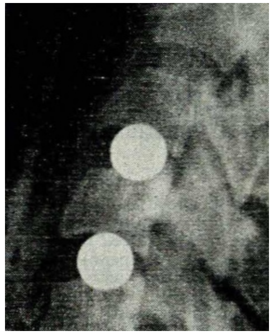
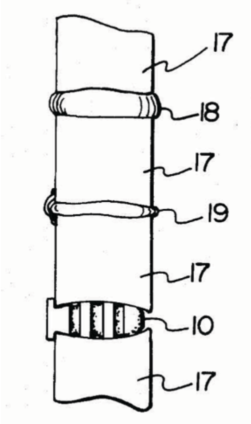
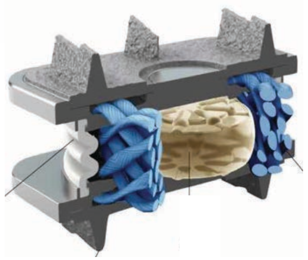






Evolution of Cervical Discs
A Clinical Overview

Dr William Sears

Wentworth Spine Clinic

Sydney Australia

4th International Symposium for Cervical and Lumbar Arthroplasty

Berlin, October 7th, 2016

Disclosures

Consultant:

- *Medtronic*
- *Paradigm Spine*
- *NuVasive*
- *LifeHealthcare*

Royalties:

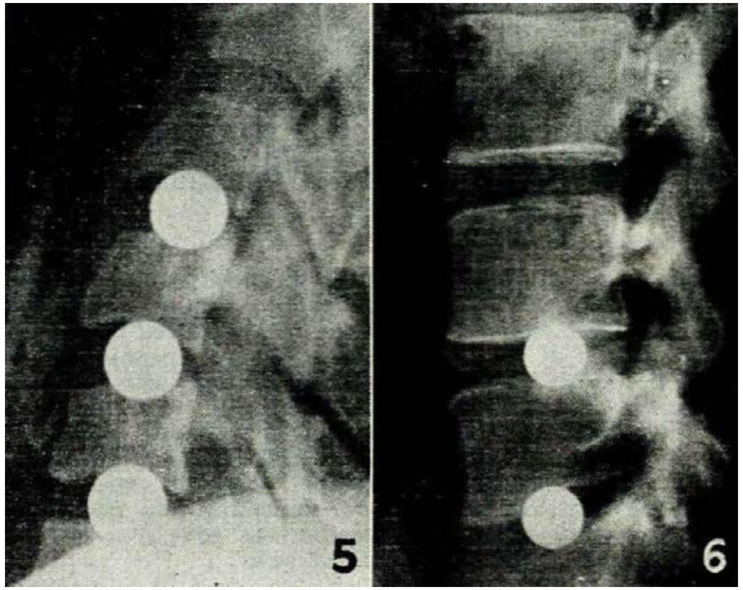
- *Medtronic – lumbar interbody fusion device*

Travel assistance:

- *Spinal kinetics*

The beginning…

- Ulf Fernström
  - Uddevalla, Sweden



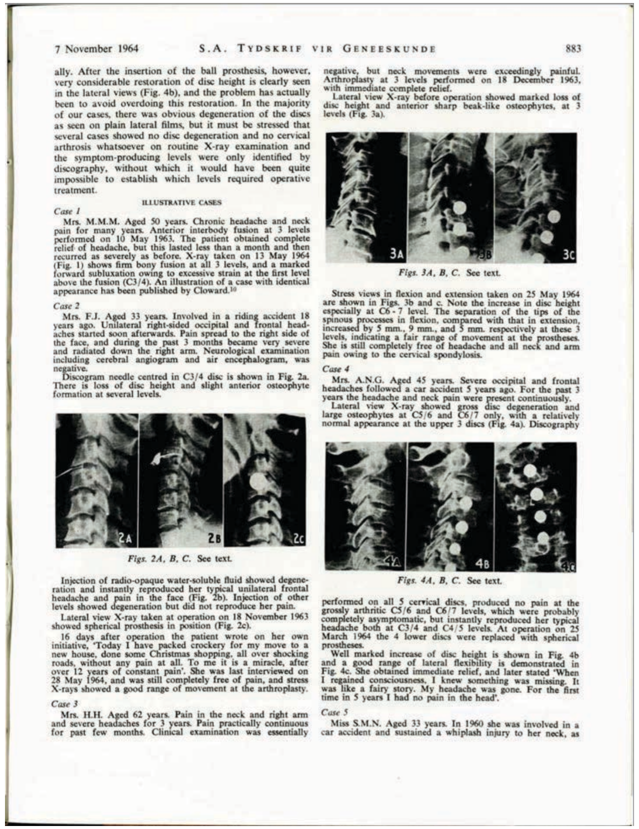
INTRACTABLE HEADACHE AND CERVICO-BRACHIALGIA TREATED BY COMPLETE REPLACEMENT OF CERVICAL INTERVERTEBRAL DISCS WITH A METAL PROSTHESIS.

Reitz H & Joubert MI. *S Afr Med J. 1964*

7 November 1964 S.A. TYDSKRIF VIR GENEESKUNDE 881

INTRACTABLE HEADACHE AND CERVICO-BRACHIALGIA TREATED BY COMPLETE REPLACEMENT OF CERVICAL INTERVERTEBRAL DISCS WITH A METAL PROSTHESIS

HJALMAR REITZ, *Orthopaedic Surgeon, Johannesburg* AND MAURITIUS J. JOUBERT, *Neuro-Surgeon, Durban*



7 November 1964 S.A. TYDSKRIF VIR GENEESKUNDE 883

Figs. 3A, B, C. See text.

Figs. 2A, B, C. See text.

Figs. 4A, B, C. See text.

884 S.A. MEDICAL JOURNAL 7 November 1964

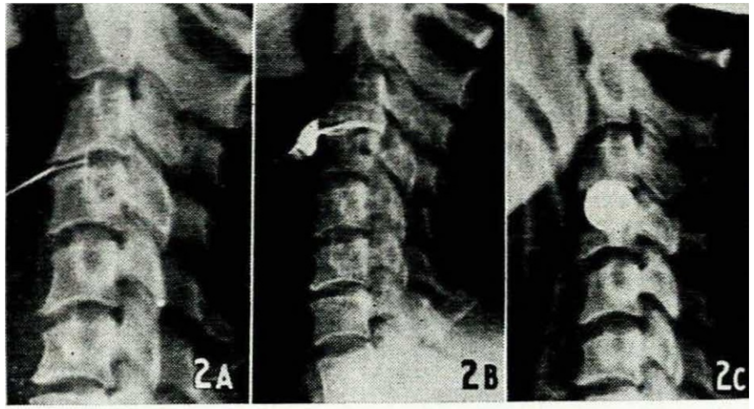
Fig. 5. See text (under 'Illustrative cases').
Fig. 6. See text.

Reitz & Joubert

Johannesburg & Durban, South Africa

November 1963 – 64

75 arthroplasties in 13 patients



Figs. 2A, B, C. See text.

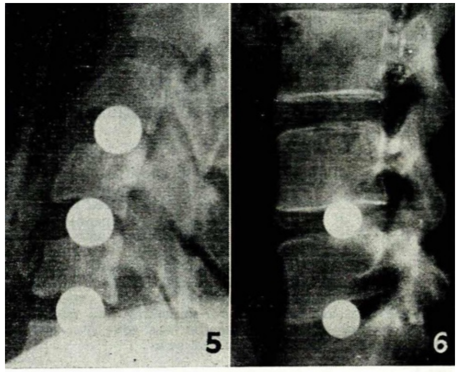
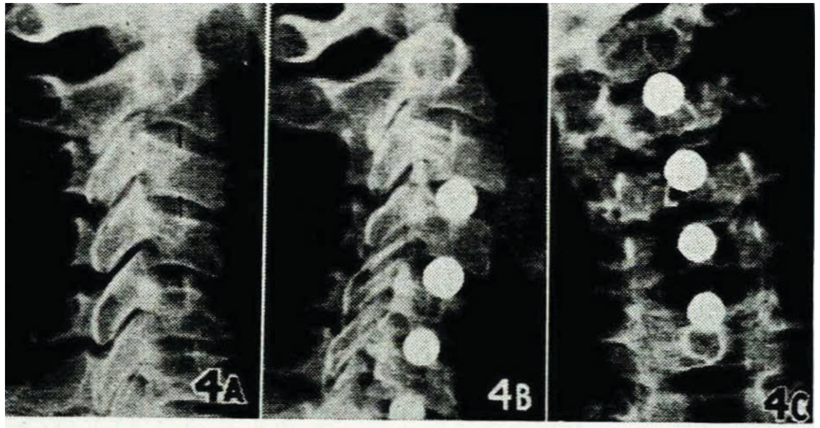
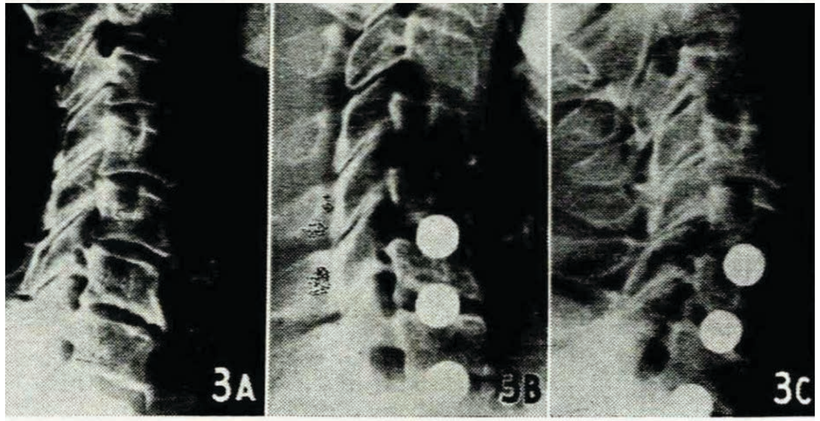


Fig. 5. See text (under 'Illustrative cases').
Fig. 6. See text.



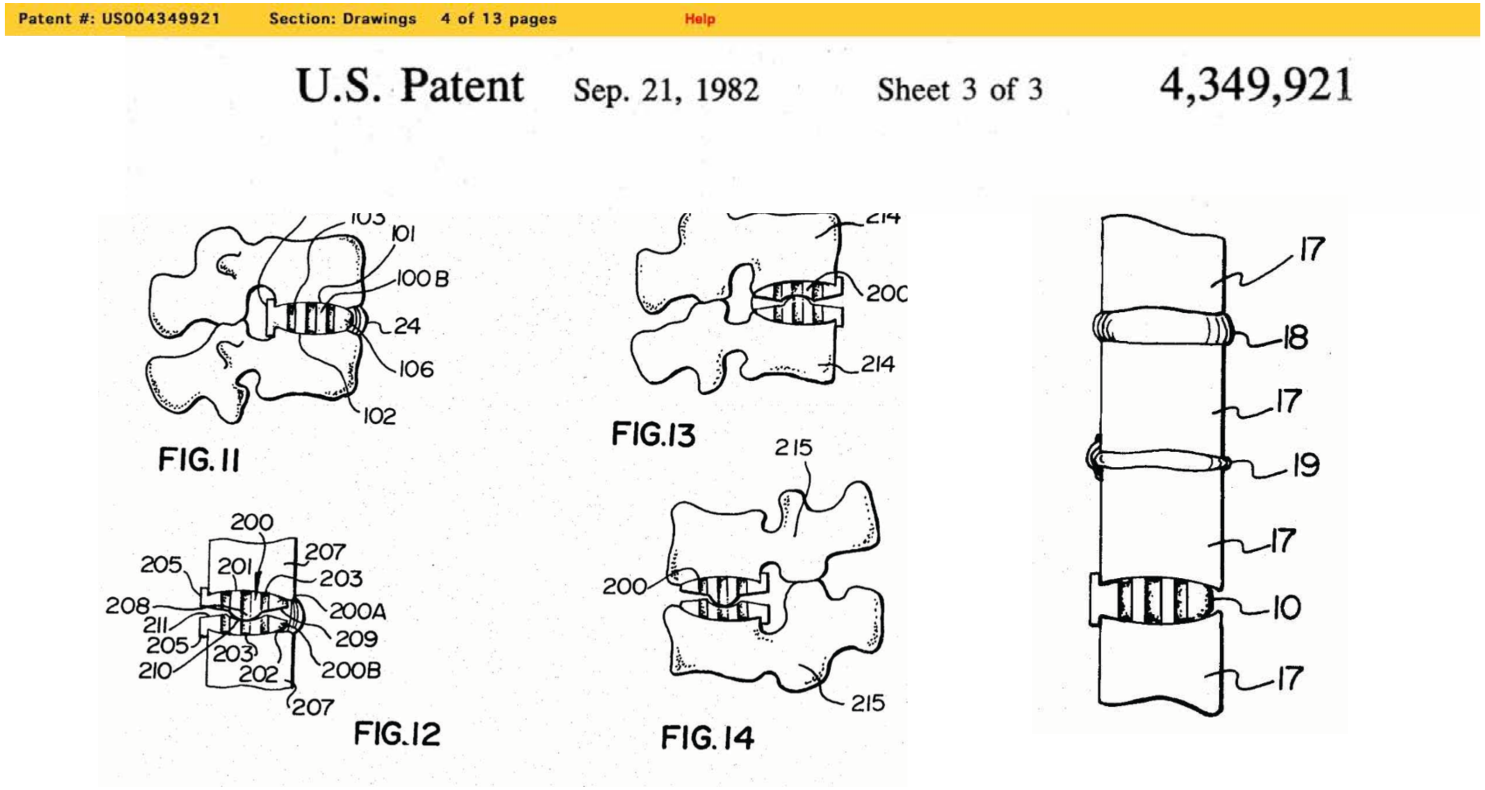
Figs. 4A, B, C. See text.



Figs. 3A, B, C. See text.

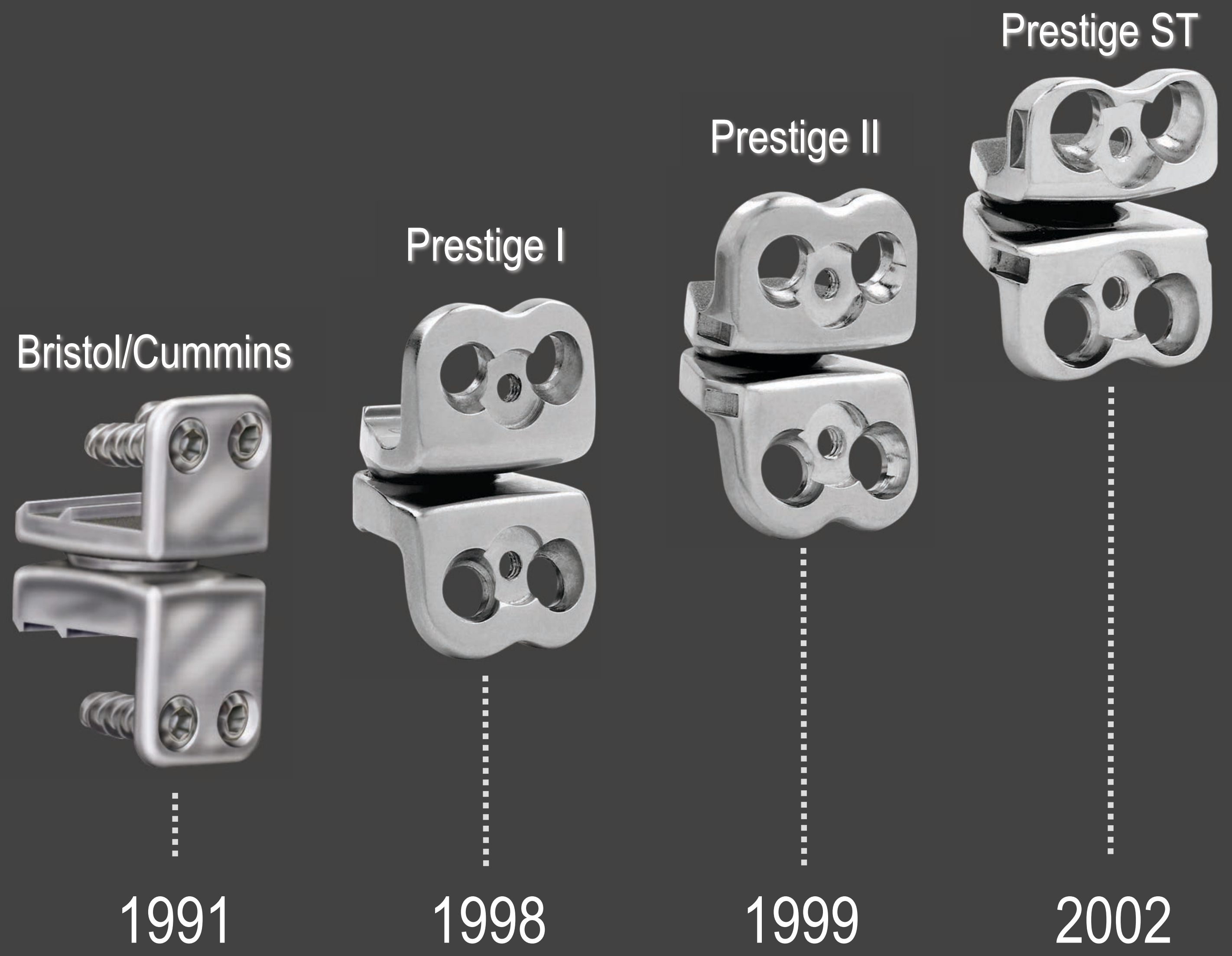
J David Kuntz, Canada

- 521 arthroplasties in 300 patients
  - 1970's – early 1980's



Bristol/Cummins Disc Frenchay Hospital, UK

1991



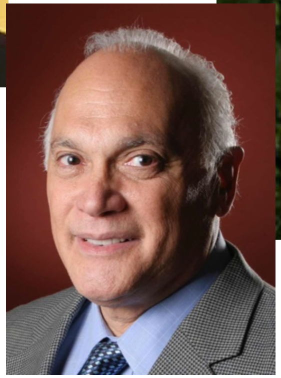
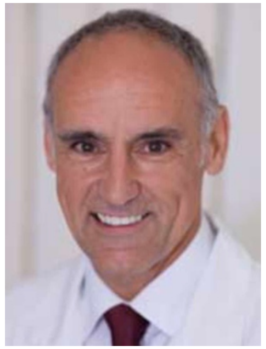
Bristol/Cummins
Prestige I
Prestige II
Prestige ST
1991
1998
1999
2002

1st Annual SAS Global Symposium on Motion Preservation Technology – May 2001, Munich

- 301 attendees
  - 2 from Australia

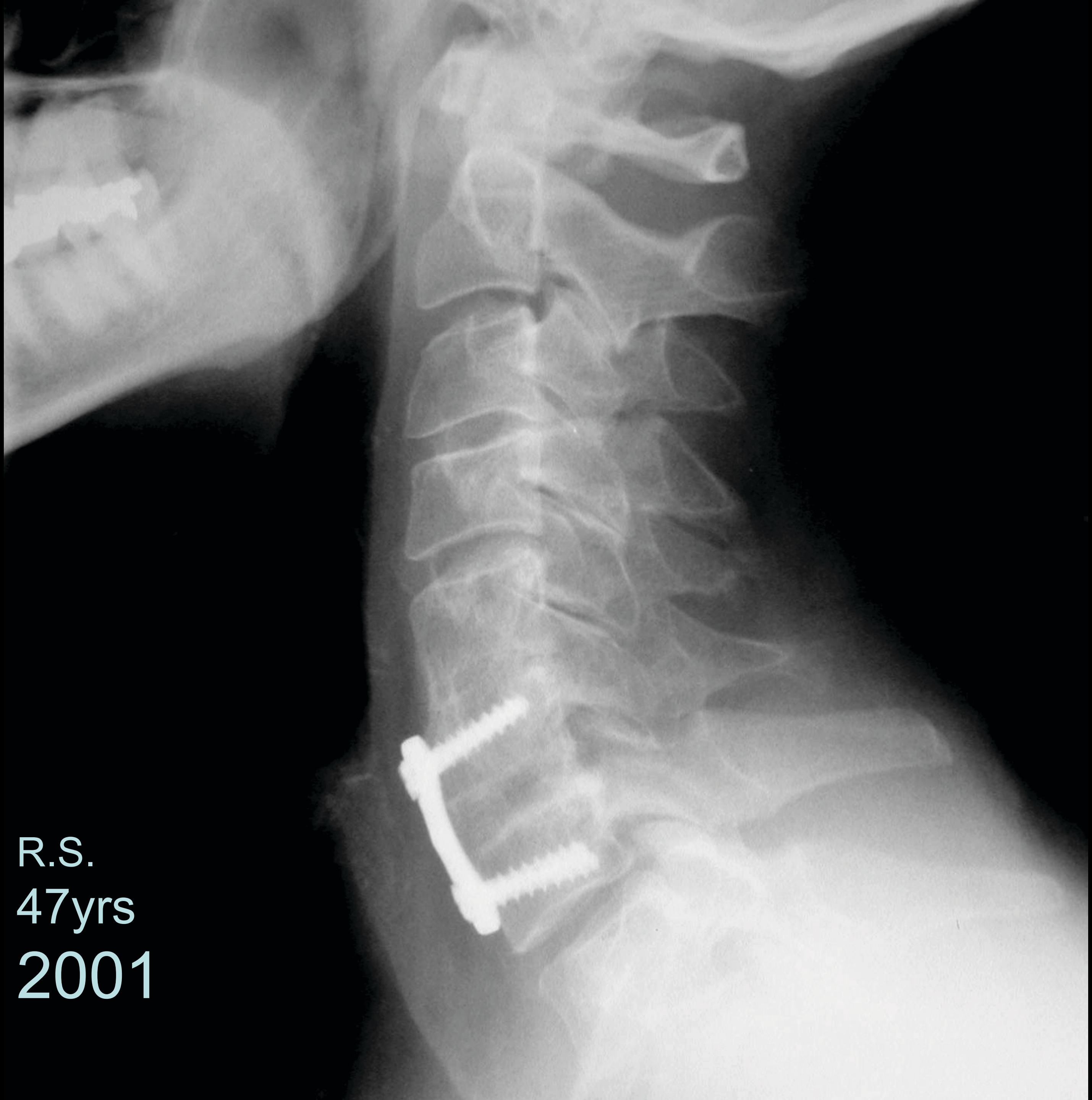




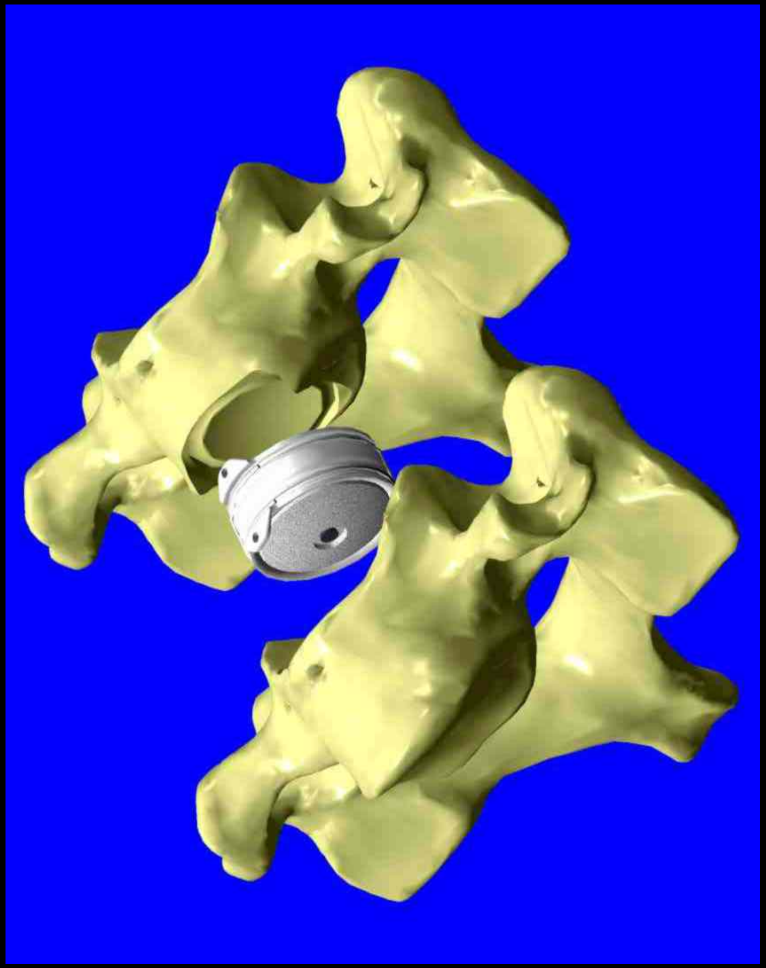

R.S.
39yrs
1992

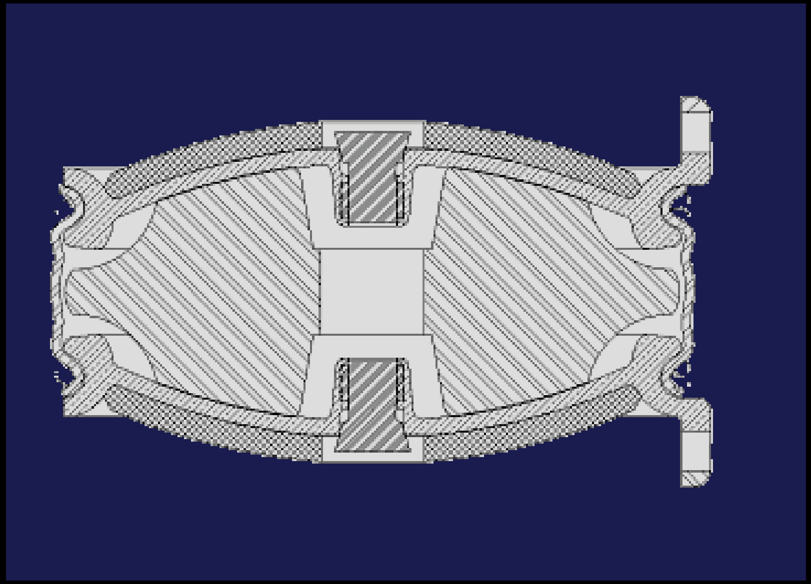
R.S.
43yrs
1997

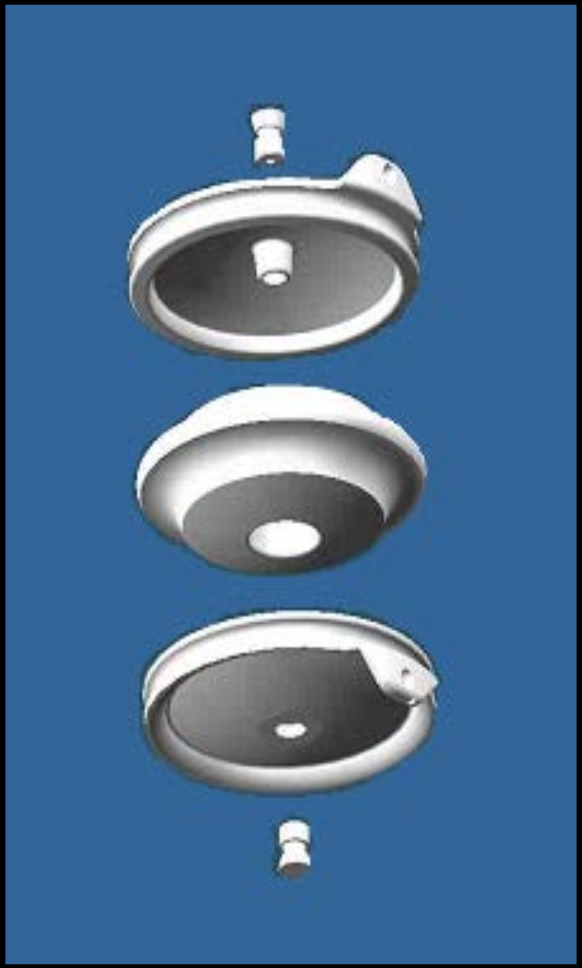

R.S.
47yrs
2001

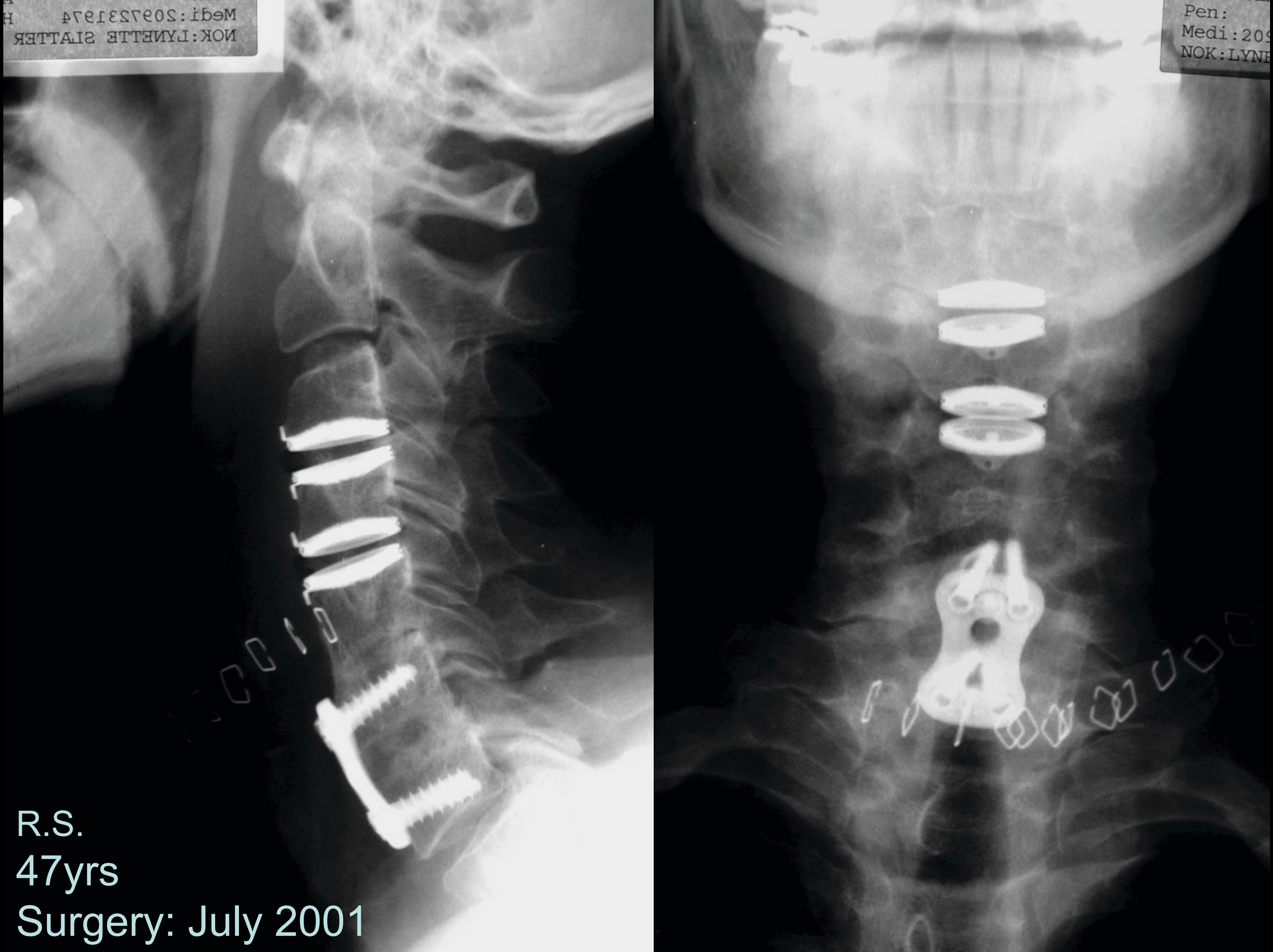
Bryan Disc

Bryan Disc





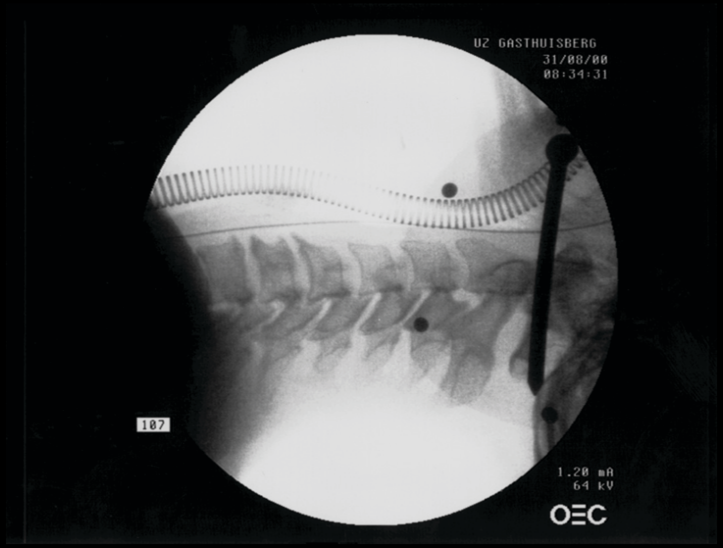


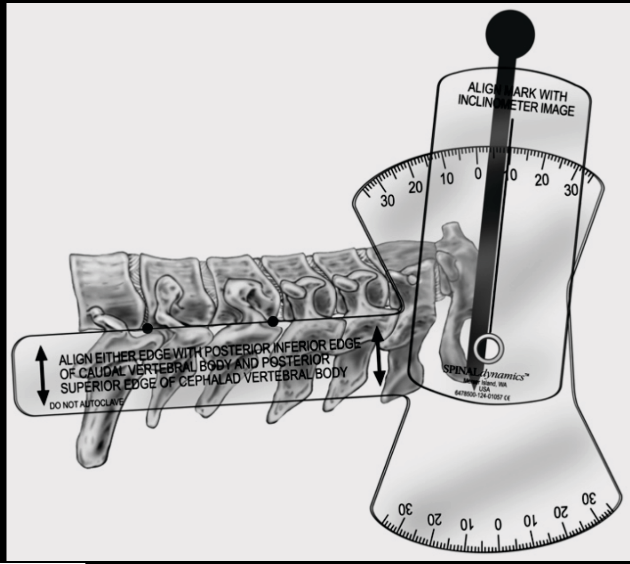


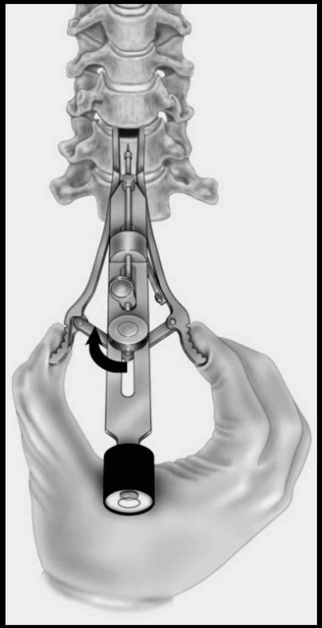
R.S.
47yrs
Surgery: July 2001

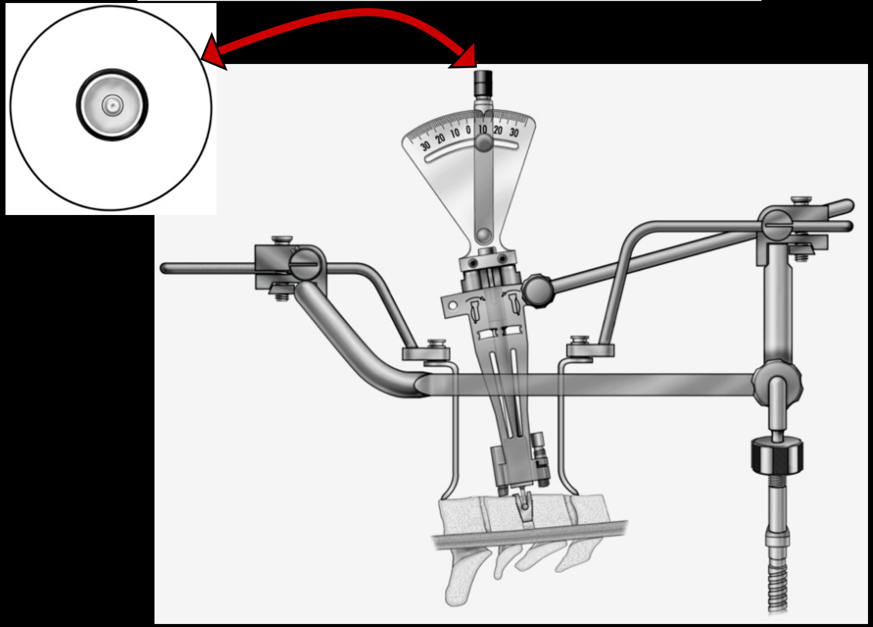
OPERATIVE SYSTEM

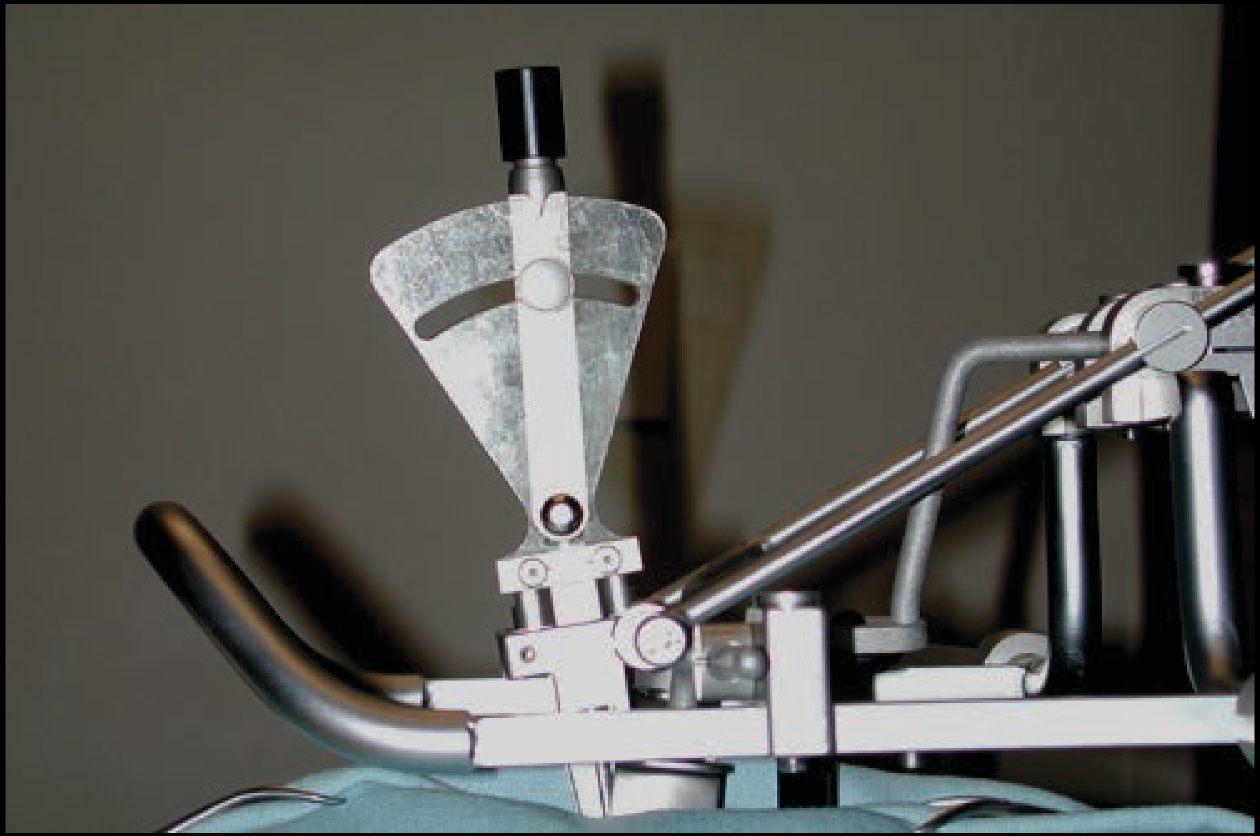
Gravity referenced stereotaxy

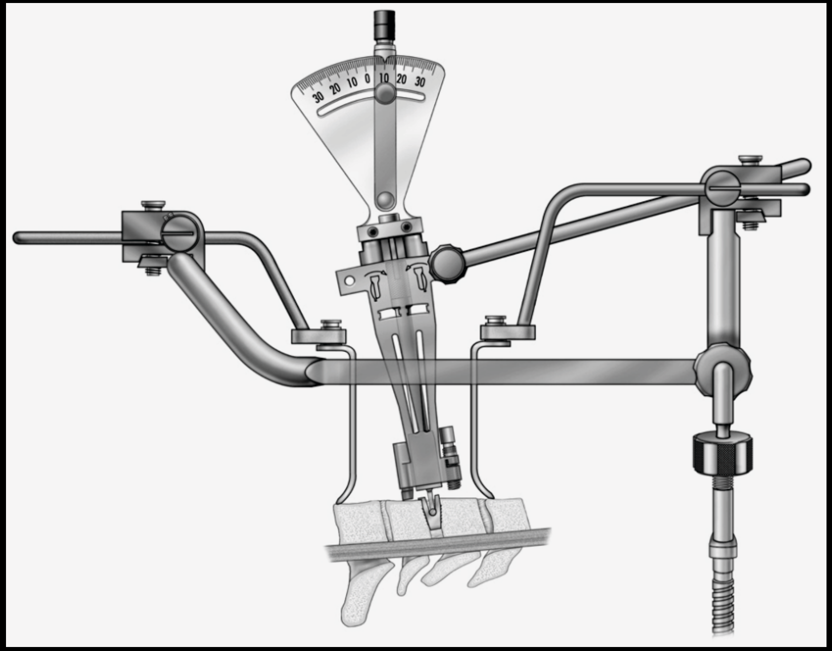




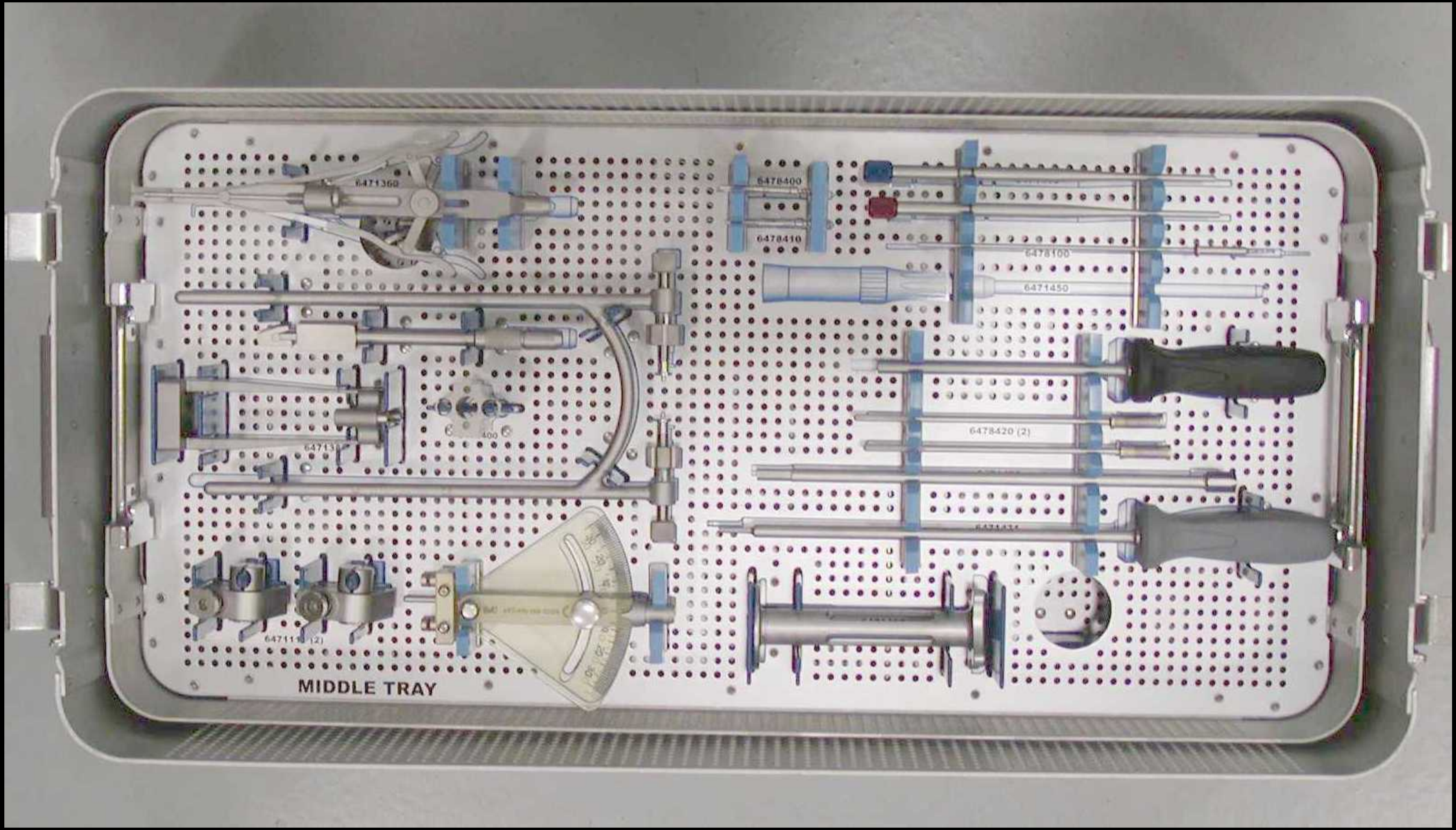


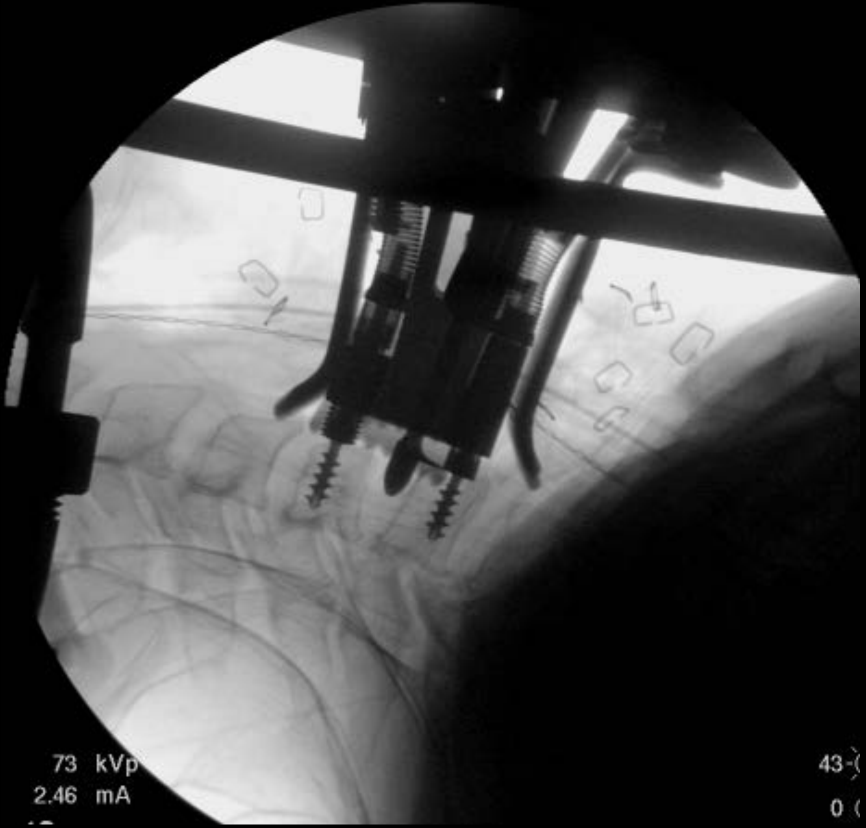


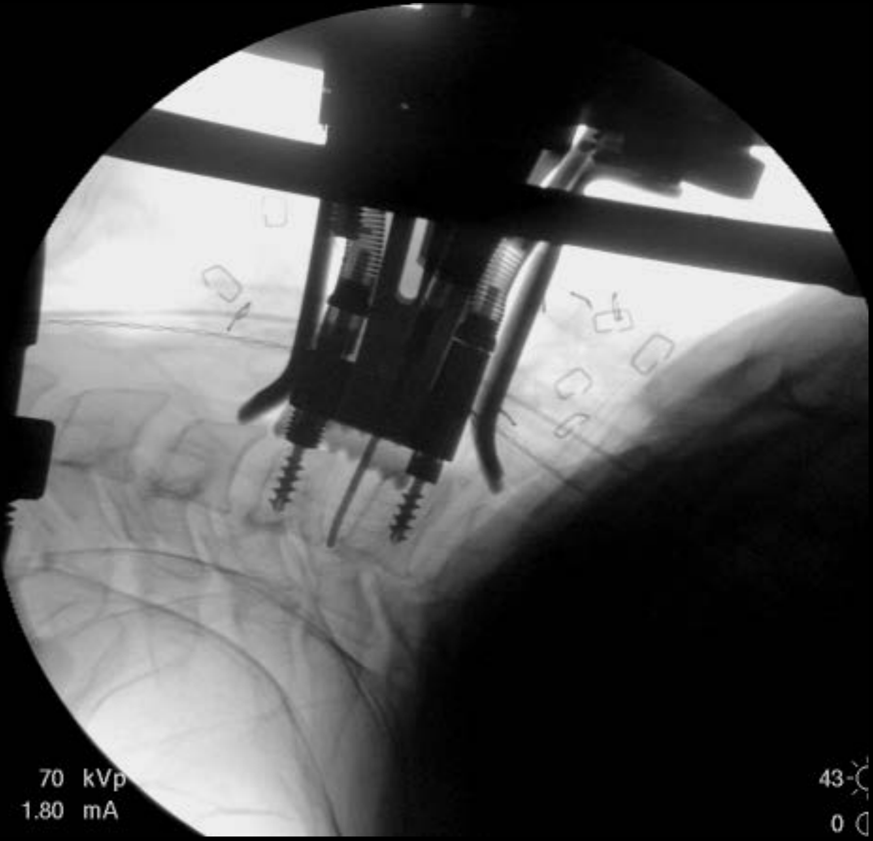



30 20 10 0 10 20 30

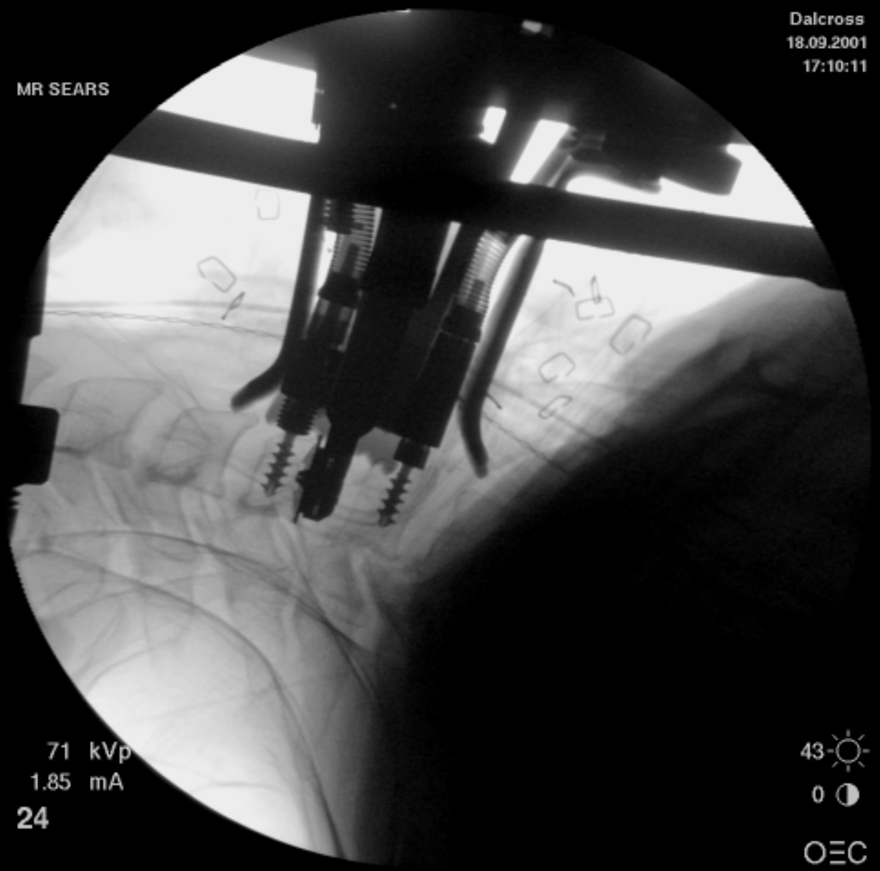
Bryan Cervical Disc Case 2
Alignment & Measurement Tools

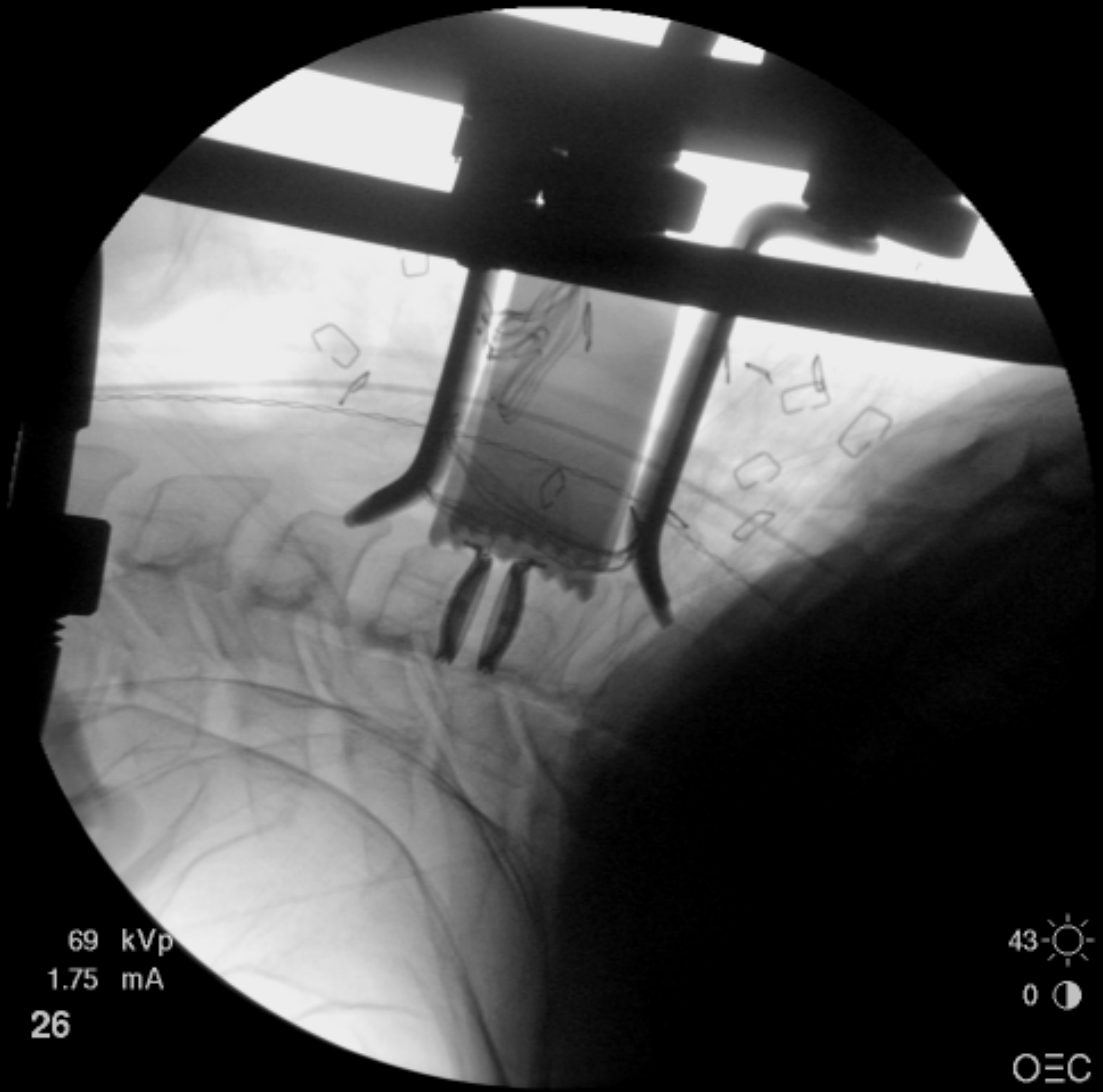


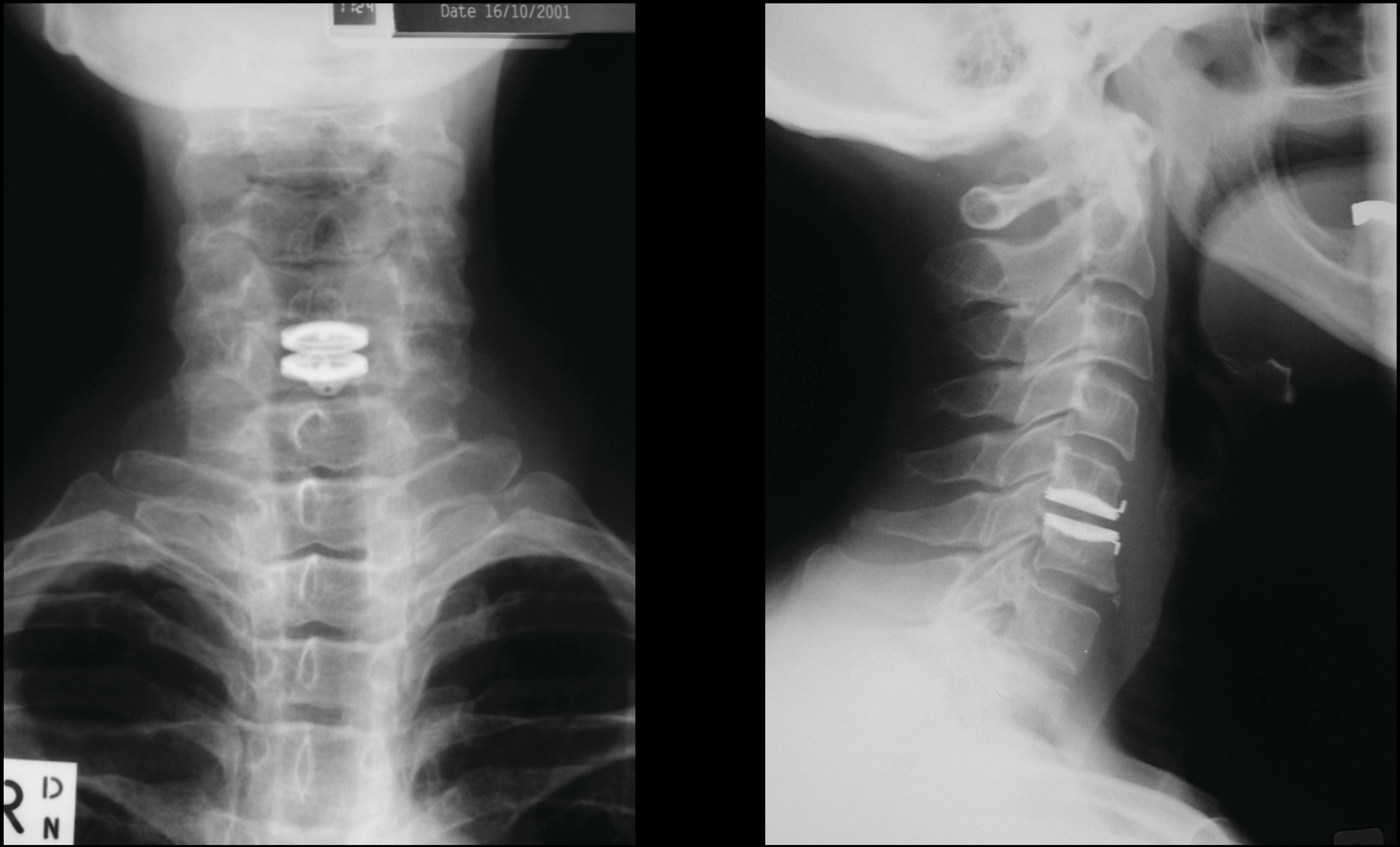

73 kVp
2.46 mA


70 kVp
1.80 mA

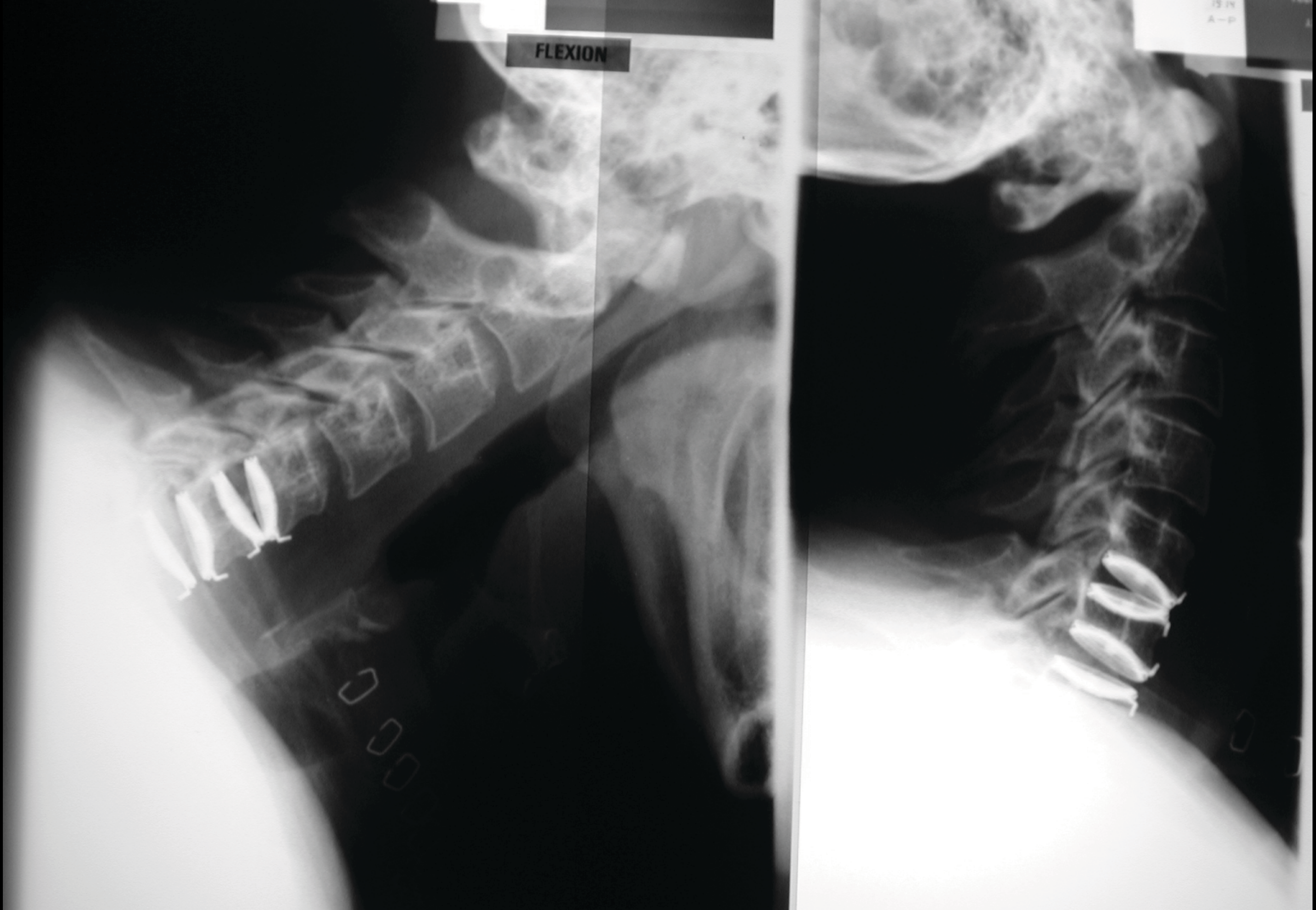

71 kVp
1.80 mA
43
0


Dalcross
18.09.2001
17:10:11
MR SEARS
71 kVp
1.85 mA
24
43
0
OEC


69 kVp
1.75 mA
26
43
0
OEC


Date 16/10/2001
R
D
N

Kyphosis


FLEXION

Sagittal malalignment
Bryan® Cervical Disc

Sears et al, *JSDT 2007*

ORIGINAL ARTICLE

Segmental Malalignment With the Bryan Cervical Disc Prosthesis—Does it Occur?

*William R. Sears, MBBS, FRACS,[*] Lali H. Sekhon, MBBS, PhD, FRACS,[†]
Neil Duggal, MD, MSc, FRCS(C),[‡] and Owen D. Williamson, GradDipClinEpi, FRACS[§]*

ORIGINAL ARTICLE

Segmental Malalignment With the Bryan Cervical Disc Prosthesis—Contributing Factors

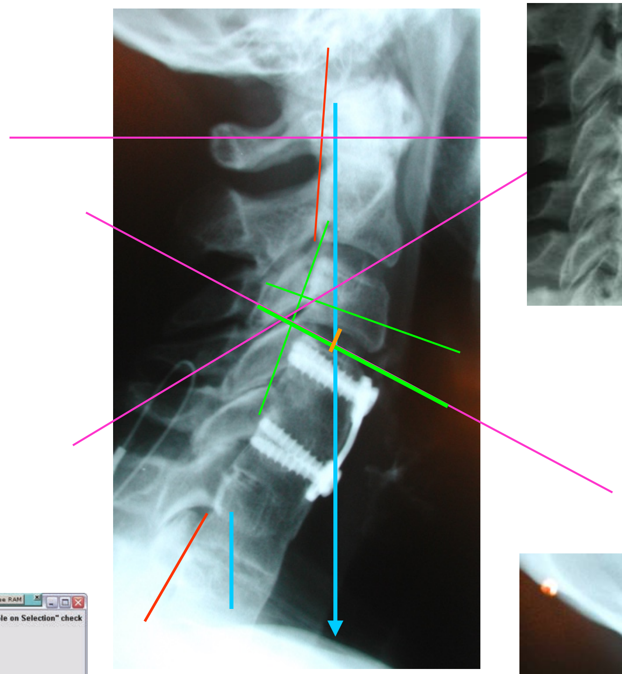
*William R. Sears, MBBS, FRACS,[*] Neil Duggal, MD, MSc, FRCS(C),[†]
Lali H. Sekhon, MBBS, PhD, FRACS,[‡] and Owen D. Williamson, GradDipClinEpi, FRACS[§]*

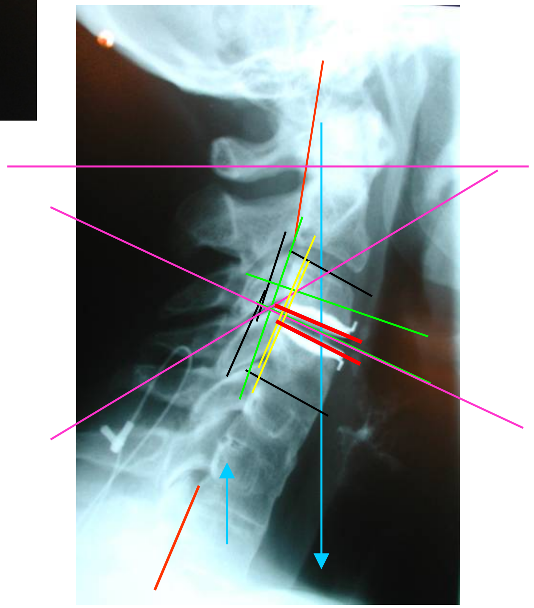
Study Design

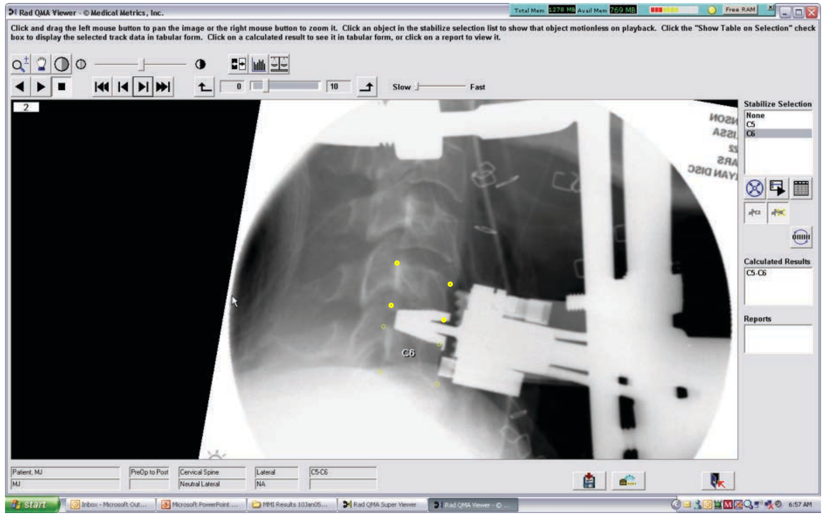
- 67 consecutive patients *(x-rays available)*
- 88 disc levels
- 3 surgeons, 2 countries

35 possible predictors studied

- Pre-Operative
- Operative
- Post-Operative

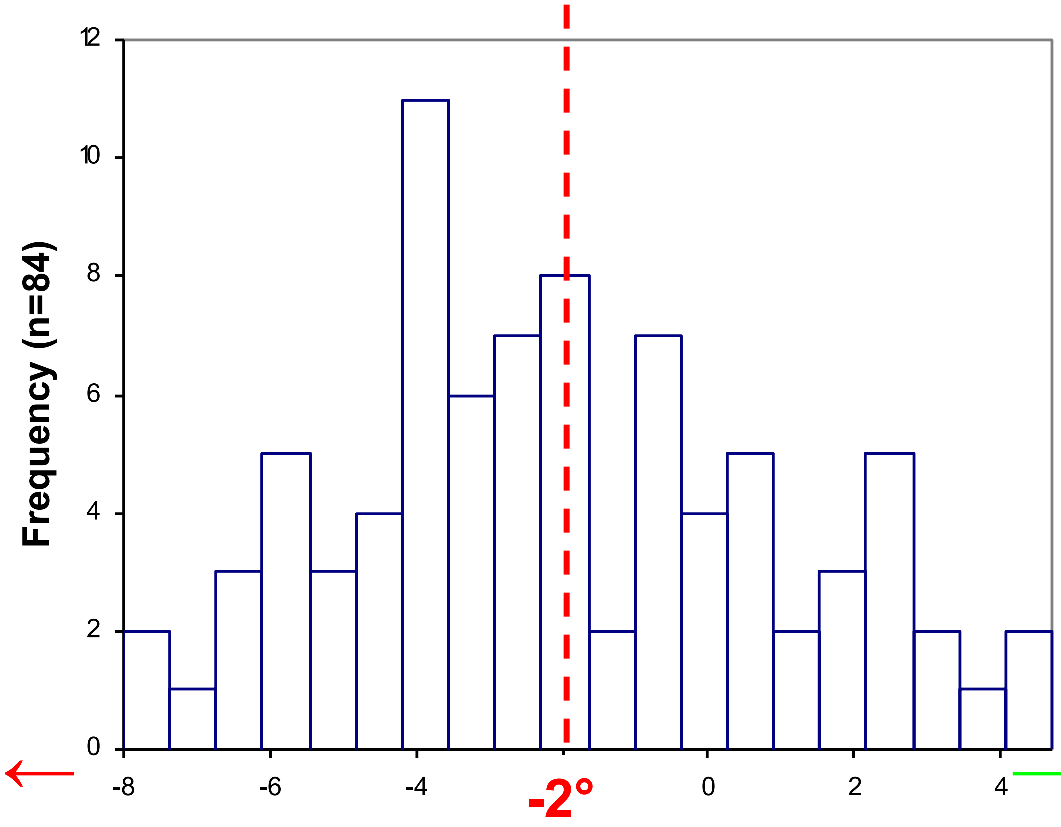






Outcome measures

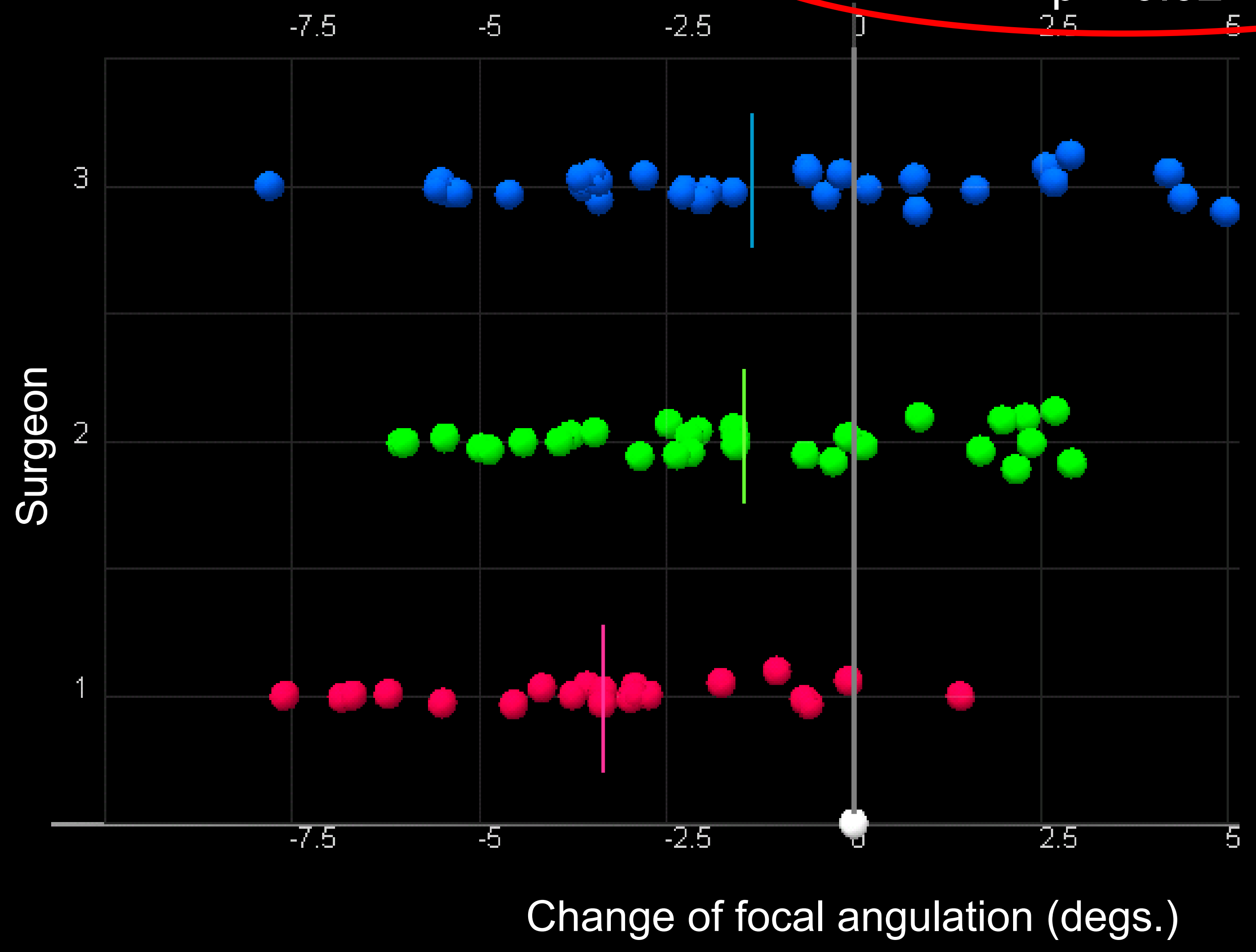
Post-op FSU angulation (n = 84)



8° Kyphosis ← → **5° Lordosis**

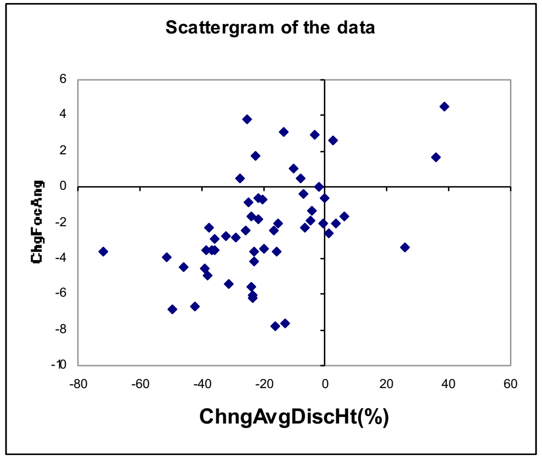
Change of FSU angulation
3 surgeons

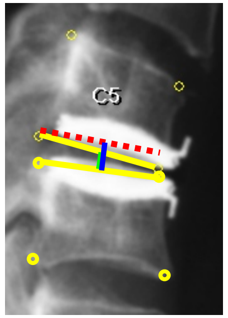
Surgeons 1& 2 vs. Surgeon 3:
p = 0.02



Change in Post-operative FSU angulation

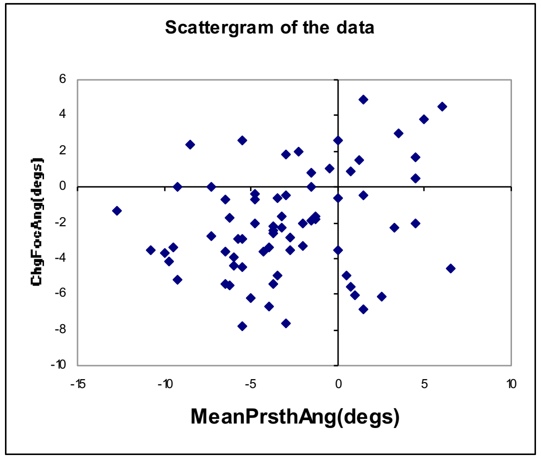
Significant uni-variate correlations

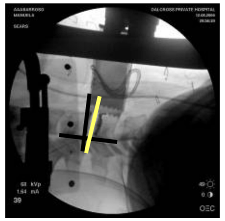




Change in avge. Disc Space height (%)

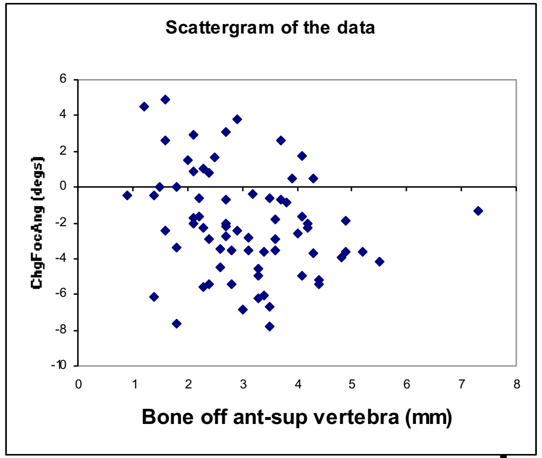
$r_s = 0.54, \ p<0.0001$

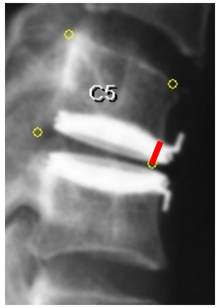




Angle of prosthesis insertion

$r_s = 0.36, \ p=0.003$

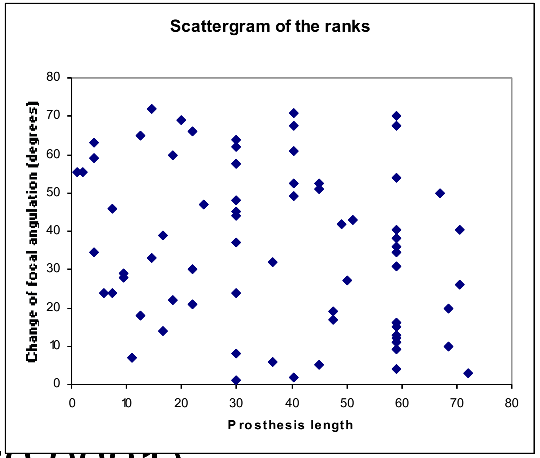




r = 0.54 (p<0.0001)

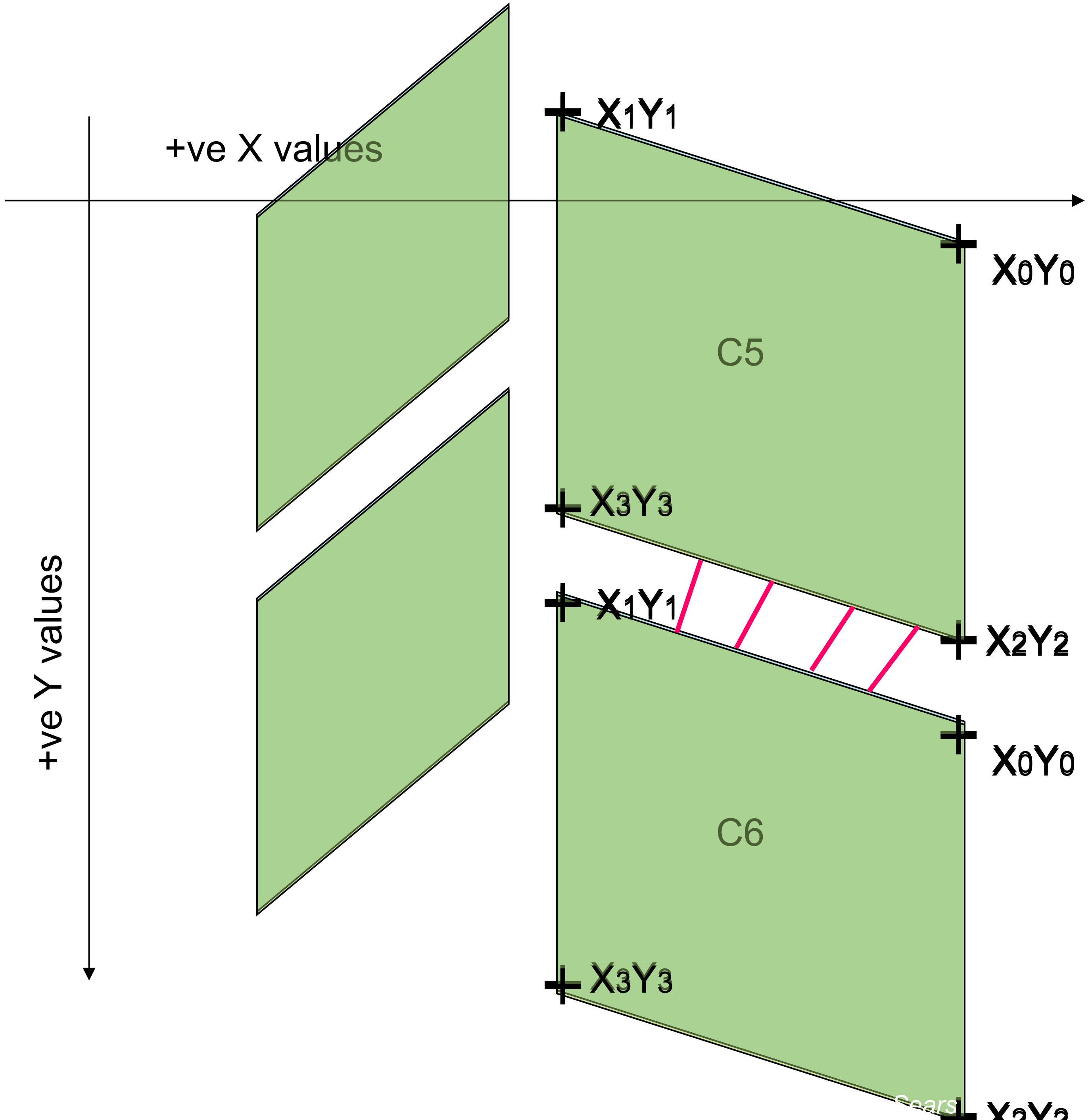
Bone removal ant-sup vertebra

$r_s = -0.28, \ p=0.02$

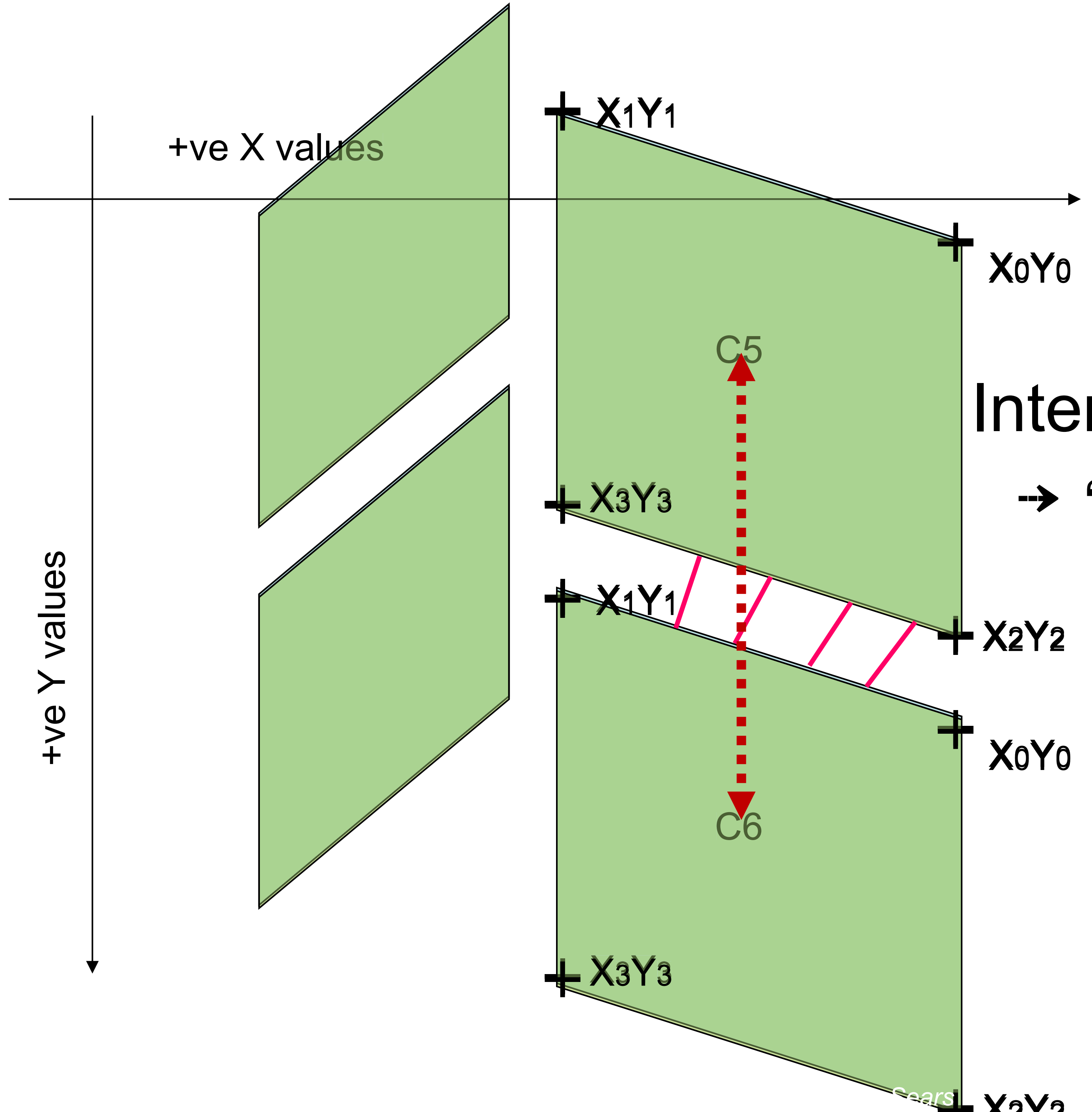


Prosthesis length

$r_s = -0.25, \ p=0.04$

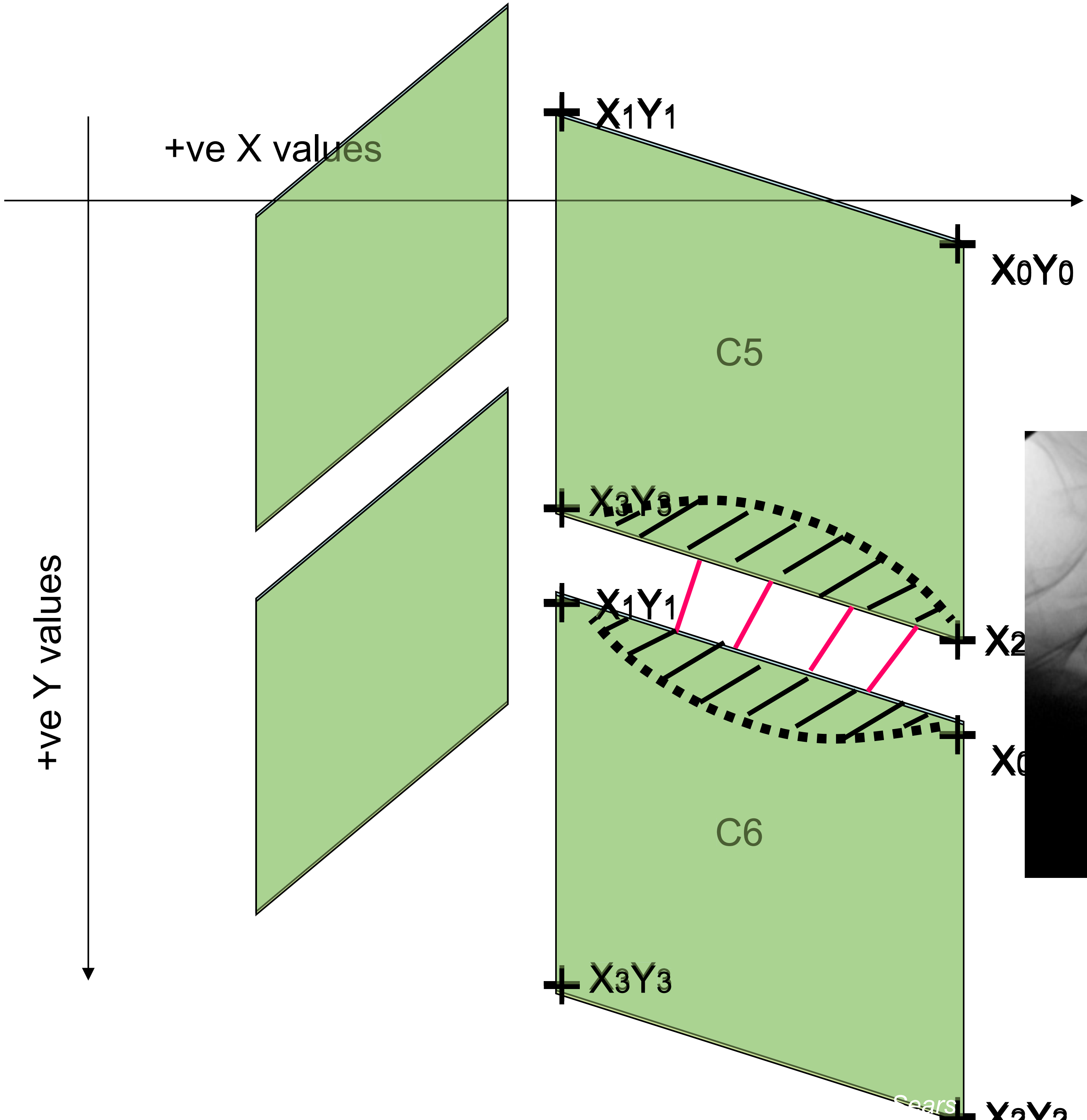


+ve X values
+ve Y values
X_1Y_1
X_0Y_0
C5
X_3Y_3
X_1Y_1
X_2Y_2
X_0Y_0
C6
X_3Y_3

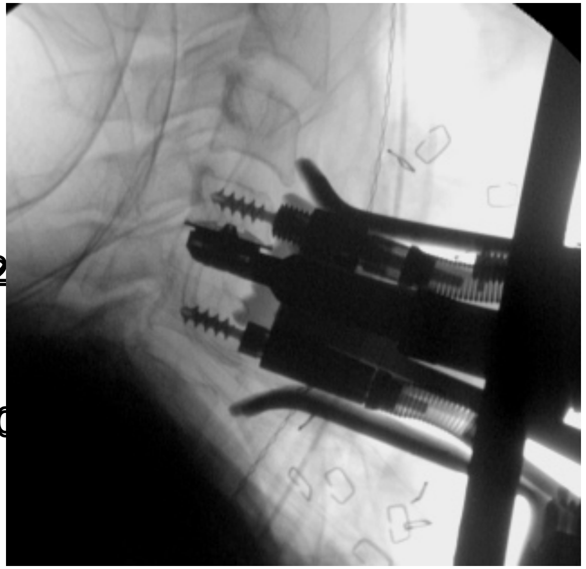


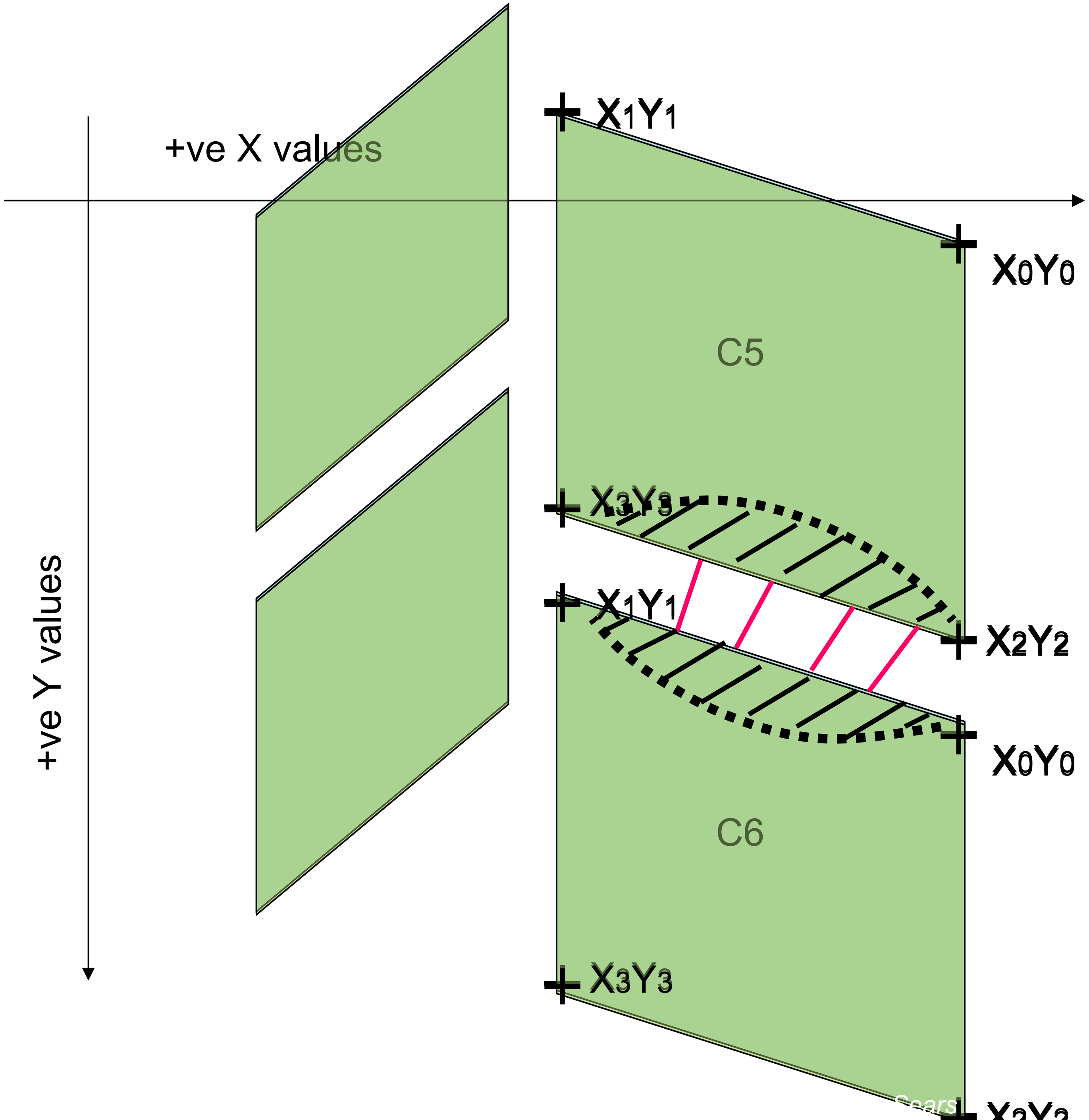
Intervertebral distance

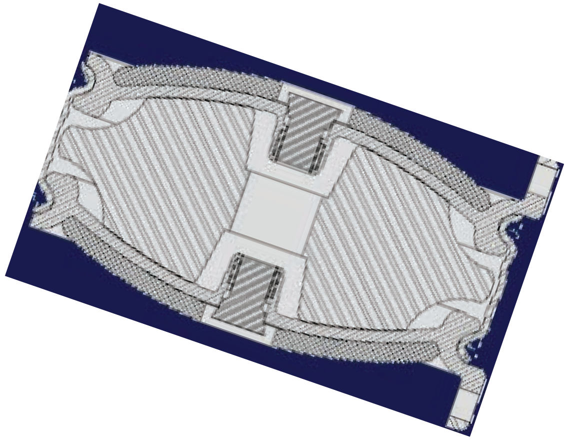
→ ‘Disc-space height’

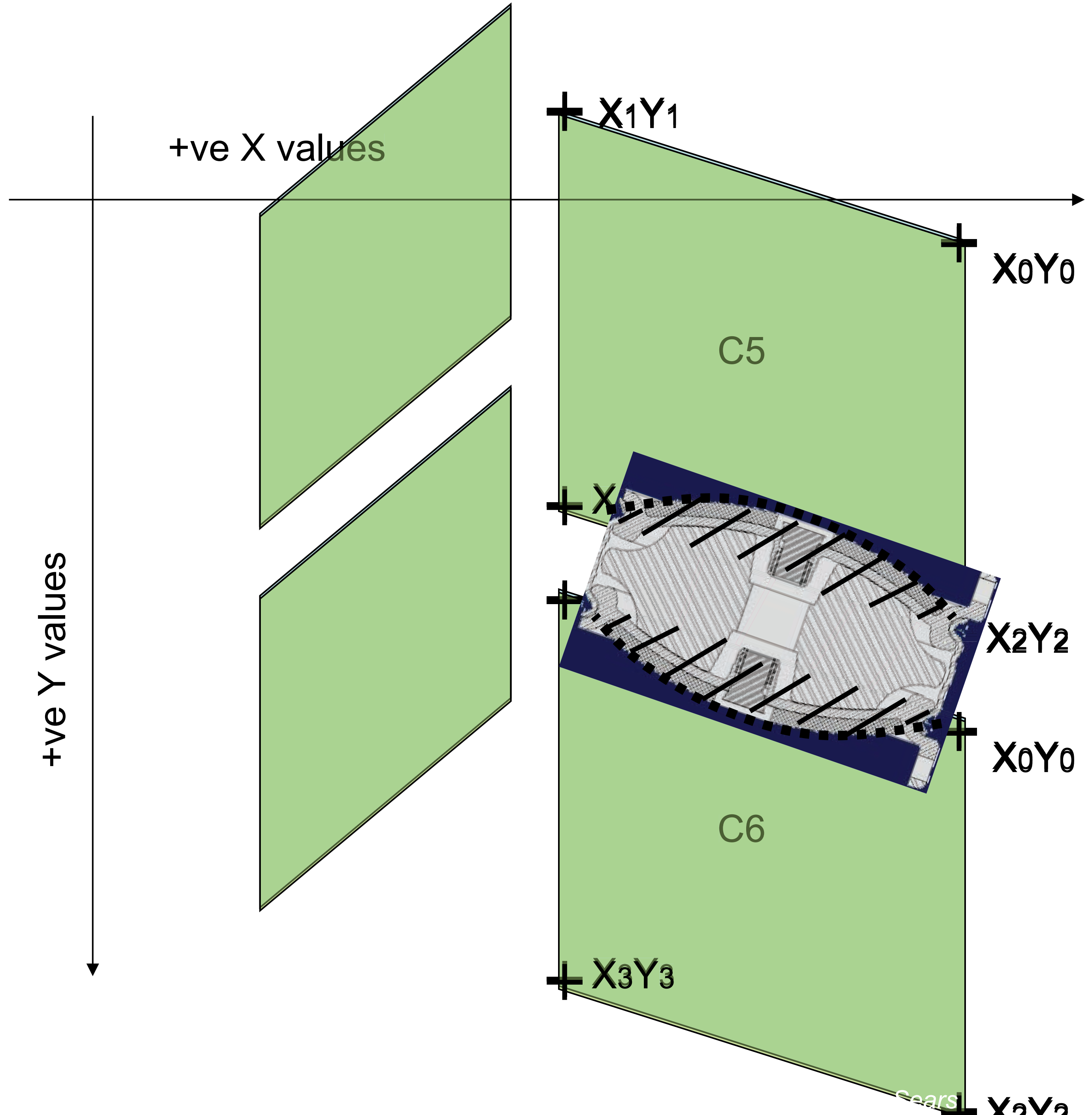


+ve X values
+ve Y values
X_1Y_1
X_0Y_0
C5
X_3Y_3
X_2
X_1Y_1
X_0
C6
X_3Y_3



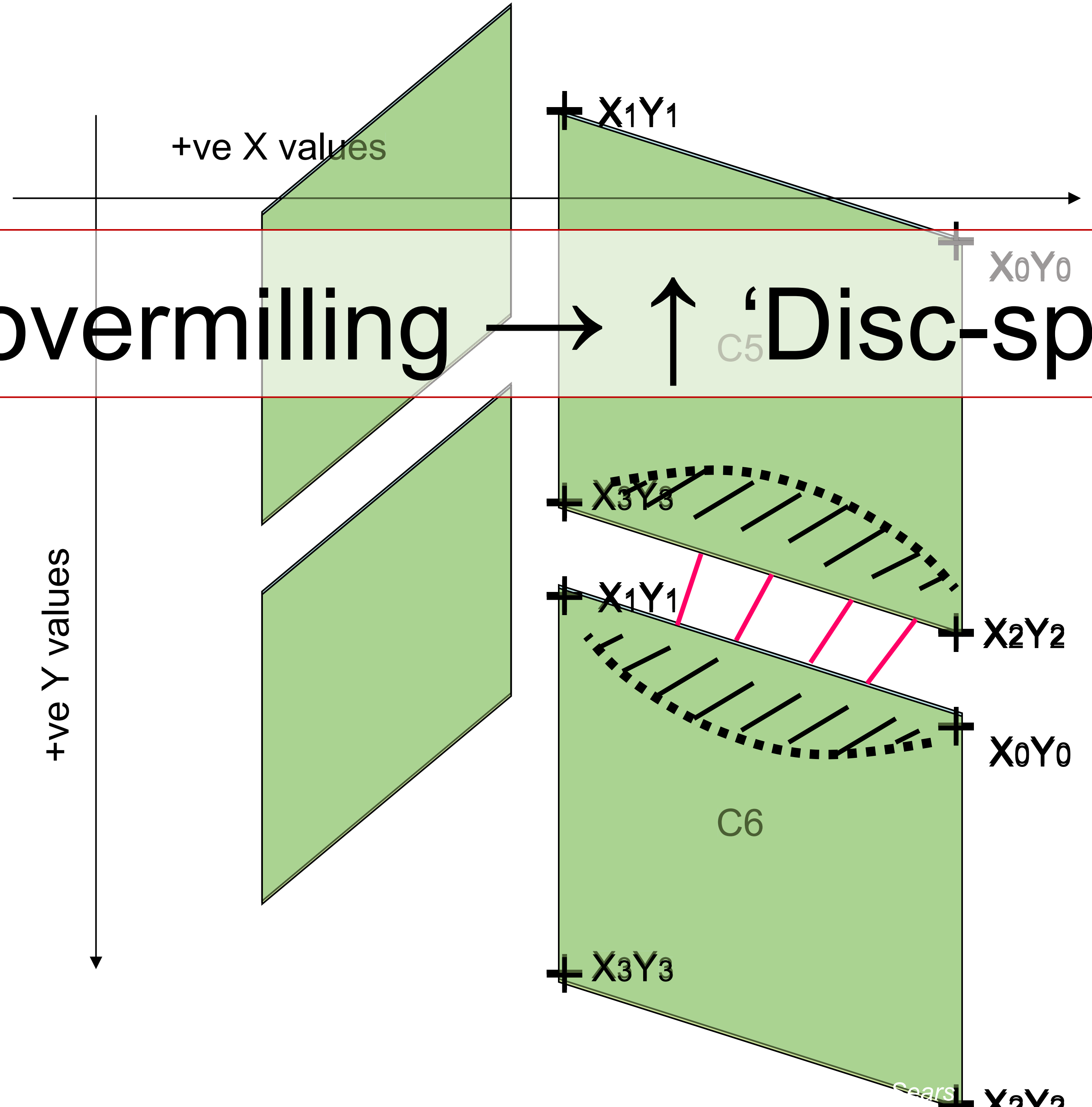

+ve X values
+ve Y values
X_1Y_1
X_0Y_0
C5
X_3Y_3
X_2Y_2
X_1Y_1
X_0Y_0
C6
X_3Y_3
X_2Y_2
Sears



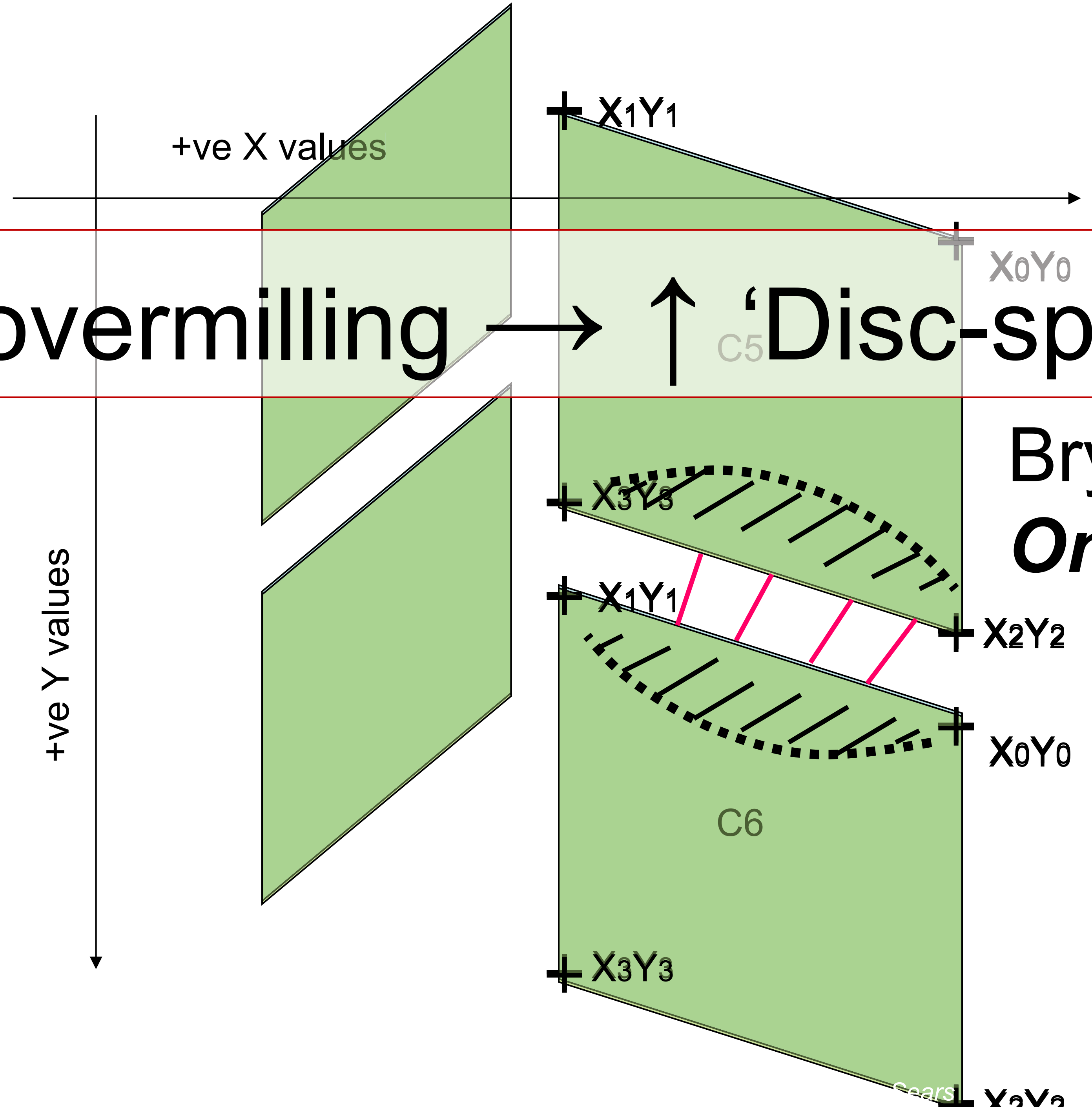


X1Y1
+ve X values
X0Y0
C5
X2Y2
X0Y0
+ve Y values
C6
X3Y3

If overmilling → ↑ ‘Disc-space height’

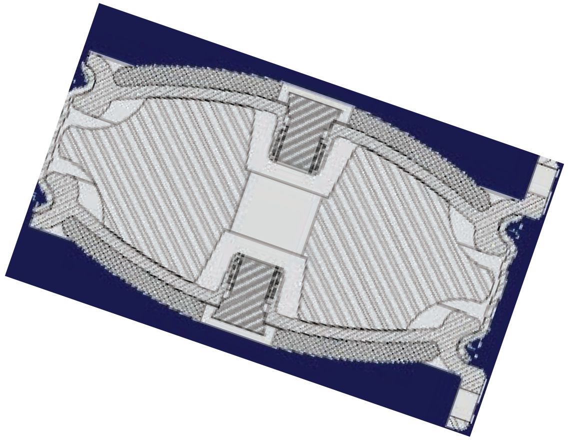


If overmilling → ↑ ‘Disc-space height’

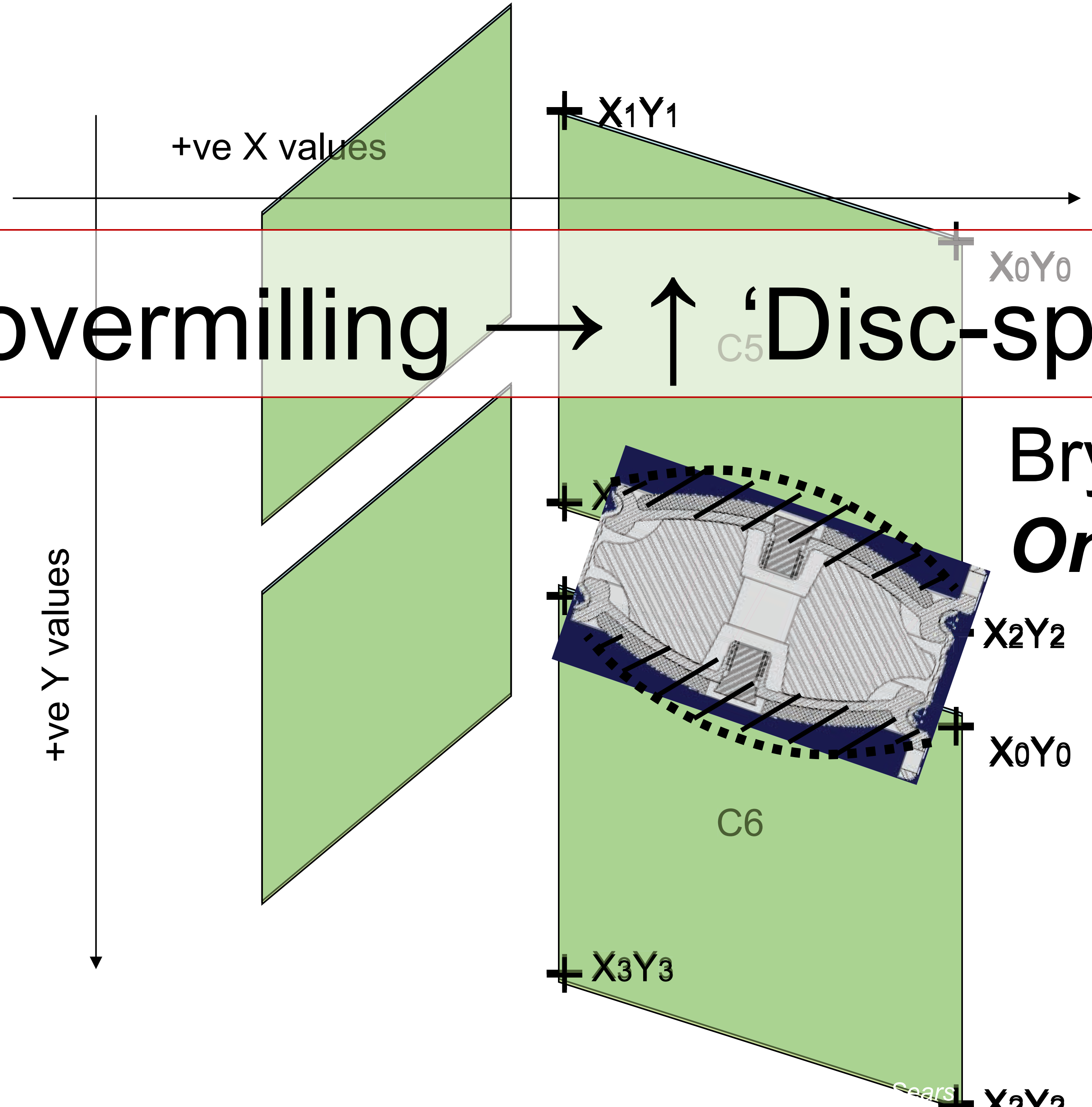


Bryan prosthesis:

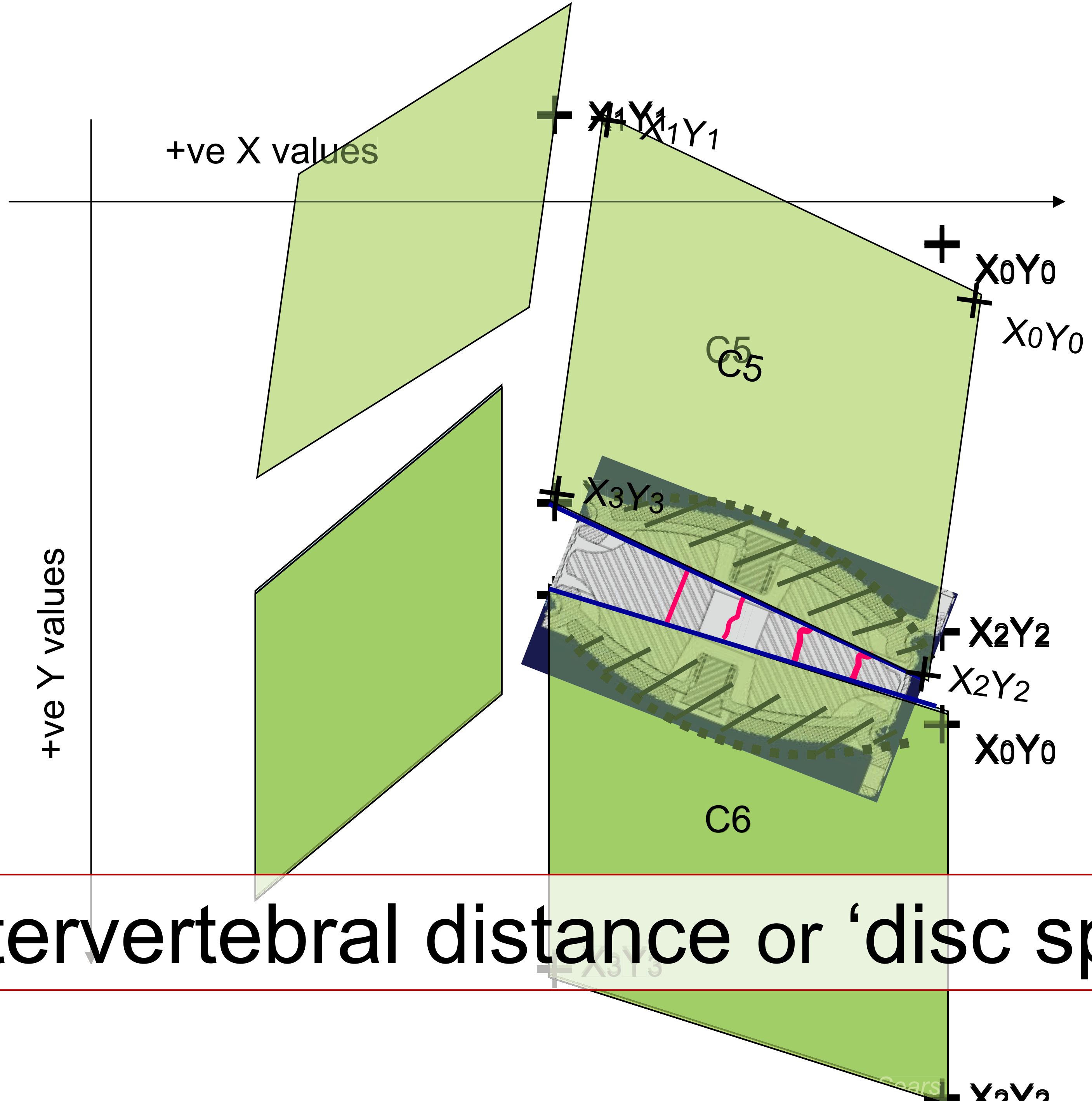
One height only



If overmilling → ↑ ‘Disc-space height’



Bryan prosthesis:
One height only



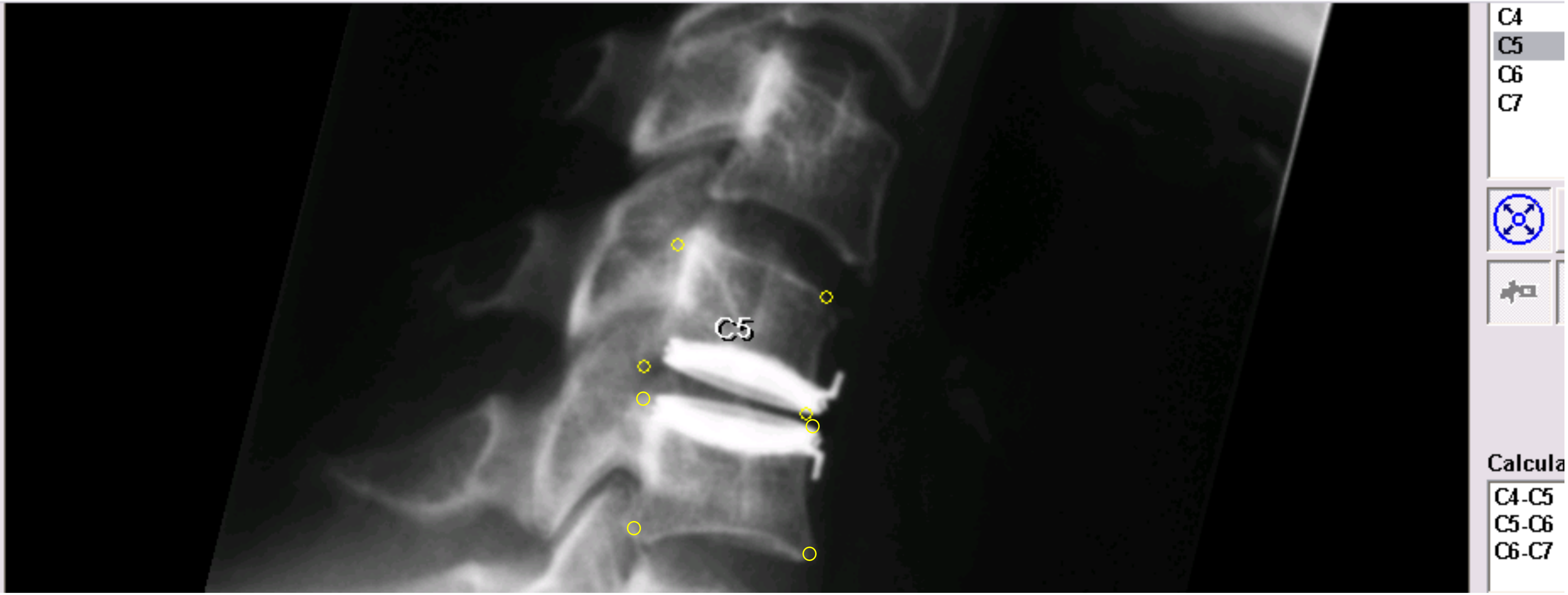
Kyphosis

↓ Intervertebral distance or ‘disc space height’

Measuring Change of Disc-space Height
(or intervertebral distance)

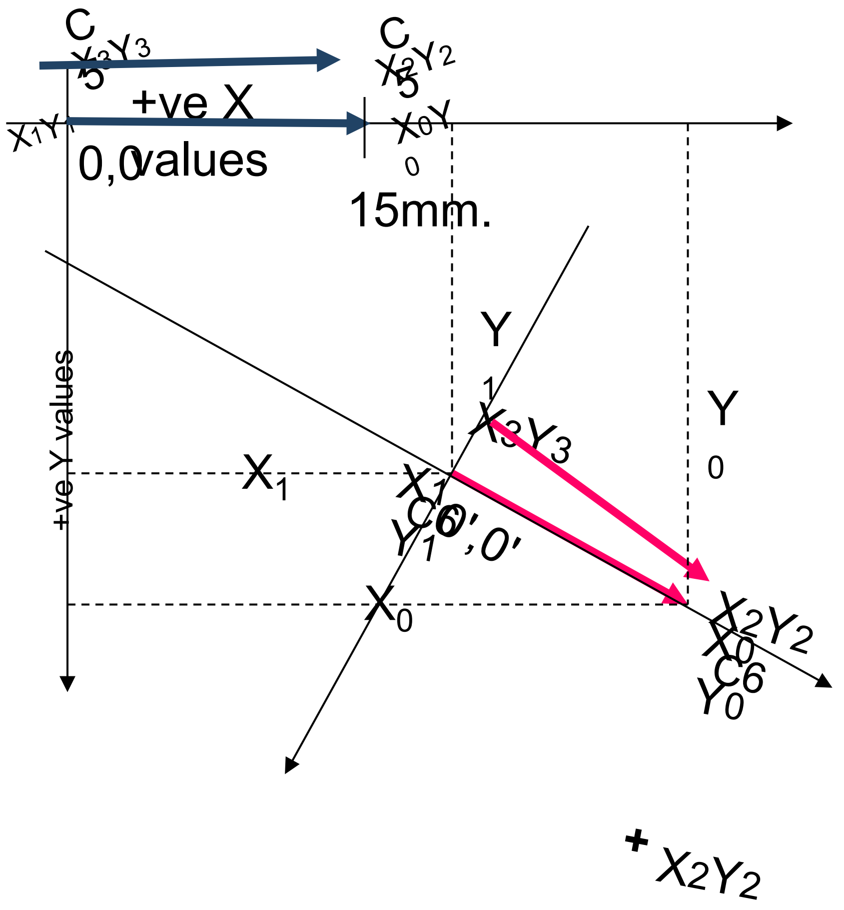
C5

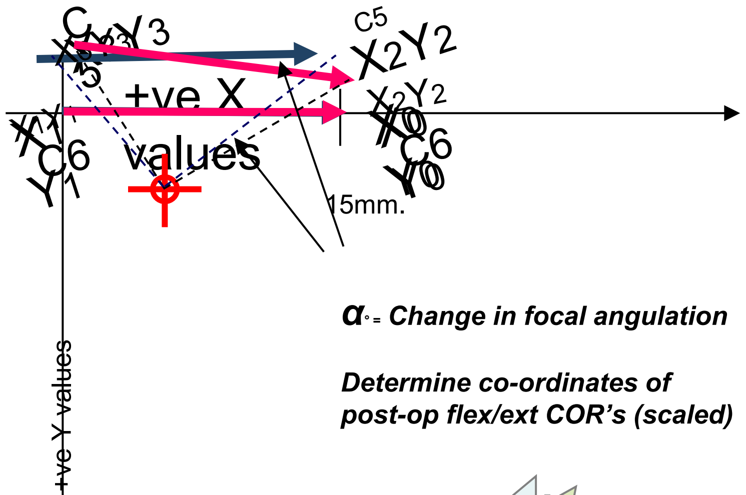
Frame	X Position (mm)	Y Position (mm)	Angle (deg)	Landmark 0 X (mm)	Landmark 0 Y (mm)	Landmark 1 X (mm)	Landmark 1 Y (mm)
0	92.55	109.65	0.00	103.20	105.30	85.50	99.00
1	70.57	96.22	14.08	79.8[illegible]	89.41	61.14	87.61



Measuring Change of Disc-space Height

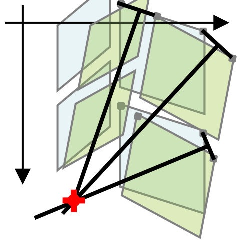
Correction for segmental kyphosis





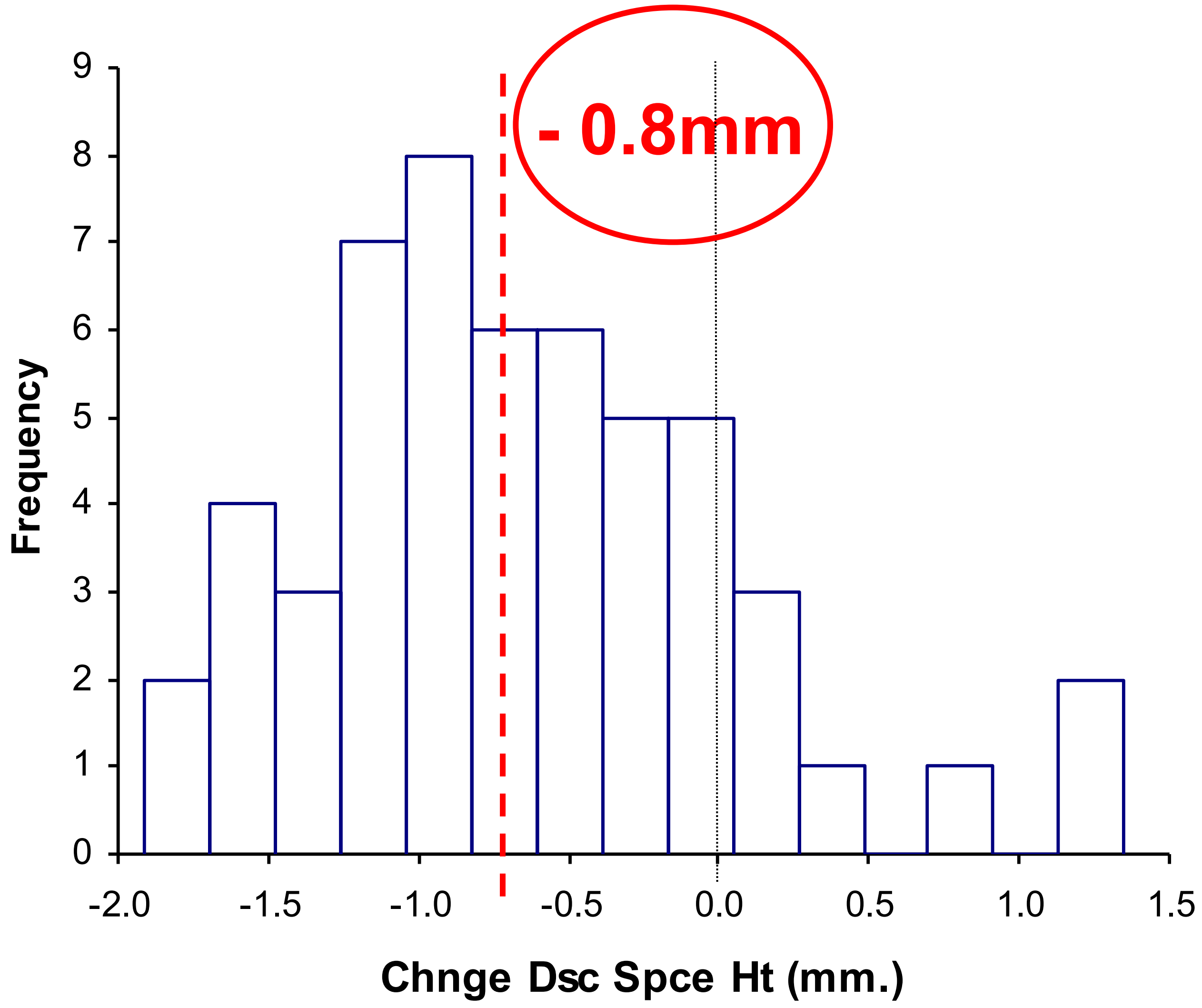
α = Change in focal angulation

Determine co-ordinates of post-op flex/ext COR's (scaled)



Corrected change of disc space height (mm.)

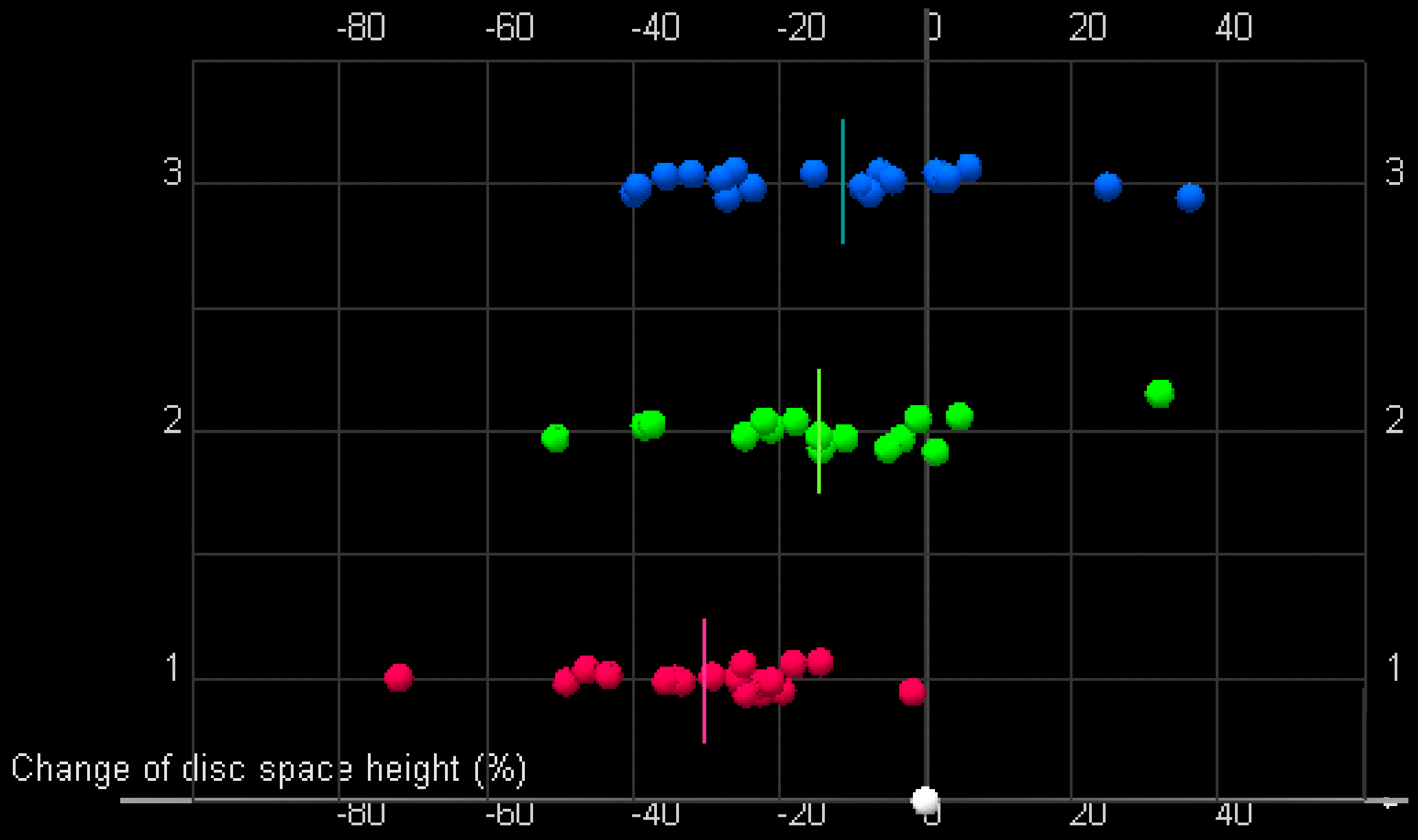
n = 53



Change (loss) of disc space height (%)

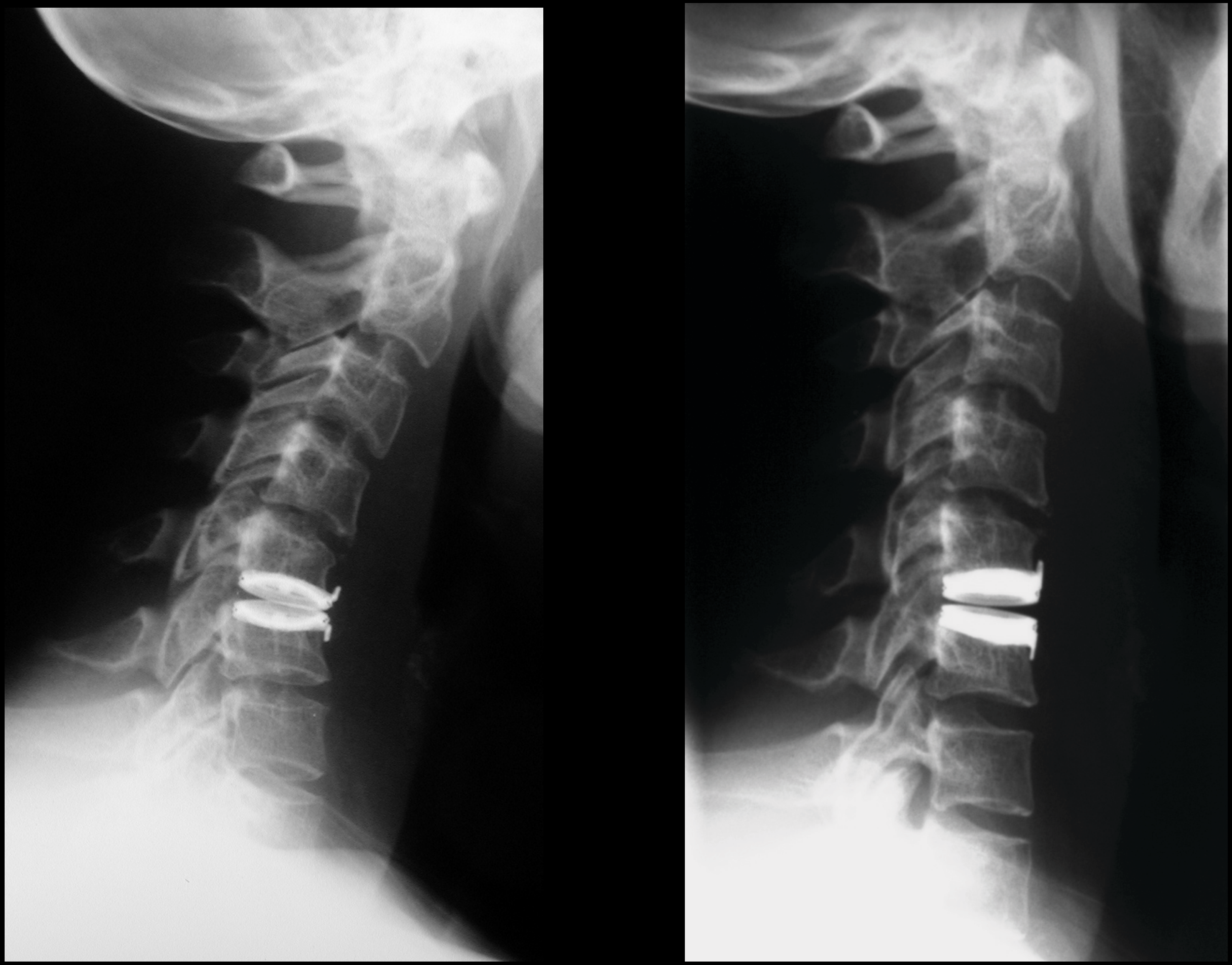
3 surgeons

Surgeon 3 vs. Surgeons 1+2:
p = 0.007



Neutral Pre & Post-ops

Custom over-height prosthesis



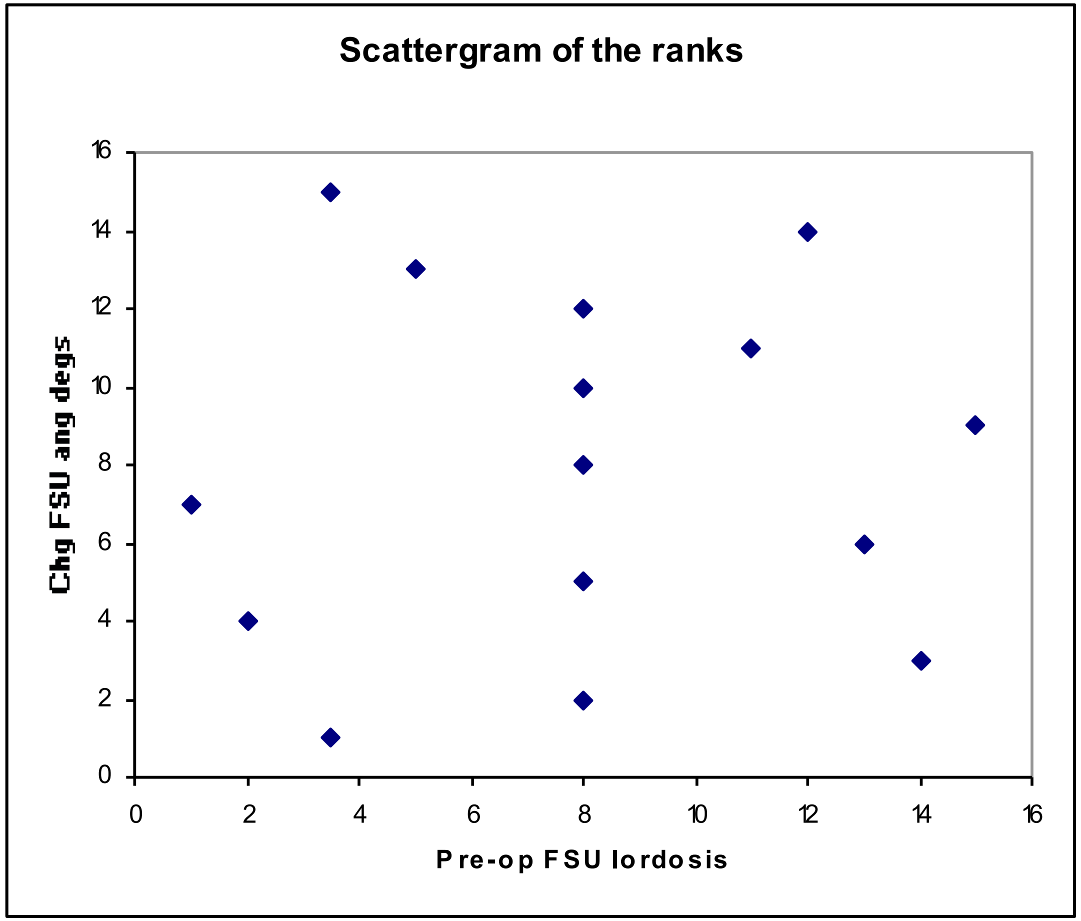
Neutral Pre and Post-ops (Revision surgery March 2, 2004)

Subsequent unpublished Study

Sears *et al*

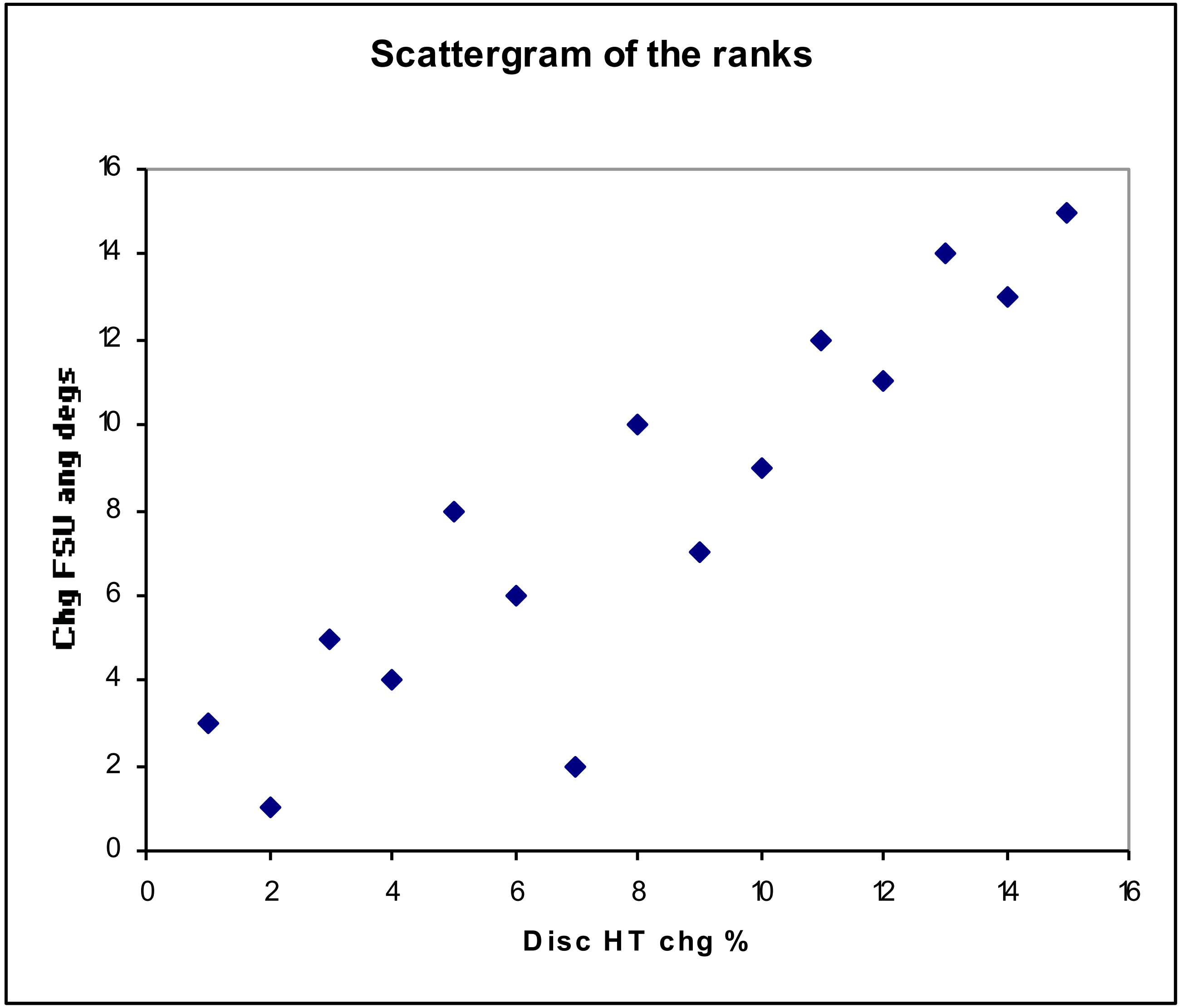
- 9 patients, 15 disc prostheses,
- September 2005 – September 2006
  - Care to avoid subsidence during disc space distraction,
  - PLL preserved where possible,
  - Deliberate undermilling

Change in index segmental lordosis *vs.* Preoperative index segmental lordosis (n=15)



$r_s = 0.058$, $p = 0.84$

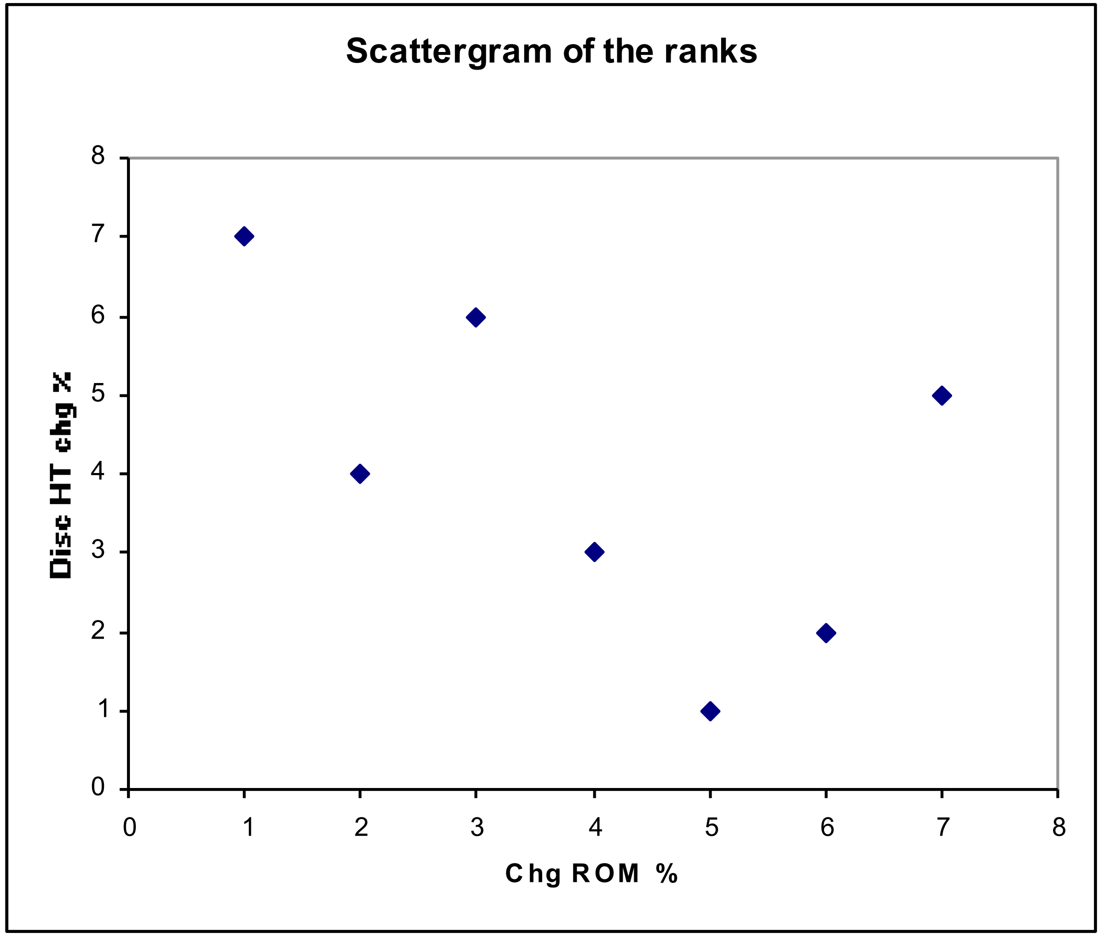
Change in FSU lordosis vs. Change in Disc Space Height (n=15)



$r_s = 0.90$

$p < 0.0001$

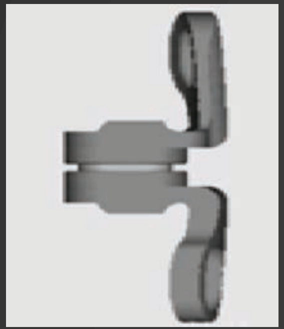
Change in Range-of-motion vs. Change in Disc Space Height (n=7)

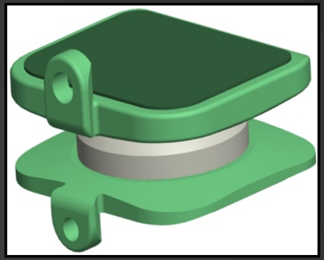


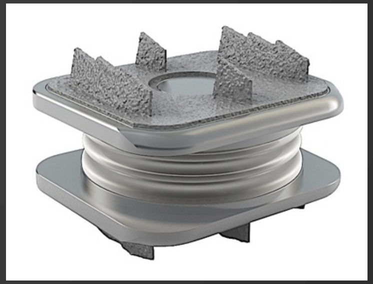
$r_s = -0.5$

$p = 0.21$

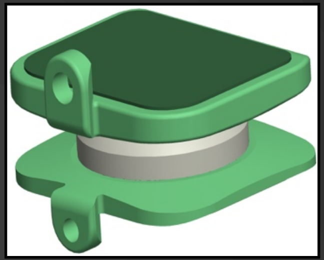
Disc prosthesis kinematics

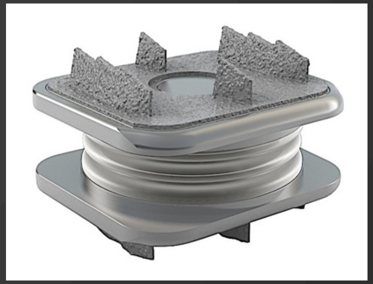


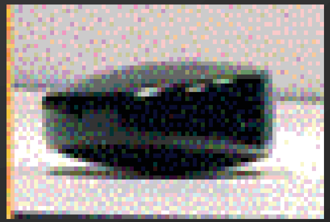


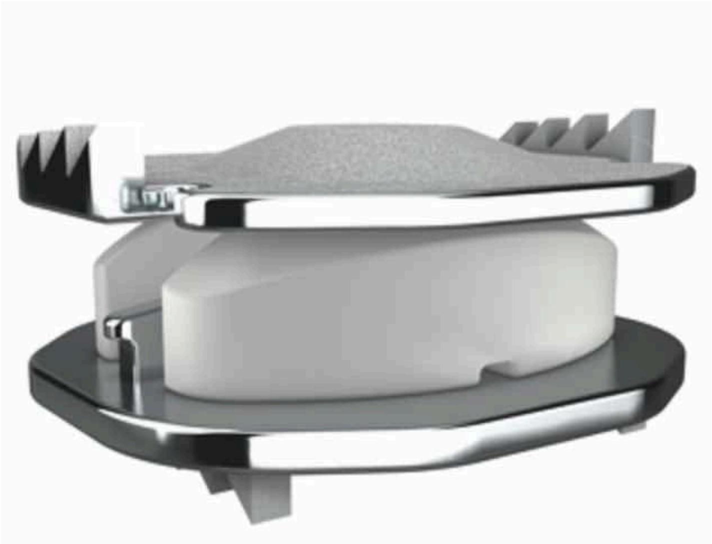


Do they matter… *clinically*?

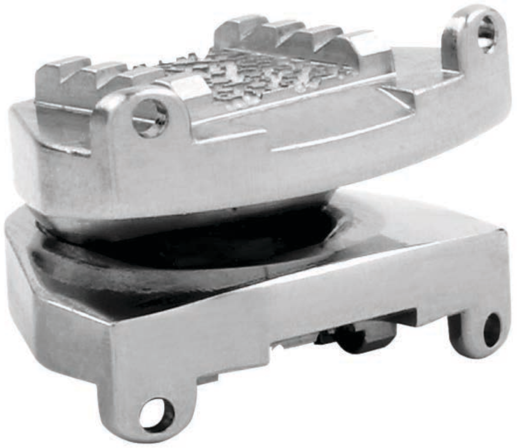






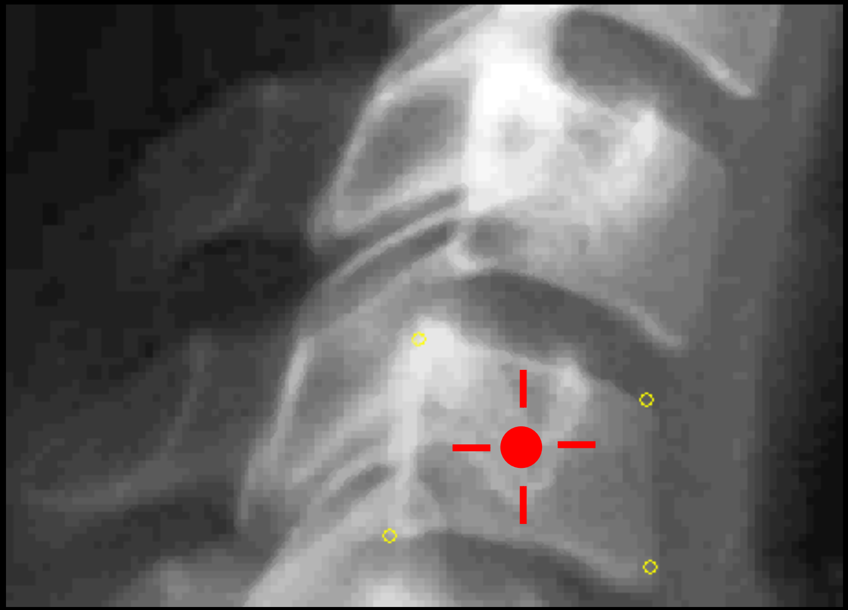


Mobile core devices
5/6 degrees-of-freedom

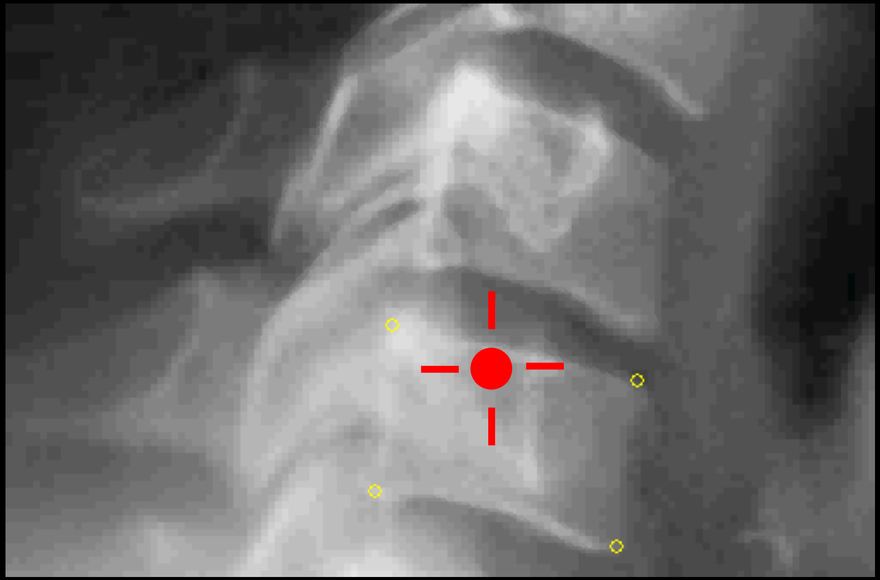


Other
5 degrees-of-freedom

Ball & socket devices
3 degrees-of-freedom

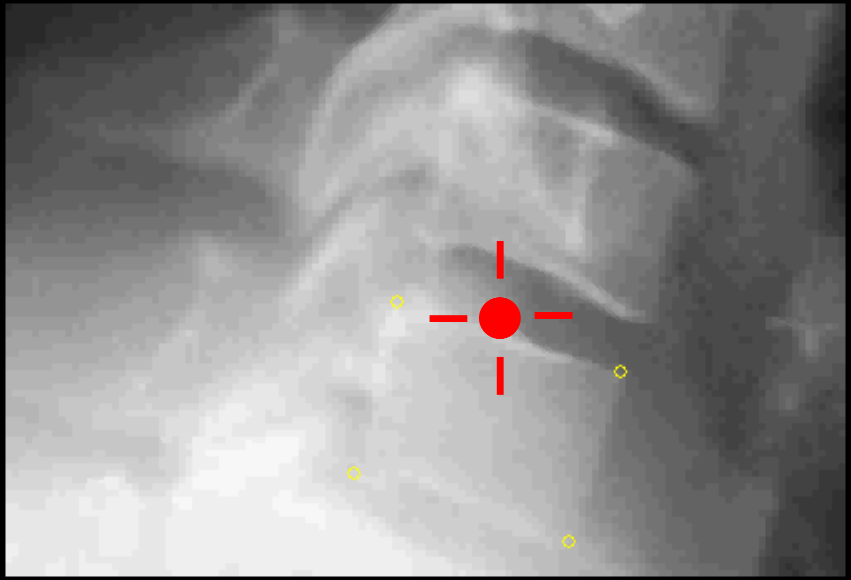


C4-C5



C5-C6

C6-C7



Cervical Segments have different inherent Centres of Rotation

*Limited device degrees-of-freedom & mismatching of a device to an individual patient kinematics may lead to **kinematic conflict***

ELSEVIER

Seminars in SPINE SURGERY

Kinematics of Cervical and Lumbar Total Disc Replacement

William R. Sears, MB, BS, FRACS,* Peter F. McCombe, MB, BS, FRACS,† and Rick C. Sasso, MD‡

This article reviews the kinematics of disc arthroplasty and the different ways that current devices attempt to replicate normal segmental motion. All disc replacements are capable of rotation but not all are able to independently translate. It is "constraint" over the degree-of-freedom controlling independent translation of a prosthesis that dictates whether its center of rotation is fixed or can attempt to adjust to that of the implanted motion segment. Ball-and-socket-type articulations are constrained, while mobile core prostheses are unconstrained. The ideal kinematic type is yet to be determined and it may be that different circumstances will be best managed by different types of prostheses.
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KEYWORDS total disc replacement arthroplasty, kinematics, biomechanics, biomechanical testing, motion constraint

The principal aim of disc arthroplasty is to replace a damaged structure with a device that will relieve pain, restore normal segmental function, and prevent or delay adjacent level disease. Integral to the biomechanical function of a disc replacement is its capacity to replicate normal segmental motion. The study of motion is "kinematics" and an understanding of kinematics is required to understand the theory of disc replacement and to be able to assess studies designed to measure disc arthroplasty function.

This article provides a guide to the kinematics of normal vertebral motion segments and a range of currently available disc arthroplasty prostheses. An overview of the types of segmental motion that occur will be discussed, including the difference between rotation, translation, and "pseudotranslation." The difference between a fixed Center or Axis of Rotation (COR or IAR) and an Instantaneous Center or Axis of Rotation (ICR or IAR) will be correlated with the concepts of

degrees-of-freedom and motion constraint and the effects

Table 2 Kinematic Classification of a Number of Currently or Previously (Acroflex) Available TDRs

	Constraint	Restraint	Limitation	Compressibility	DOF3d	DOF2d	COR Mobility
Charite	Unconstrained	Unrestrained	Limited	Incompressible	5	2	Y–
Bryan	Unconstrained	Unrestrained	Limited	Compressible	6	3	Y
eDISC	Unconstrained	Restrained	Unlimited	Compressible	6	3	Y
ProDisc	Constrained	Unrestrained	Limited	Incompressible	3	1	N
PCM	Constrained	Unrestrained	Unlimited	Incompressible	3	1	N
Maverick	Constrained	Unrestrained	Limited	Incompressible	3	1	N
Prestige	Unconstrained	Unrestrained	Limited	Incompressible	4	2*	Y and N
Acroflex	Unconstrained	Restrained	Limited	Compressible	6	3	Y

*Two in the sagittal plane and one in each of the coronal and axial planes.

be considered in either two- or three-dimensional space and may involve rotation (change in orientation) and/or transla-

*Sydney NeuroSpine Clinic and Departments of Neurosurgery, Royal North Shore, and Dalcross Private Hospitals, Sydney, Australia.
†Department of Orthopedics, Royal Brisbane Hospital, Brisbane, Australia.
‡Indiana Spine Group, Indiana University School of Medicine, Indianapolis, IN.
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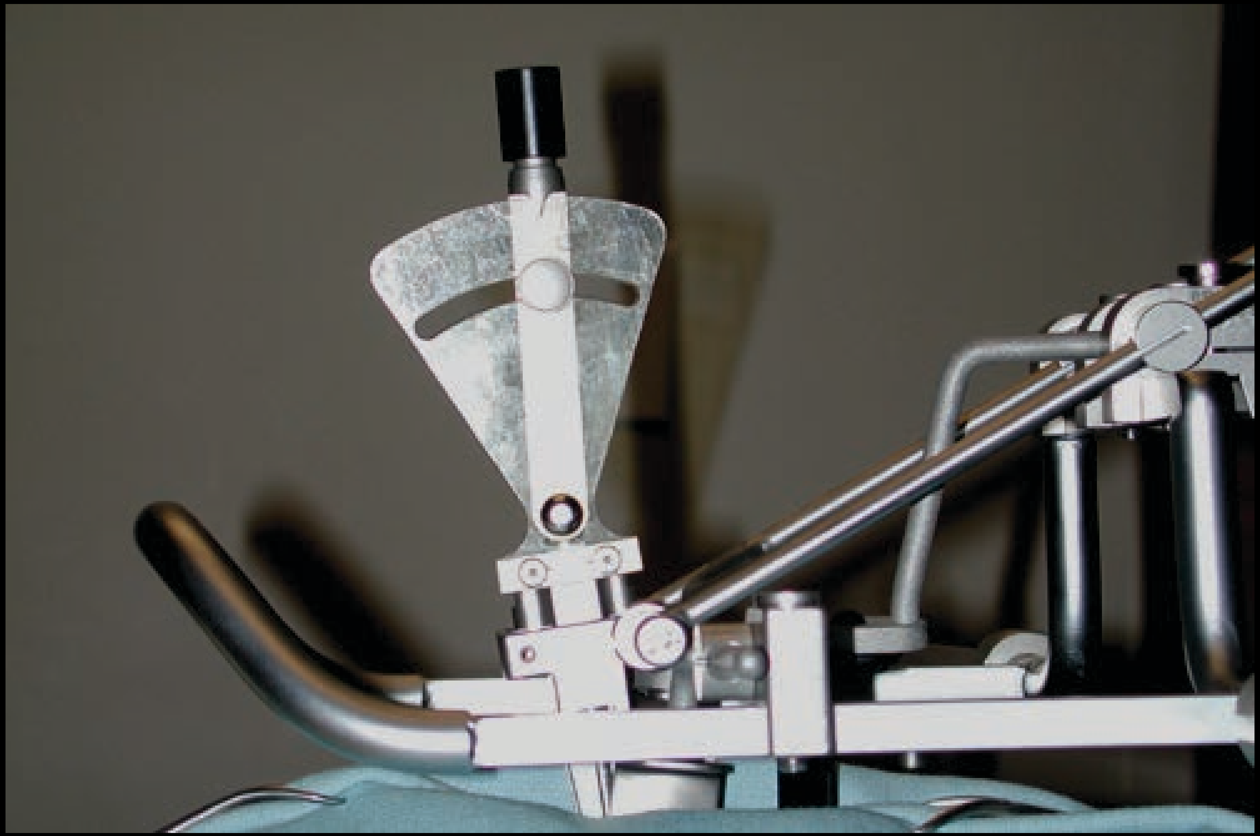
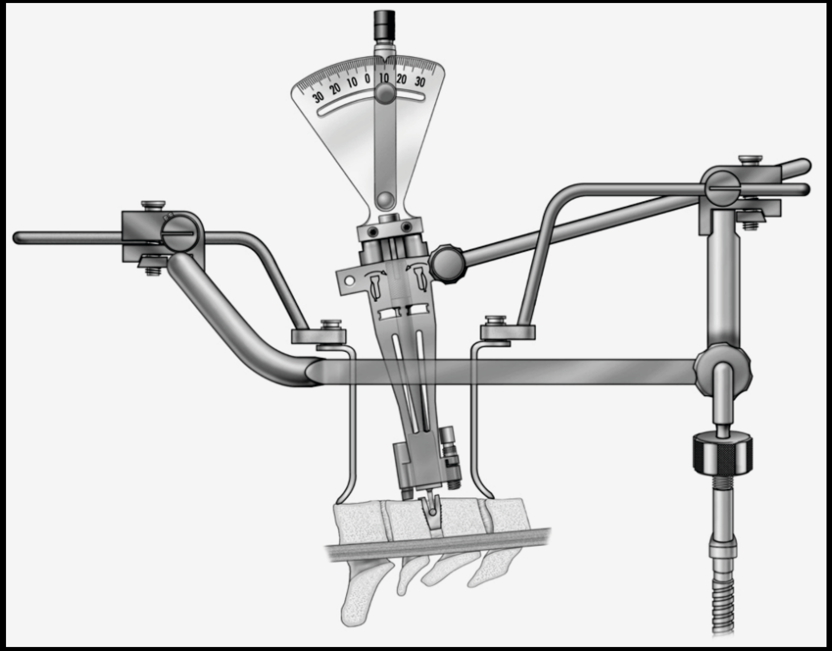
Address reprint requests to William Sears, Sydney NeuroSpine Clinic, Level 10, Tower B, 799 Pacific Highway, Chatswood, NSW, 2067, Australia. E-mail: neurospine@mac.com.

1040-7383/06/$-see front matter © 2006 Elsevier Inc. All rights reserved.
doi:10.1053/j.semss.2006.03.013

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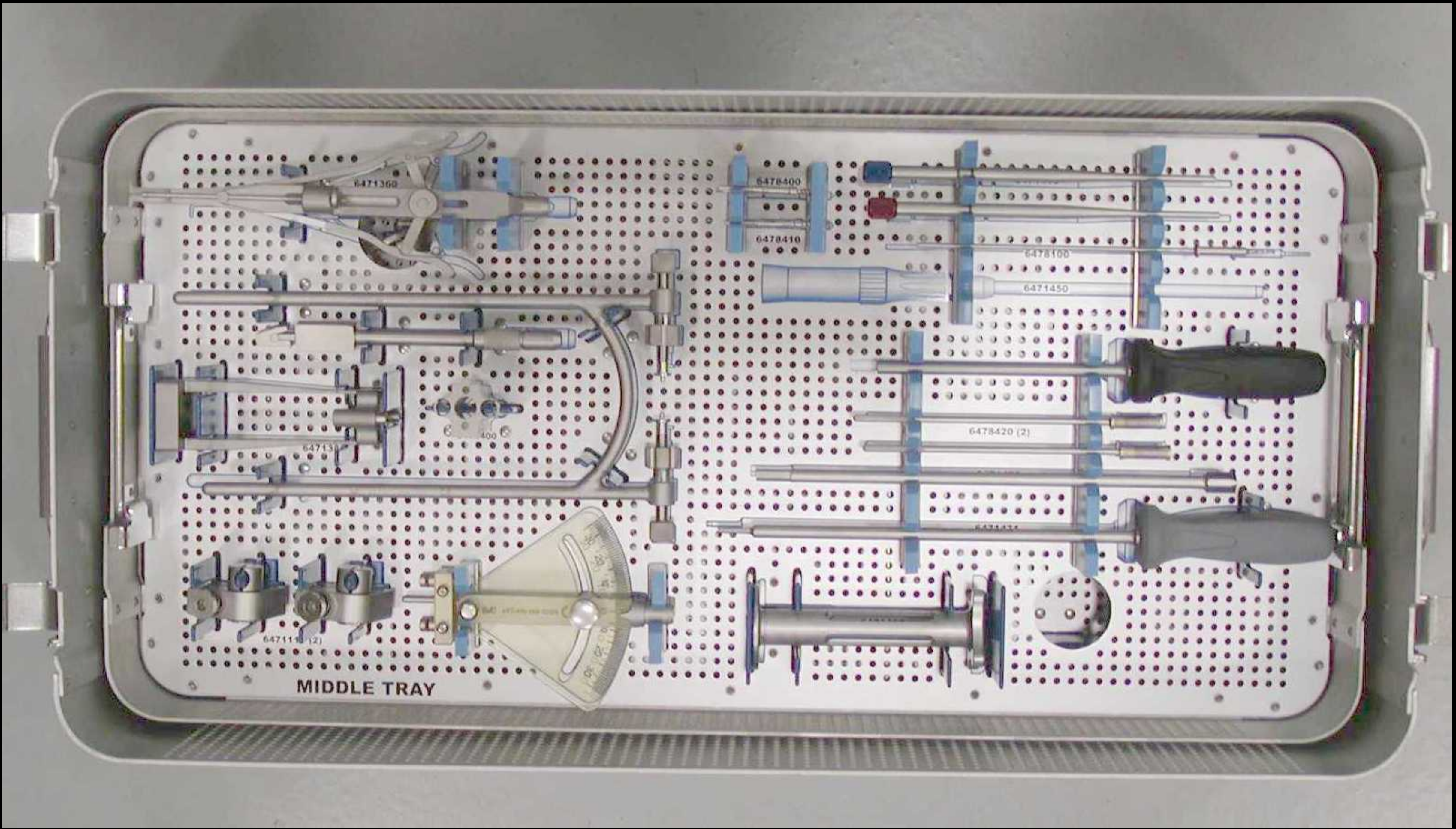
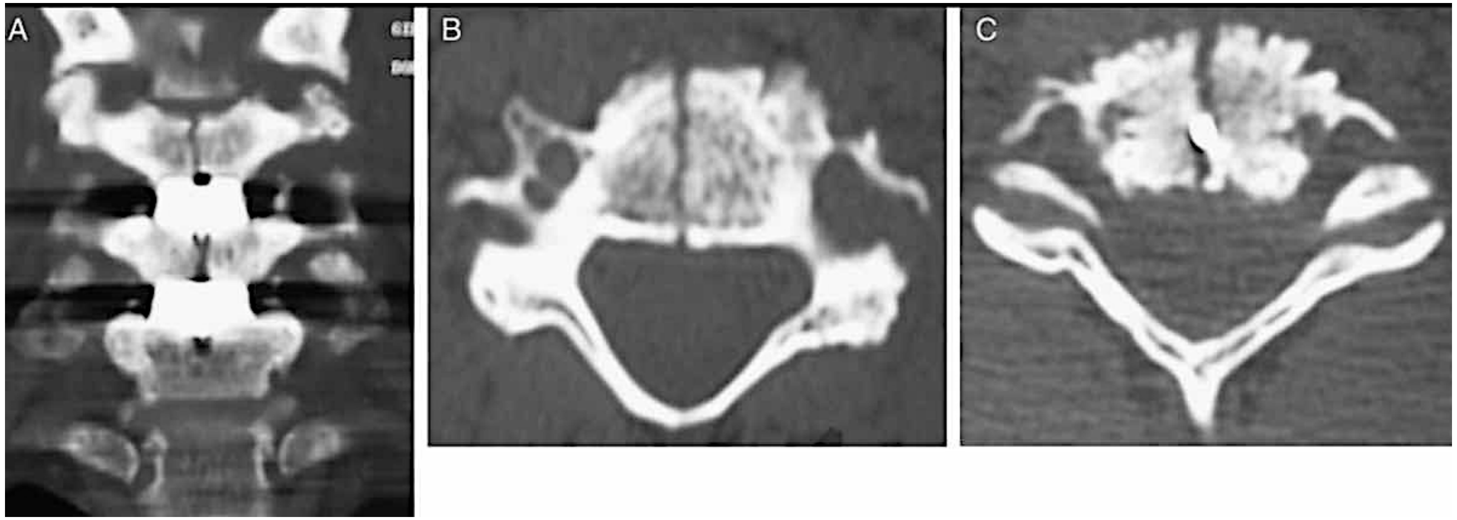


6471360
6478400
6478410
6478100
6471450
6478420 (2)
(2)
MIDDLE TRAY

Clinical Goals of Cervical Disc Arthroplasty

- Safety
  - Operative
  - Lifetime
- Efficacy
  - Clinical outcomes
    - Early
    - Late
  - Secondary surgery
    - Adjacent segment disease
    - Same segment disease
  - Imaging
- Cost effectiveness
  - Primary surgery
  - Secondary surgery



Clinical Goals of Cervical Disc Arthroplasty

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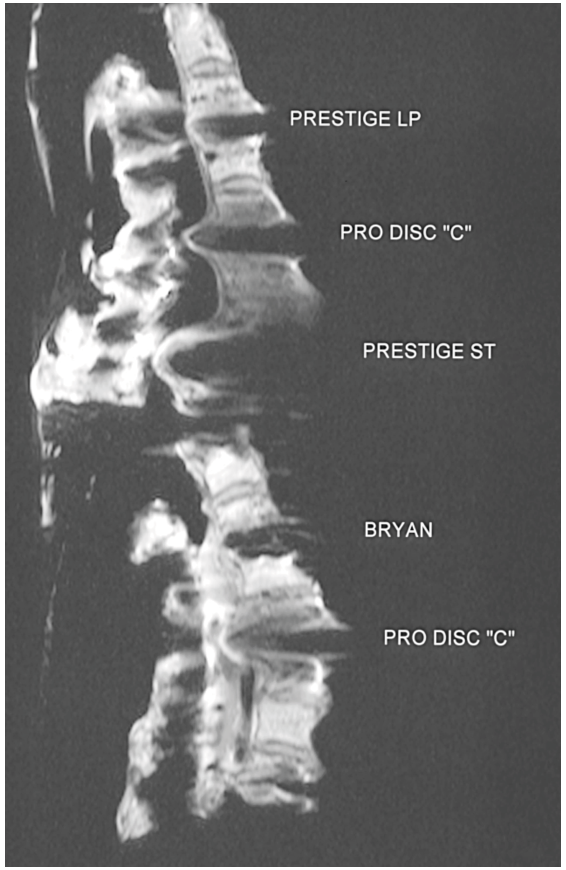
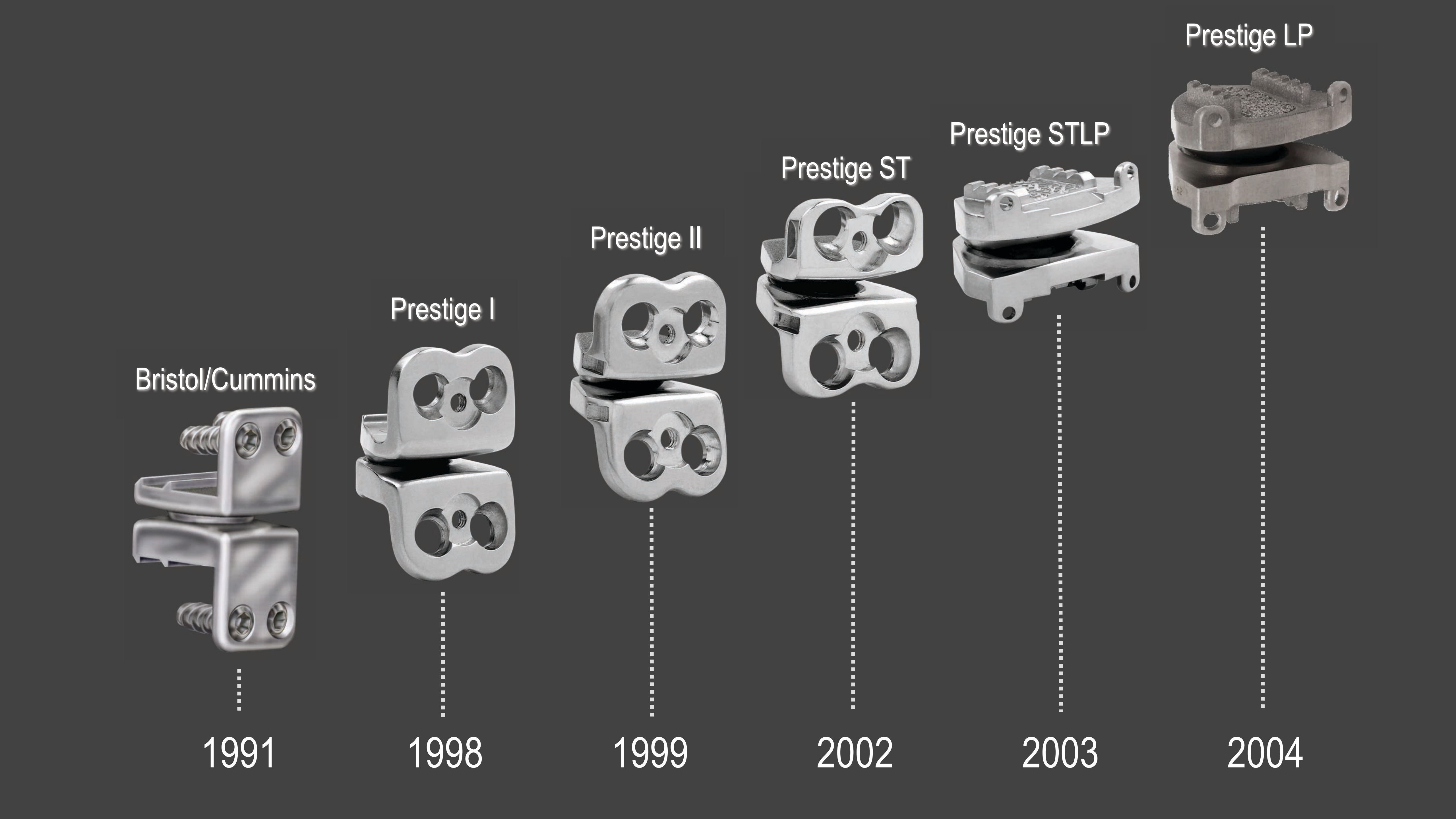
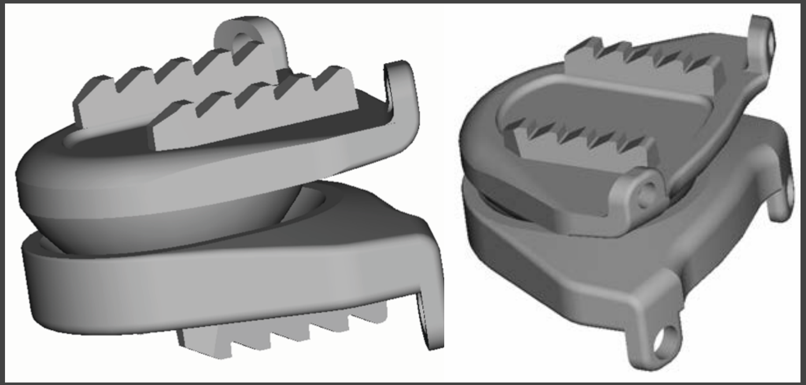
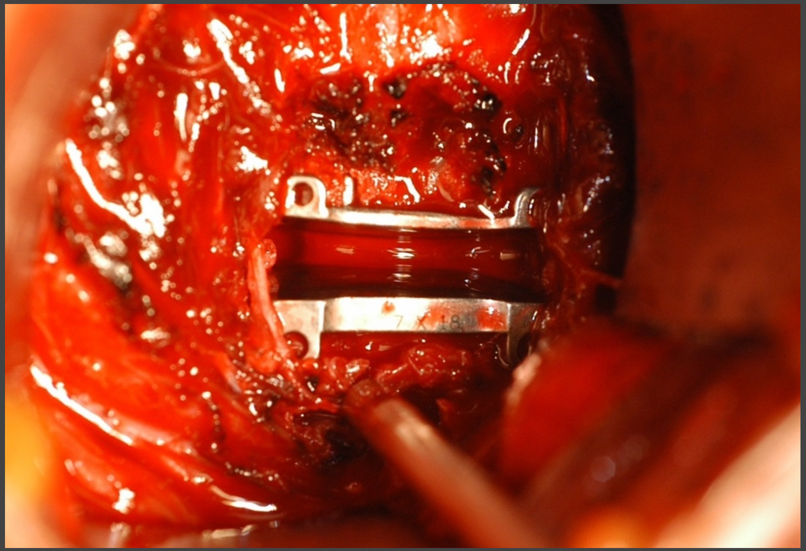
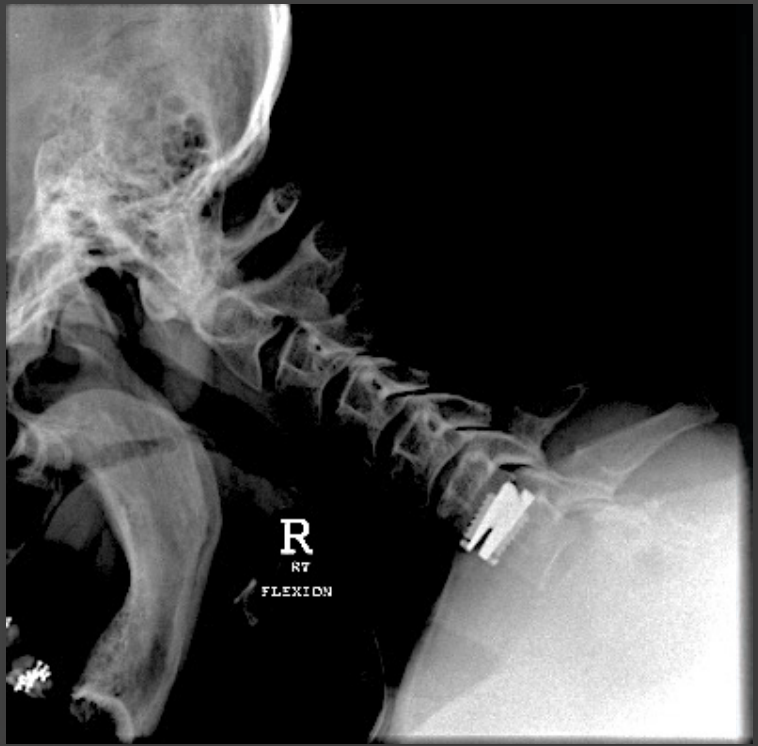



Bristol/Cummins
Prestige I
Prestige II
Prestige ST
Prestige STLP
Prestige LP
1991
1998
1999
2002
2003
2004

Prestige LP







Clinical Goals of Cervical Disc Arthroplasty

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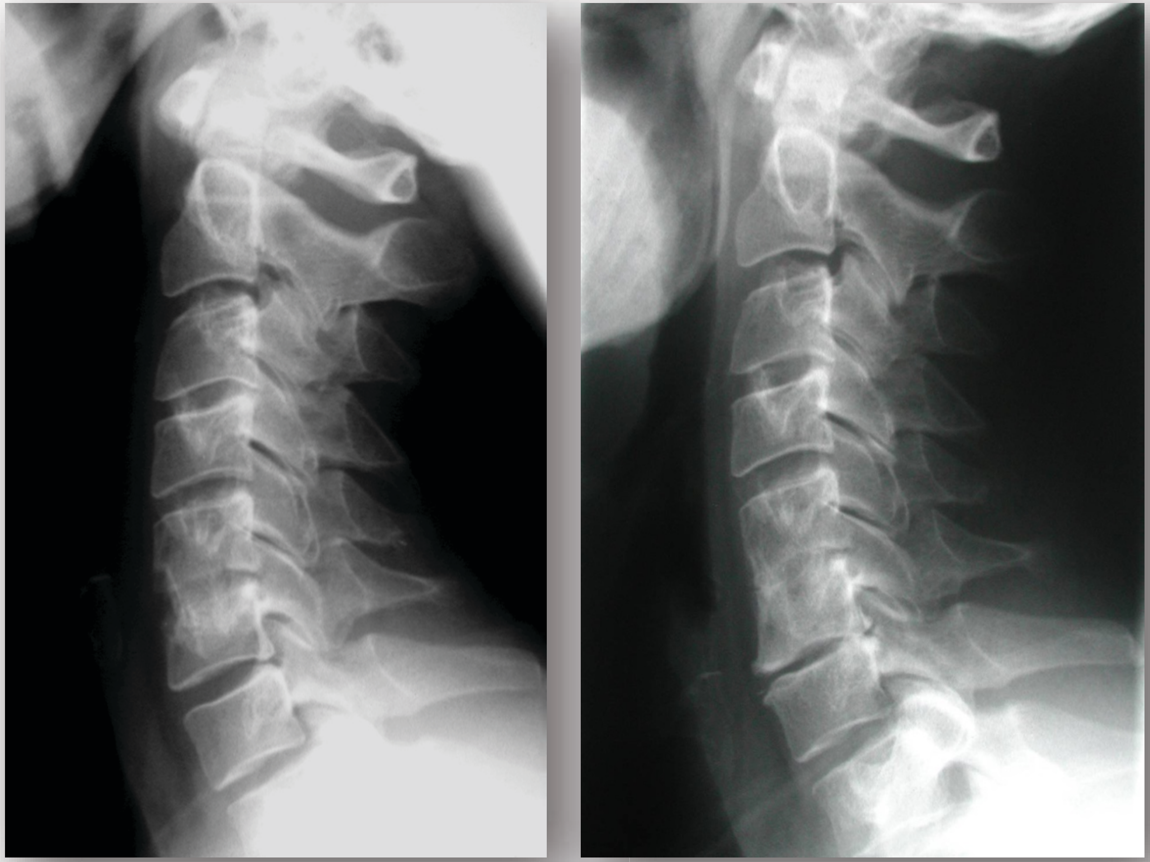

Clinical Goals of Cervical Disc Arthroplasty

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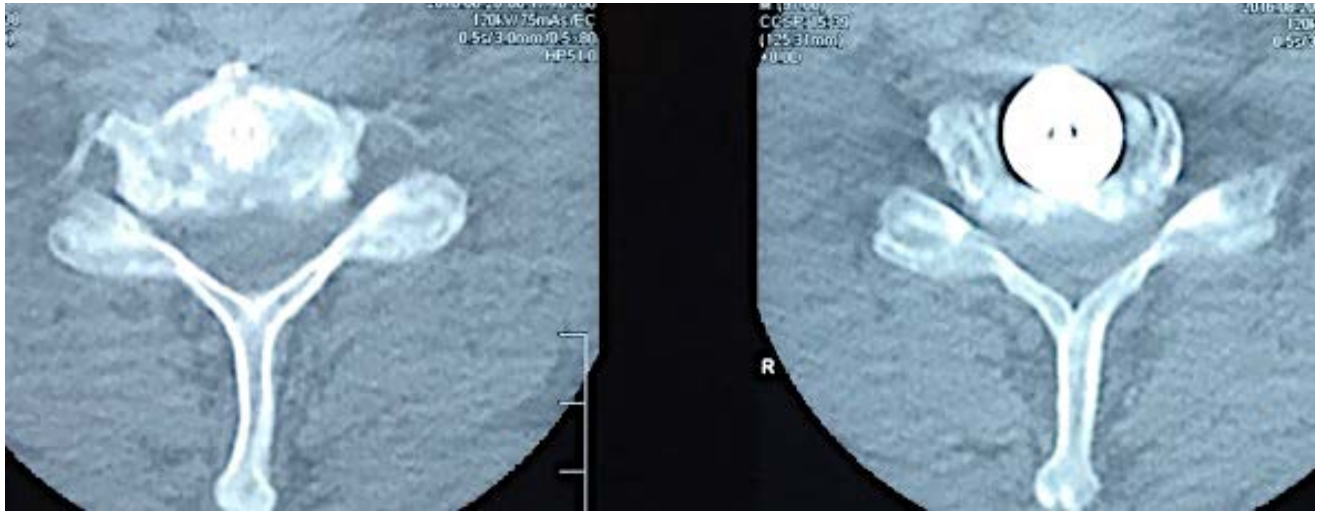
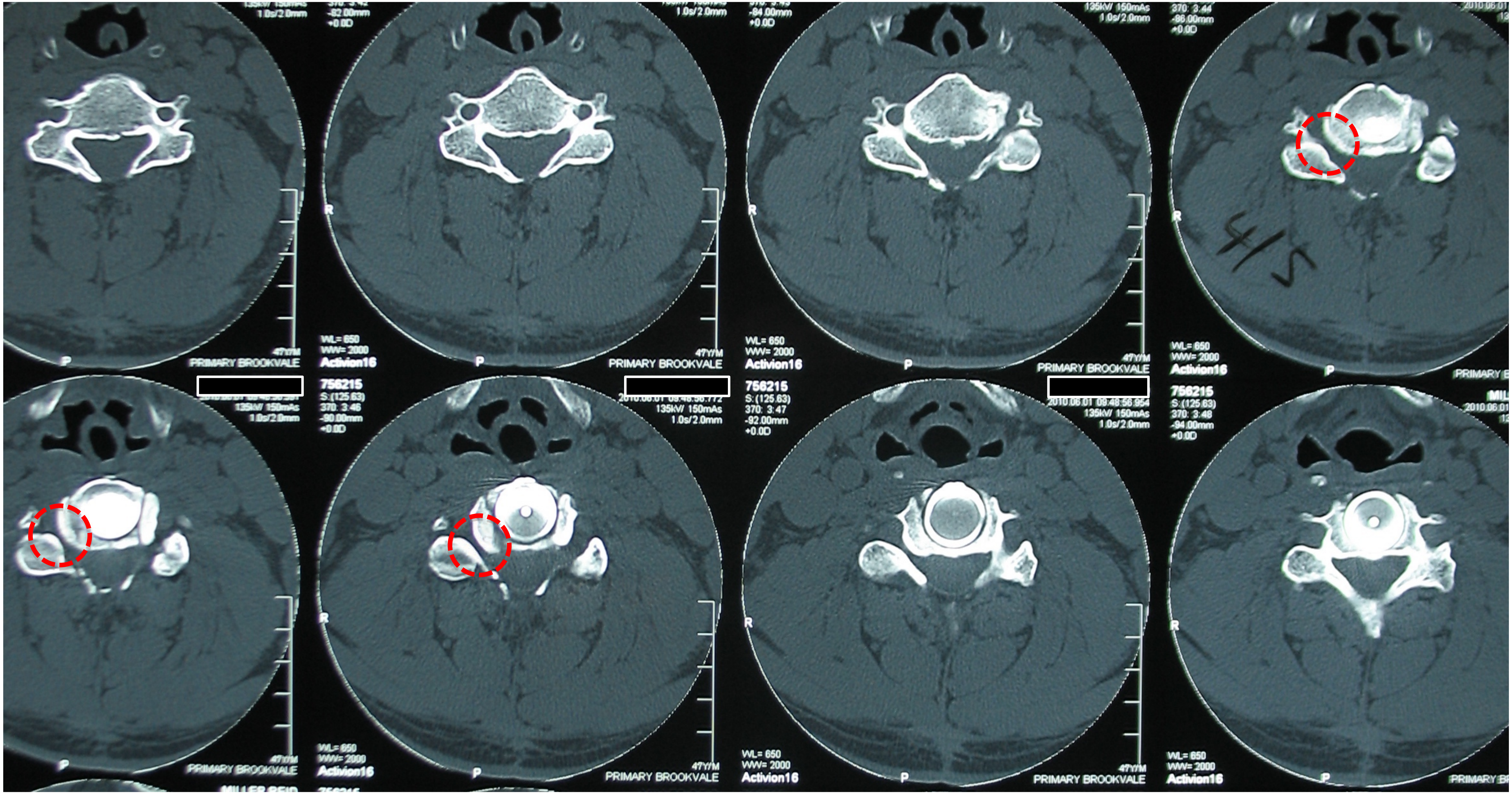


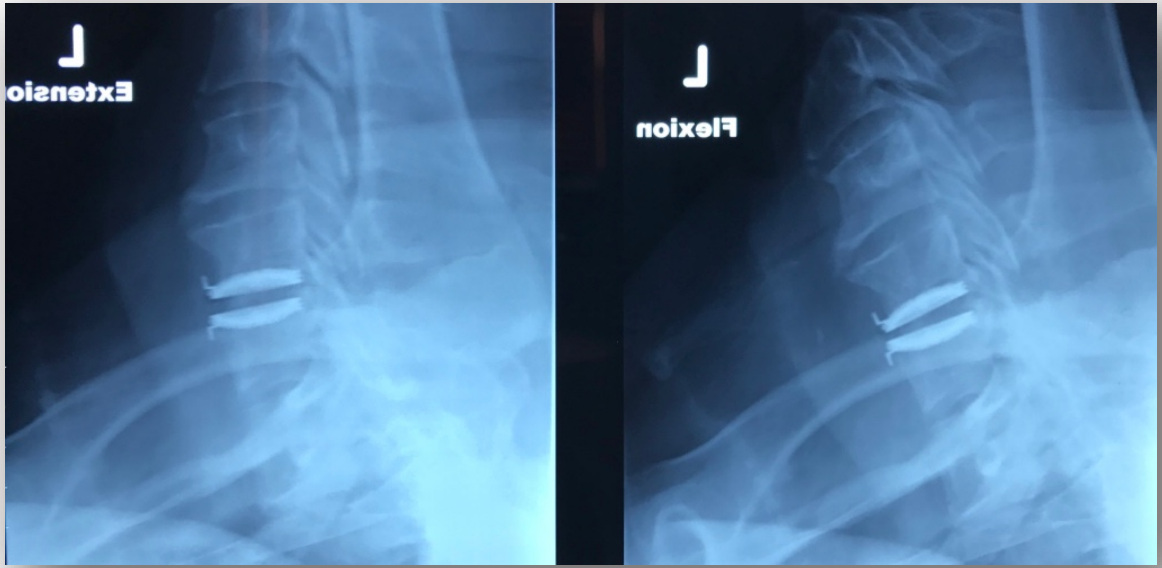
Same segment disease?

Male 47yrs, 7 years post Bryan TDR



1.0s/2.0mm
-82.00mm
+0.0D
1.0s/2.0mm
-84.00mm
+0.0D
135kV/ 150mAs
1.0s/2.0mm
370: 3:44
-86.00mm
+0.0D
R
47Y/M
PRIMARY BROOKVALE
WL= 650
WW= 2000
Activion16
[redacted]
756215
S:(125.63)
370: 3:46
-90.00mm
+0.0D
R
47Y/M
PRIMARY BROOKVALE
WL= 650
WW= 2000
Activion16
[redacted]
756215
S:(125.63)
370: 3:47
-92.00mm
+0.0D
R
47Y/M
PRIMARY BROOKVALE
WL= 650
WW= 2000
Activion16
[redacted]
756215
S:(125.63)
370: 3:48
-94.00mm
+0.0D
R
4/5
135kV/ 150mAs
1.0s/2.0mm
47Y/M
PRIMARY BROOKVALE
WL= 650
WW= 2000
Activion16

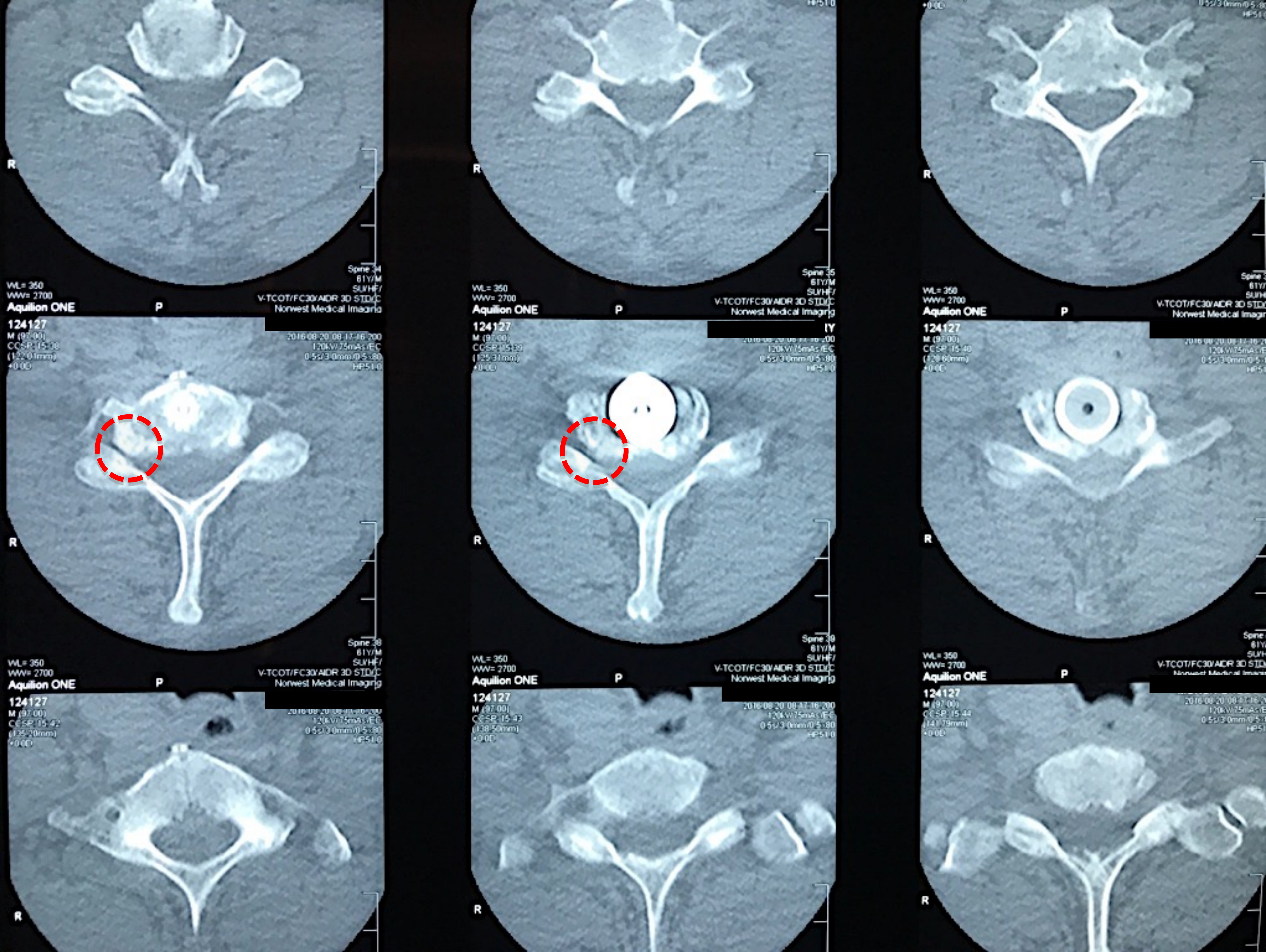
Male 47yrs, Bryan disc, *Sept 2002*



Post-op 14years

Now aged 61years

Radicular pain



Load-displacement behaviour of a bi-convex sliding core prosthesis under pre-load

O' Leary, Patwardhan et al, Spine J, 2005

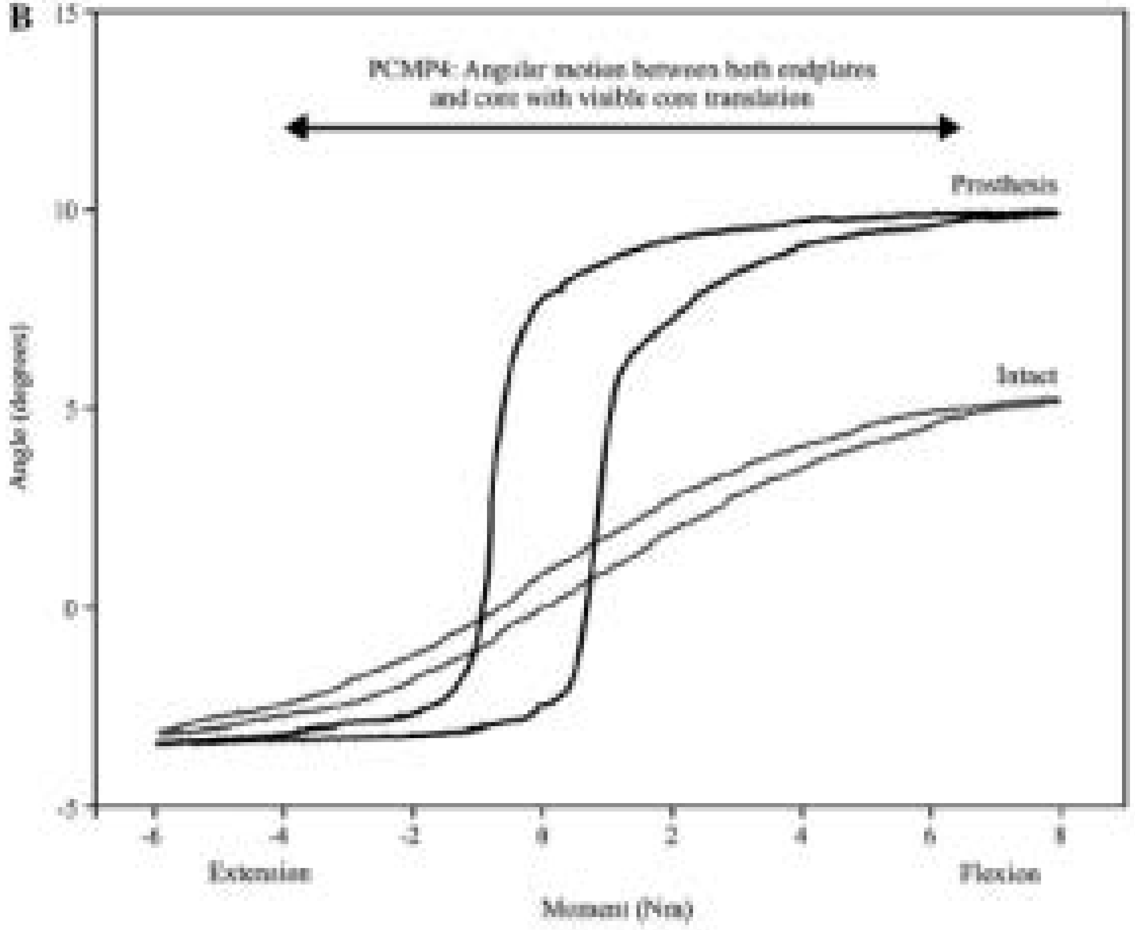
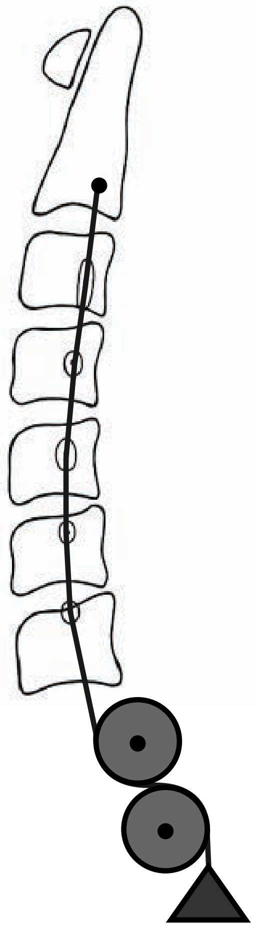


Fig. 3. Load versus angular displacement graphs. (A) An L5-S1 motion segment. (B) An L4-L5 motion segment.



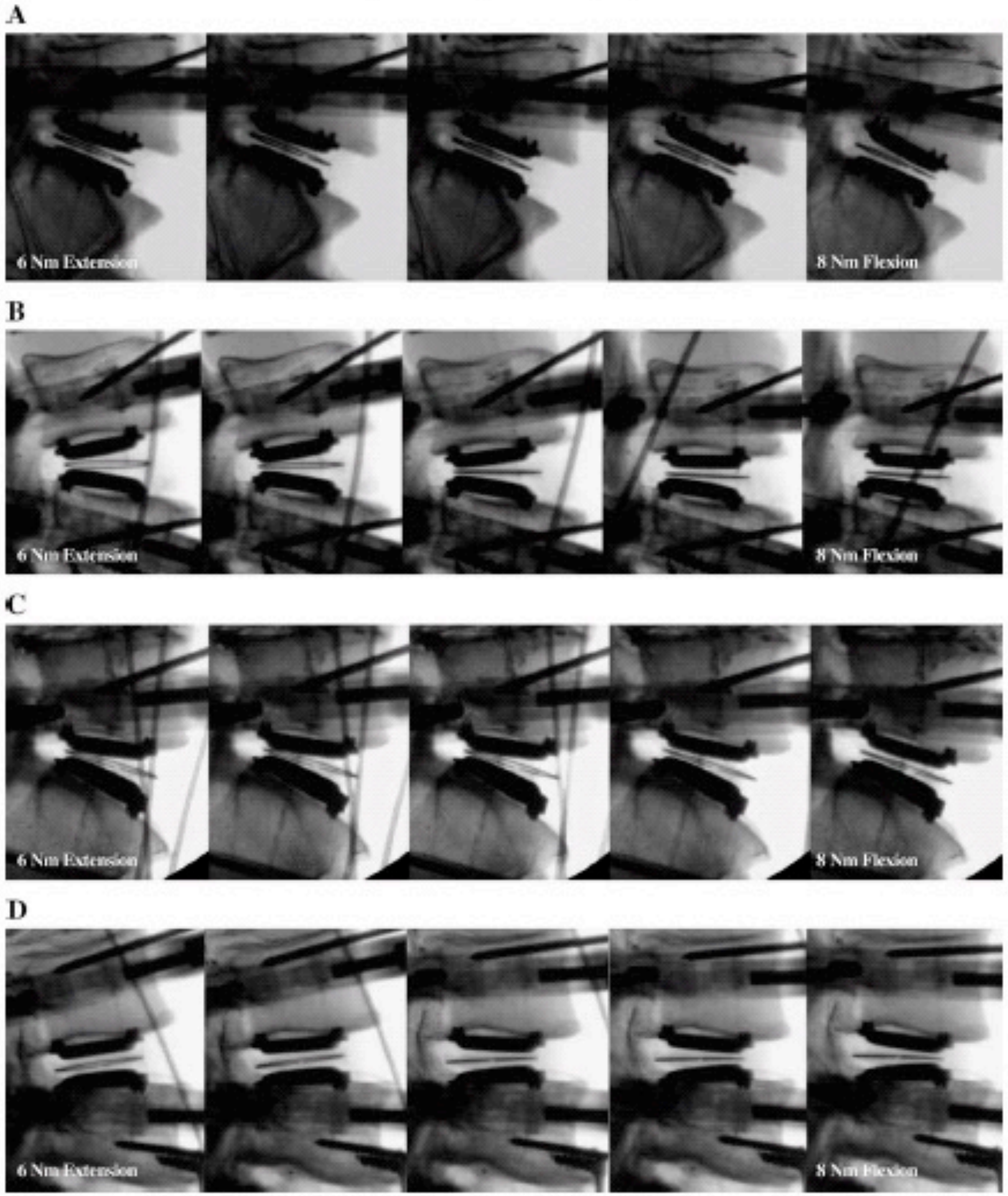
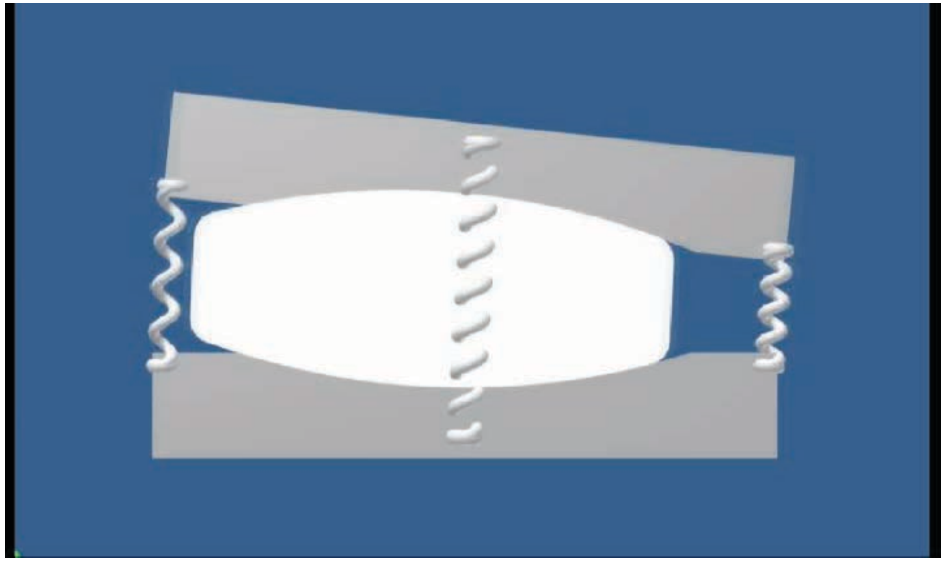


Fig. 2. Prosthesis component motion patterns (PCMPs). (A) Angular motion predominantly between the upper end plate and core, with little or no visible core translation (PCMP1). (B) Lift-off of upper prosthesis end plate from core or of core from lower end plate (PCMP2). (C) Core entrapment, resulting in a locked core over a portion of the range of motion (PCMP3). (D) Angular motion between both the upper and lower end plates and core, with visible core translation (PCMP4).

Core locking/‘balistic’ movement



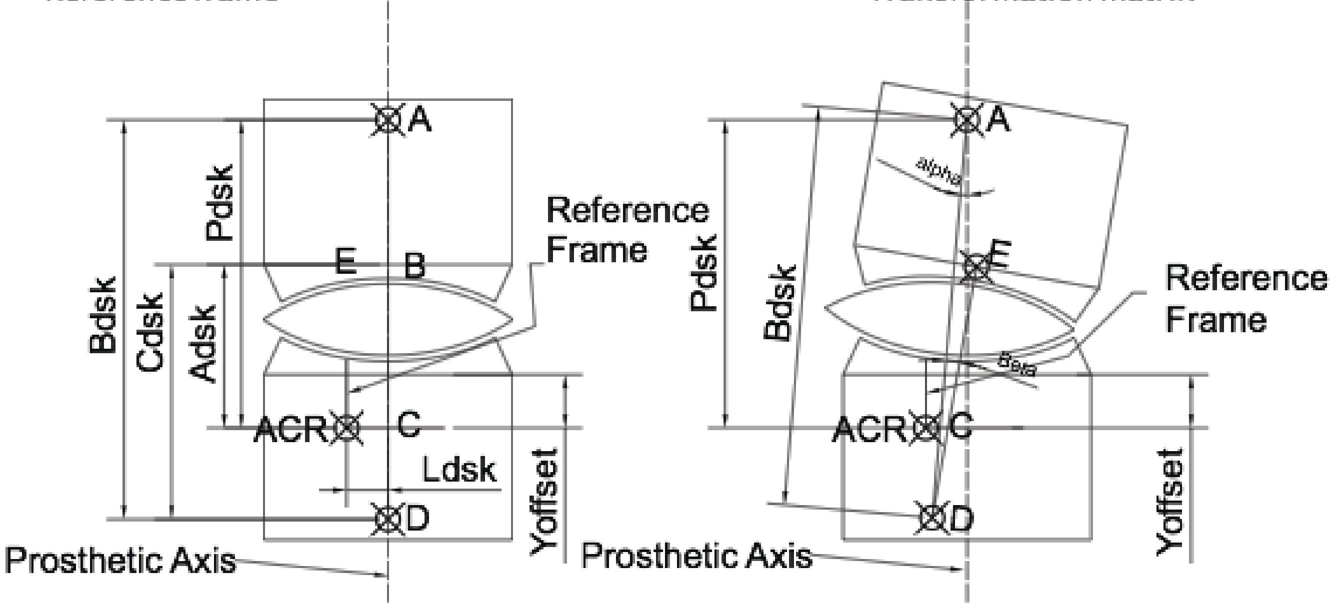
Courtesy of Dr Peter McCombe

$$FR1=\begin{bmatrix}\vec{n}_x & \vec{o}_x & \vec{p}_x\\ \vec{n}_y & \vec{o}_y & \vec{p}_y\\ 0 & 0 & 1\end{bmatrix}$$

Reference frame

$$T=\begin{bmatrix}\cos\alpha & -\sin\alpha & \Delta x\\ \sin\alpha & \cos\alpha & \Delta y\\ 0 & 0 & 1\end{bmatrix}$$

Transformation matrix



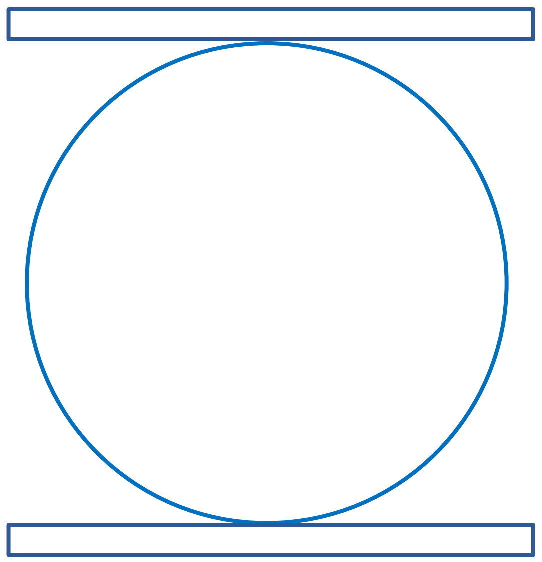
$$AFR2=\begin{bmatrix}1 & 0 & Ldsk\\ 0 & 1 & Pdsk\\ 0 & 0 & 1\end{bmatrix}*\begin{bmatrix}\cos\alpha & -\sin\alpha & 0\\ \sin\alpha & \cos\alpha & 0\\ 0 & 0 & 1\end{bmatrix}*\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & -Bdsk\\ 0 & 0 & 1\end{bmatrix}*\begin{bmatrix}\cos\beta & -\sin\beta & 0\\ \sin\beta & \cos\beta & 0\\ 0 & 0 & 1\end{bmatrix}*\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & Cdsk\\ 0 & 0 & 1\end{bmatrix}*\begin{bmatrix}1 & 0 & -Ldsk\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix}$$

$$f(\alpha,\beta)=-(\cos\alpha\cdot\cos\beta-\sin\alpha\cdot\sin\beta)\cdot Ldsk+(-\cos\alpha\cdot\sin\beta-\sin\alpha\cdot\cos\beta)\cdot Cdsk+\sin\alpha\cdot Bdsk+Ldsk)$$

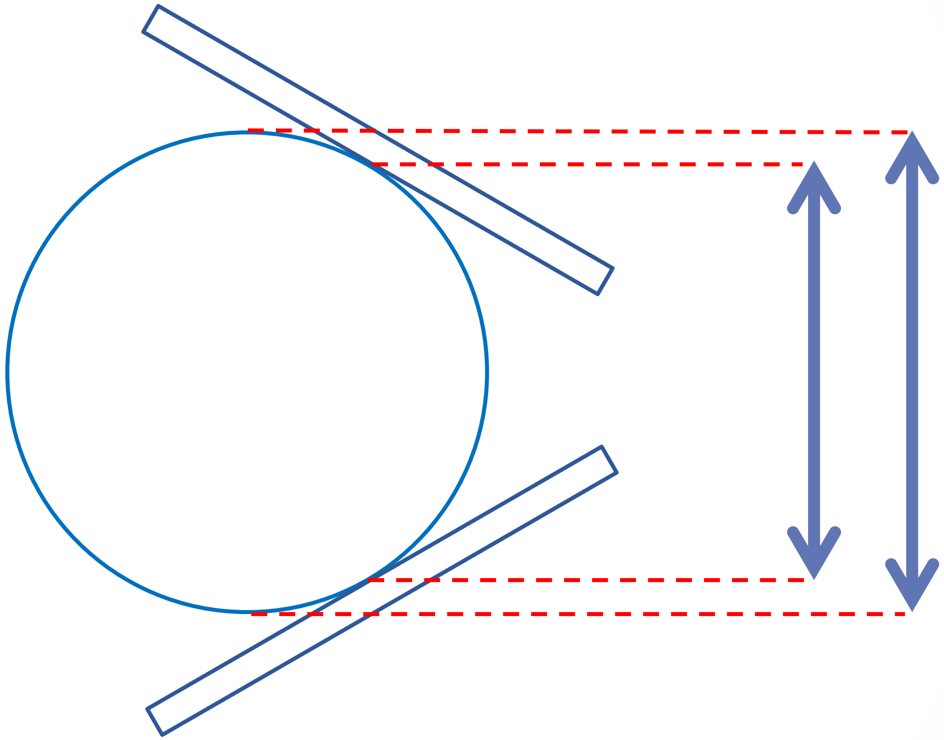
$$g(\alpha,\beta)=-(\sin\alpha\cdot\cos\beta+\cos\alpha\cdot\sin\beta)\cdot Ldsk+(\cos\alpha\cdot\cos\beta-\sin\alpha\cdot\sin\beta)\cdot Cdsk-\cos\alpha\cdot Bdsk+Pdsk)$$

Courtesy of Dr Peter McCombe

Higher potential energy position



Lower potential energy position



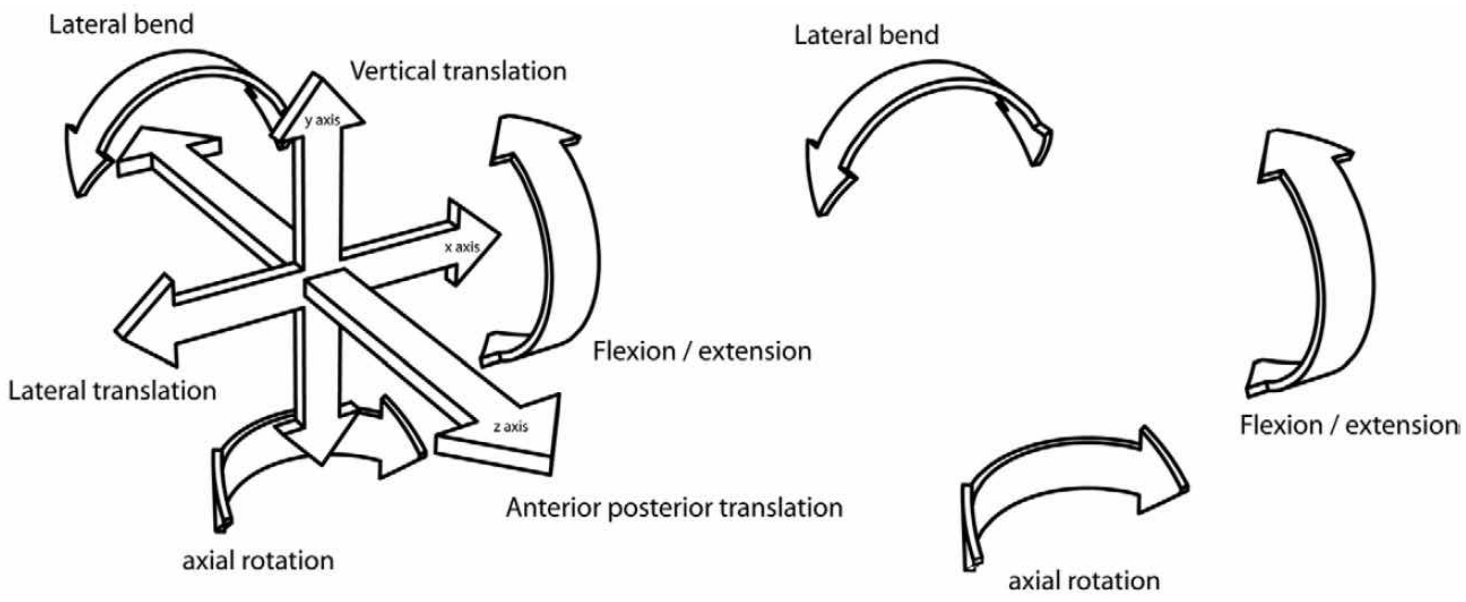


Table 2 Kinematic Classification of a Number of Currently or Previously (Acroflex) Available TDRs

	Constraint	Restraint	Limitation	Compressibility	DOF3d	DOF2d	COR Mobility
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eDISC	Unconstrained	Restrained	Unlimited	Compressible	6	3	Y
ProDisc	Constrained	Unrestrained	Limited	Incompressible	3	1	N
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Prestige	Unconstrained	Unrestrained	Limited	Incompressible	4	2*	Y and N
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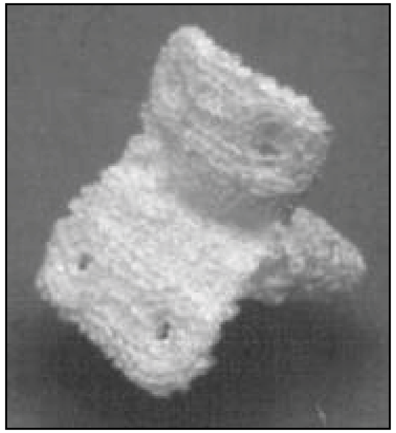
*Two in the sagittal plane and one in each of the coronal and axial planes.

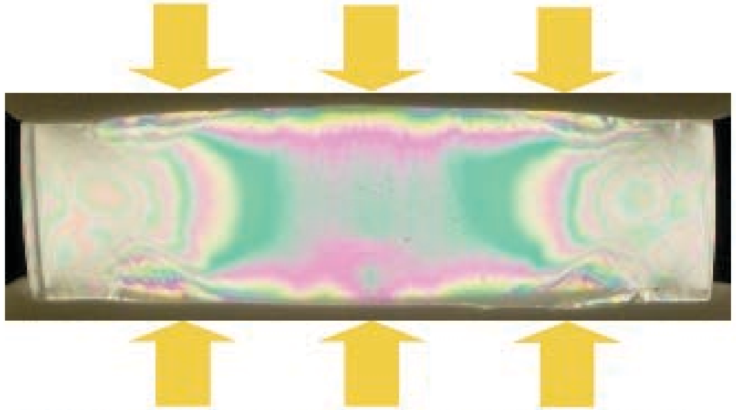
Visco-elastic, polymer discs



Visco-elastic prostheses Cadisc™-L

Cadisc™-L Graduated Modulus Technology

The gradual transition in material properties results in amore even distribution of internal stress for improved durability.

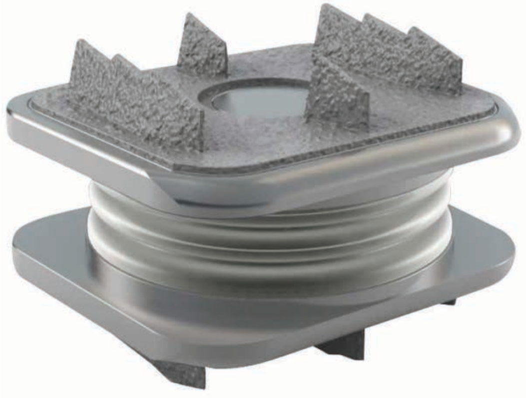


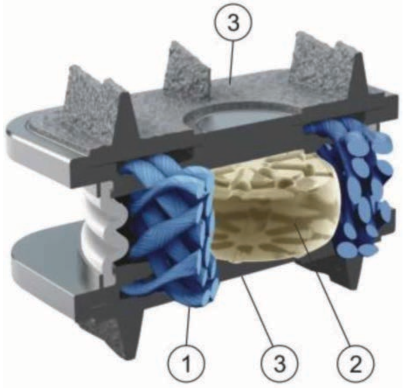
Polarised light image of Cadisc™-L under axial load.
Courtesy of Dr. J. Gwynne, University of Cambridge

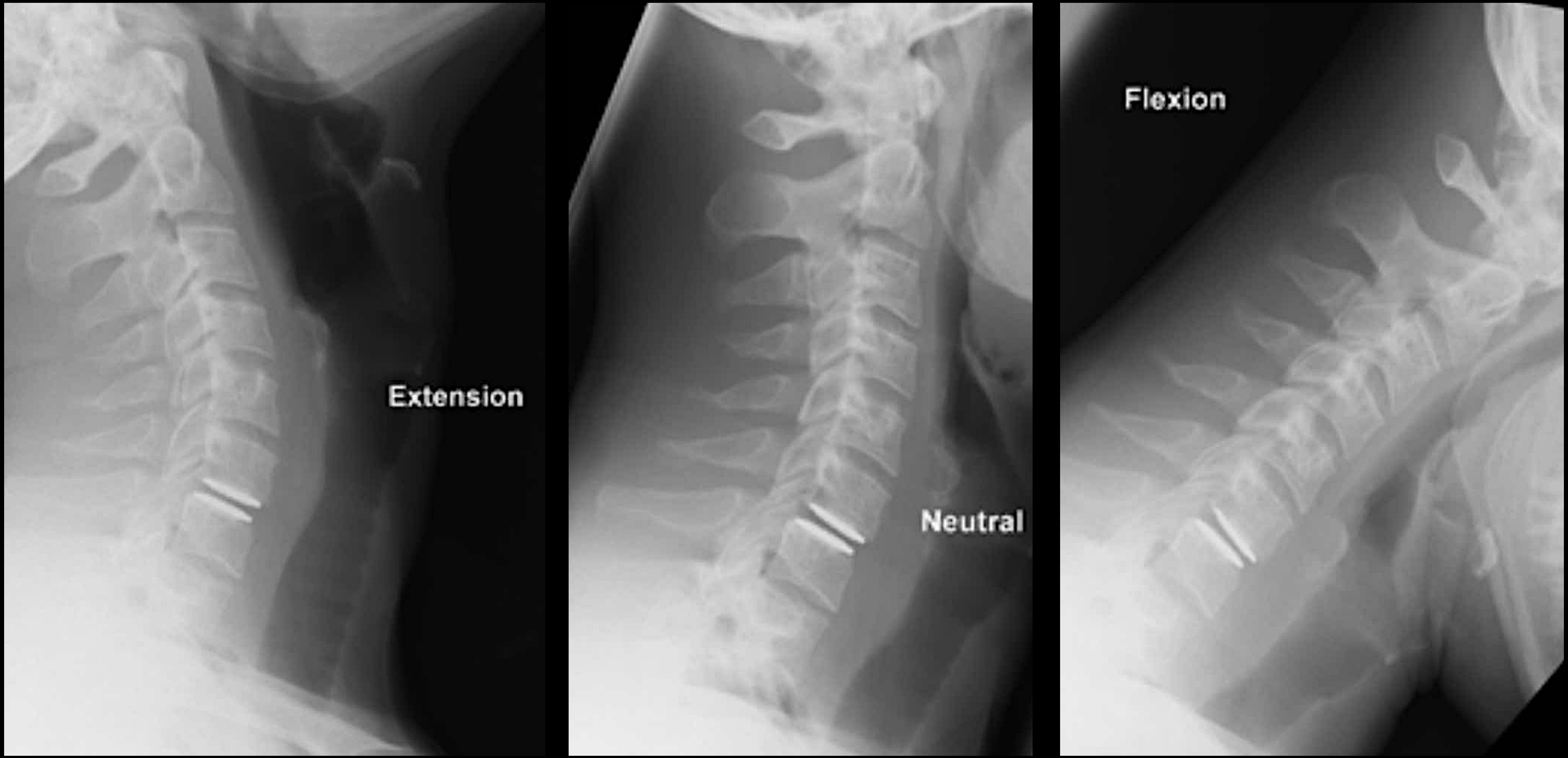
Visco-elastic, polymer discs

- Seek a balance between axial load bearing and bending capacity
- Lack primary fixation
  - Prone to Loosening
  - Prone to Expulsion
- Polymer characteristics may change with tissue fluid uptake

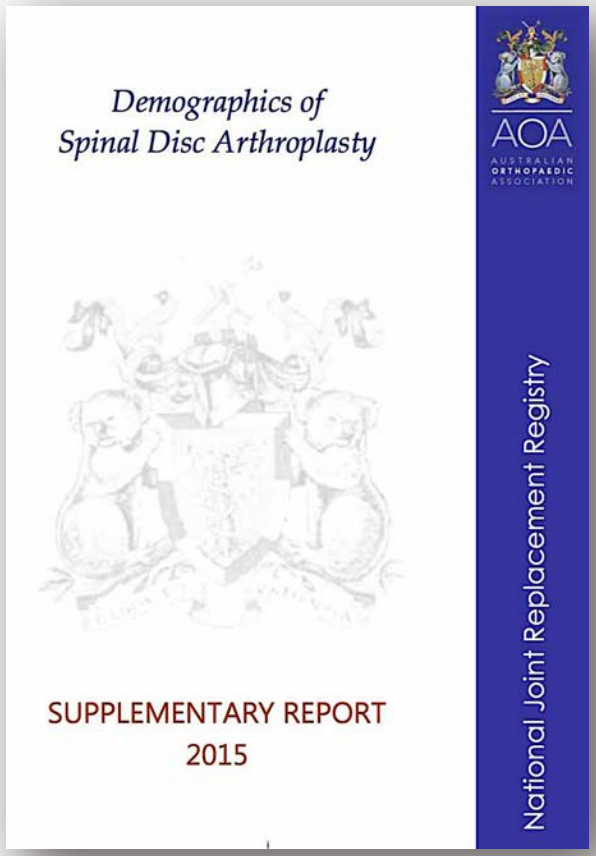
M6-C disc






Extension
Neutral
Flexion

AUSTRALIAN ORTHOPAEDIC ASSOCIATION
NATIONAL JOINT REPLACEMENT REGISTRY


Demographics of
Spinal Disc Arthroplasty

SUPPLEMENTARY REPORT
2015

National Joint Replacement Registry

Table SD12 Most Used Ball Trough Prostheses in Primary Spinal Ball Trough Replacement

2008		2011		2012		2013		2014	
N	Model	N	Model	N	Model	N	Model	N	Model
30	Prestige	10	Prodisc-C	4	Prestige	48	Prodisc-C	51	Prodisc-C
4	Wallis	4	Prestige	2	Prodisc-C	23	Prestige	37	Prestige
3	Prodisc-C			1	Bryan	11	Bryan	5	Mobi-C
3	X-Stop					1	Mobi-C	4	Bryan

Table SD18 Most Used Disc Prostheses in Primary Cervical Intervertebral Disc Replacement

2008		2011		2012		2013		2014	
N	Model	N	Model	N	Model	N	Model	N	Model
2	Spinal Disc (DePuy)	24	M6	47	M6	98	M6	176	M6
		5	CerviCore	12	Baguera	1	Discocerv	2	Baguera
		3	Baguera	2	Discover			2	Discocerv

Indications

Table SD11 Primary Spinal Ball Trough Replacement by Primary Diagnosis

Primary Diagnosis	Number	Percent
Disc Disease With Radiculopathy	242	83.7
Disc Disease Without Radiculopathy	21	7.3
Spondylolisthesis	6	2.1
Post Laminectomy Or Discectomy	6	2.1
Pain Of Unknown Cause	5	1.7
Adjacent Segment Syndrome	4	1.4
Adjacent To Concurrent Fusion	3	1.0
Other	2	0.7
TOTAL	289	100.0

Table SD17 Primary Cervical Intervertebral Disc Replacement by Primary Diagnosis

Primary Diagnosis	Number	Percent
Disc Disease With Radiculopathy	350	88.2
Disc Disease Without Radiculopathy	32	8.1
Adjacent To Concurrent Fusion	4	1.0
Post Laminectomy Or Discectomy	2	0.5
Pain Of Unknown Cause	2	0.5
Adjacent Segment Syndrome	2	0.5
Other	5	1.3
TOTAL	397	100.0

Conclusions

- Cervical disc replacement surgery is increasingly popular worldwide
- Critics are less vocal
- Devices have improved dramatically over the last 25 years