Significance of thoracic kyphosis



- Balances LL
- Increases with age

Life is a kyphosing event

Significance of lumbar lordosis

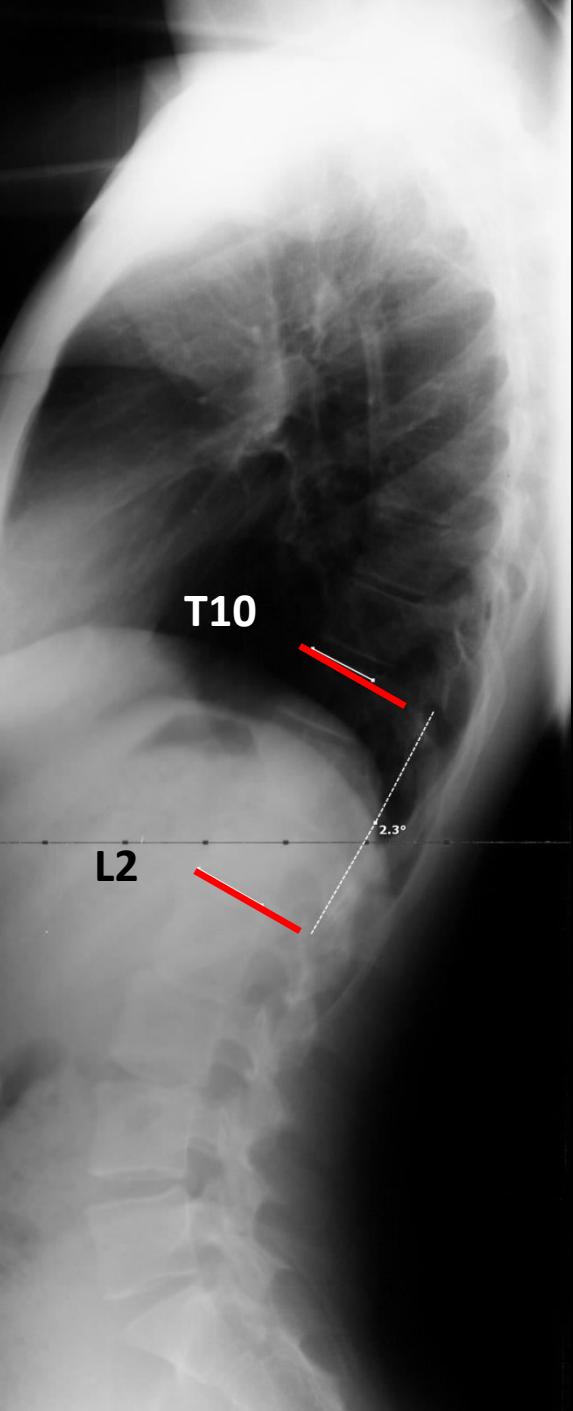


- ☒ Counters anterior drift of plumb line
- ☒ Action of erector spinae





TL Junction

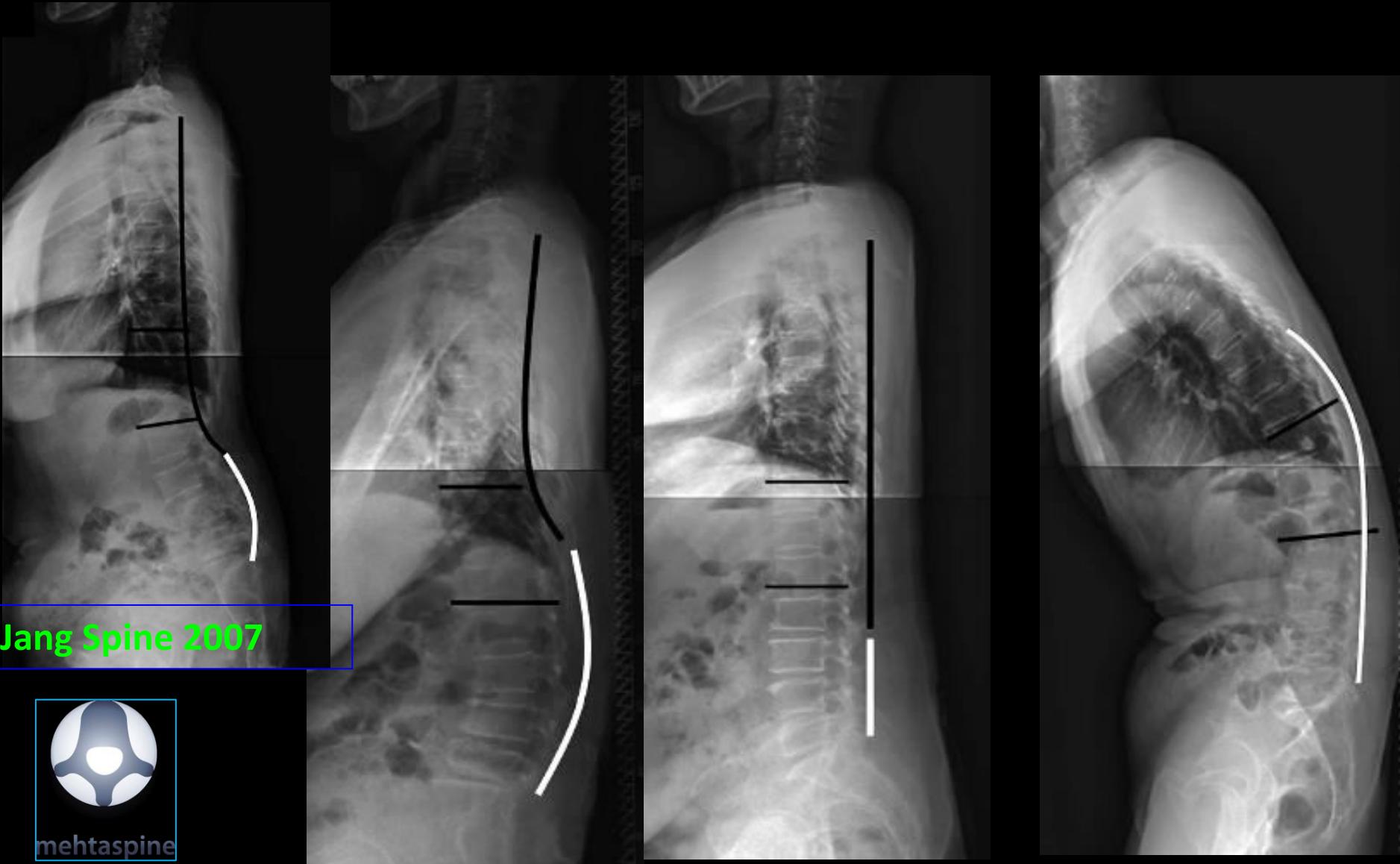


Flat (0 deg)



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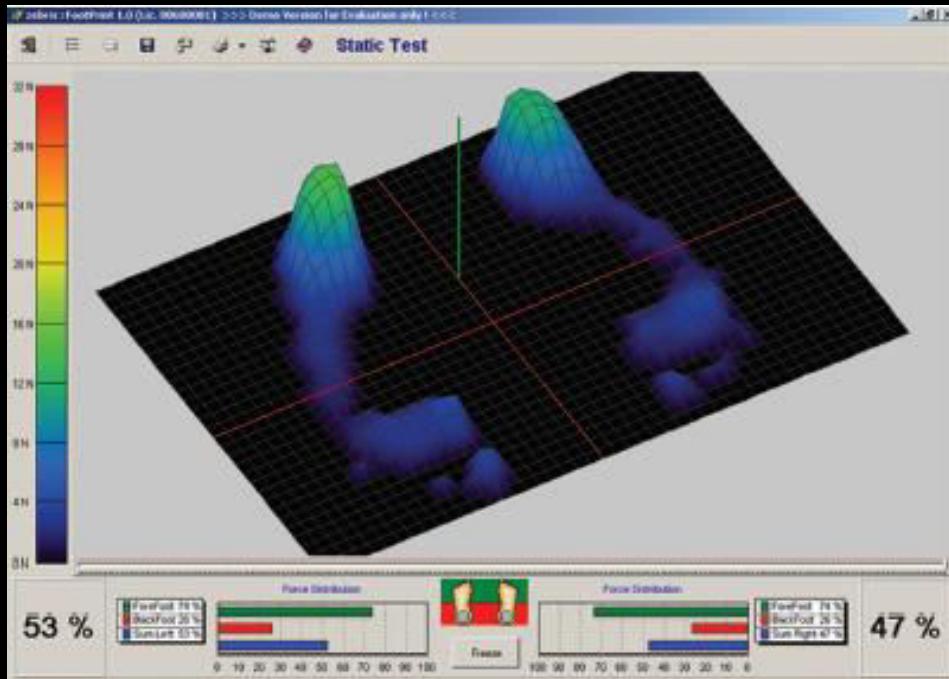
TL junctional sagittal profile



Jang Spine 2007



Ground reaction force ≠ C7 plumb line



- 153 volunteers (force plate + Xrays)

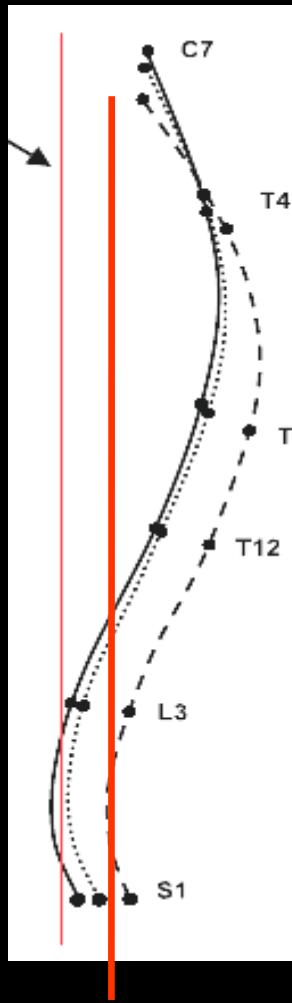
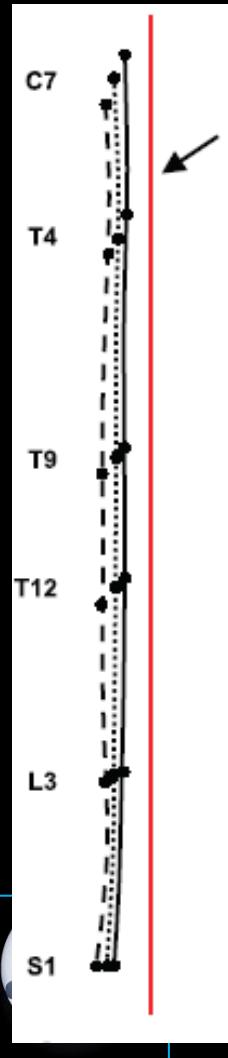
- C7 plumb line and gravity line not collinear

Standing lateral Xray ≠ customary standing balance

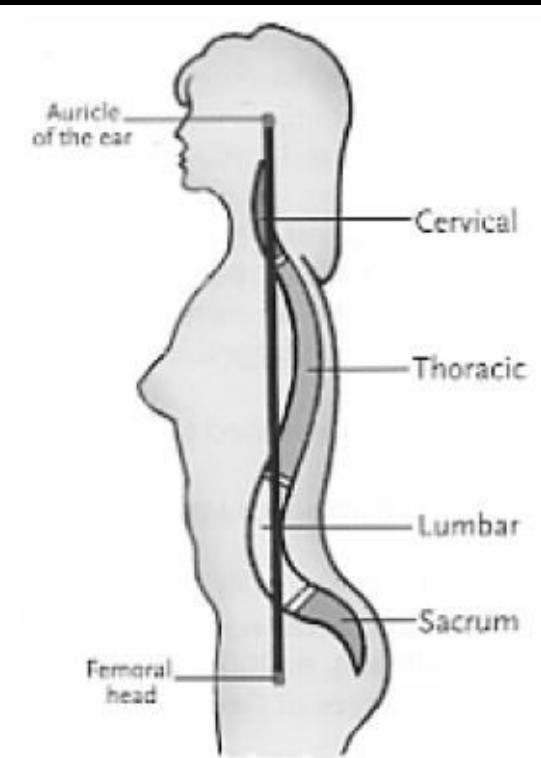
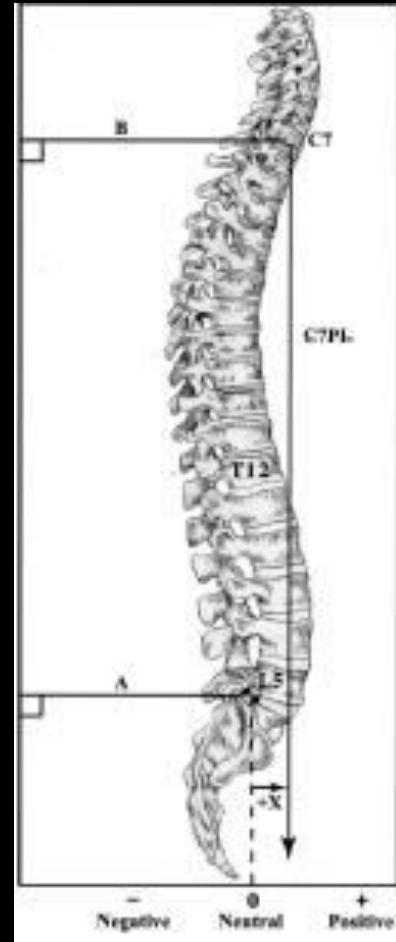


Global sagittal alignment affected by arm position Marks Spine 2003

Gravity line



Sagittal vertical line





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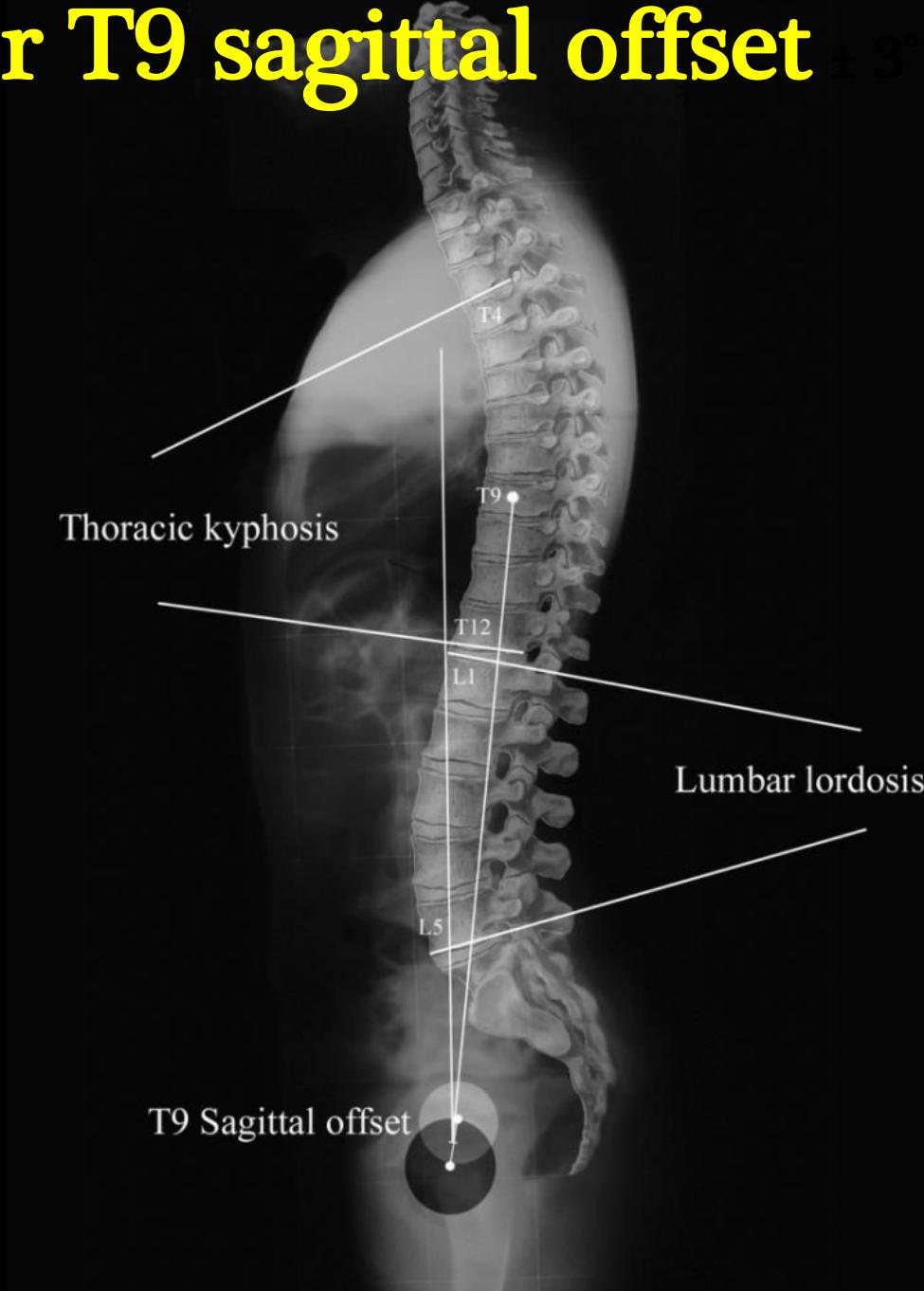
Sagittal vertical axis



Plumb-line shifts:

- ☒ Front Positive
- ☒ Back Negative
- ☒ S1 corner Neutral

T1 or T9 sagittal offset $\pm 3^\circ$



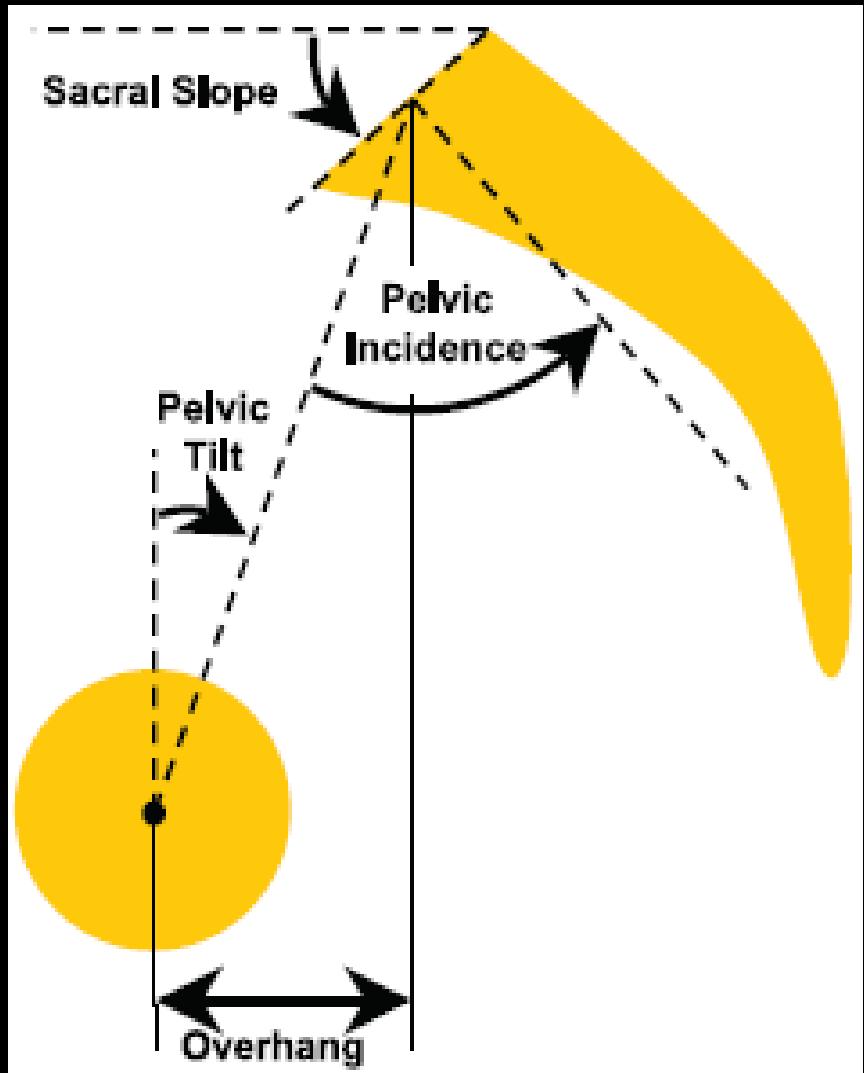
The Pelvis vertebra: Prof Jean Dubousset



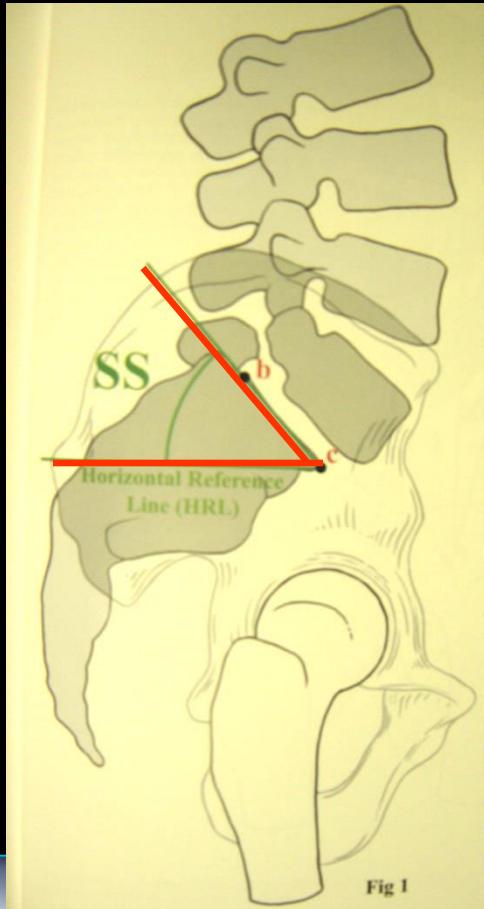
Regulator of Alignment
Link between trunk and lower extremities

Pelvic measures

- ¤ Sacral slope (SS)
- ¤ Pelvic tilt (PT)
- ¤ Pelvic incidence (PI)

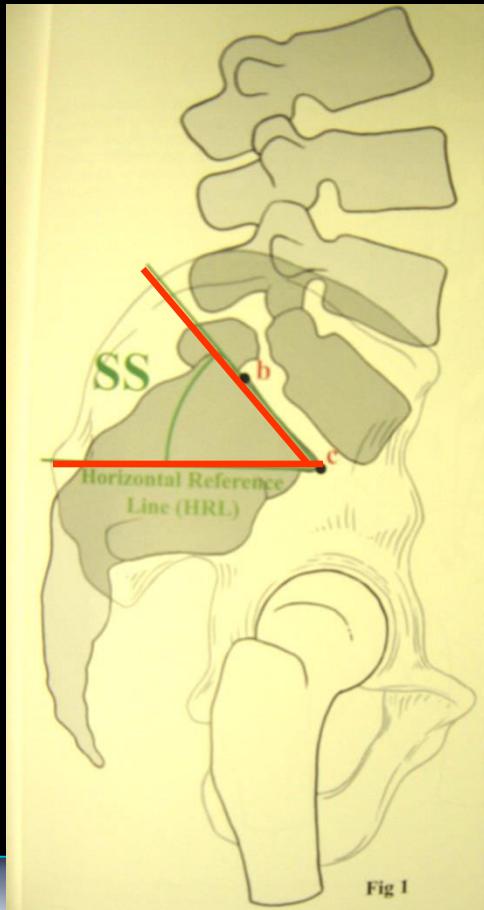


Sacral slope



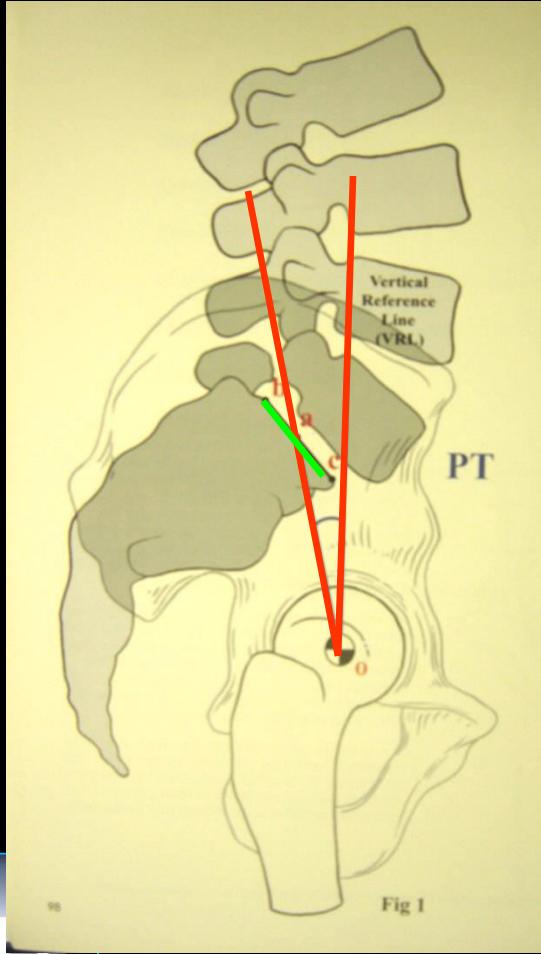
- ¤ Horizontal & cranial sacral end plate tangent
- ¤ $41^\circ \pm 8.4^\circ$ (Vialle JBJS 2005)

Significance of sacral slope



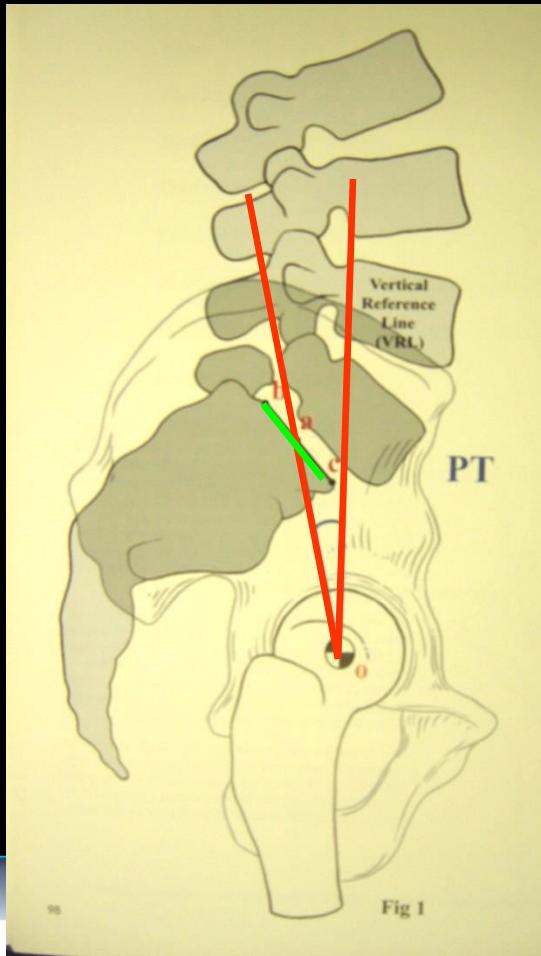
- ¤ Reverse proportion to lumbar lordosis
- ¤ Changes in growth linked to bipedal posture
- ¤ Sacral vertical when child stands, not much change after

Pelvic tilt



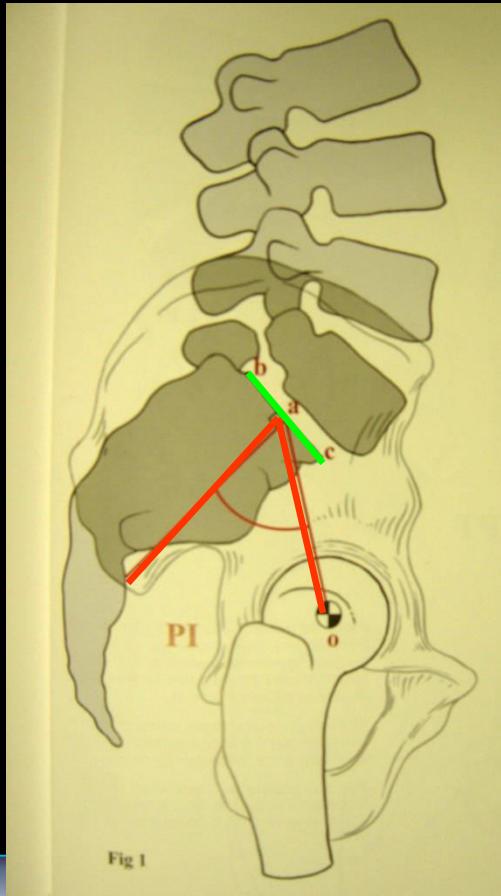
- ☒ Vertical
- ☒ Line between
 - ∅ middle of cranial sacral end plate
 - ∅ centre of the bicoxo-femoral axis
- ☒ $13^\circ \pm 6^\circ$ (Vialle JBJS 2005)

Significance of pelvic tilt



- ¤ Centre of gravity over LL
- ¤ Maintains sacral plate posterior to the hip
- ¤ Increases with age

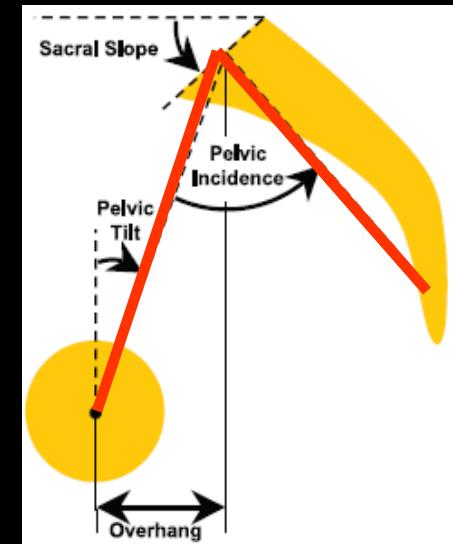
Pelvic incidence

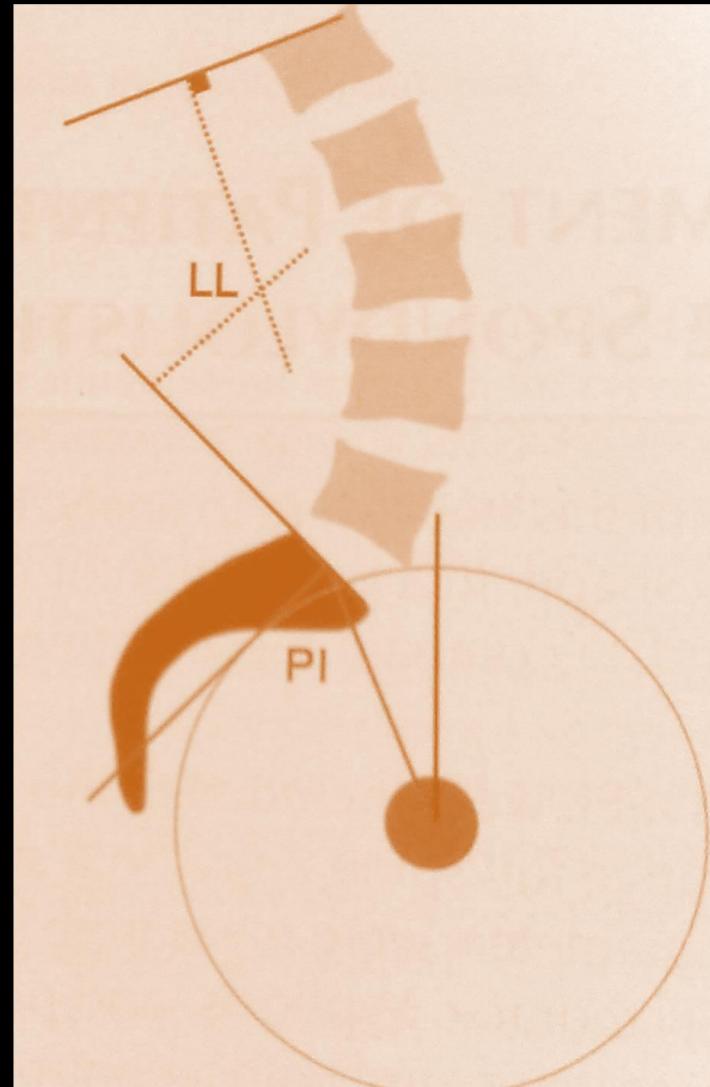
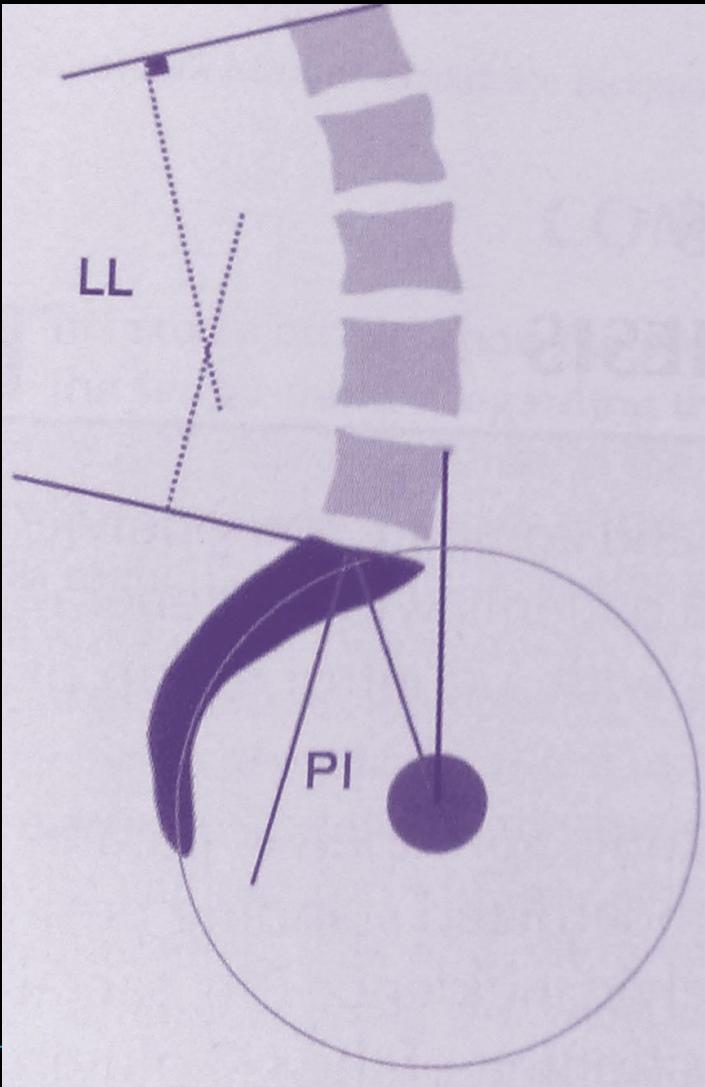


- ❑ Perpendicular to the middle of the cranial sacral end plate
- ❑ Middle to the bicoxo-femoral axis
- ❑ Key parameter
- ❑ $55^\circ \pm 10.6^\circ$ (Vialle JBJS 2005)

Sagittal alignment and growth

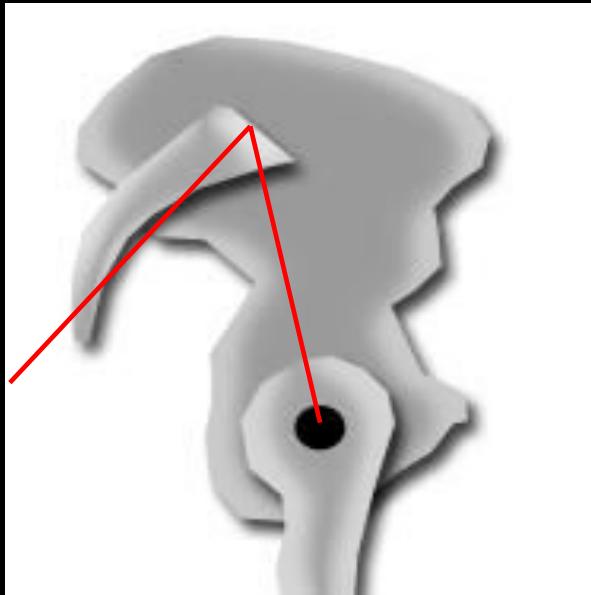
- ☒ PI ↑ 4 – 18 yrs
- ☒ PT; LL ↑ with age; position dependant
- ☒ SS achieved when walking starts



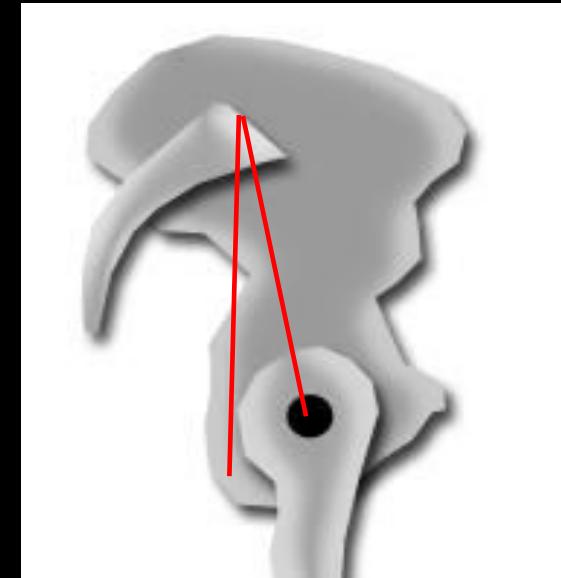


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Normal Sagittal Alignment: The Pelvis



Pelvic Incidence (PI, 40-65°)

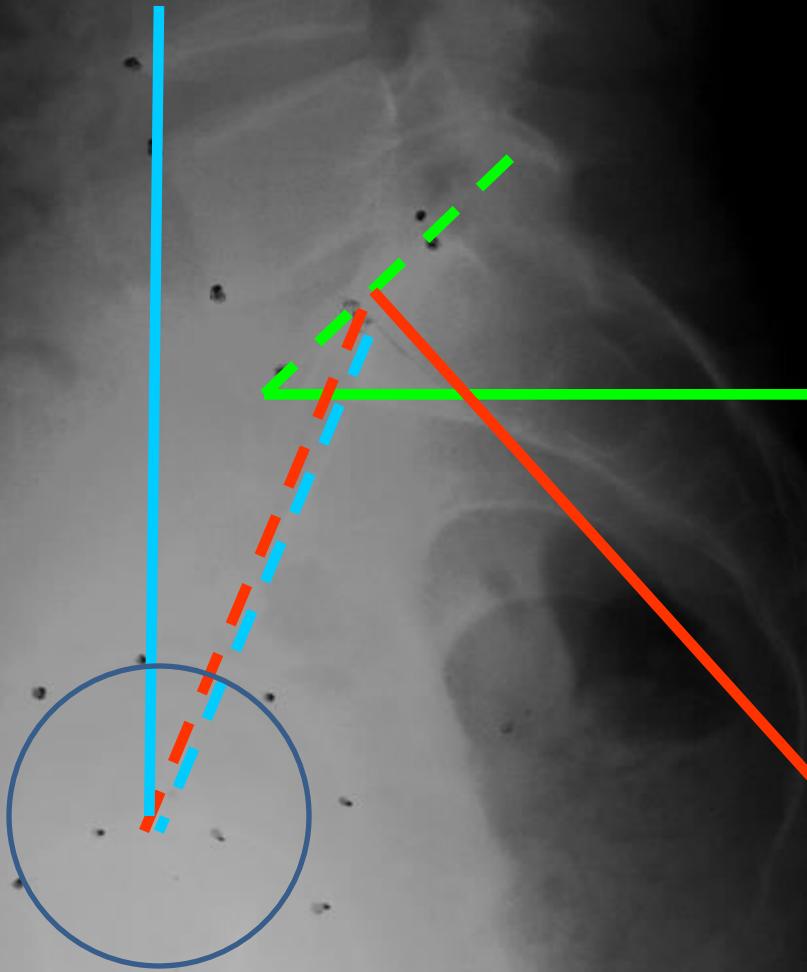
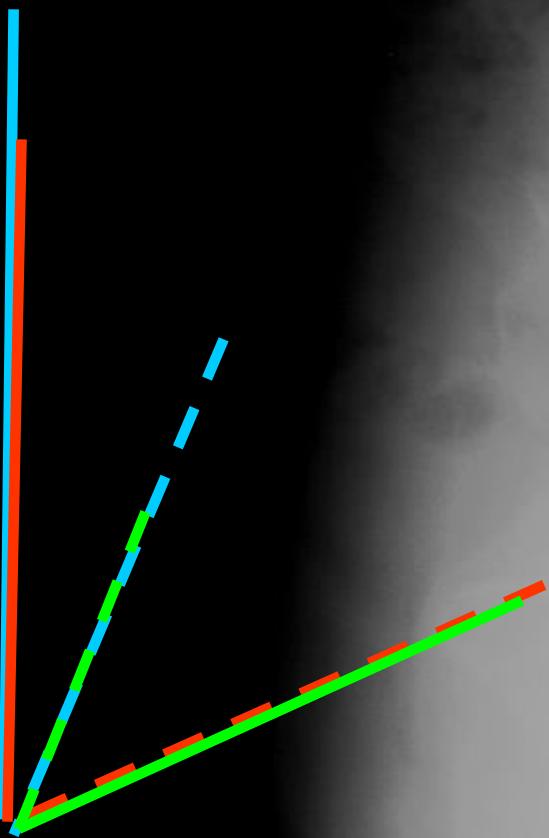


Pelvic Tilt (PT, 10-25°)

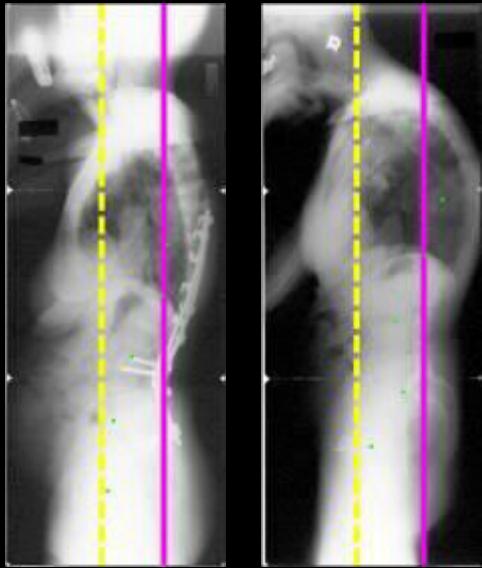
Morphologic Parameter

Compensatory Parameter

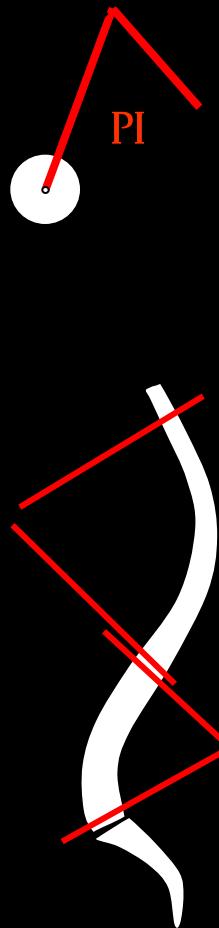

$$PI = PT + SS$$



Predictive model construction

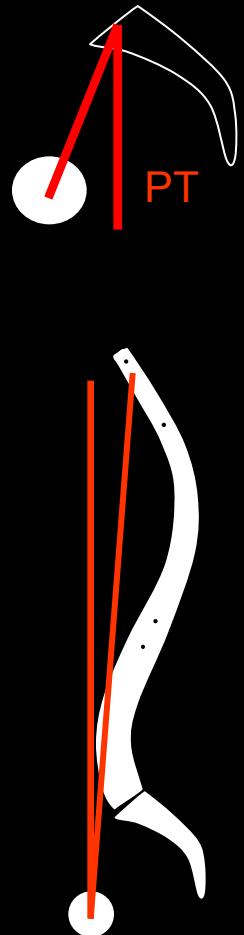


168 Adult with spinal Deformity
36 inch free standing xrays
Spineview® Analysis



Regional Curves

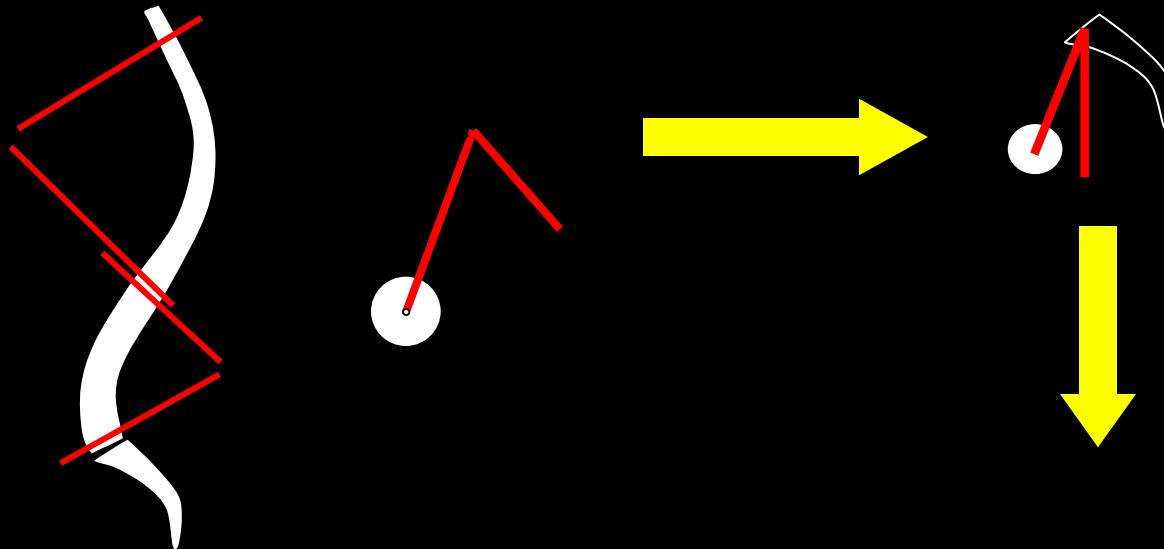
Multi-Linear Model



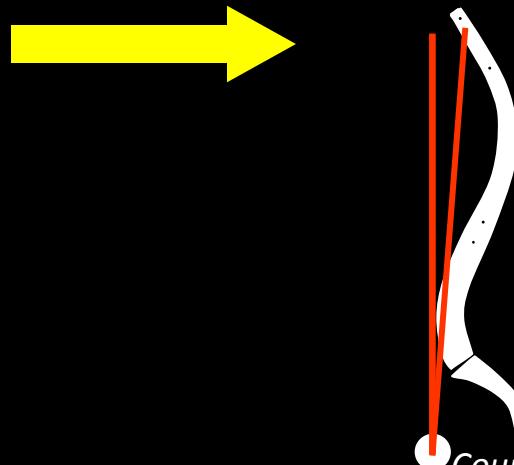
T1 Sagittal Tilt

Courtesy Frank Schwab

Multi-Linear Regression Analysis



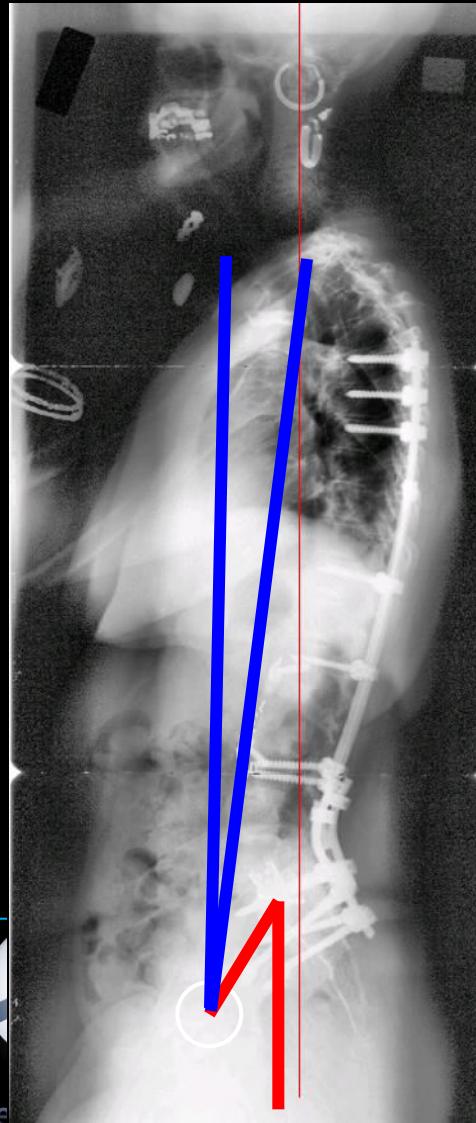
Pelvic incidence +
Maximal lordosis +
Maximal kyphosis



Predicted
Pelvic Tilt
 $r=0.93$,
std error = 4.7°

Predicted
T1 Sagittal Tilt
 $r=0.81$
std error = 3°

Sagittal alignment prediction



Pelvic Tilt

Mean error 4.6°

SD 3.6°

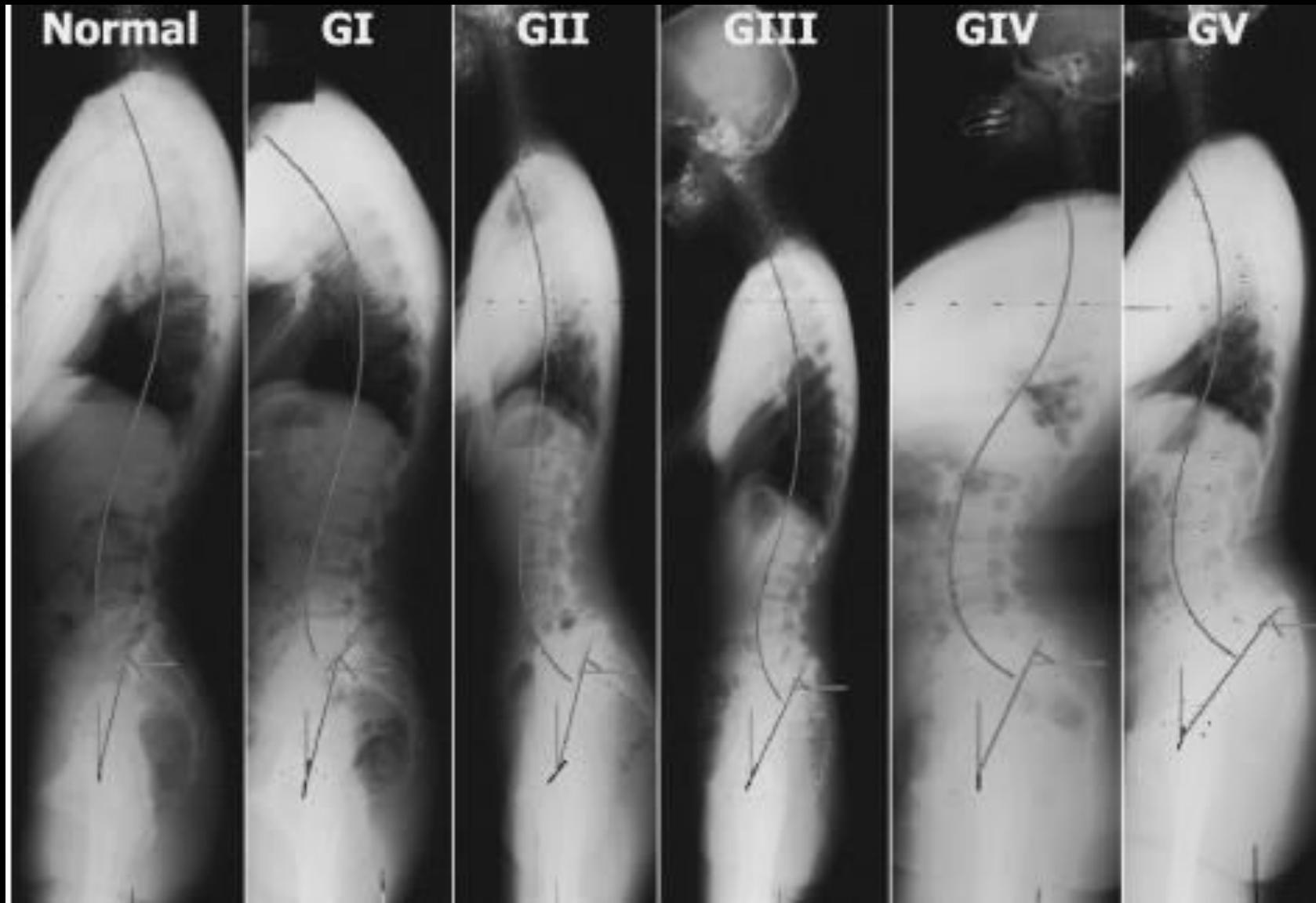
T1 sagittal tilt

mean error 3.5°

SD 2.7°

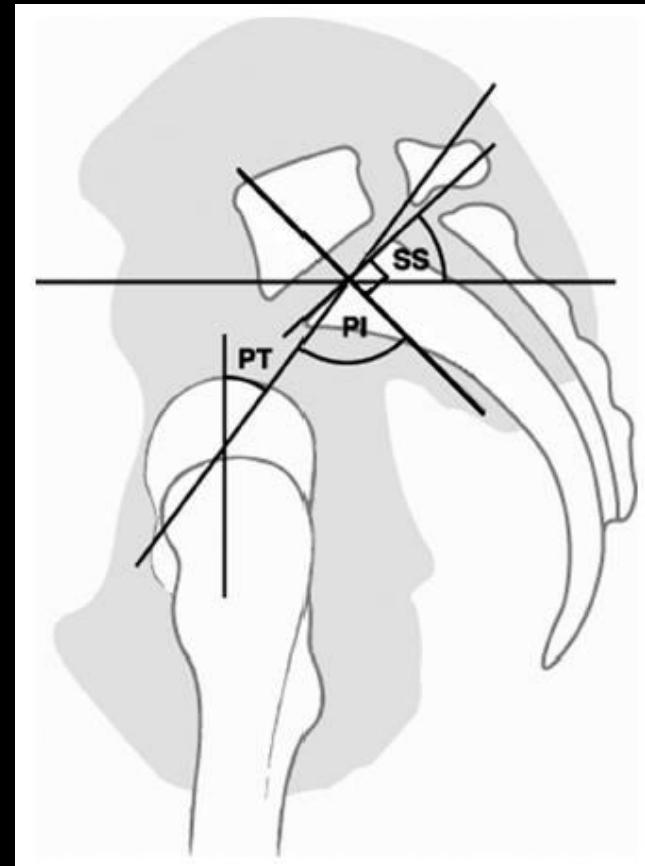
Courtesy Frank Schwab

Spondylolisthesis



Idiopathic scoliosis

- ❑ 53 Lenke 1A; 51 Lenke 5; 50 controls
- ❑ Lenke 1A: ↑ SS ↓ Th Kyphosis
- ❑ Lenke 5: ↑ PT
- ❑ ↑ Pelvic incidence in both groups





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TK 71°

LL 53°

PI 41°

PT 12°

SS 29°

Pathology

- ❑ Pain generators
- ❑ Compensatory mechanisms
- ❑ Mal-alignment patterns

Spino-pelvic pathology patterns

Progressive kyphosis



Gravity line drifts forwards



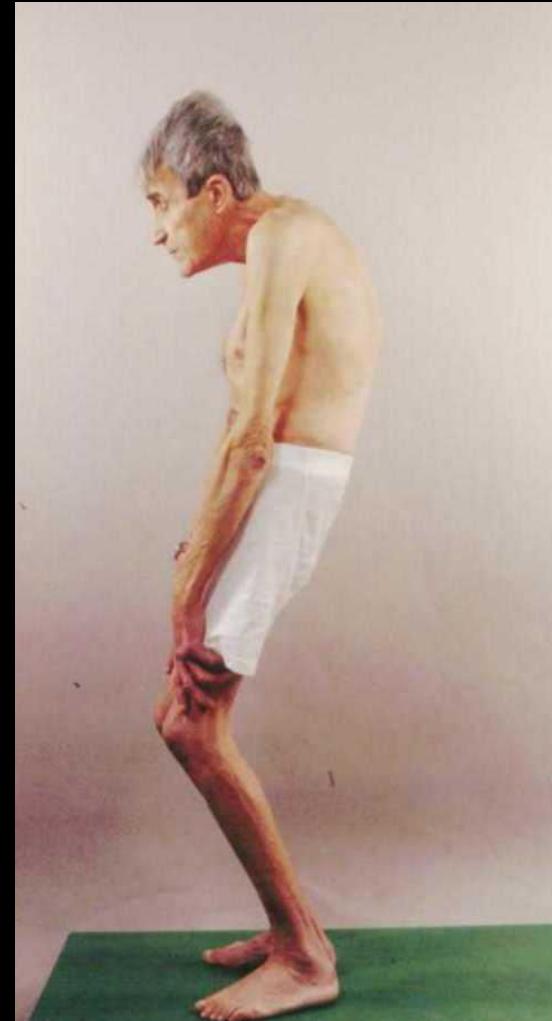
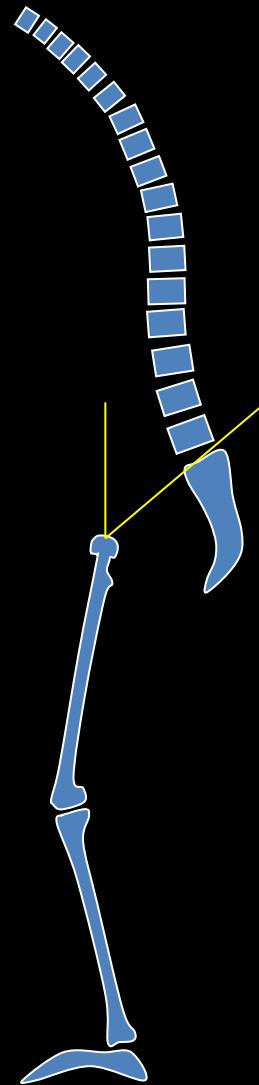
Pelvis rotates backwards



Sacral slope decreases



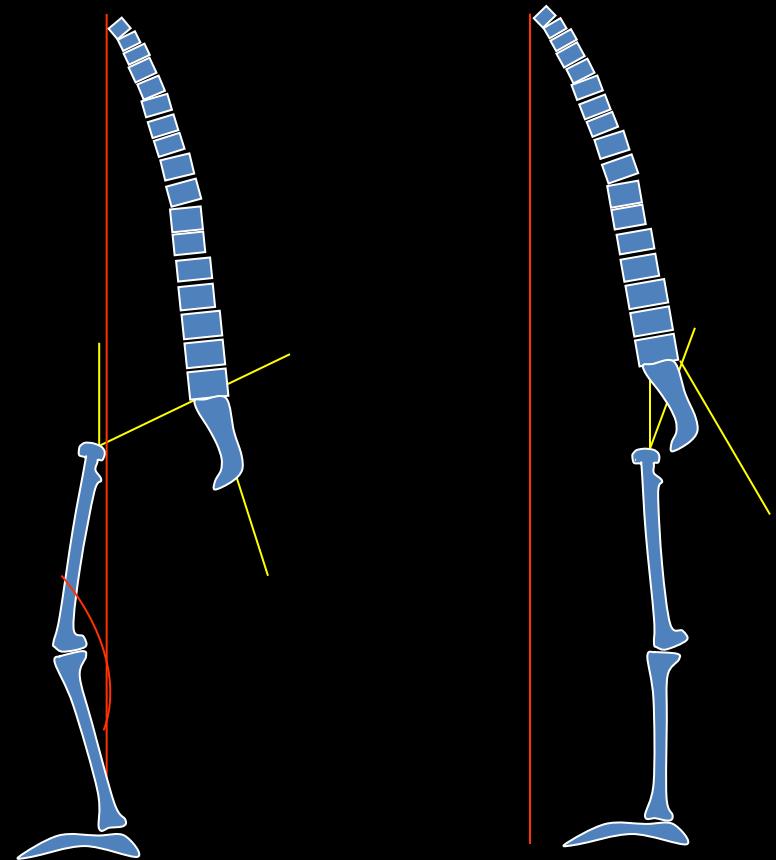
Knee flexion



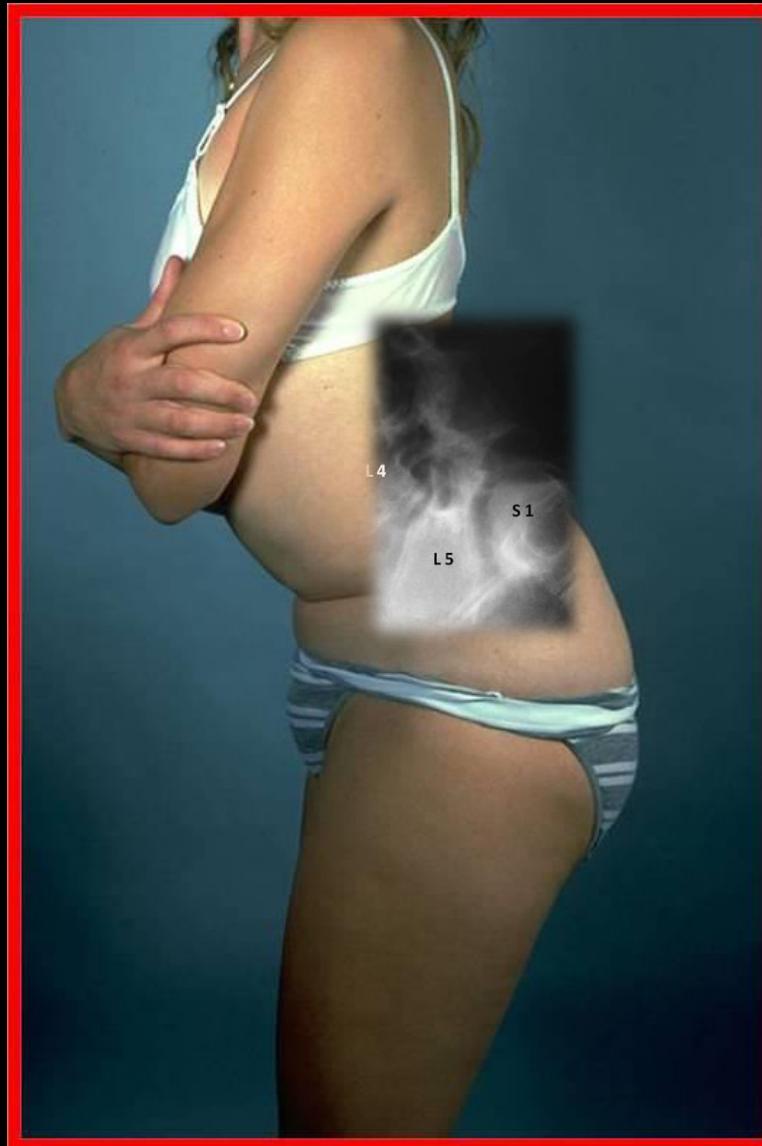
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Spino-pelvic compensation

- ¤ PI regulates PT
- ¤ Higher PI
↓
Better compensation



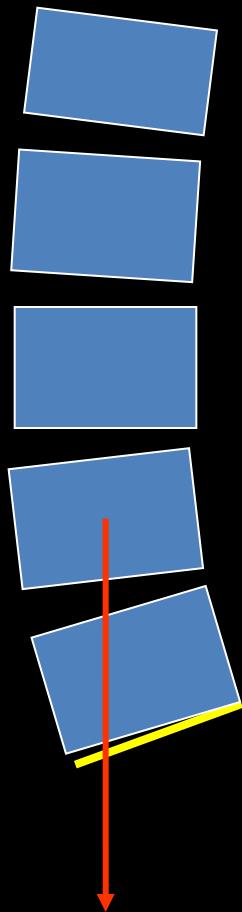
Spondyloptosis



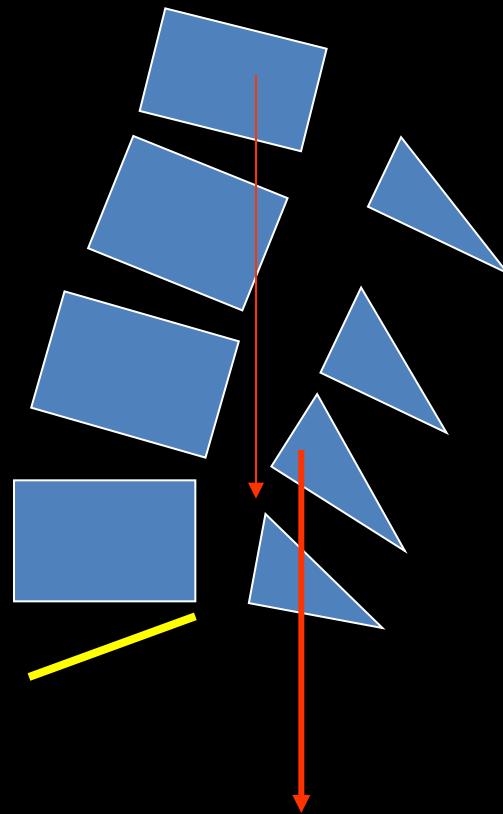
Sagittal profile mal-alignment patterns



Degenerative patterns

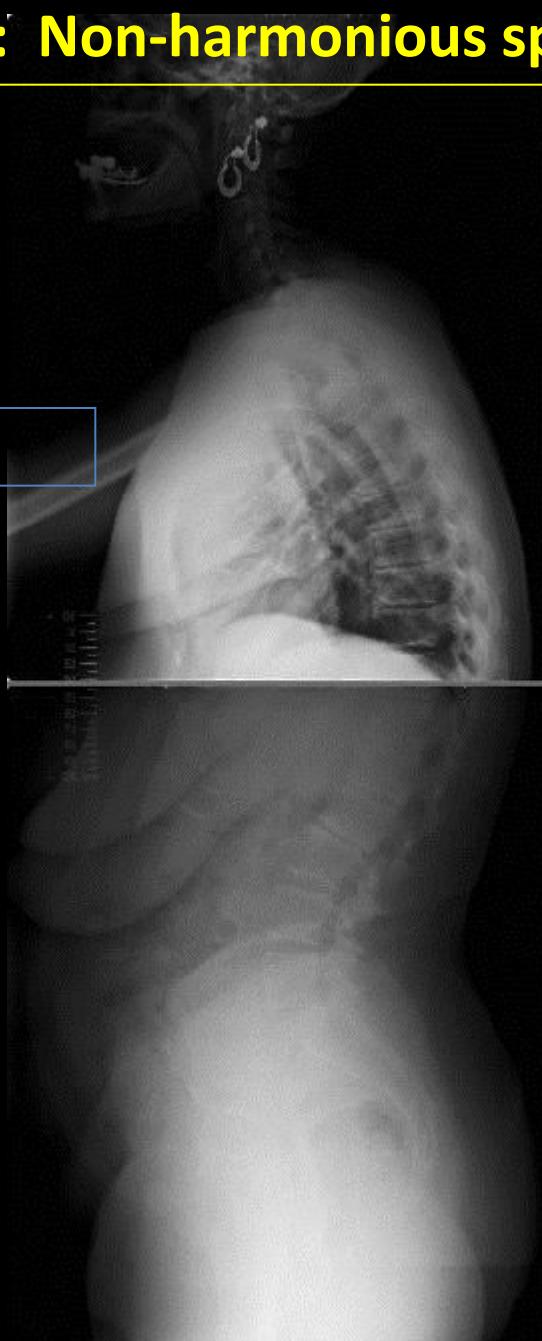
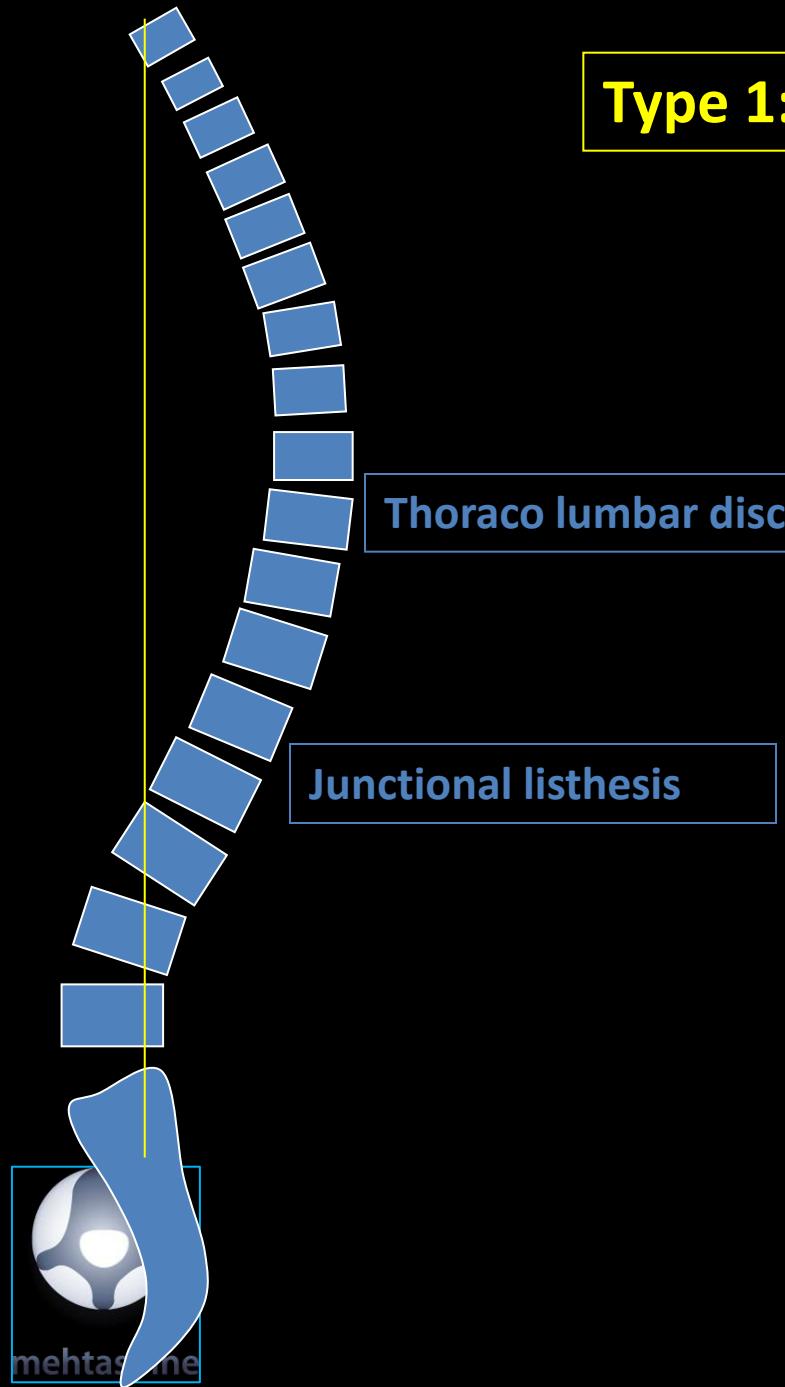


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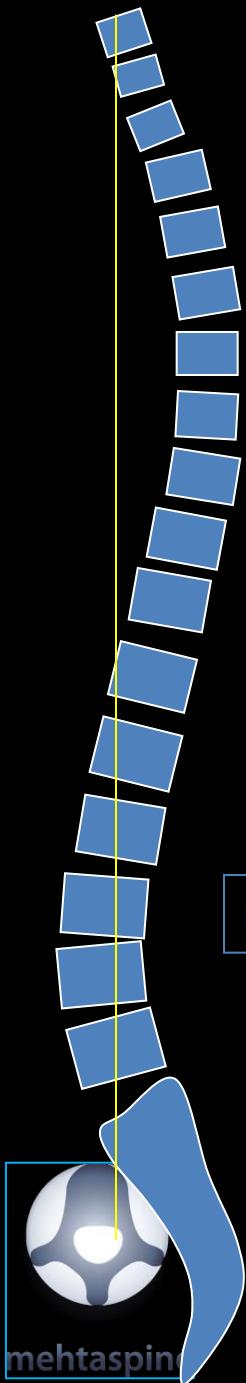
Eurospine 2007
Bruxelles

Type 1: Non-harmonious spine

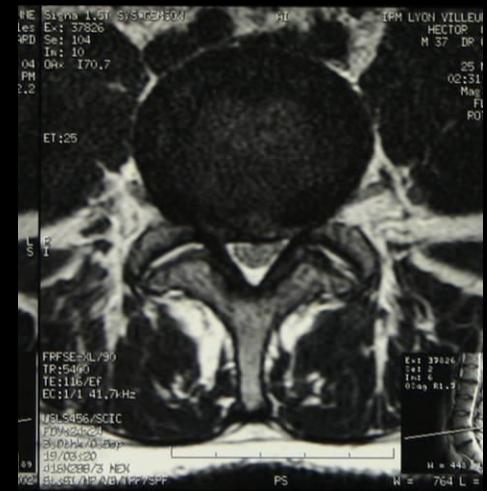


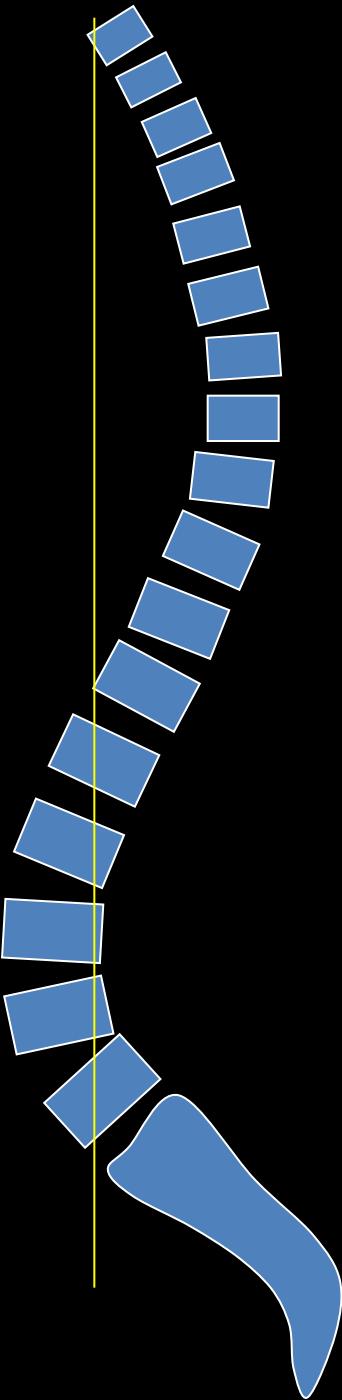
Eurospine 2007
Bruxelles

Type 2: Harmonious but Flat Back

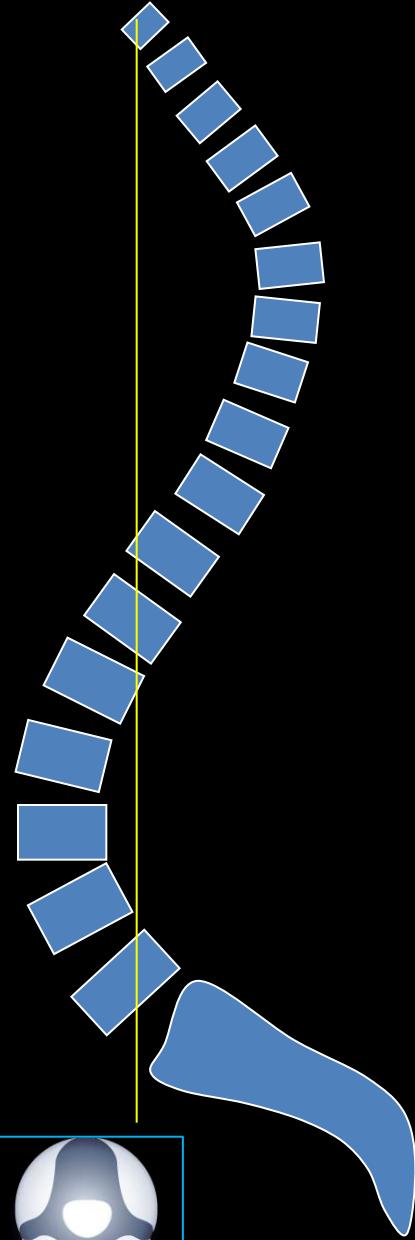


Early disc degeneration





**Type 3: The most harmonious
("probably a good back")**



Type 4: Harmonious but hyper-curved.

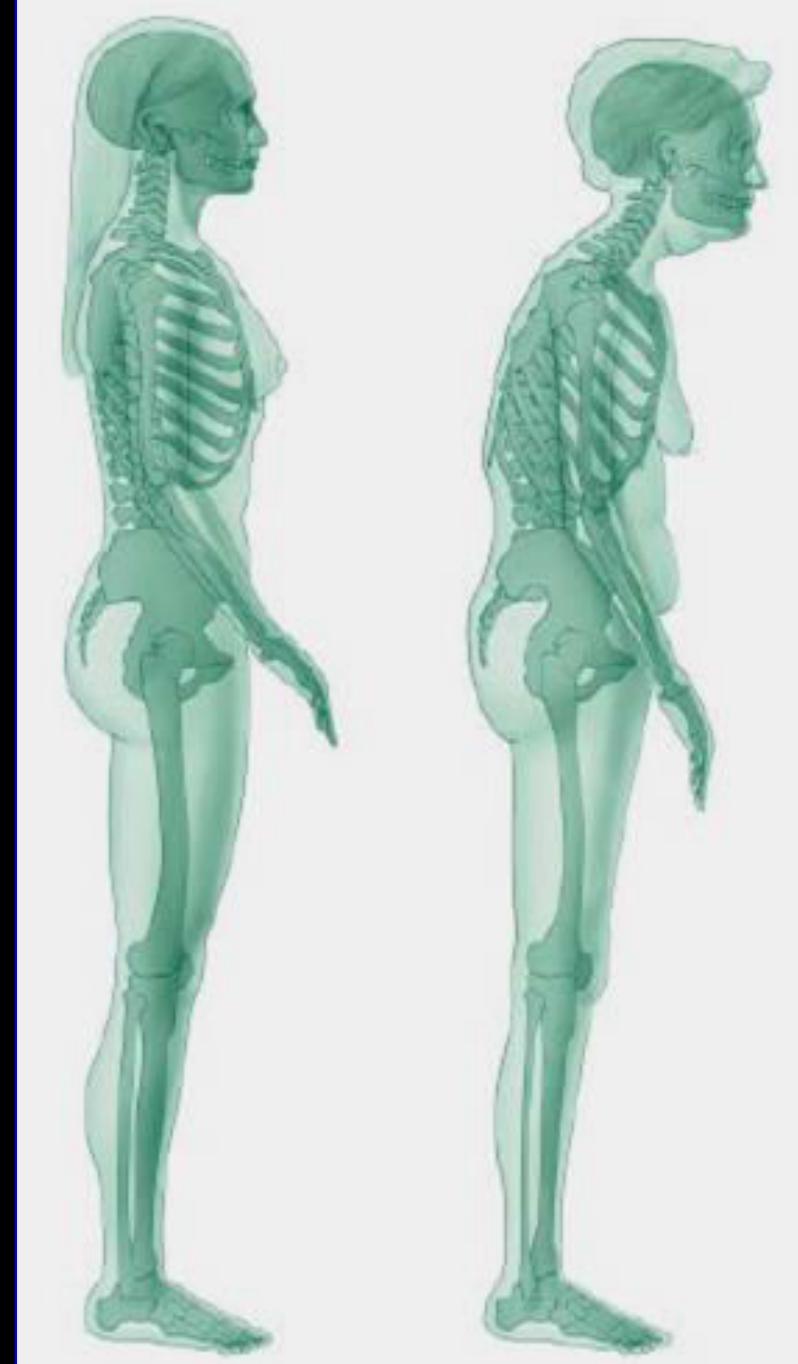
- When young: very strong
 - High PI
 - Good lordosis
- With aging
 - will lose lordosis
 - pelvic tilt increases to compensate for anterior imbalance



Lumbar stenosis + spondylolisthesis

Spectrum of pathology

- ☒ Discs
- ☒ Facet joints
- ☒ Stenosis
- ☒ Deformity





59 / F

AP Cobb 26°

CSL 7 cm

Pelvic:

PI 55°

SS 20°

PT 35°

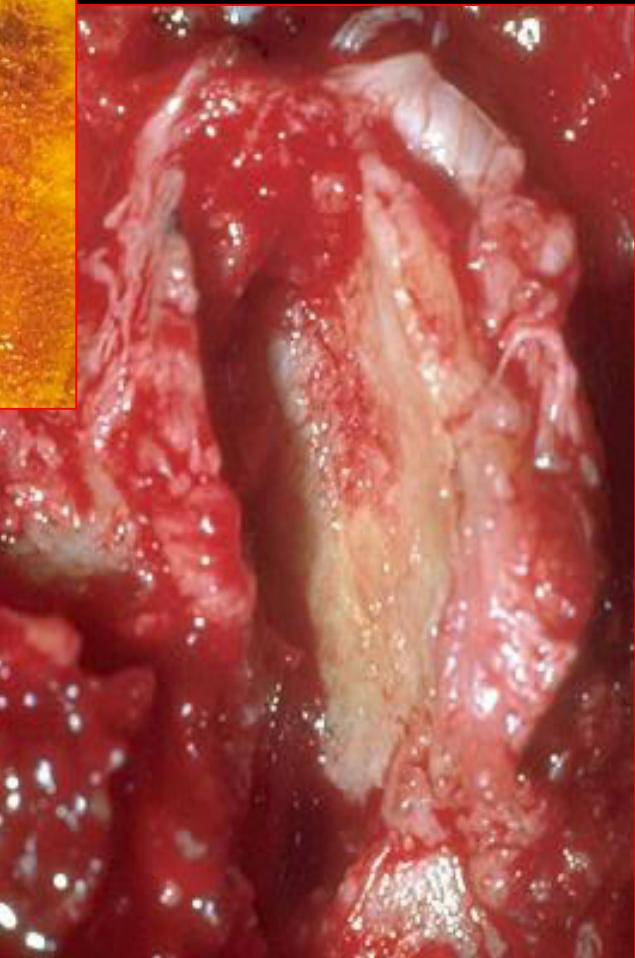
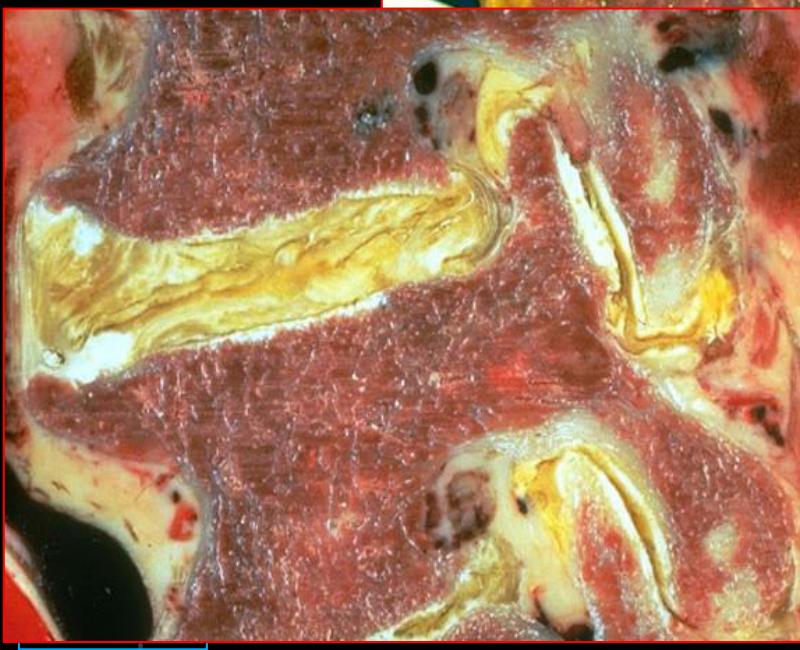
LL 44°

TL 66°

TK 56°

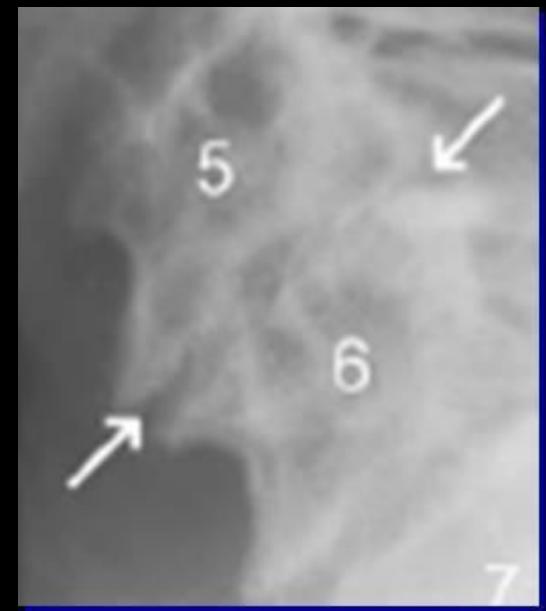
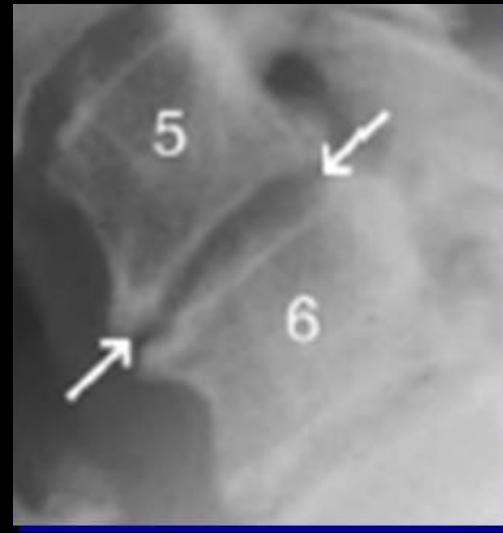
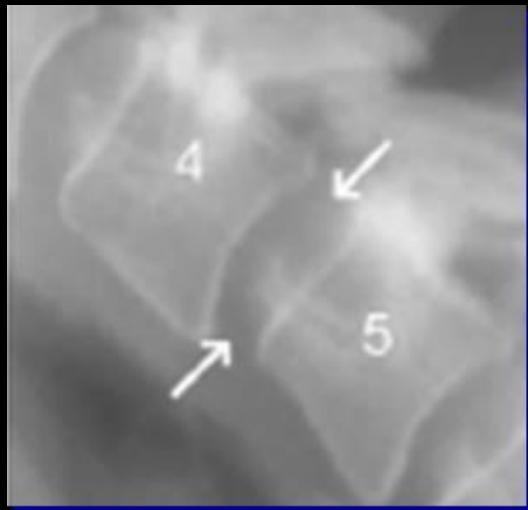
SVA 11 cm

Pain generators



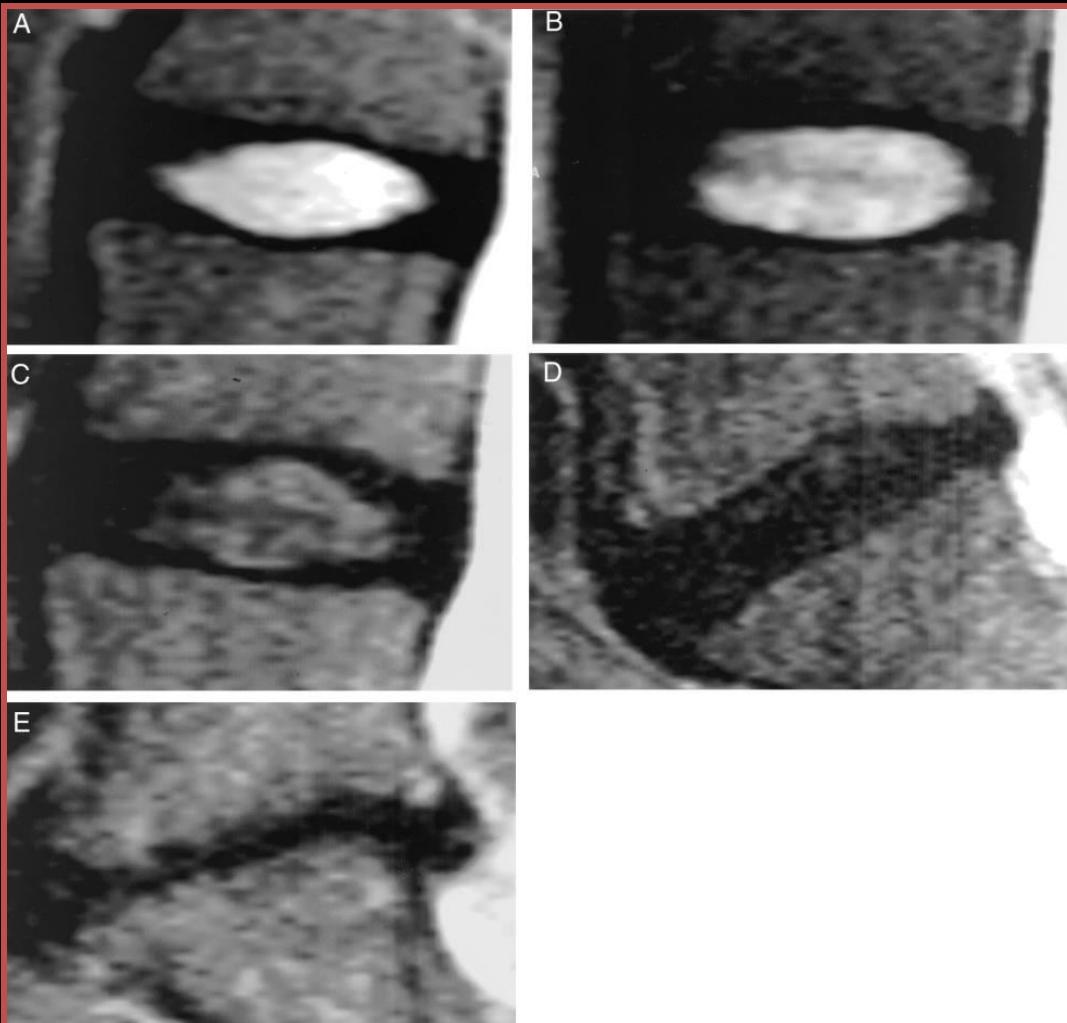
Disc related changes affecting the sagittal profile

Progressive loss of disc height



Magnetic Resonance Classification of Lumbar Intervertebral Disc Degeneration

Christian W. A. Pfirrmann, MD,* Alexander Metzdorf, MD,† Marco Zanetti, MD,* Juerg Hodler, MD,* and Norbert Boos, MDT



- ☒ Disc signal
- ☒ Disc height
- ☒ Nuclear - annular transition



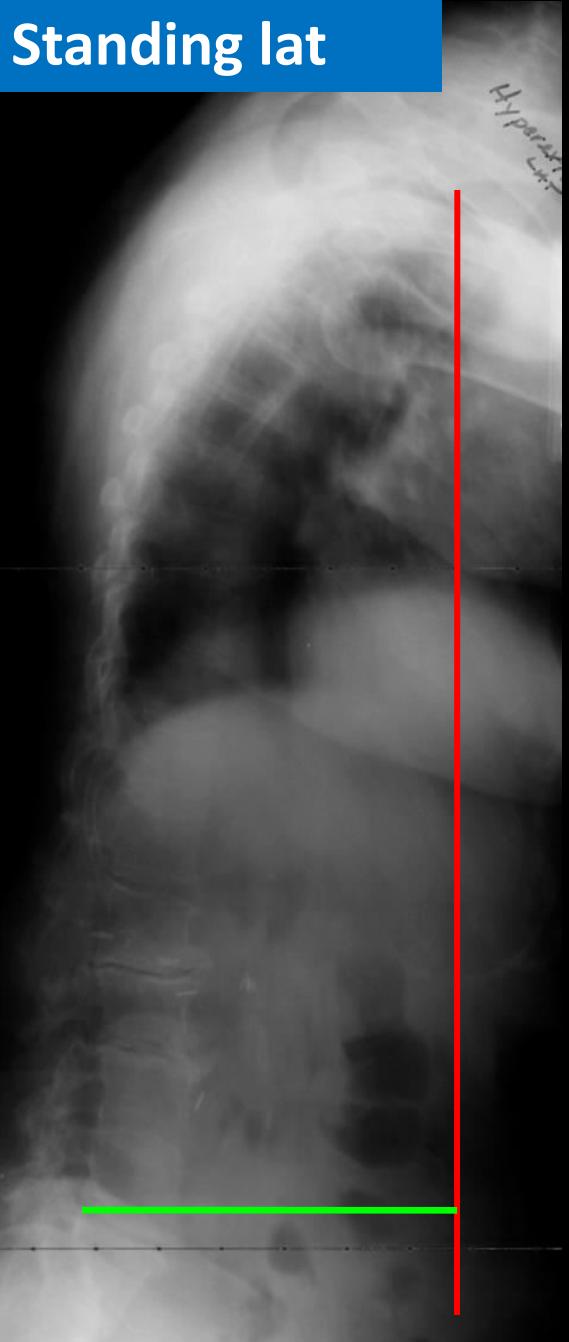
15 9:45AM



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Standing lat



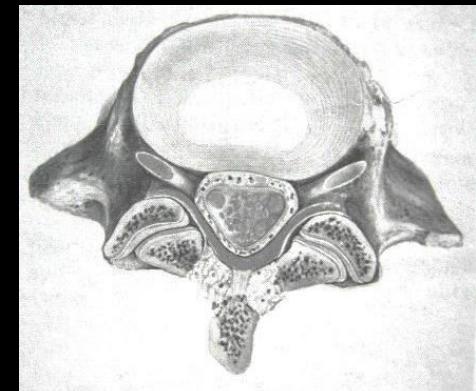
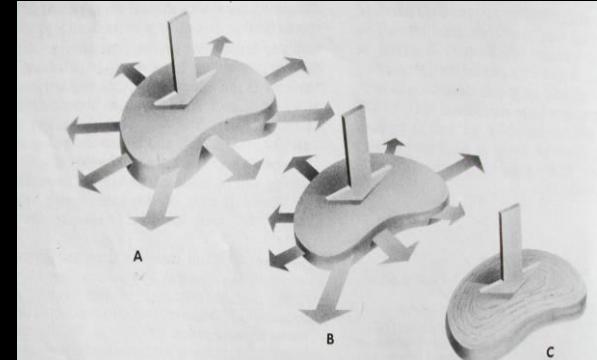
Hyperext lat



mehtaspi

Facet joint related changes affecting the sagittal profile

- ☒ Di-artrodiyal joints
- ☒ Degenerative changes under-recognised
- ☒ Relevance in pathology and surgical management



- *resistance of the annulus to torque is reduced*
- *increased mechanical demand on posterior elements*

Krismer et al. Spine 1996

Latham et al. Clin Biomech 1994

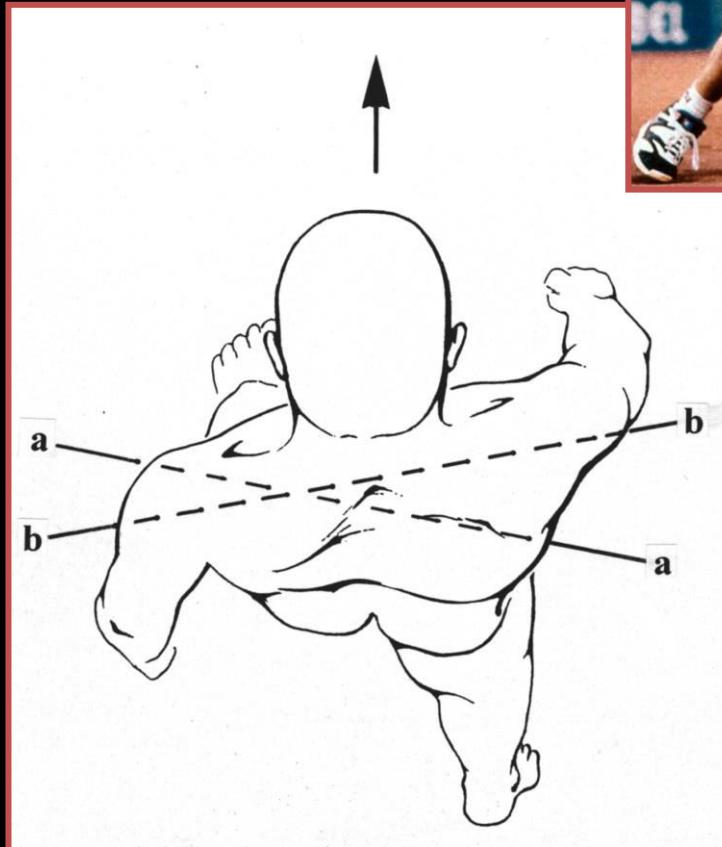
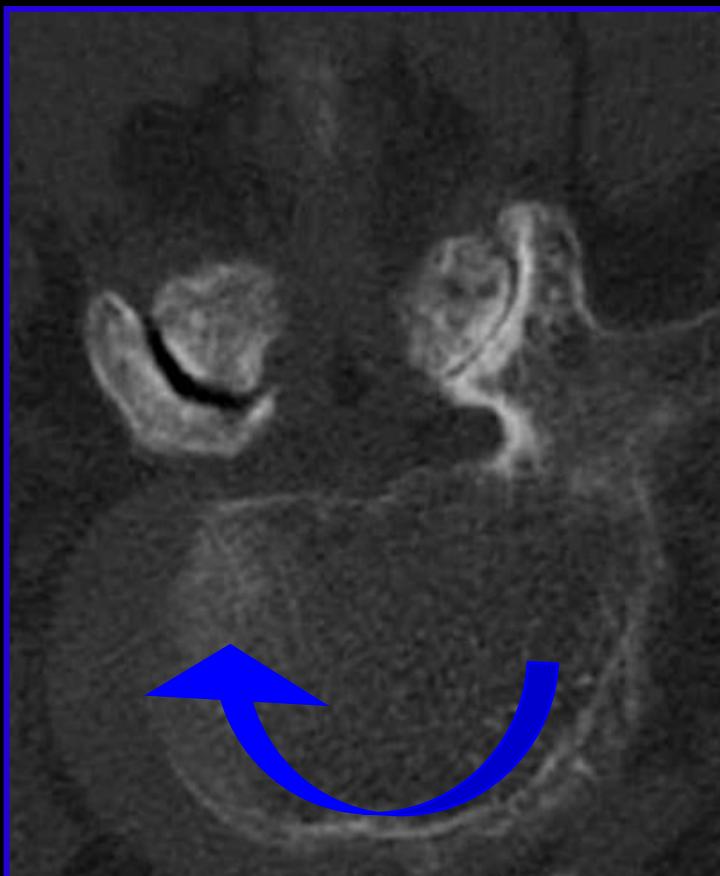
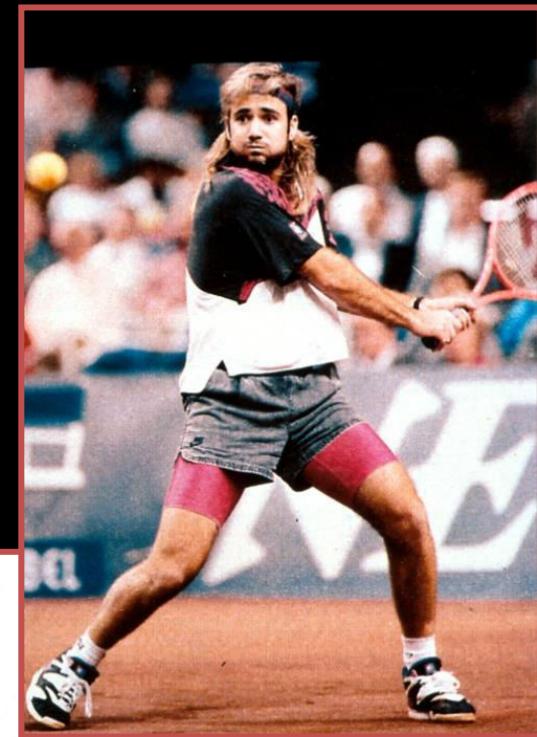
Mimura et al. Spine 1994



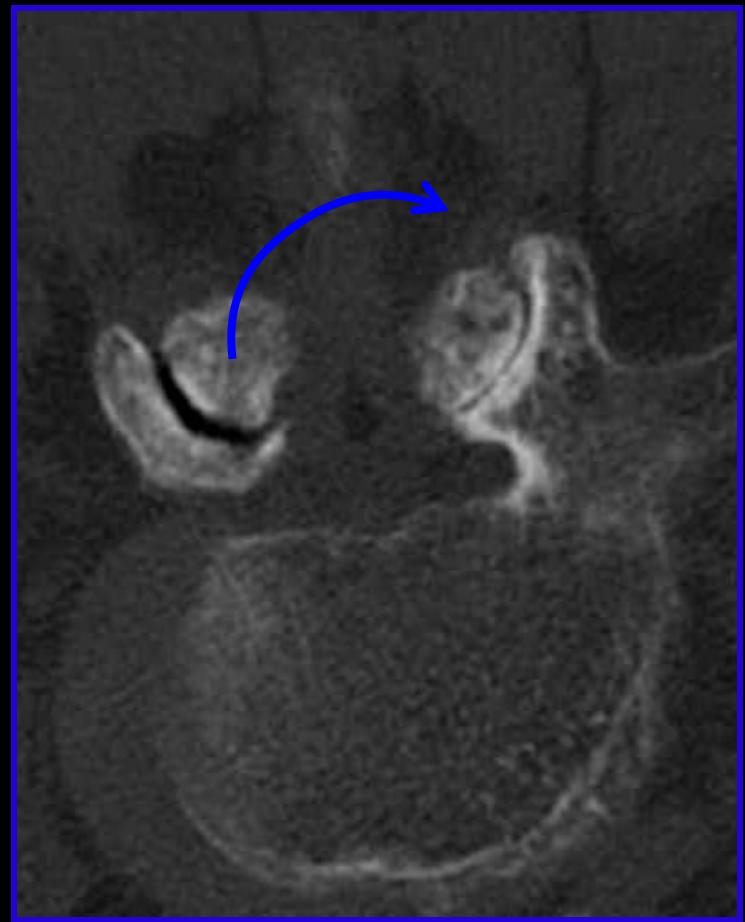
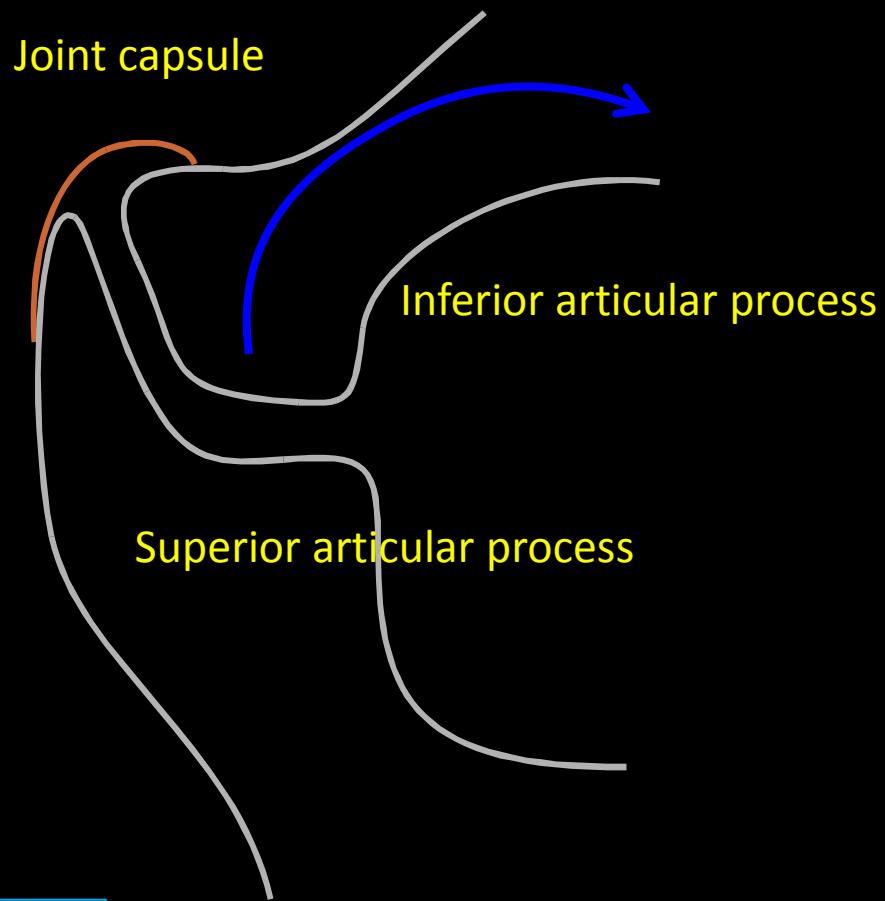
Courtesy Bronek Boszczyk

Degeneration of the lumbar motion segment:

- ❑ begins with disc degeneration
- ❑ leads to axial rotational instability

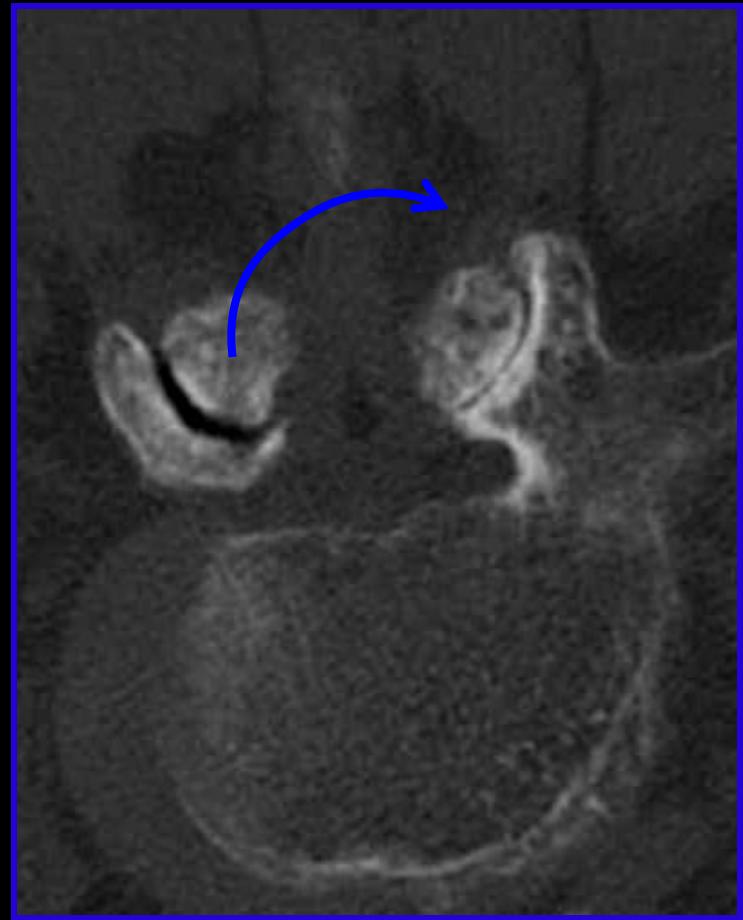
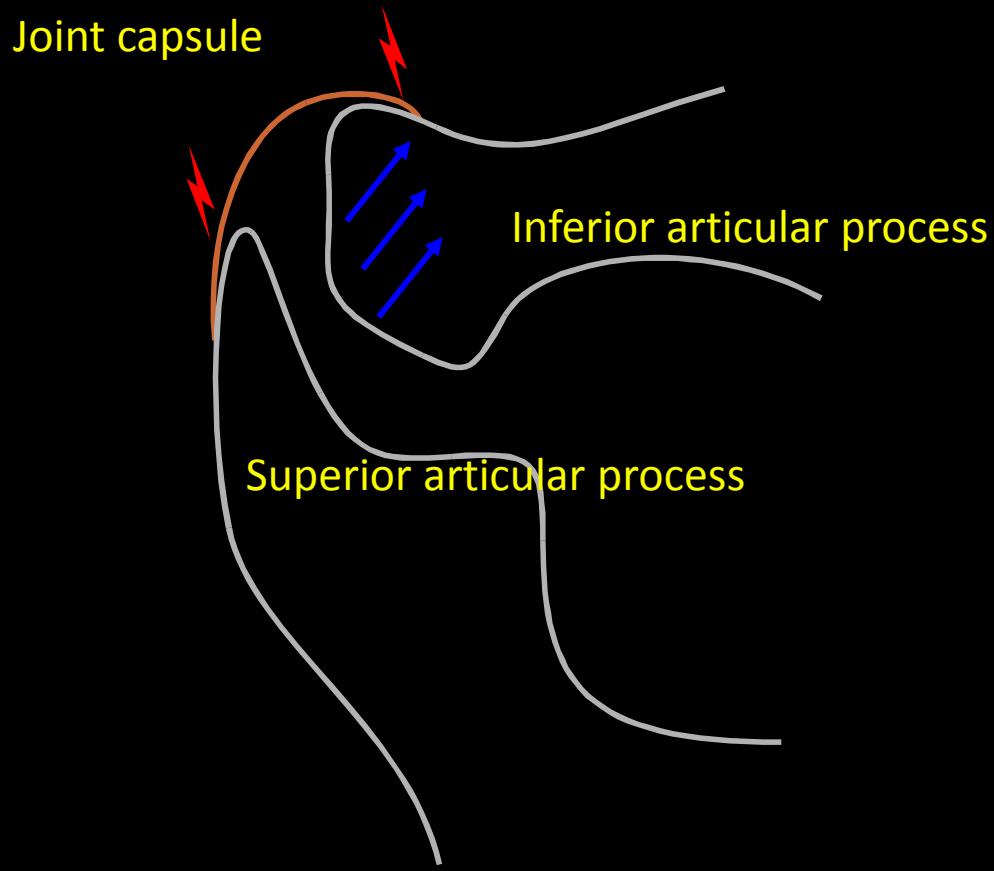


Courtesy Bronek Boszczyk

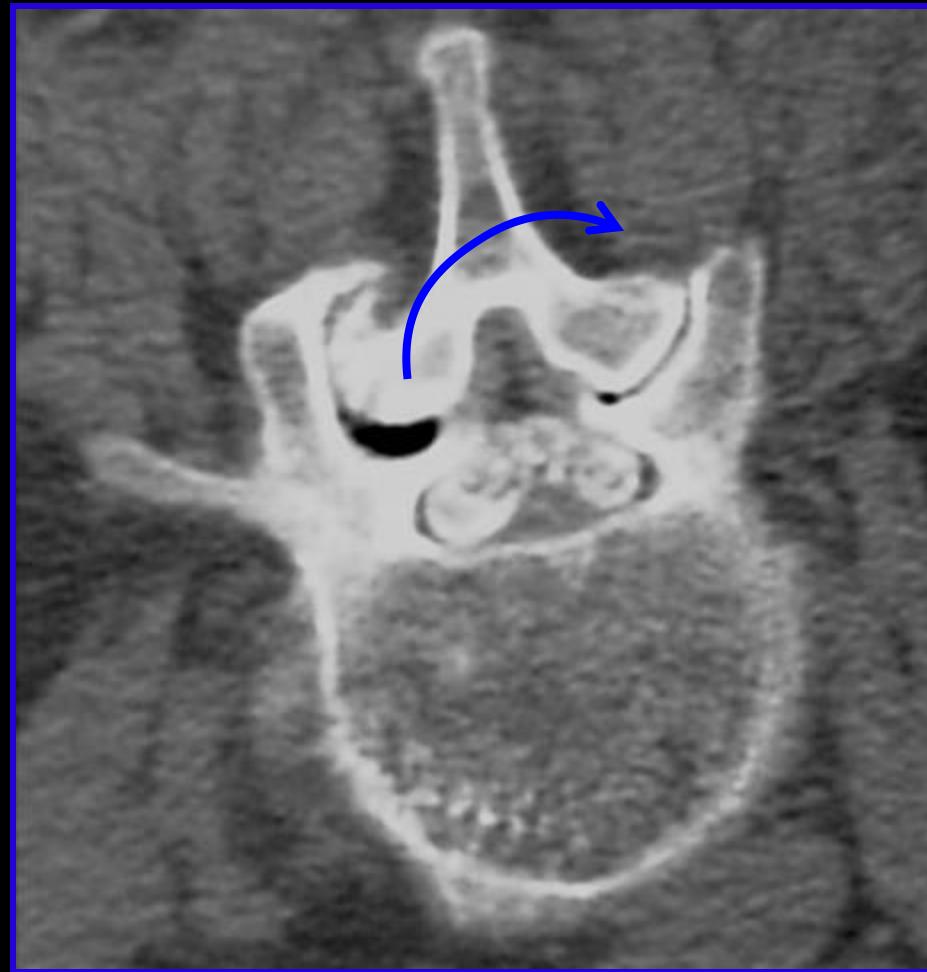
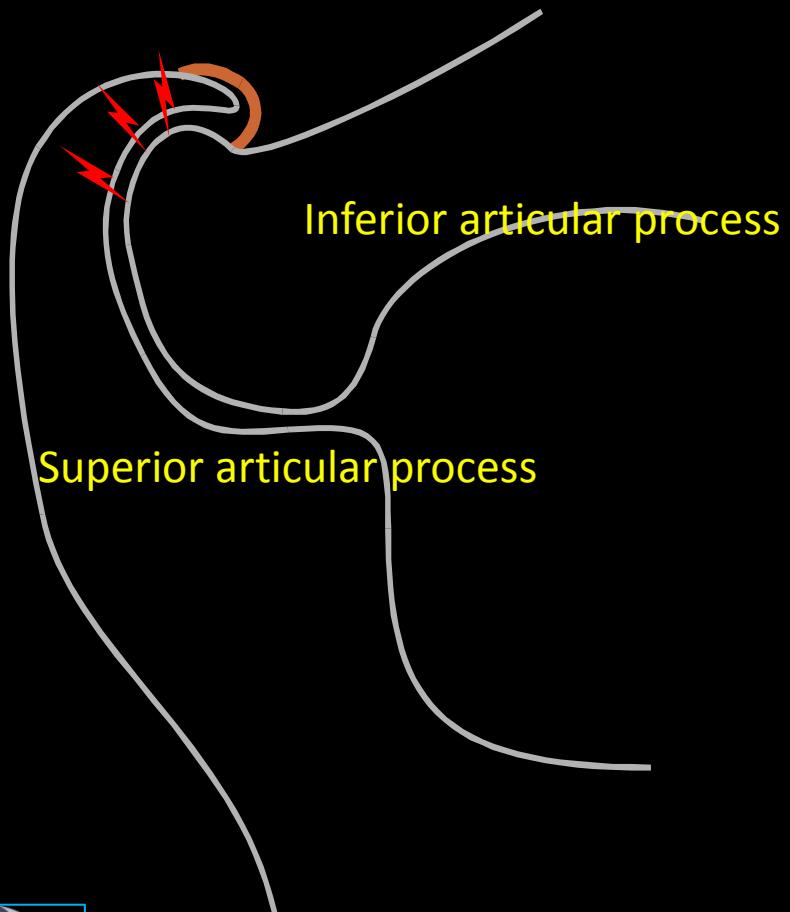


Increased axial rotation in disc degeneration

Courtesy Bronek Boszczyk

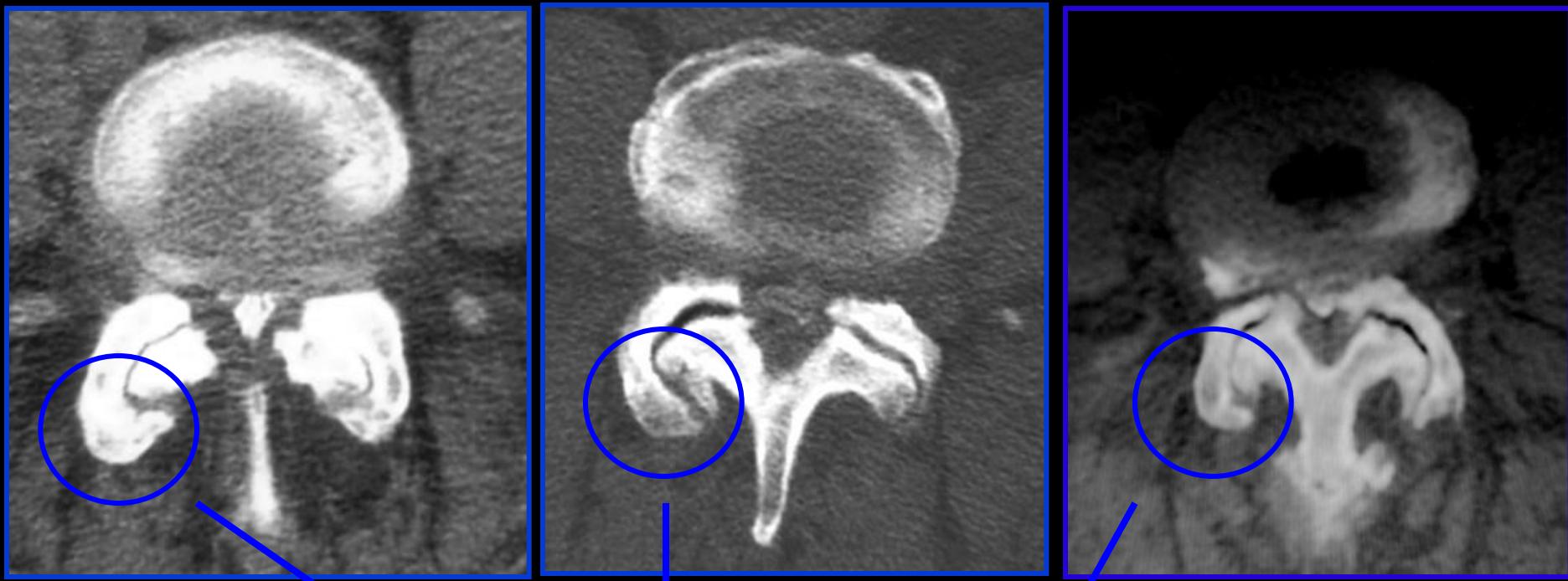


Increased axial rotation in disc degeneration results in shear of the enthesis and direct pressure upon the capsule



Encompassing joint formation develops through direct contact of enthesophytes in advanced degeneration

Courtesy Bronek Boszczyk



Annular contraction in advanced disc degeneration and joint remodelling result in restabilisation of the motion segment



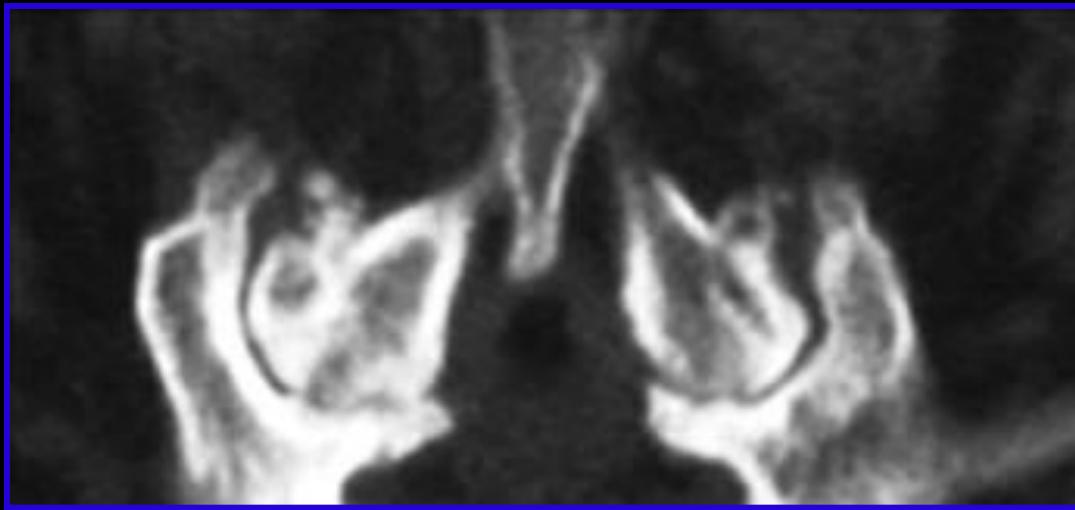
Kirkaldy-Willis & Farfan Clin Orthop 1982

Courtesy Bronek Boszczyk



Spontaneous fusion as final stage of restabilisation

Annular contraction in advanced disc degeneration and joint remodelling result in restabilisation of the motion segment



In contrast to other joints, reactions of the joint capsule / enthesis are seen before permanent cartilage damage

Early restoration of disc biomechanics may prevent progression to stage of permanent damage

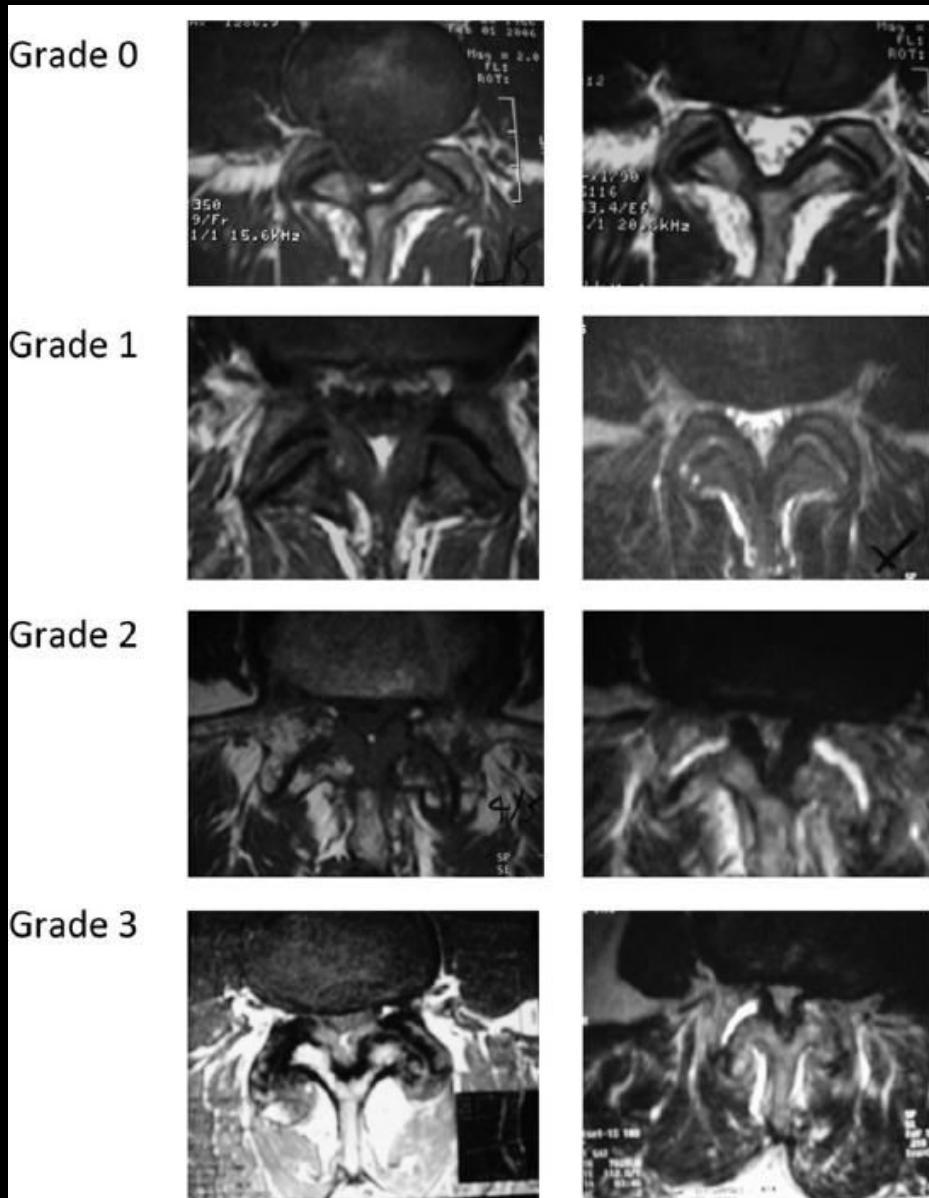
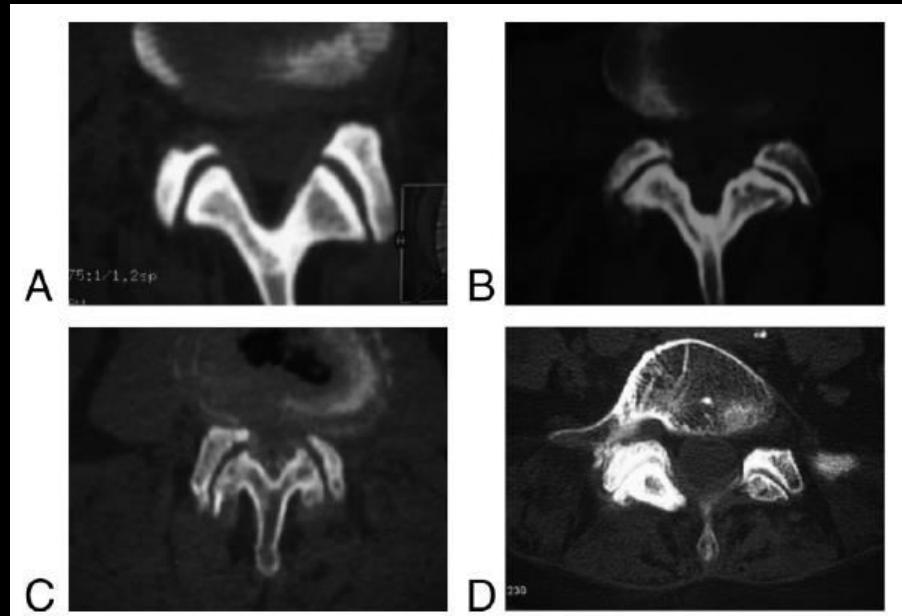


Vernon-Roberts & Pirie Rheumatol Rehabil 1977
Fujiwara et al. Eur Spine J 1999

Courtesy Bronek Boszczyk

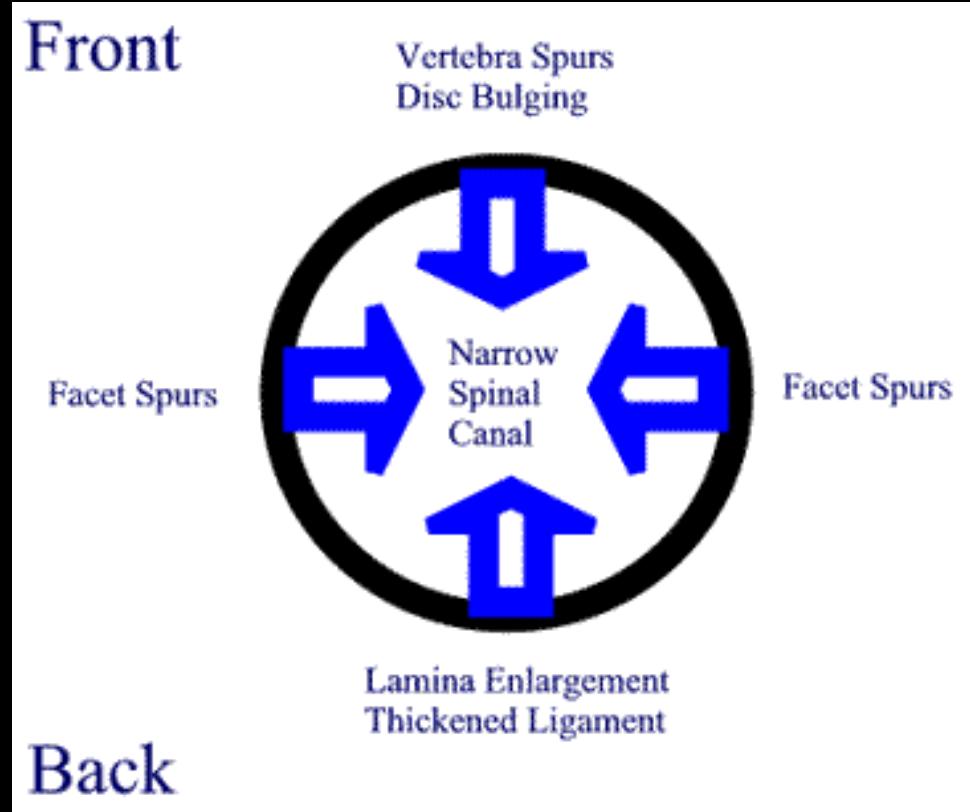
Facet joint degeneration

- ☒ Joint width
- ☒ Articular erosions
- ☒ Sub-chondral sclerosis
- ☒ Osteophytes
- ☒ Tropsim
- ☒ Angle

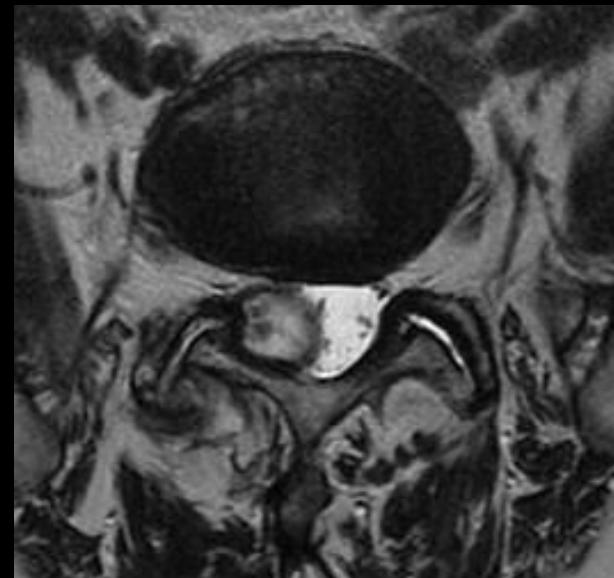
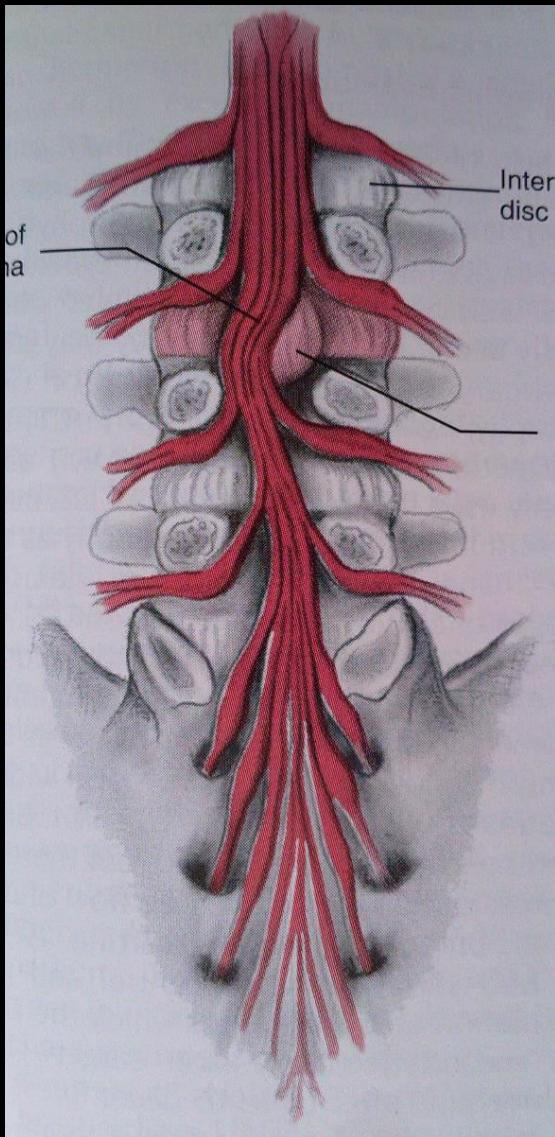


Stenosis

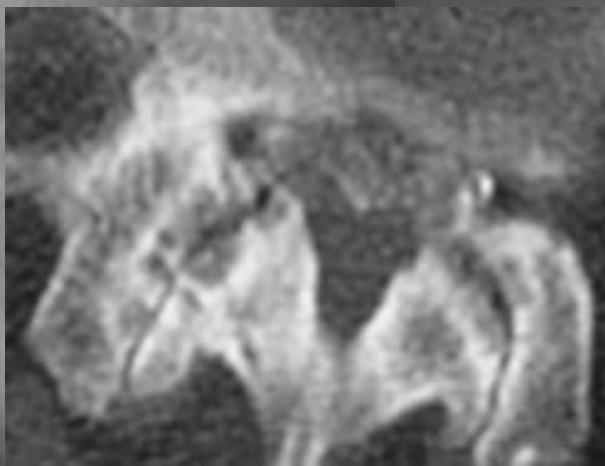
- ¤ Classical posture, stance
- ¤ Spinal claudication
- ¤ Constitutionally narrowing



Lumbar canal stenosis



A
82
O



Genesis of the deformity





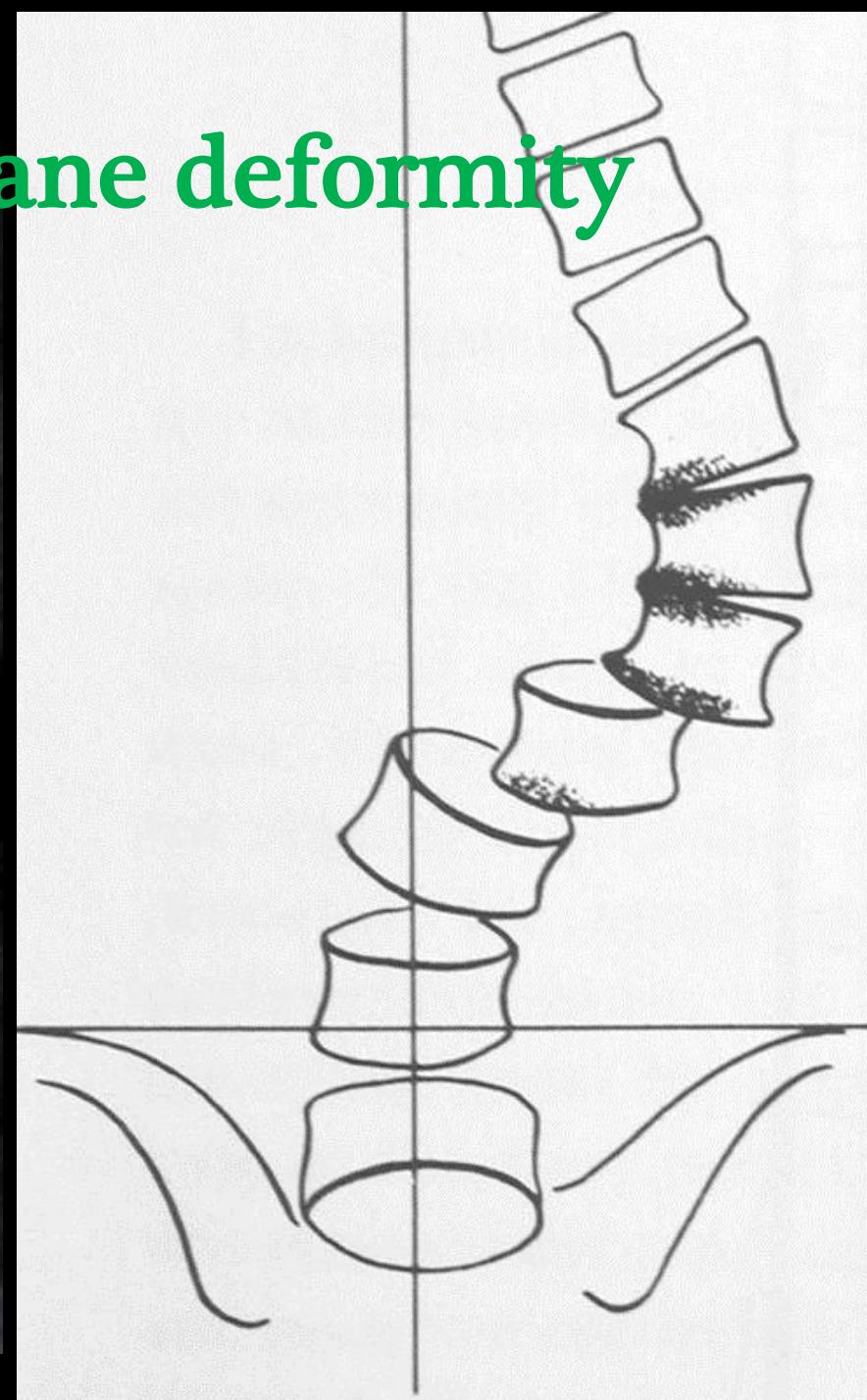
Idiopática

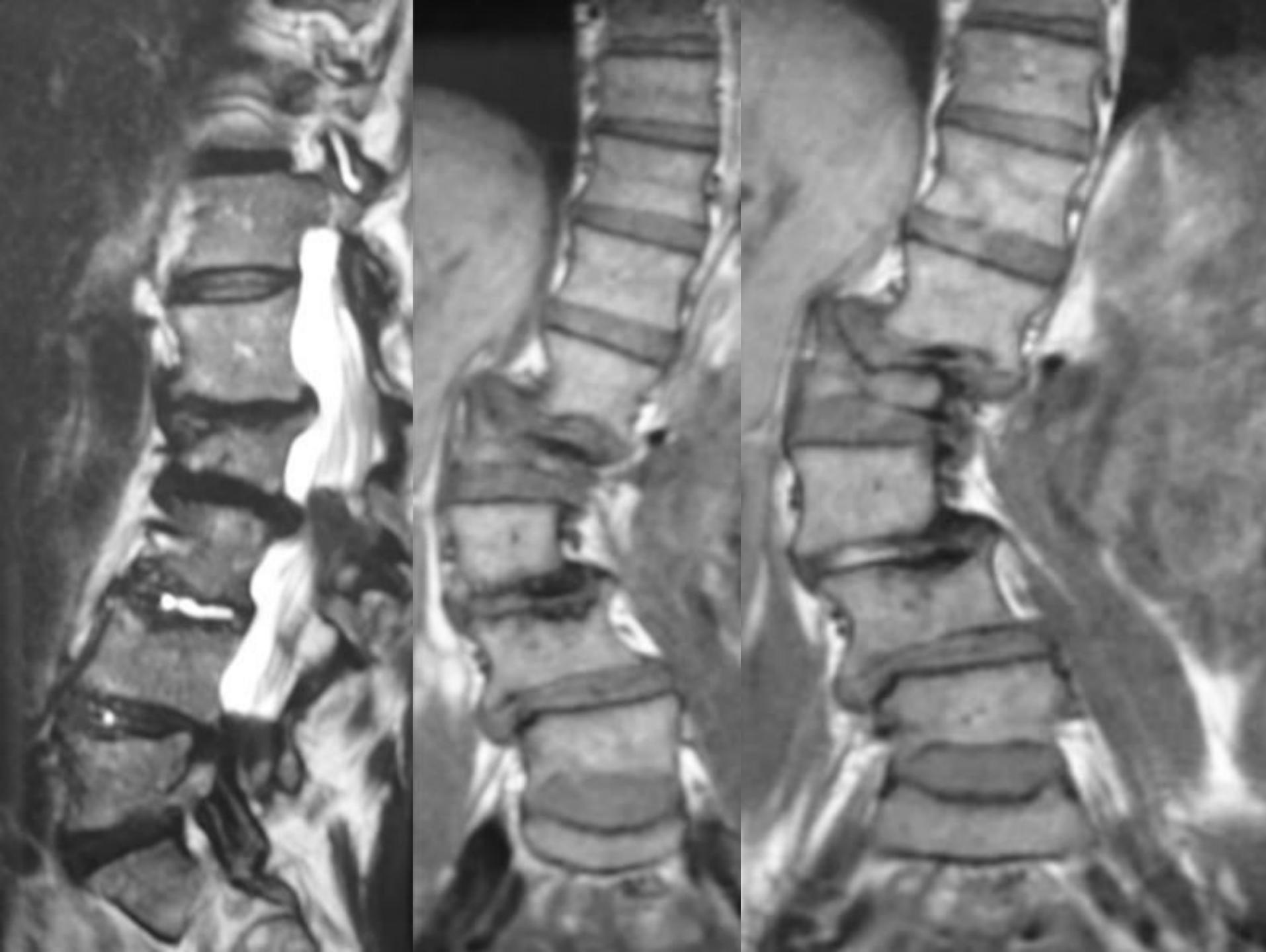


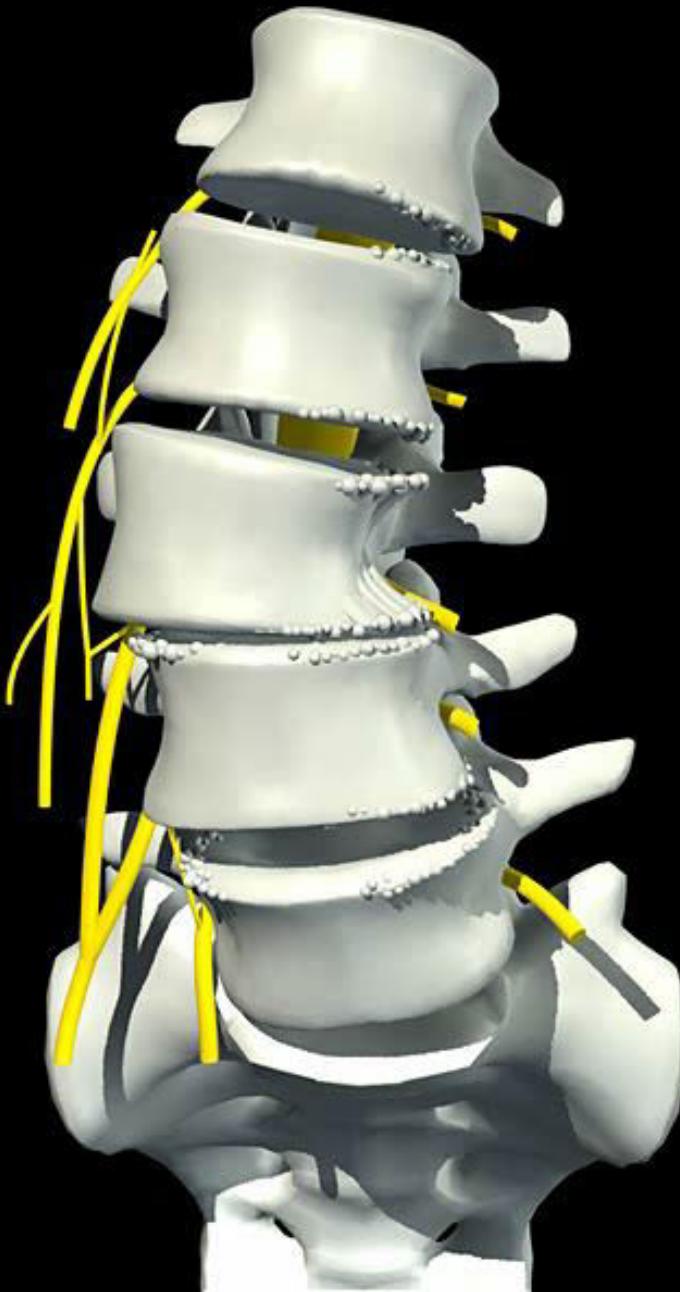
mehtaspine

Erect

The coronal plane deformity







mehtas

SRS-Schwab Adult Spinal Deformity Classification: A Validation Study

Curve types

T Thoracic only

with lumbar curve < 30°

L TL / Lumbar only

with thoracic curve <30°

D Double Curve

with at least one T and one
TL/L, both > 30°

S Sagittal Deformity

for coronal curve <30° AND
moderate to severe modifier(s)

Modifiers

PI minus LL

A : within 10°

B : moderate 10-20°

C : marked >20°

Pelvic Tilt

L : PT<20°

M : PT 20-30°

H : PT>30°

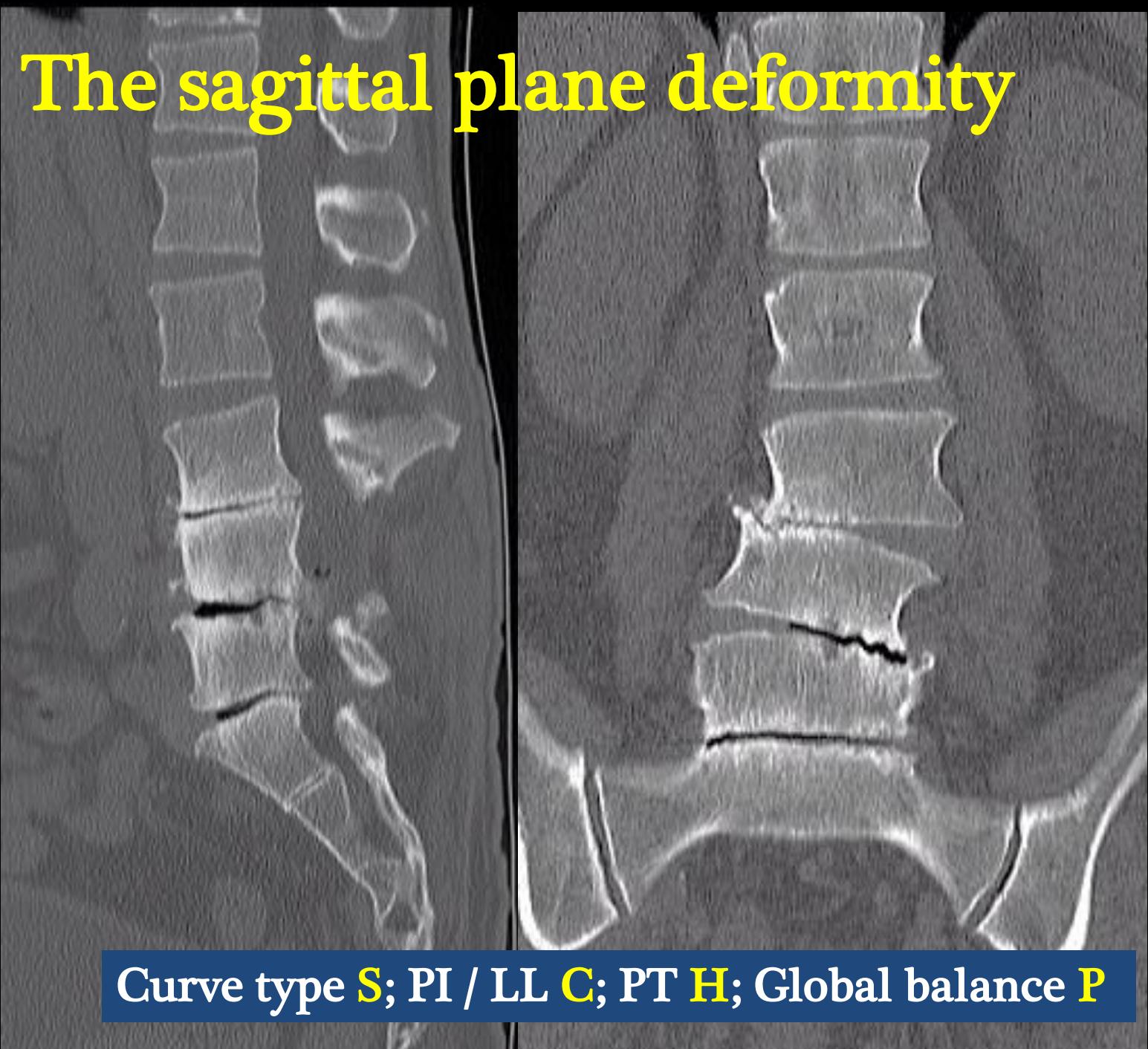
Global Balance

N : SVA < 4cm

P : SVA 4 to 9.5cm

VP : SVA > 9.5cm

The sagittal plane deformity



Clinical effects of plumb-line shifts

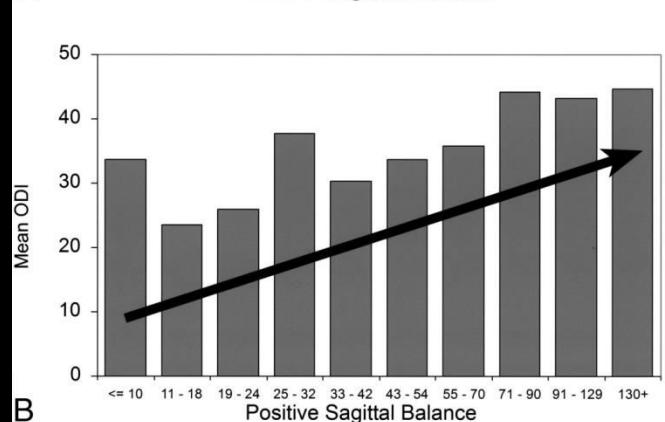
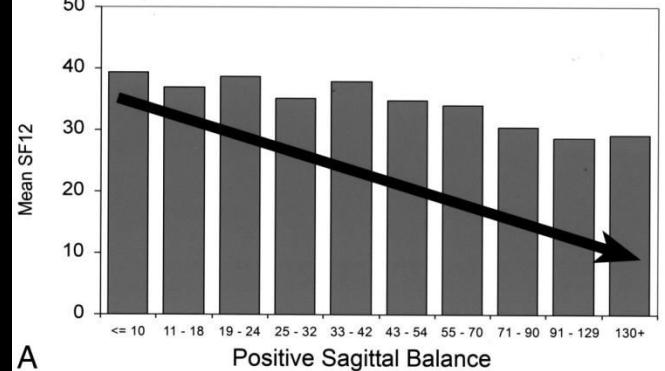
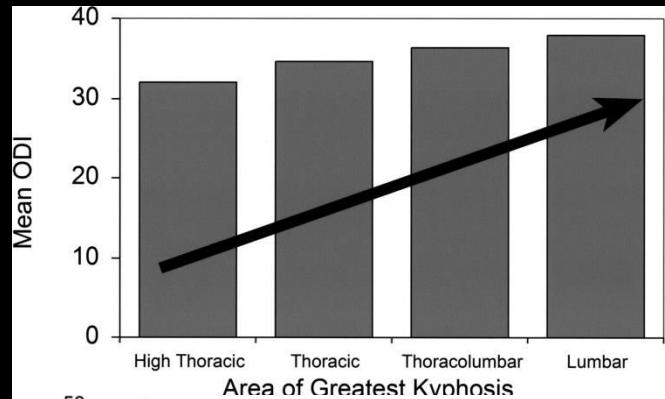
Glassman, Bridwell et al. Spine 2005

Increasing disability
SF-12, SRS-29, ODI ($p < 0.001$)

Table 1. Correlation Between Positive Sagittal Balance and Health Status Scores Using SF-12, SRS-29, and ODI Measures

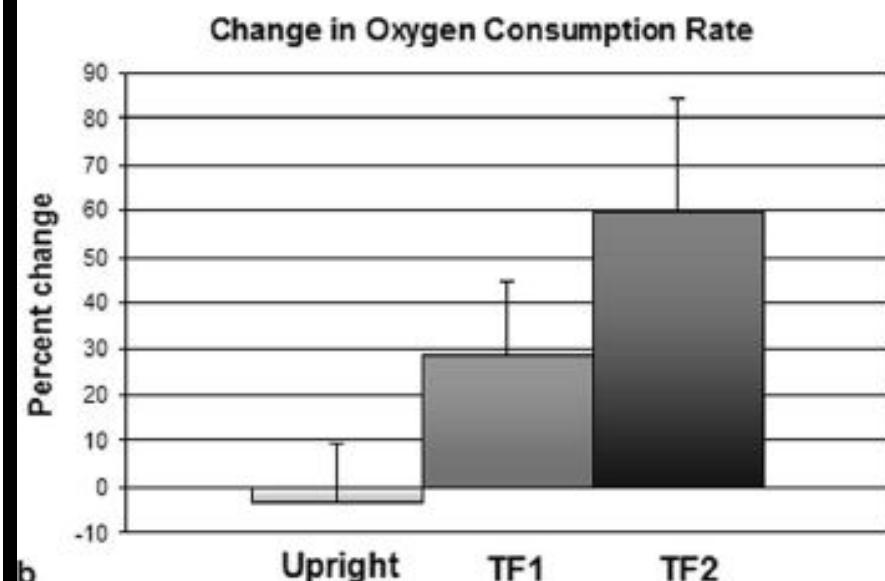
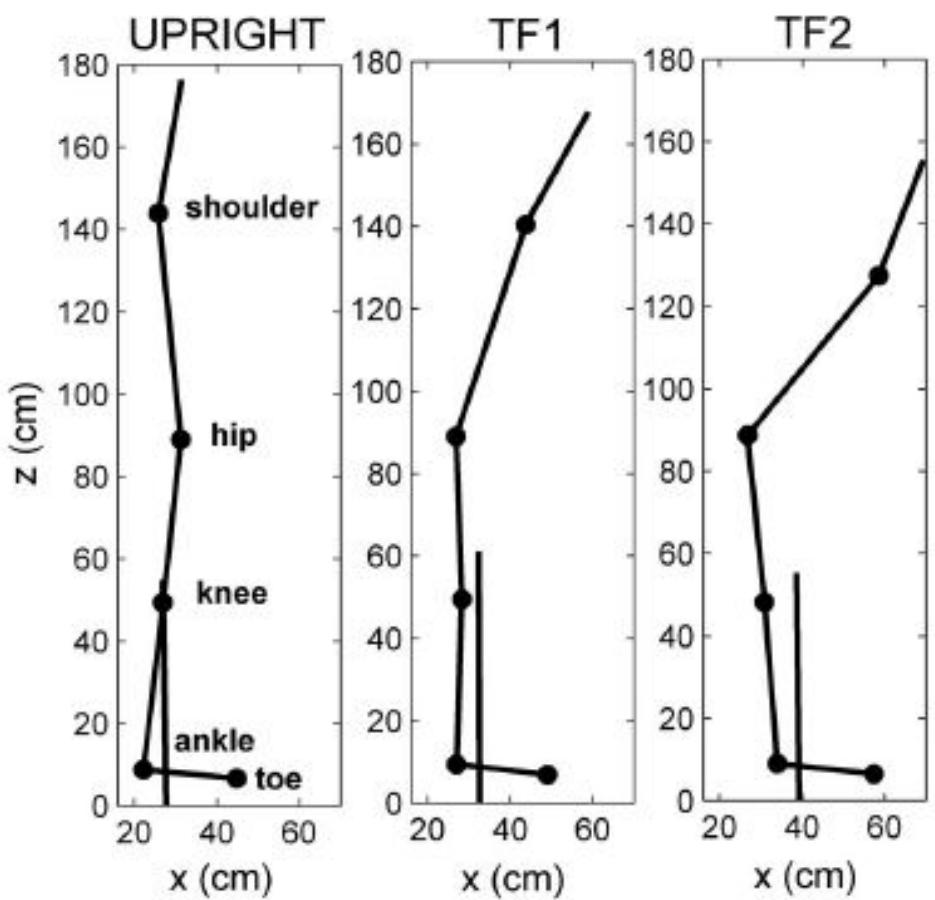
Measure	Spearman rho	No. Cases	P
SF-12v2 PCS	-0.292	284	0.000001
SF-12v2 MCS	-0.075	284	0.206 (NS)
SRS pain	-0.207	351	0.0000917
SRS activity	-0.247	350	0.0000029
SRS total	-0.264	350	0.000001
Oswestry overall	0.281	349	0.000001

MCS = mental health composite score; NS = not significant.



The Effect of Trunk-Flexed Postures on Balance and Metabolic Energy Expenditure During Standing

Devjani Saha, MS,*† Steven Gard, PhD,*†‡ Stefania Fatone, PhD, BPO(Hons),*‡
and Stephen Ondra, MD§



Aims of intervention

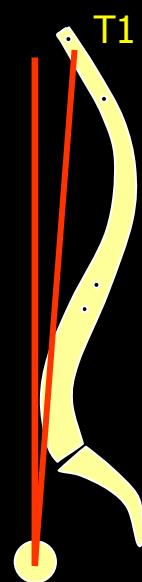
1. Achieve fusion
2. Adaptation of the lordosis
3. Restore plumb line

Alignment objectives



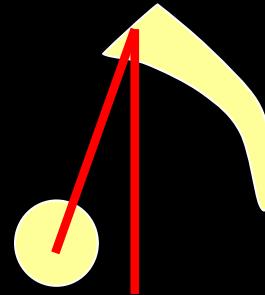
SVA

<5cm



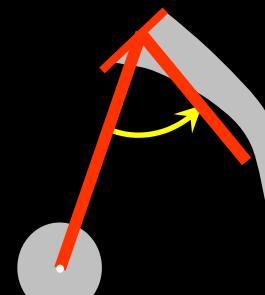
T1 Tilt

< 0°



PT

< 25°



PI

Proportional:
 $LL = PI \pm 9^{\circ}$

Aim 1: achieve fusion

- ☒ Good pain relief; 69 – 87%

Kostuik Clin Orthop 1973

Swank JBJS Am 1981

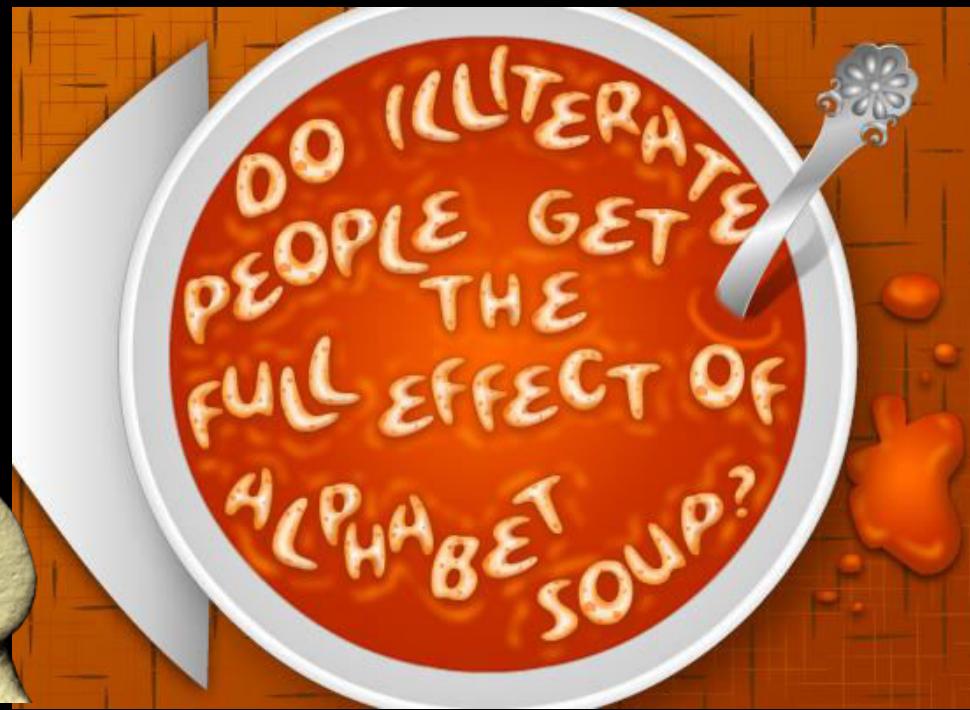
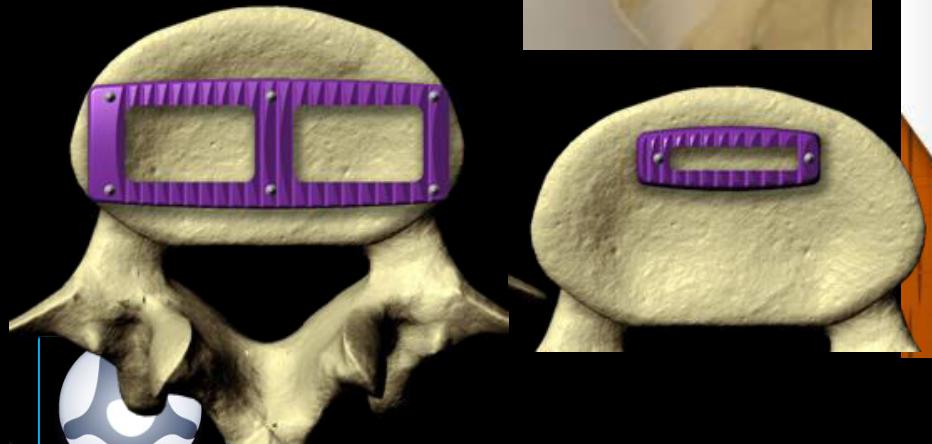
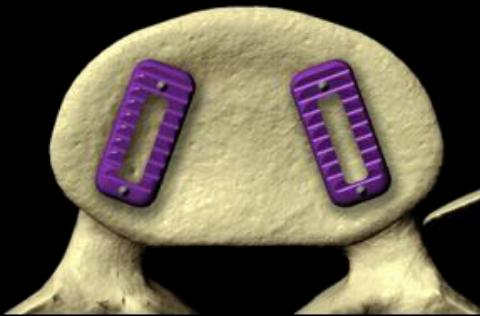
- ☒ Improvement in the lumbar lordosis

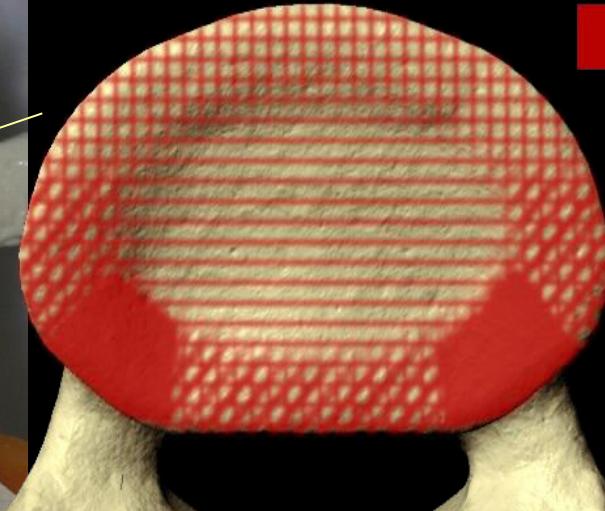
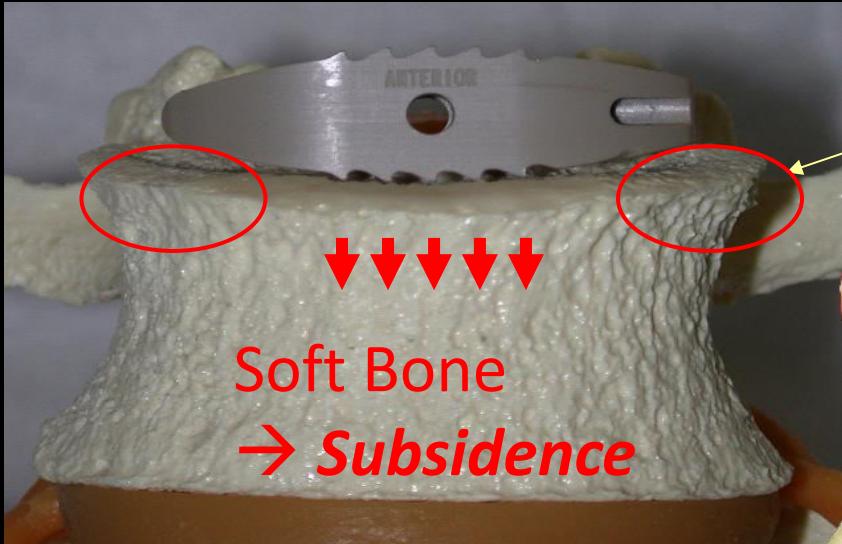
- ☒ Anterior column load sharing



Inter-body Support: Lumbar spine

ALIF PLIF TLIF XLIF LLIF DLIF

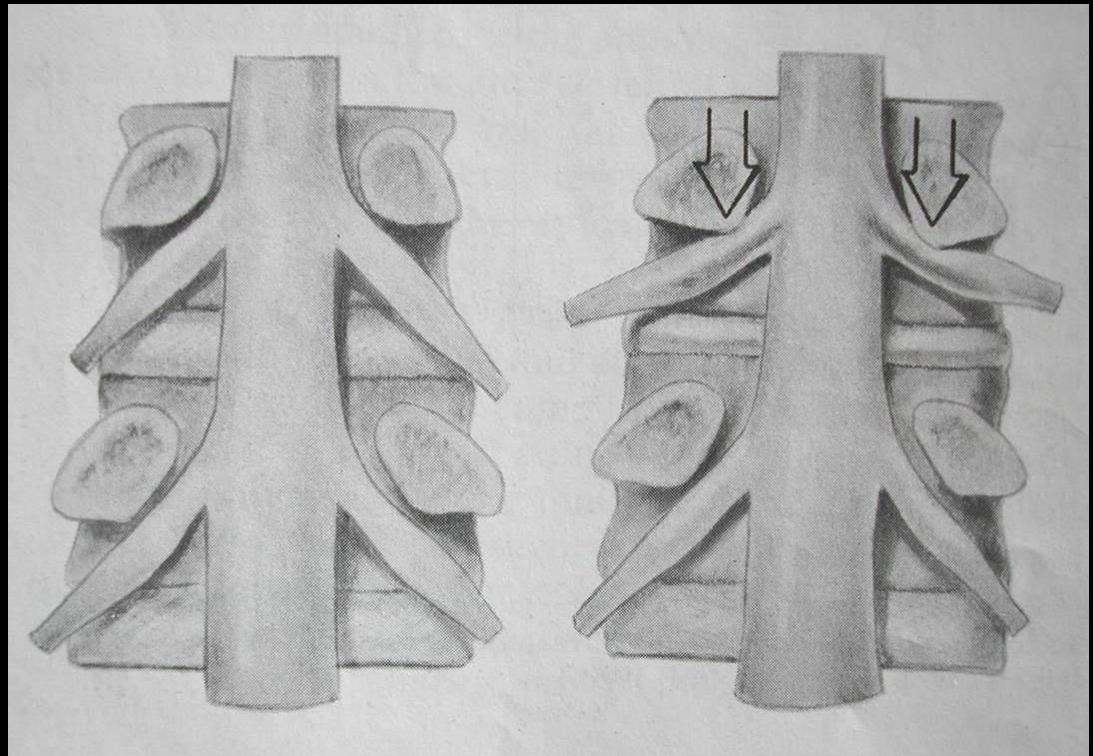




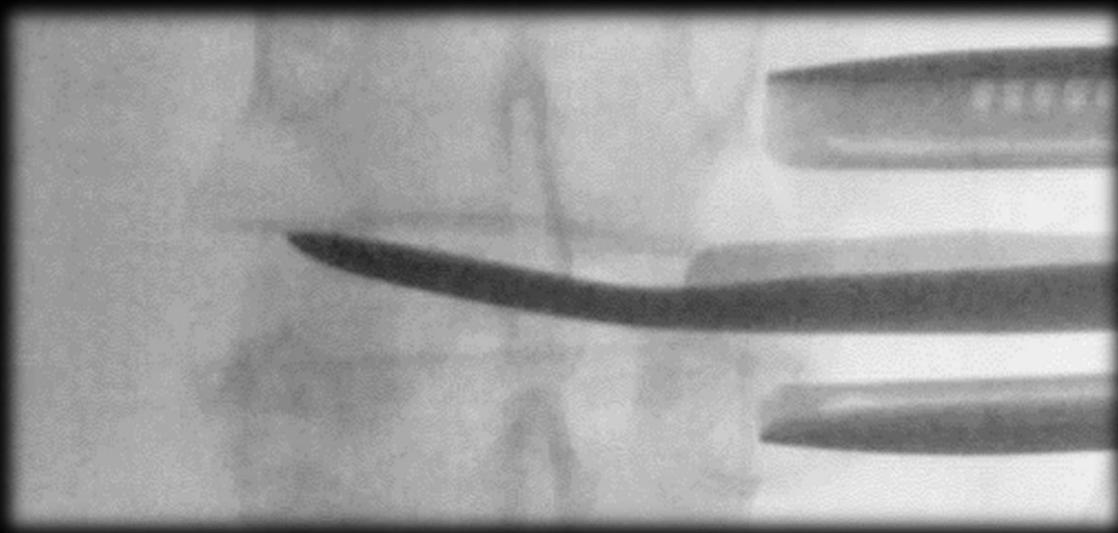
Inter-body fusion

- ☒ Bio-mechanical stability
- ☒ Restores lordosis
- ☒ Improves fusion rate
- ☒ Indirect canal, foraminal decompression

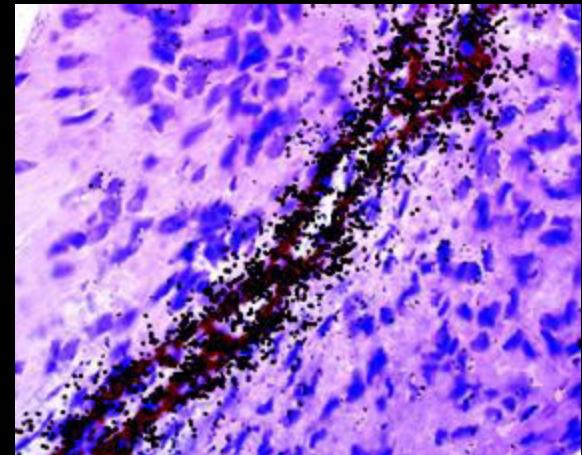
Cunningham Spine 2002
Polly J Spinal Disorders 2000
Kuklo Spine 2001



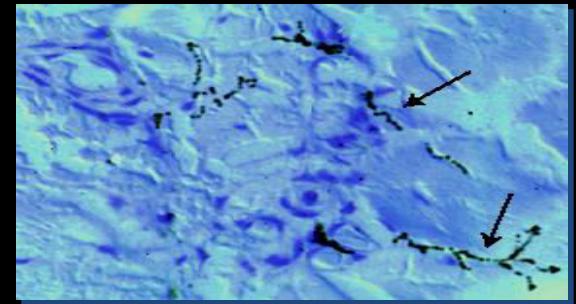
Effect of abnormal loads on cell metabolism



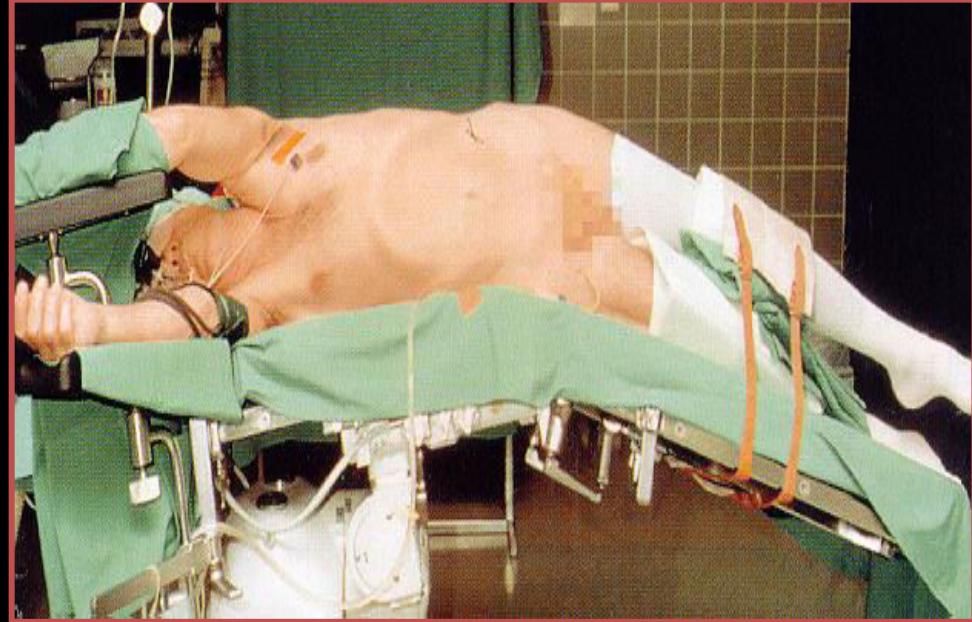
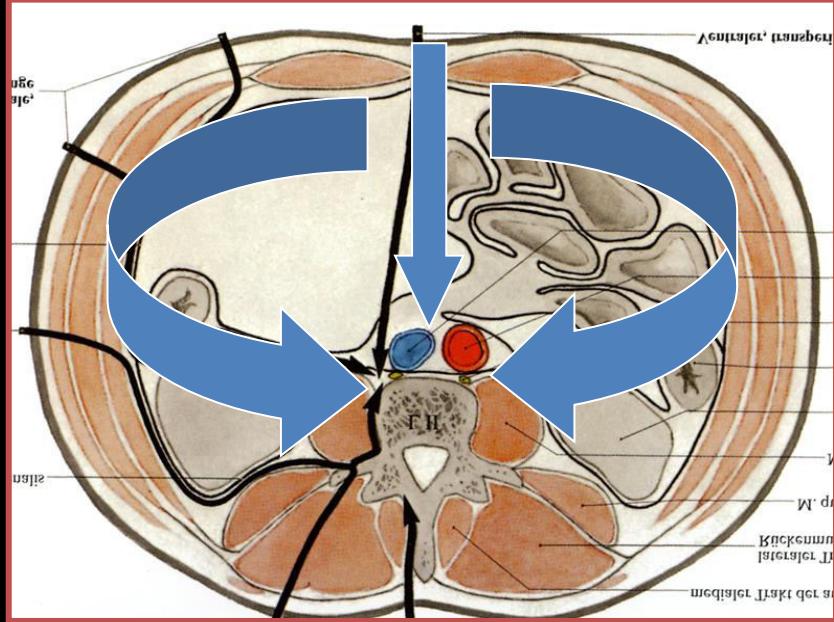
Good Annular Release



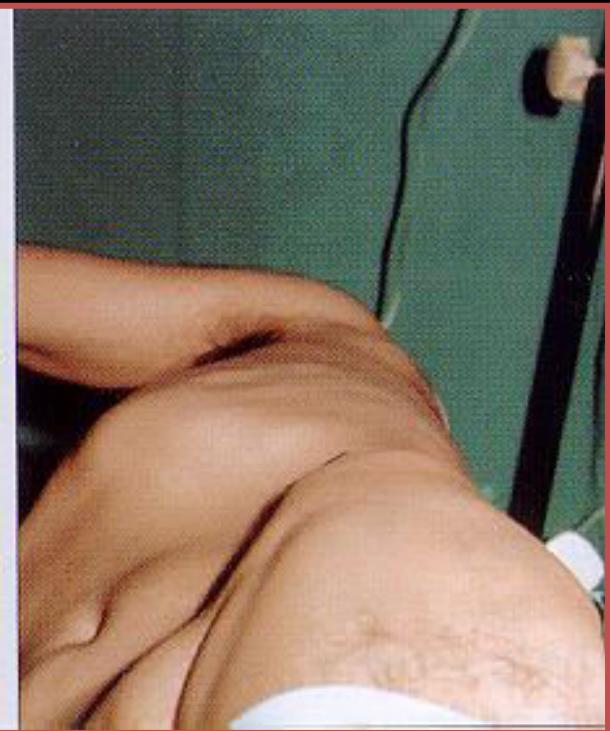
Angiogenesis



Nerve growth



Level	Tilt
L2/3	40°
L3/4	30°
L4/5	20°



Lat. Femoral cut. N

L4

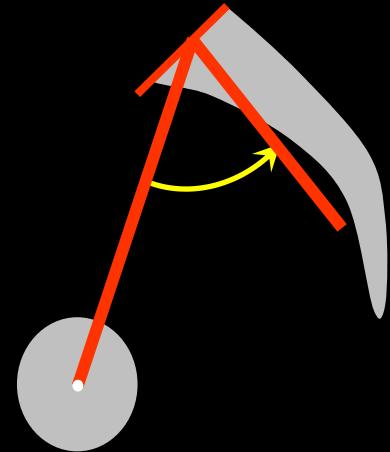
L5

L3 N.



Aim 2: adaptation of lordosis

- Excise facet joints

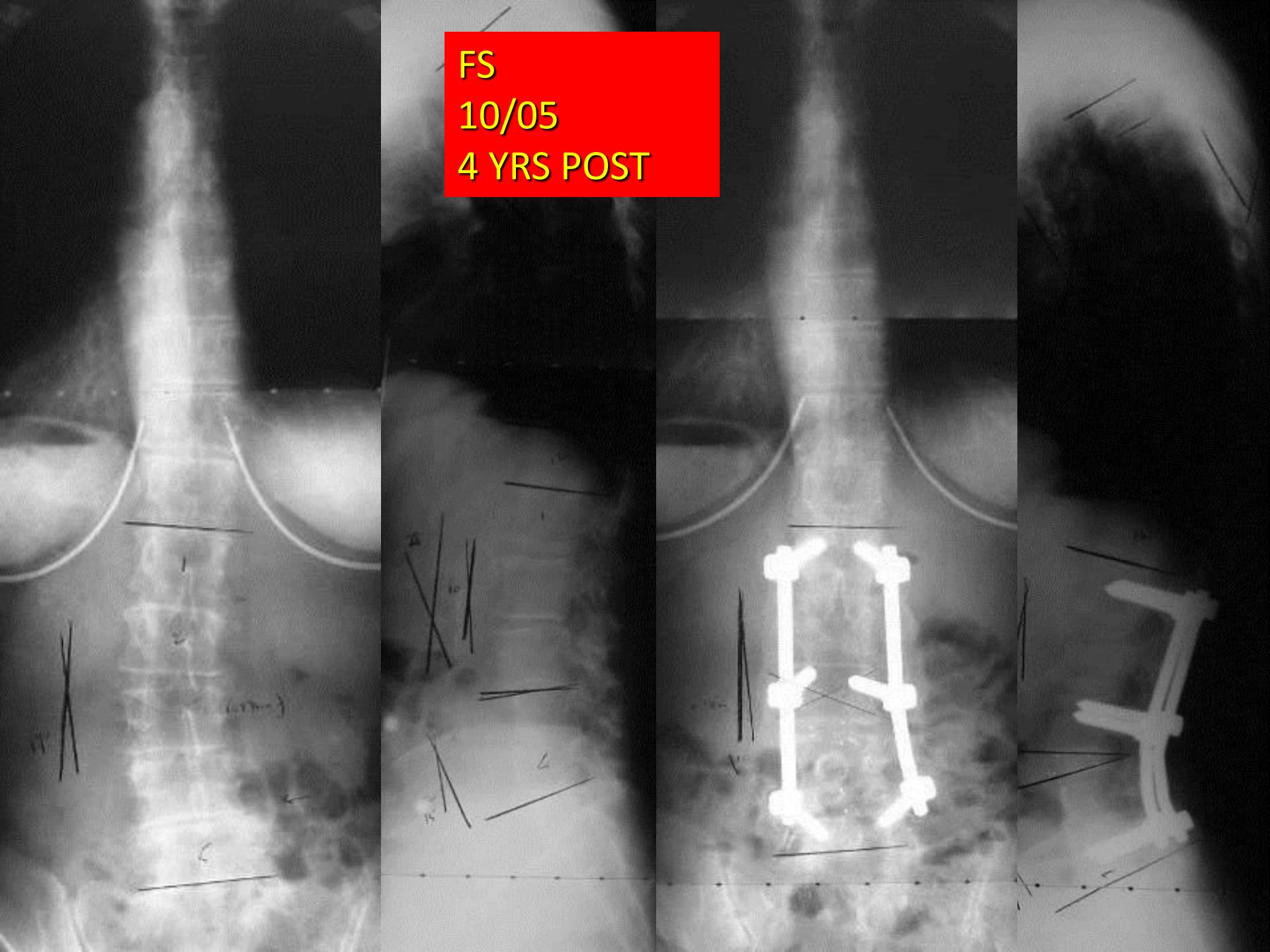


- 'Open' degenerate disc spaces

$$\text{LL} = \text{PI} \pm 90^\circ$$

- Measure the PI, and build in the lordosis

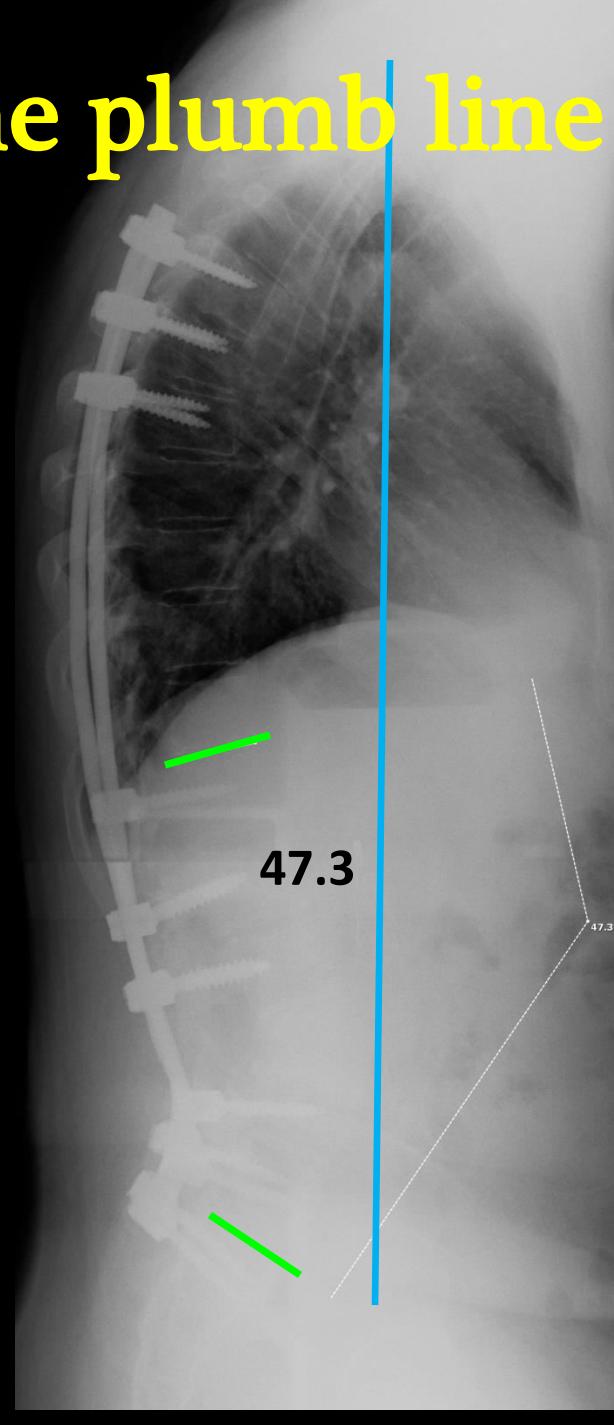
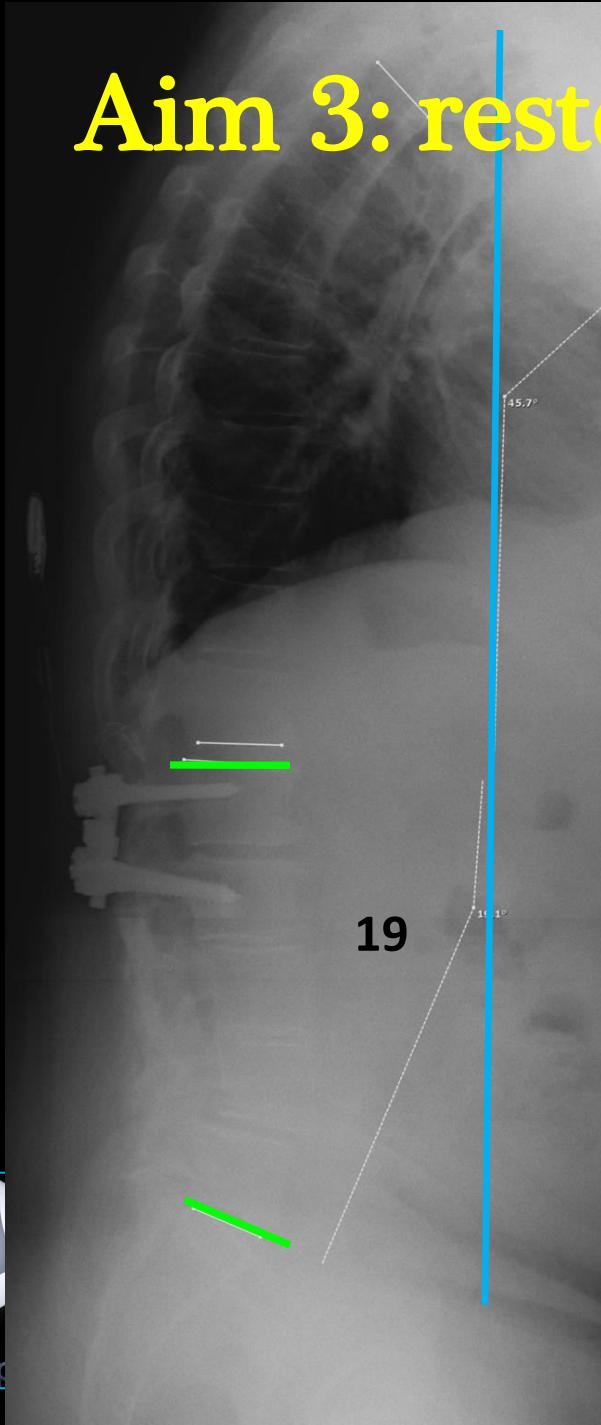
FS
10/05
4 YRS POST



FS
10/05
4 YRS POST



Aim 3: restore the plumb line



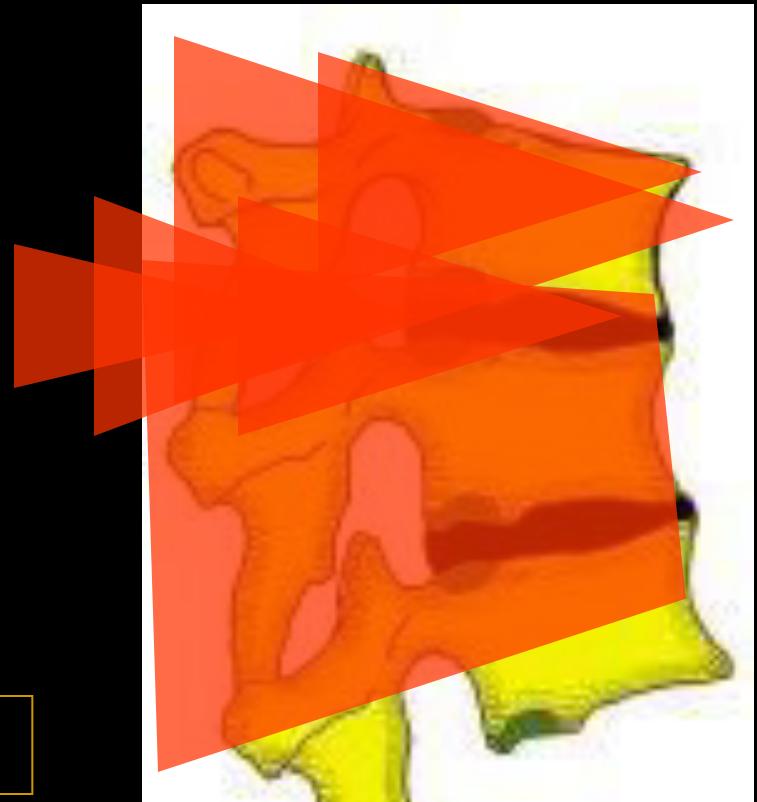
Advanced strategies



Osteotomy: anatomical considerations

6 grades of destabilization:

1. partial facet joint
2. complete facet joints
3. partial body[#]
4. partial body and disc[#]
5. complete body + discs[#]
6. >1 body, adjacent[#]



#

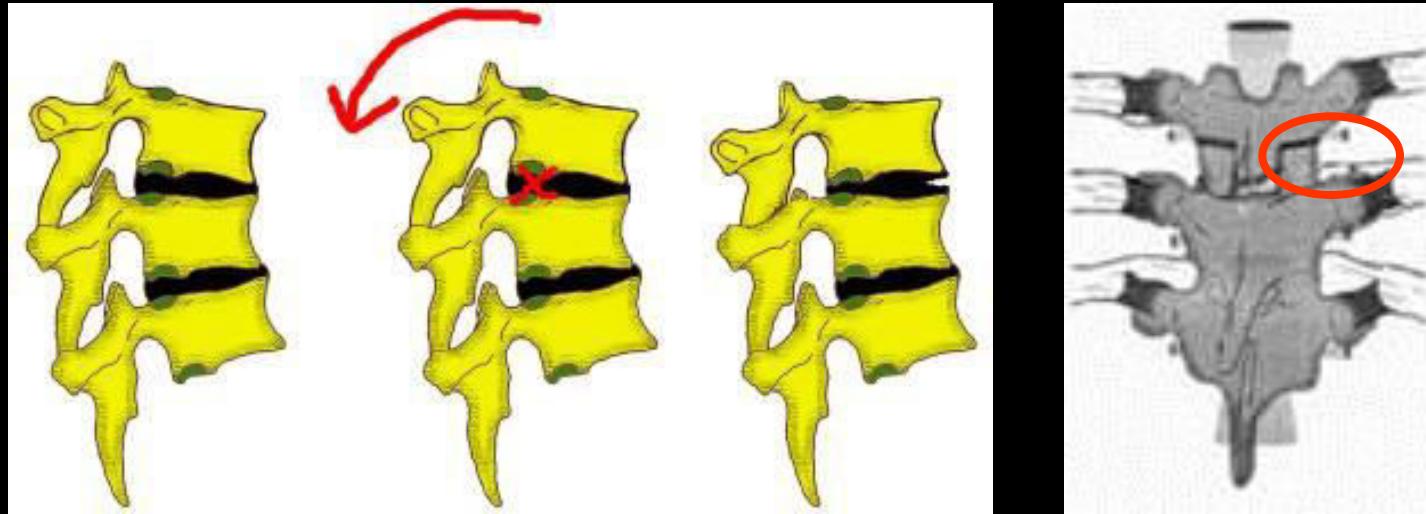
posterior vs. anterior/posterior



mehtaspine

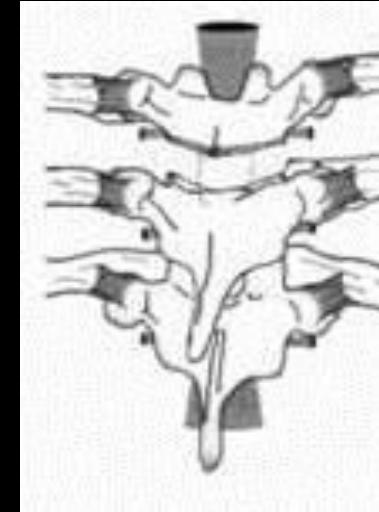
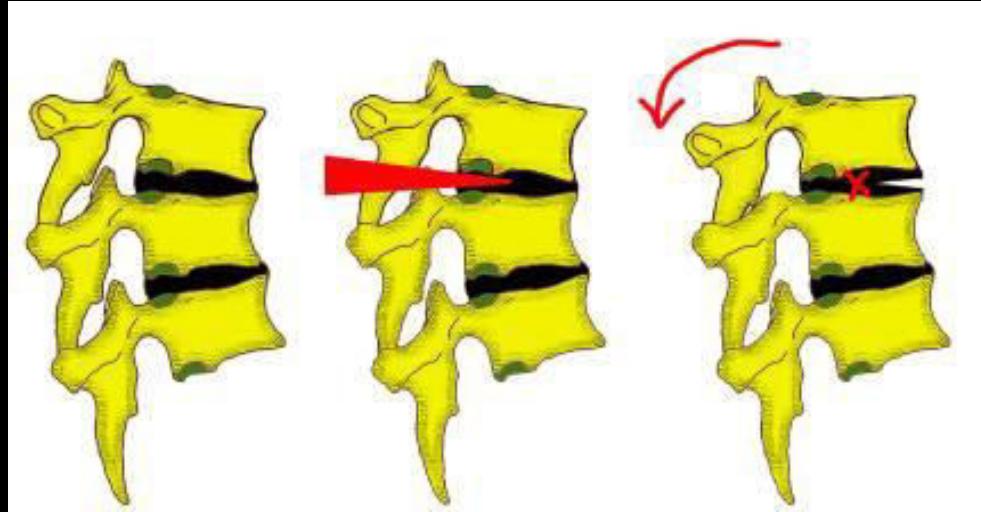
Courtesy Frank Schwab

Grade I - Partial Facet Resection



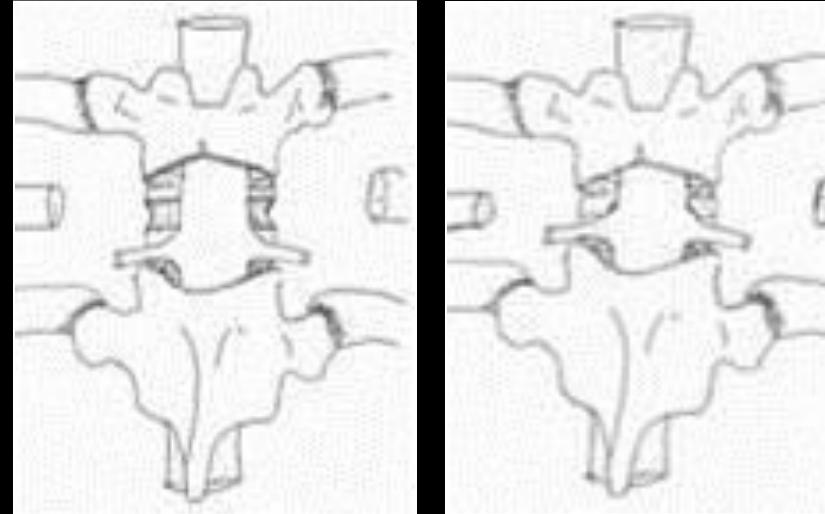
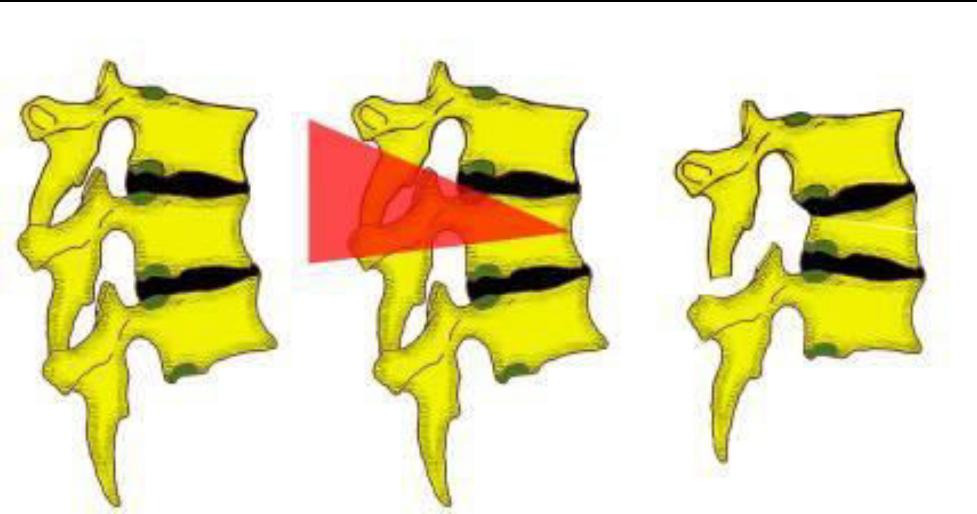
Best suited when anterior column flexibility
Inferior facet resection + capsule

Grade II - Complete facetectomy



Anterior column mobility necessary
Superior and inferior facet resection
Spinous processes

Grade III - Partial body resection



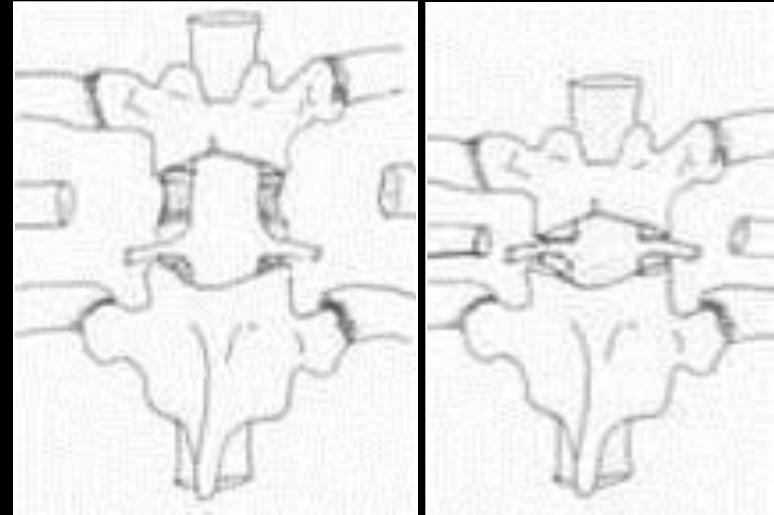
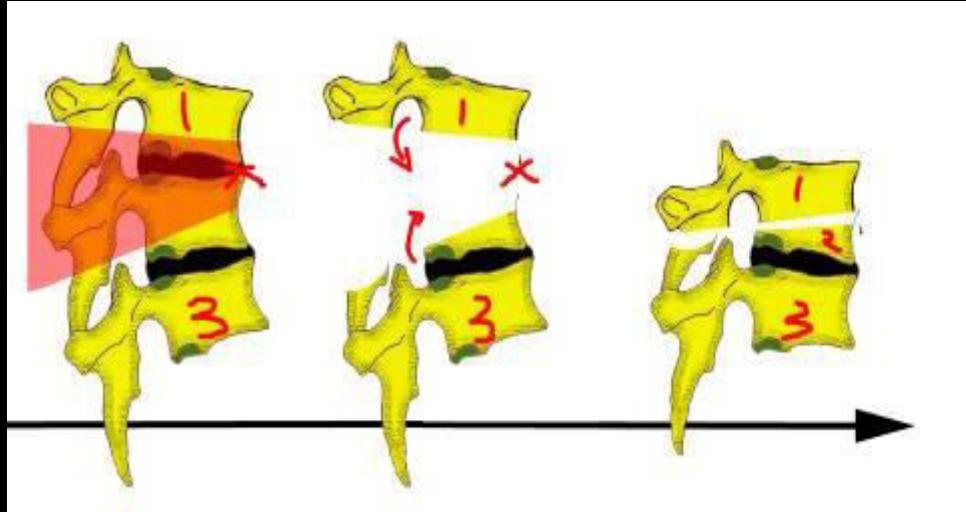
Most suited when $>20^\circ$ segmental correction needed

Appropriate even through fusion

All levels of spine possible

Preferable below conus

Grade IV - partial vertebra + disc

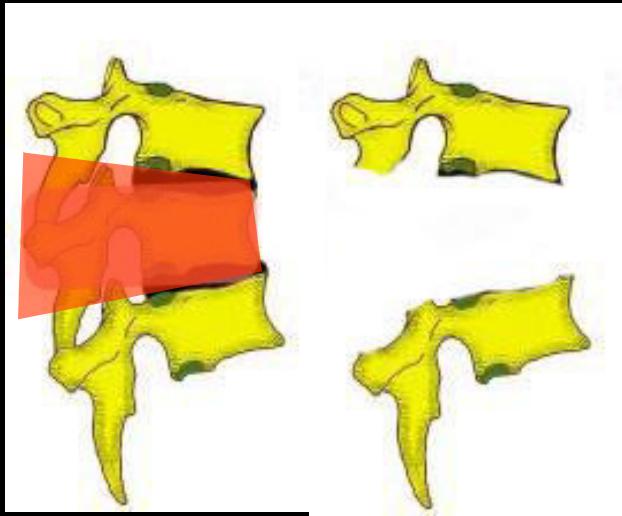


Permits limited 3-plane correction

Rib resection necessary in thoracic spine

Add anterior support/cage when marked shortening

Grade V - Complete vertebra + discs

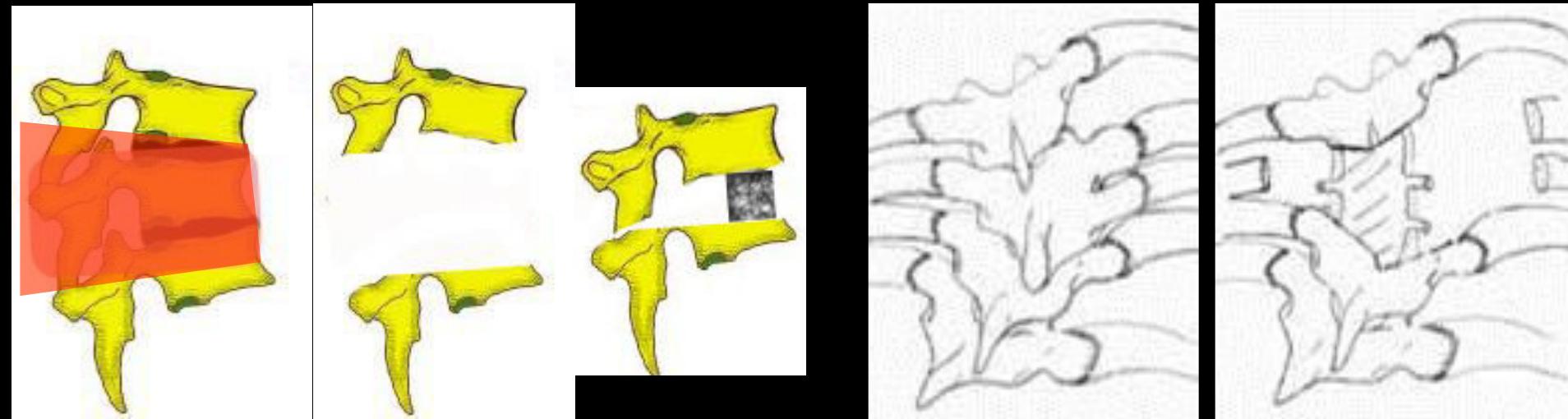


Permits 3-plane correction

Rib resection necessary in thoracic spine

Add anterior support/cage

Grade VI - More than 1 Vertebra + discs

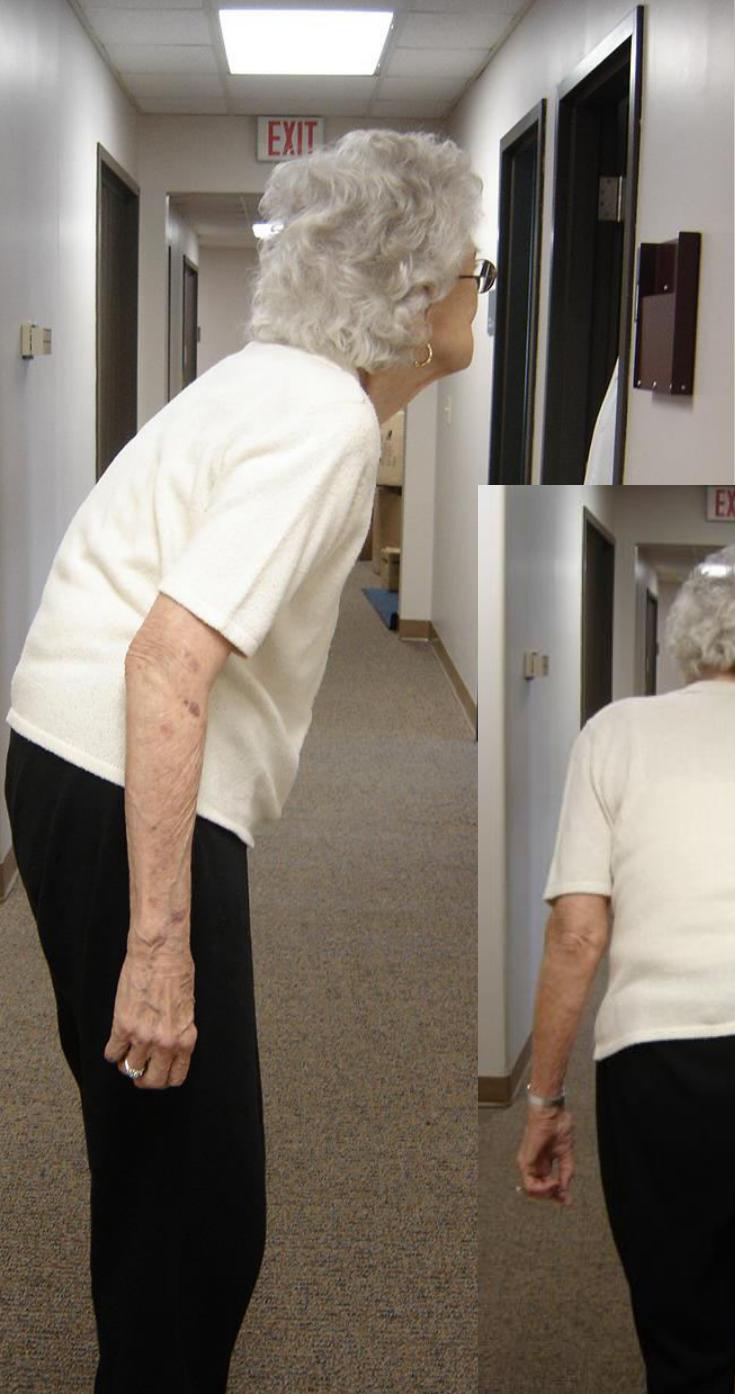


Permits 3-plane correction

Rib resection necessary in thoracic spine

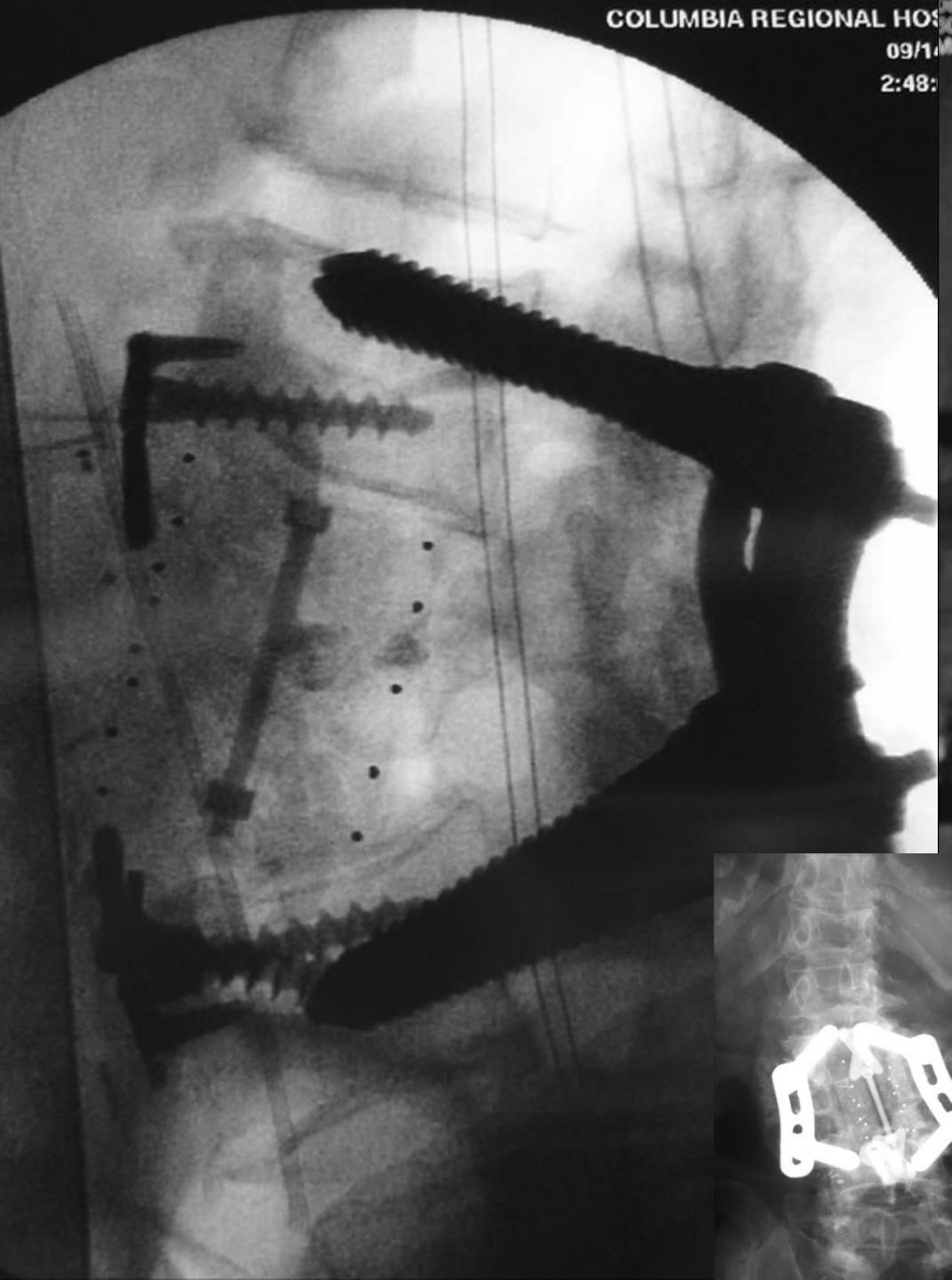
Add anterior support/cage





**MM
86Y**

COLUMBIA REGIONAL HOS
09/17/00
502 IMA 16
09/17/00 MPR 3
2:48:



Spin: -90
Tilt: -2



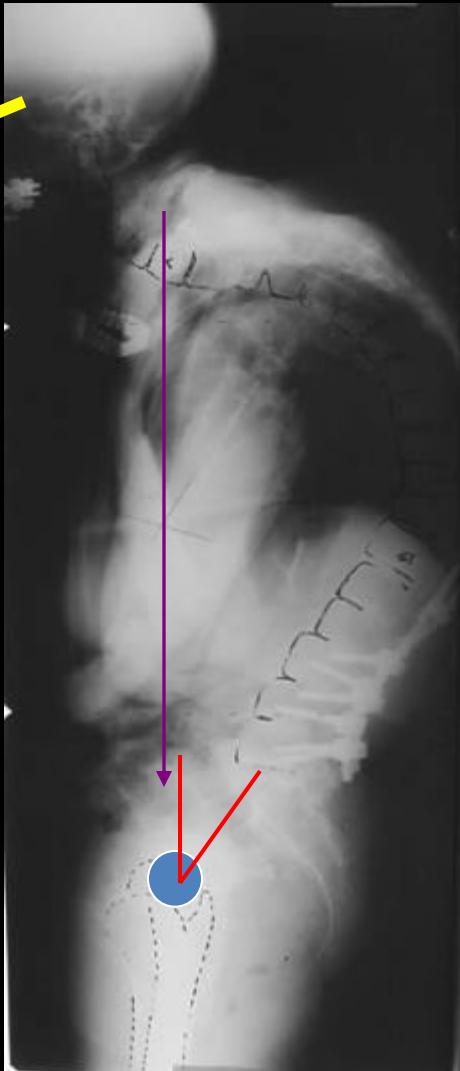
154918



Iatrogenic Junctional Kyphosis

Pre Op

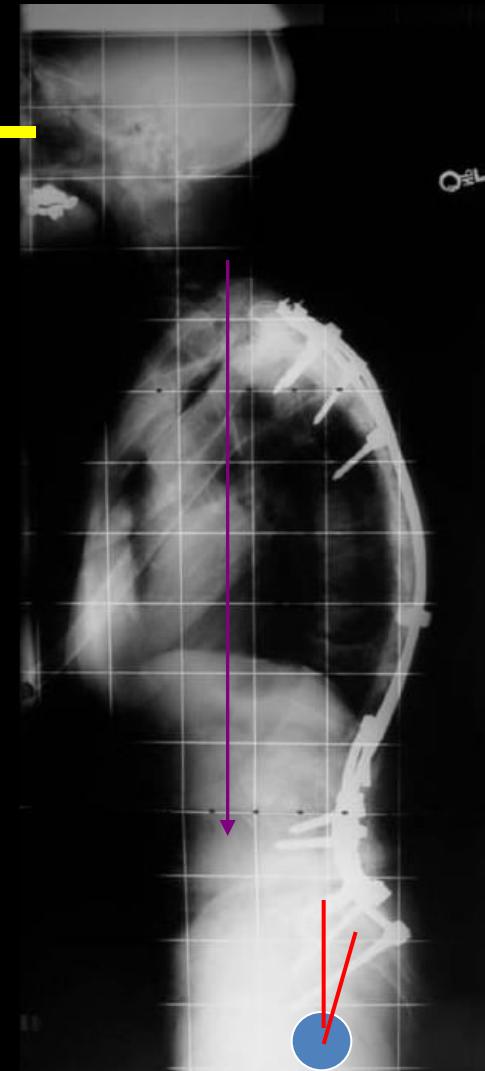
PI = 42°
•PT = 38°
•SVA = 128mm
•LL = 33°
•TK = 86°



Post Op

PI = 42°
•PT = 17°
•SVA = 24mm
•LL = 60°
•TK = 62°

G2 + G3
osteotomies



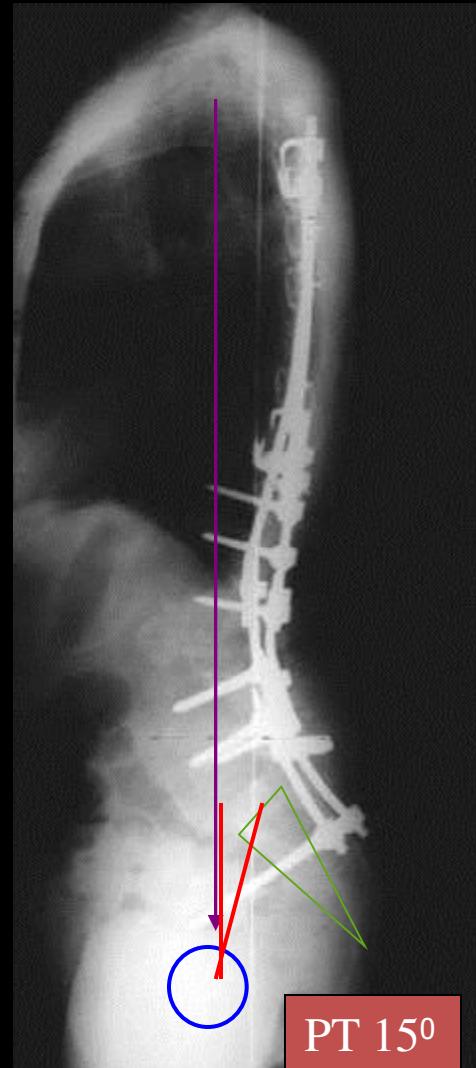
Pre op

- PI = 47°
- PT = 35°
- SVA = 40 mm
- LL = 32°
- TK = 32°



Post Op

- PI = 47°
- PT = 15°
- SVA = 16 mm
- LL = 42°
- TK = 36°



Courtesy Frank Schwab

Transitional failure

Changes above or below a long fusion:

- ☒ Loss of correction
- ☒ Progression of deformity
- ☒ Junctional degeneration / stenosis
- ☒ Acute # or loss of fixation
- ☒ Proximal or distal junctional kyphosis

STANDING
LEFT

Proximal level for fusion

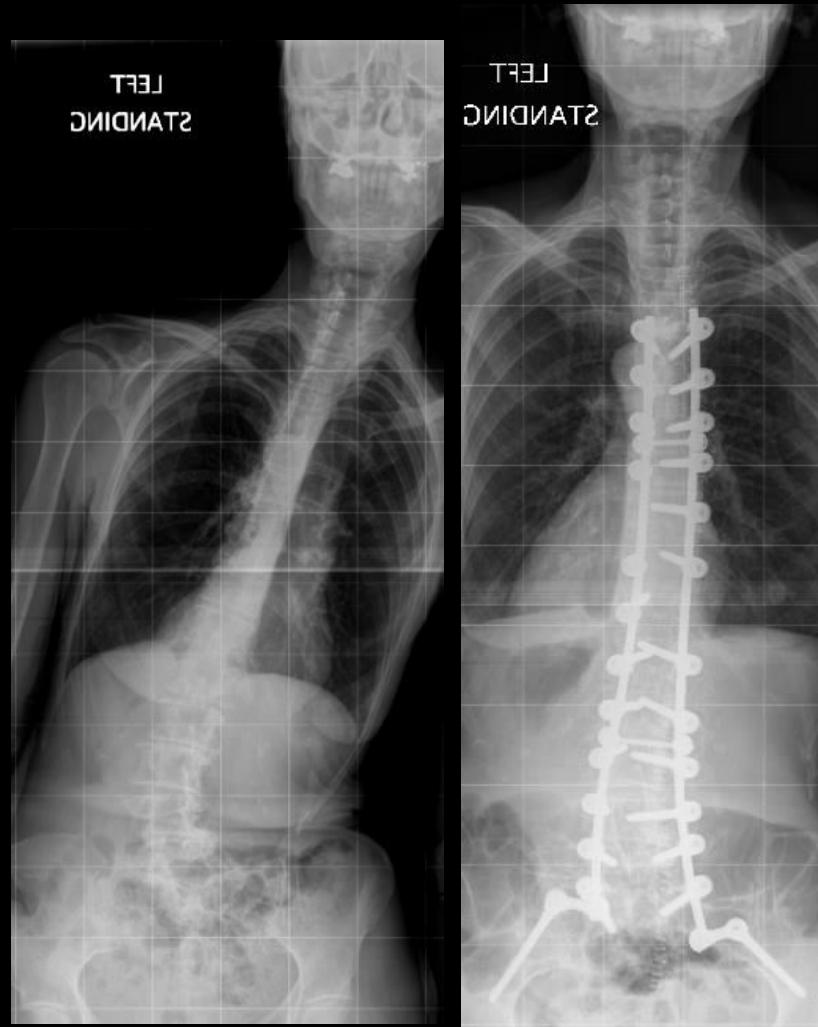
- ❑ Never stop at the apex of a kyphosis
- ❑ Always T2,
Sometimes T3,
Occasionally T4,
Never below T5

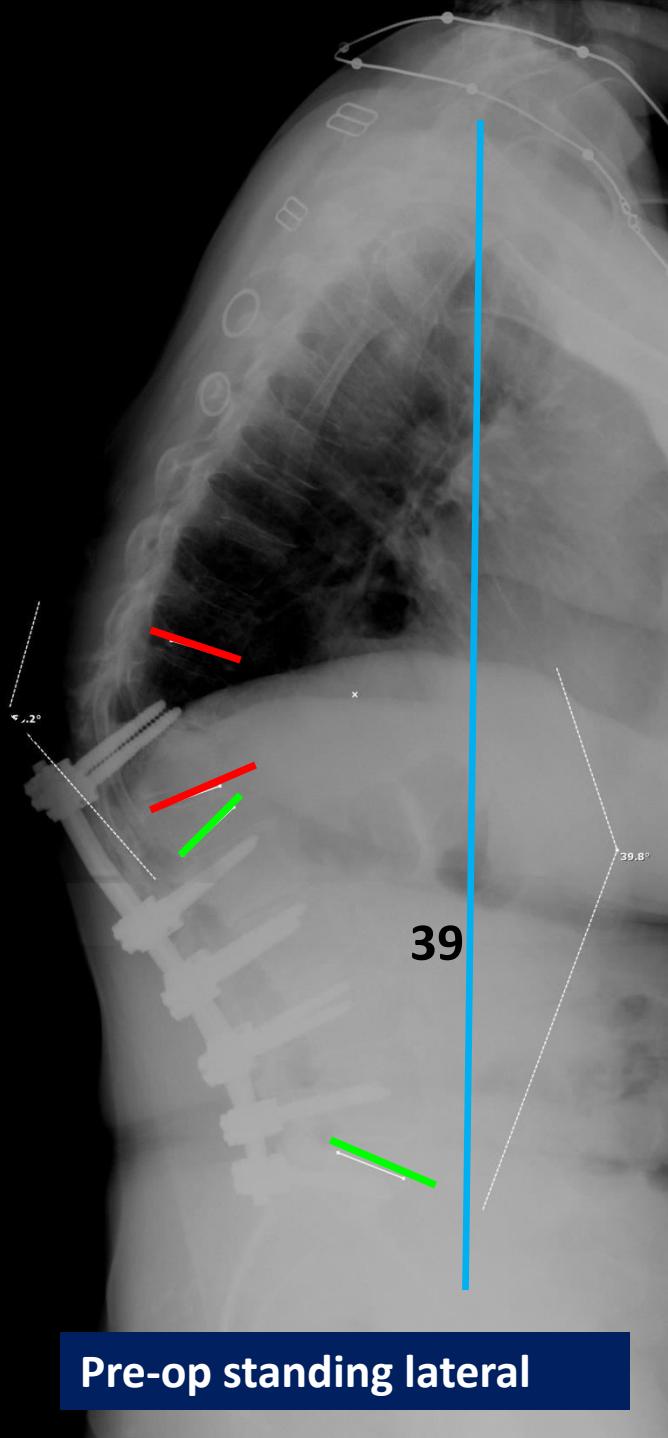


Distal level for fusion: L5 or sacrum

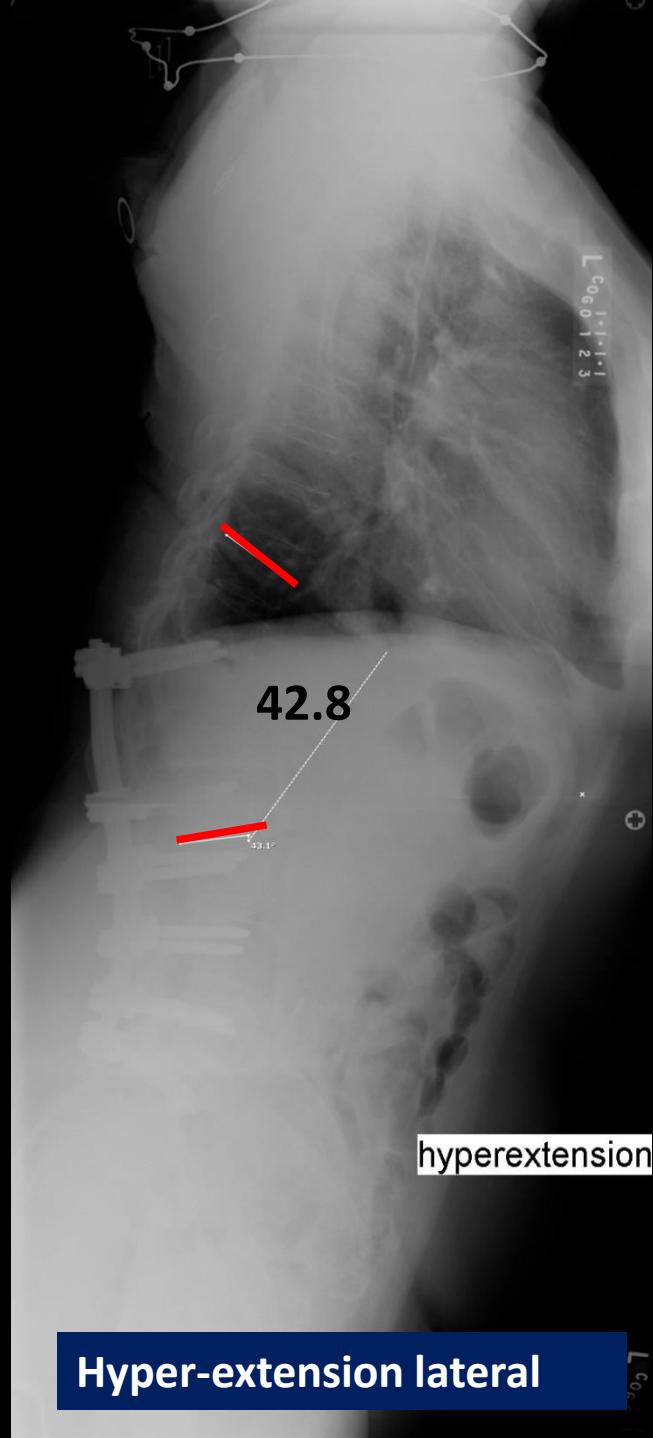
Bridewell's absolute indications to fuse to the sacrum:

1. L5S1 spondylolisthesis
2. Previous L5S1 laminectomy
3. Stenotic L5S1 requiring decompression
4. Oblique take-off of L5
5. Degeneration of L5S1 motion segment





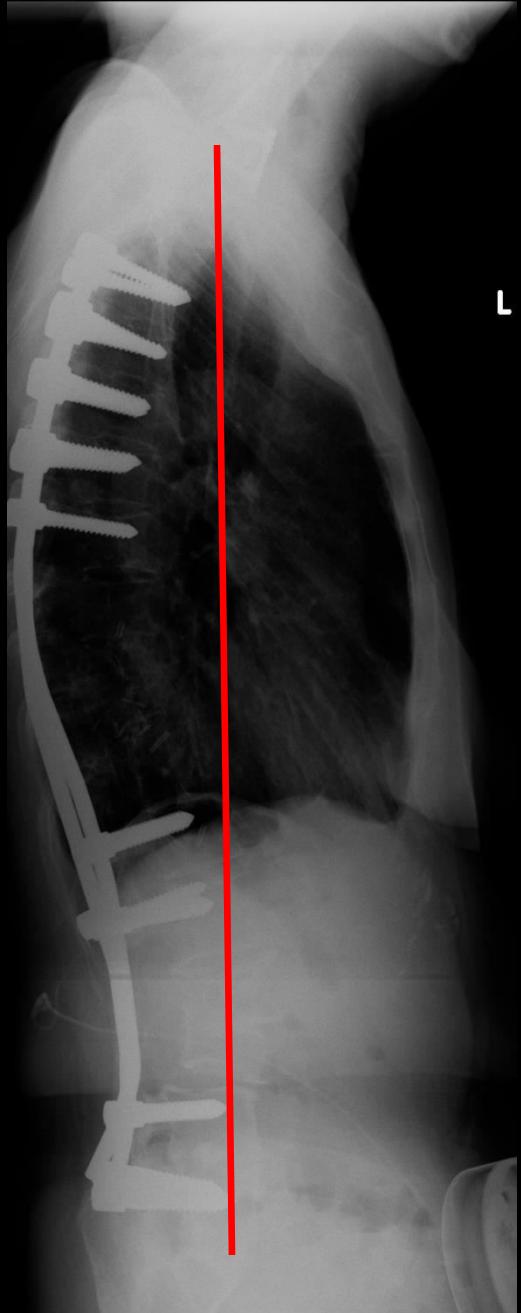
Pre-op standing lateral



Hyper-extension lateral



mehtaspine





mehtaspine

Adult Deformity : Clinical impact

☒ Significant

- ∅ Spondylolisthesis *
- ∅ Lateral Subluxation
- ∅ Lumbar lordosis *
- ∅ Thoracolumbar alignment *
- ∅ Apical level
- ∅ Sagittal Balance (SVA) *

* Most parameters relate to the sagittal plane

☒ Not significant

- ∅ Coronal Cobb
- ∅ Age
- ∅ Adolescent vs. de-novo scoliosis



Statistically significant: SRS-22, ODI, SF-12/36

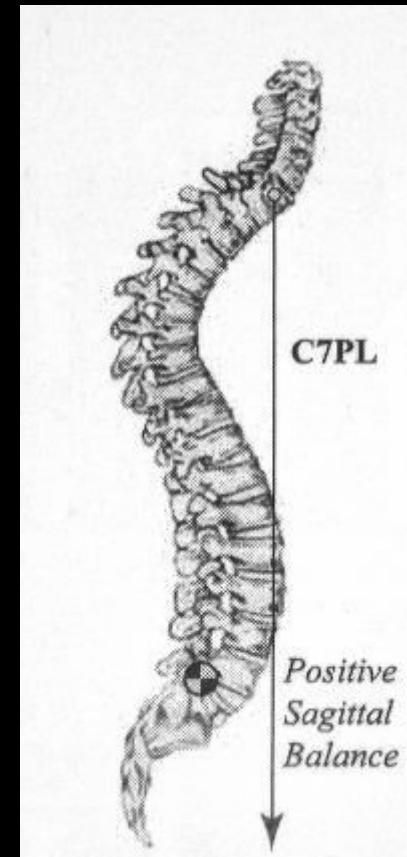
Loss of global alignment

- ☒ Plumbline shift anteriorly



=> Increasing disability
SF-12, SRS-29, ODI ($p<0.001$)

=> Lumbar kyphosis marked disability
SRS-29, ODI ($p<0.05$)



Causes of imbalance

- ☒ Degeneration (loss of lordosis)
- ☒ Fused ‘flat’
- ☒ Pseudarthrosis
- ☒ Transitional failure
- ☒ Poor selection of levels
- ☒ Thoracic hyper-kyphosis

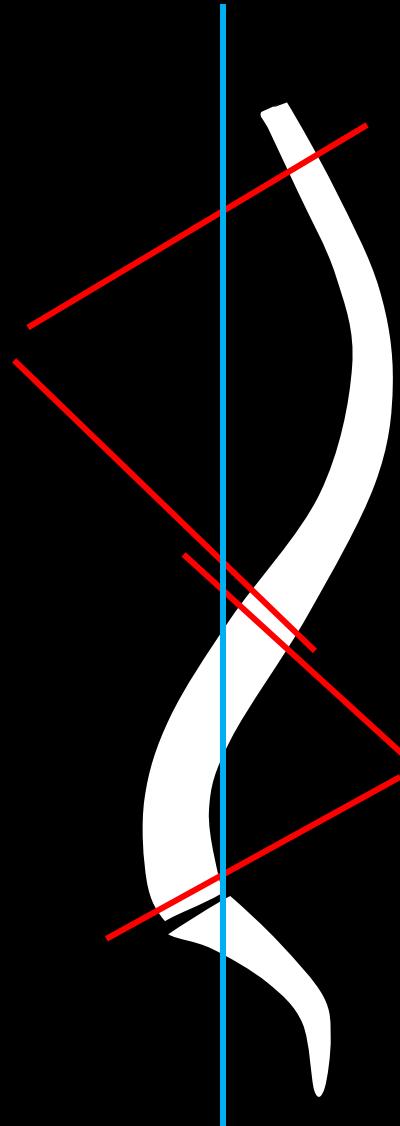


Aims of intervention

1. Achieve fusion
2. Adaptation of the lordosis
3. Restore plumb line

Treatment goals

- ☒ Address foraminal stenosis
- ☒ Address lordosis
- ☒ Balance the coronal & sagittal planes
- ☒ Excise facets; spacers in ‘empty’ discs



Management philosophy

- ☒ Customise the plan for each patient
- ☒ Identify and optimise issues in patients' health
- ☒ Have clear understanding of patients' expectations
- ☒ Identify the pathology causing the problem





mehtaspine



.....not too hot to handle !



Avoid the 'AP-only' trap!

Think lateral

Think lordosis

R C O G 0 1 2 3

Respect and Restore the sagittal profile!