

Evolution of Cervical Discs A Clinical Overview

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Berlin, October 7th, 2016

Disclosures

Consultant:

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

Royalties:

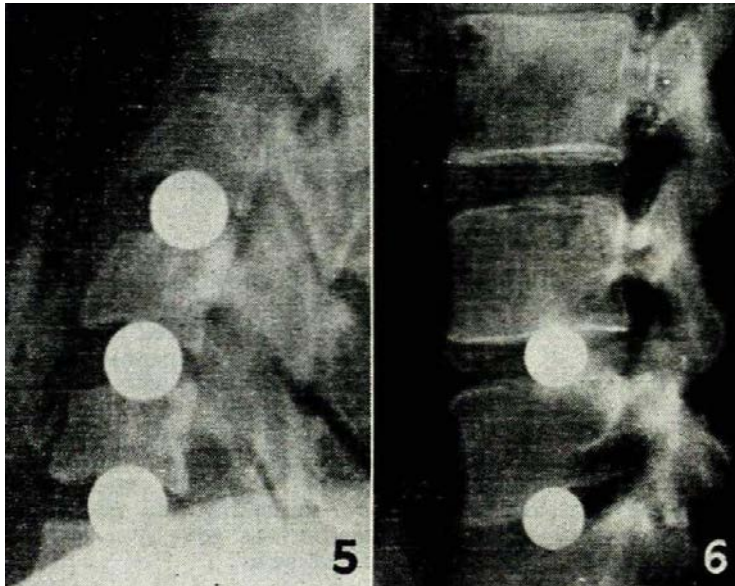
- *Medtronic – lumbar interbody fusion device*

Travel assistance:

- *Spinal kinetics*

The beginning...

- Ulf Fernström
 - Uddevalla, Sweden



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

Reitz H & Journer M. *S Afr Med J.* 1964

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

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

The relief of severe disabling neck pain owing to cervical spondylosis, with its common complications of brachialgia, and recurrent or sometimes continuous headache, both in the suboccipital and retro-orbital regions of the head, is frequently a surgical problem, when the usual conservative measures fail.

Cervical Spondylosis

Cervical spondylosis is very common and is the cause of symptoms in a large number of people over the age of 45. Kellgren and Lawrence, as quoted by Lord Brain,¹ found radiological evidence of disc degeneration in over 80% of persons after the age of 55 in a large series of cases investigated.

He states specifically 'Headache is one of the commonest presenting symptoms in cervical spondylosis'.

Kaney *et al.*² described headache as the outstanding symptom in numerous cases of cervical disc prolapse, and Smith and Robinson³ also record that disc degeneration is a cause of 'occipital and hemispherical headaches'.

Some of the symptoms of cervical spondylosis can be explained on an anatomical basis.

(a) *Paracentral osteophytes*, arising from the Luschka and zygapophysial (paravertebral) joints, encroach on the intervertebral foramen and give rise to pain in the neck and brachial radiculitis. If compression of the nerve root is severe, then wasting and weakness of the muscles of the arm and hand, associated with paraesthesia and reflex changes, will occur.

(b) *Centrally placed posterior osteophytes or bars*. These can interfere with cord function, with the production of spastic paraparesis. As myelopathy increases, the patient will become progressively incapacitated, with increased muscular tone and hyperreflexia, absent abdominal and cremasteric reflexes, and a positive Babinski sign. The patient gradually loses control over his legs although muscle power is at first interfered with only slightly.

(c) *Degenerative changes in the intervertebral disc*. The nucleus pulposus may either be absorbed and desiccated, or herniated backwards, where it can cause symptoms by direct pressure on the cord or nerve roots. When there is marked loss of disc height the bony rims of adjacent vertebral bodies actually come into direct contact with each other, and can pinch the annular fibrous, which is exceedingly pain-sensitive and contains sympathetic nerve endings supplied by the sim-vertebral nerve. This direct weight-bearing and friction between the vertebral rims, which should be well separated by the internal pressure of the normal nucleus pulposus, is a likely cause of the osteophytes which form around the periphery of the disc in advanced cases. Apart from the well-known symptoms of brachialgia or brachial neuritis and pain in the neck, these changes are an exceedingly common cause of intractable headaches, which are often labelled 'congenital migraine' and treated as such.

Characteristically, the cervical spondylosis headache awakens the patient from sleep, often at a constant time in

the early morning. It is dull and starts in the suboccipital region but frequently spreads to the back of the eyes, where it can become throbbing in nature and of unbearable severity. It may be completely unilateral, and then resembles a typical 'classical migraine' or hemispheric. At first the attacks are intermittent and paroxysmal, but in longstanding cases the headache and neck pain are sometimes continuously present. Most patients will note that they are reasonably well while upright, but symptoms commence soon after lying down and they cannot get the head and neck in a comfortable position on a pillow. The mechanism of producing headache owing to disc degeneration is unknown. We have seen severe frontal headaches of many years' duration completely cured by surgical treatment to a single disc as low as C7-D1 level.

(d) *Vertebral artery compression or irritation*. Hutchinson and Yates⁴ drew attention to the effect of narrowing of the vertebral artery upon the cerebral circulation as a whole. In spondylosis spines osteophytes from the Luschka joints project laterally and can interfere markedly with the cerebral circulation. The occurrence of brain stem infarction with a fatal outcome after osteopathic manipulation has been recorded many times.⁵ Involvement of the vertebral artery must be suspected in all cases of tinnitus, vertigo, deafness and unsteadiness on the feet, owing to interference with the blood supply to the labyrinth. Attacks of unconsciousness, 'drop attacks', transient visual disturbances, homonymous hemianopia and transient weakness of one or other side of the body can be explained by the direct effect of a mechanical reduction of vertebral blood flow in the cerebral circulation. Kovacs⁶ has demonstrated that compression of the vertebral artery by subluxation at the paravertebral joints is a frequent cause of severe headache. Our treatment of choice in these cases, is the vertebral artery decompression operation, as described by Jung.⁷

REASONS FOR ATTEMPTING ARTHROPLASTY OF CERVICAL SPINE

The only certain method of relieving all pain in a degenerated joint anywhere in the body, is excision and bony fusion, but the two penalties which must always be paid are the loss of movement at the joint and the effects of such other, and can pinch the annular fibrous, which is exceedingly pain-sensitive and contains sympathetic nerve endings supplied by the sim-vertebral nerve. This direct weight-bearing and friction between the vertebral rims, which should be well separated by the internal pressure of the normal nucleus pulposus, is a likely cause of the osteophytes which form around the periphery of the disc in advanced cases. Apart from the well-known symptoms of brachialgia or brachial neuritis and pain in the neck, these changes are an exceedingly common cause of intractable headaches, which are often labelled 'congenital migraine' and treated as such.

Characteristically, the cervical spondylosis headache awakens the patient from sleep, often at a constant time in

ally. After the insertion of the ball prosthesis, however, very considerable restoration of disc height is clearly seen in the lateral views (Fig. 4b), and the problem has actually been to avoid overdoing this restoration. In the majority of our cases, there was obvious degeneration of the discs as seen on plain lateral films, but it must be stressed that several cases showed no disc degeneration and no cervical arthrosis whatsoever on routine X-ray examination and the symptom-producing levels were only identified by discography, without which it would have been quite impossible to establish which levels required operative treatment.

ILLUSTRATIVE CASES

Case 1
Mrs. M.M.M. Aged 50 years. Chronic headache and neck pain for many years. Anterior interbody fusion at 3 levels performed on 10 May 1961. The patient obtained complete relief of headache, but this lasted less than a month and then recurred as severely as before. X-ray taken on 13 May 1964 (Fig. 1) shows firm bony fusion at all 3 levels, and a marked forward subluxation owing to excessive strain at the first level above the fusion (C3/4). An illustration of a case with identical appearance has been published by Cloward.⁸

Case 2
Mrs. F.J. Aged 33 years. Involved in a riding accident 18 years ago. Unilateral right-sided occipital and frontal headaches started soon afterwards. Pain spread to the right side of the face, and during the past 3 months became very severe and radiated down the right arm. Neurological examination including cerebral angiogram and air encephalogram, was negative.

Case 3
Mrs. A.N.G. Aged 45 years. Severe occipital and frontal headaches followed a car accident 5 years ago. For the past 3 years the headache and neck pain were present continuously.

Case 4
Miss S.M.N. Aged 33 years. In 1960 she was involved in a car accident and sustained a whiplash injury to her neck, as

usually, but neck movements were exceedingly painful. Arthroplasty at 3 levels performed on 18 December 1963, with immediate complete relief.

Lateral view X-ray before operation showed marked loss of disc height and anterior sharp beak-like osteophytes, at 3 levels (Fig. 3a).

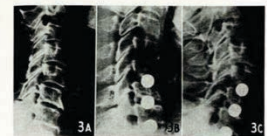


Fig. 3A, B, C. See text.

Stress views in flexion and extension taken on 25 May 1964 are shown in Figs. 3b and c. Note the increase in disc height especially at C6-7 level. The separation of the tips of the spinous processes in flexion, compared with that in extension, increased by 5 mm, 9 mm, and 5 mm, respectively at these 3 levels, indicating a fair range of movement at the prosthesis. She is still completely free of headache and all neck and arm pain owing to the cervical spondylosis.

Case 5
Miss S.M.N. Aged 33 years. In 1960 she was involved in a car accident and sustained a whiplash injury to her neck, as

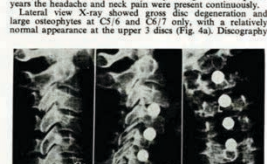


Fig. 4A, B, C. See text.

performed on all 5 cervical discs, produced no pain at the newly arthritic C5/6 and C6/7 levels, which were probably completely asymptomatic, but instantly reproduced her typical headache both at C3/4 and C4/5 levels. At operation on 25 March 1964 the 4 lower discs were replaced with spherical prostheses.

Well marked increase of disc height is shown in Fig. 4b and a good range of lateral flexibility is demonstrated in Fig. 4c. She obtained immediate relief, and later stated 'When 28 May 1964 and was still completely free of pain, and stress views on 12 May 1964 showed a good range of movement at the arthroplasty.

Case 6
Mrs. H.H. Aged 62 years. Pain in the neck and right arm and severe headaches for 3 years. Pain practically continuous for past few months. Clinical examination was essentially

well as concussion with unconsciousness for half an hour. Severe headaches started immediately afterwards, usually in attacks which lasted continuously for 3 or 4 days. The headaches were at first thought to be due to a post-concussion syndrome. X-ray examination showed no spondylosis and no loss of disc space. Discography immediately reproduced her typical unilateral pain behind the right eye, severely at 1 level and slightly at 2 more levels. This lateral view taken at operation shows the prostheses in position at 3 levels between C3 and C6. She was asked to write out a full description of her symptoms in her own words, which she did immediately before the operation. 'I have been suffering from headaches continuously since my accident 3 years ago. The pain starts at the back of the head (the right side) and spreads to the top of the head and behind the eyes. It burns so severely that on occasions I become bilious. The pain at times lasts for 3 days and I find it very difficult to get comfortable at night. I take no pain pills. The severe pain occurs approximately every 10 days. On occasion the pain is slight. All in all about 2 or 3 days a week I might not have a headache. My neck pains when I turn to either side and also backwards and forwards—the bottom part of the neck, and the shoulders hurt. I also have pain in my arms, and pins and needles and cramp in my right hand. The pain in the arm is just shooting pain. My neck gets very tired and I sometimes feel I cannot hold my head up and have to rest it on my hands. The neck aches particularly on the right side and mostly when I have had a very busy day at work and have not been able to relax.

The patient obtained complete relief of headache and arm pain following operation, and she also stated specifically that the extreme tiredness and the feeling that her head was too heavy for her neck was completely relieved. At a recent examination, there was no recurrence and her only complaint was of some fibrositic pain in the trapezius muscles (Fig. 5).

Case 7
Mr. R.W.R. Aged 30 years. Severe low backache and sciatica, unrelieved by laminectomy. After the implant operation on 24 March 1963 he obtained immediate relief and was ambulant within 48 hours.

To date (10 June 1964) we have performed a total of 75 cervical disc arthroplasties with the spherical prosthesis, on 32 patients. We have also implanted the same prosthesis in 19 lumbar discs in 12 patients, for discogenic backache and sciatica (Fig. 6).

This series started in November 1963, which is naturally

too recent to enable any final conclusions to be drawn, but we can definitely state that the clinical results so far have been infinitely better than our past experiences over many years with spinal fusion procedures. Intractable headache, sometimes of more than 20 years' duration, has been completely relieved in nearly every instance, and so far no case has relapsed. The majority of cases were ambulant on the first or second postoperative day, and the average post-operative period of hospitalization has been 4 days. Two cases left hospital less than 48 hours after operation, and several patients exhibited a conspicuous euphoria, which is understandable after sudden relief of severe and continuous pain of long standing. A complete review of these cases not less than 2 years after operation will give some indication of the long-term prognosis. Harmon has several 7-year follow-up results after lumbar implantation, with remarkably good function and freedom from pain still present.

In cases in which pain recurs after a solid bony arthrodesis, the problem is frequently insoluble. Even if multiple levels have already been fused, the only procedure which then remains, and is often done, is the operative fusion of still more levels.

Arthroplasty however, is a much less destructive procedure, and as demonstrated by Coventry⁹ in the case of the hip joint, if pain should recur some years later it is exceedingly likely that it can be treated successfully by a comparatively simple surgical revision of the arthroplasty with a larger or better prosthesis, or as a last resort by a localized fusion operation, which is currently the commonest method for the cervical spine.

1. Brain, H. (1962); *Brit. Med. J.*, 71, 711.
2. Kellgren, J.H., and Lawrence, J.S. (1958); *J. Bone Jt. Surg.*, 40A, 826.
3. Lord, Brain, H., and Lawrence, J.S. (1959); *J. Bone Jt. Surg.*, 41A, 107.
4. Hutchinson, E.C., and Yates, P.O. (1956); *Brain*, 79, 319.
5. Kovacs, A. (1937); *Acta radiol. (Stockh.)*, 43, 45.
6. Kovacs, A. (1937); *Acta radiol. (Stockh.)*, 43, 45.
7. Harman, N.M., and Smith, A.J. (1962); *Clin. Orthop.*, 24, 84.
8. Robinson, R.E. (1962); *J. Bone Jt. Surg.*, 44A, 106.
9. Cloward, R.B. (1961); *Clin. Orthop.*, 27, 51.
10. Harmon, N.M. (1962); *Personal communication*.
11. Coventry, M.B. (1964); *J. Bone Jt. Surg.*, 46A, 200.



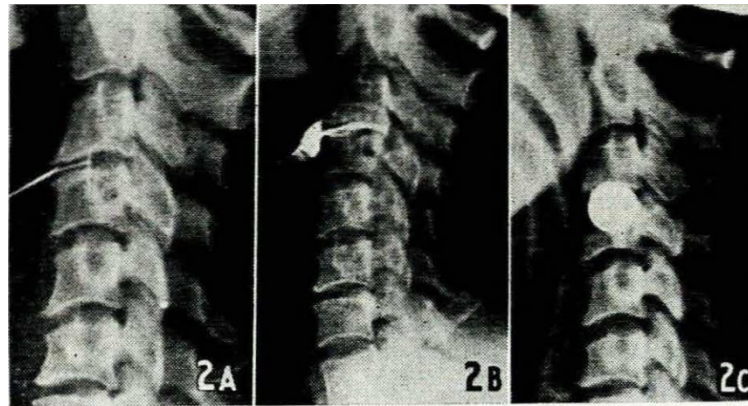
Fig. 5. See text (under 'Illustrative cases'). Fig. 6. See text.

Reitz & Joubert

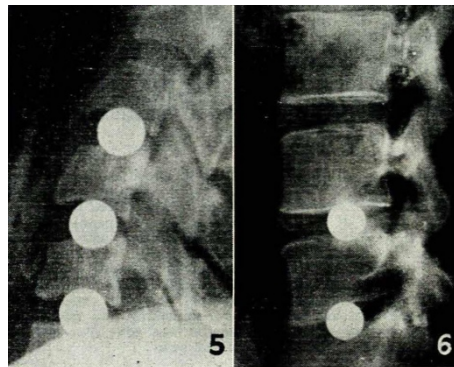
Johannesburg & Durban, South Africa

November 1963 – 64

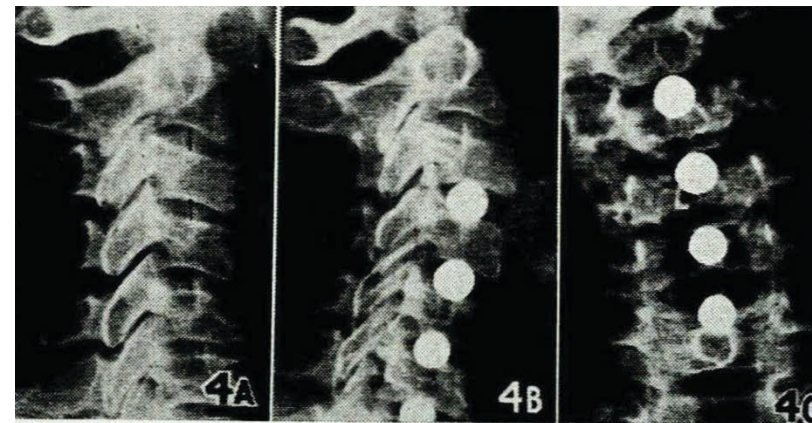
75 arthroplasties in 13 patients



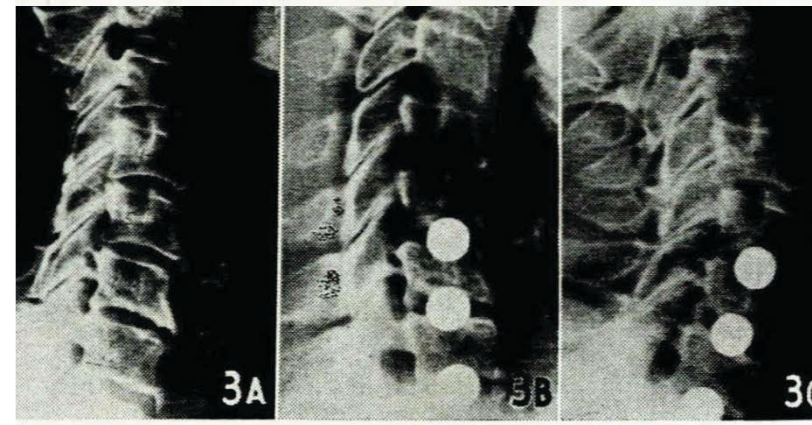
Figs. 2A, B, C. See text.



*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



Patent #: US004349921

Section: Drawings 4 of 13 pages

[Help](#)

U.S. Patent

Sep. 21, 1982

Sheet 3 of 3

4,349,921

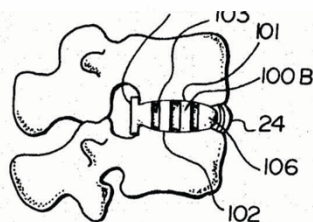


FIG. II

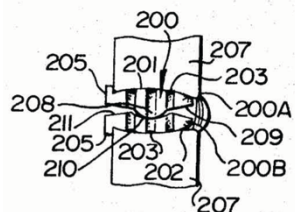


FIG. 12

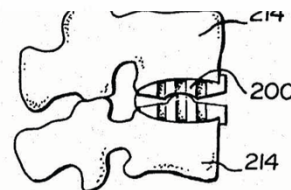


FIG. 13

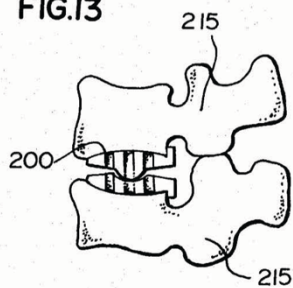
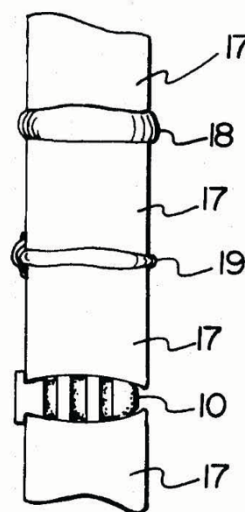


FIG. 14



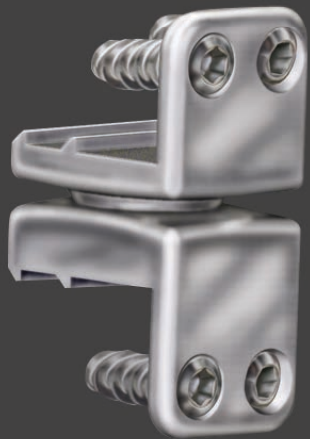
Bristol/Cummins Disc Frenchay Hospital, UK



1991

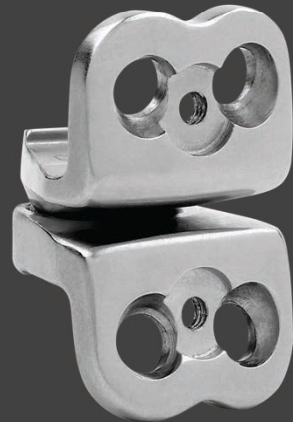


Bristol/Cummins



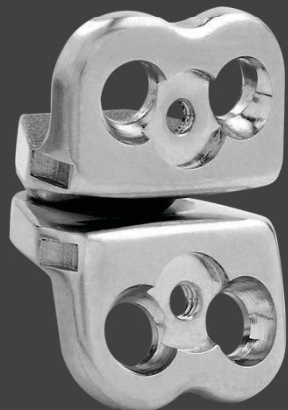
1991

Prestige I



1998

Prestige II



1999

Prestige ST



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



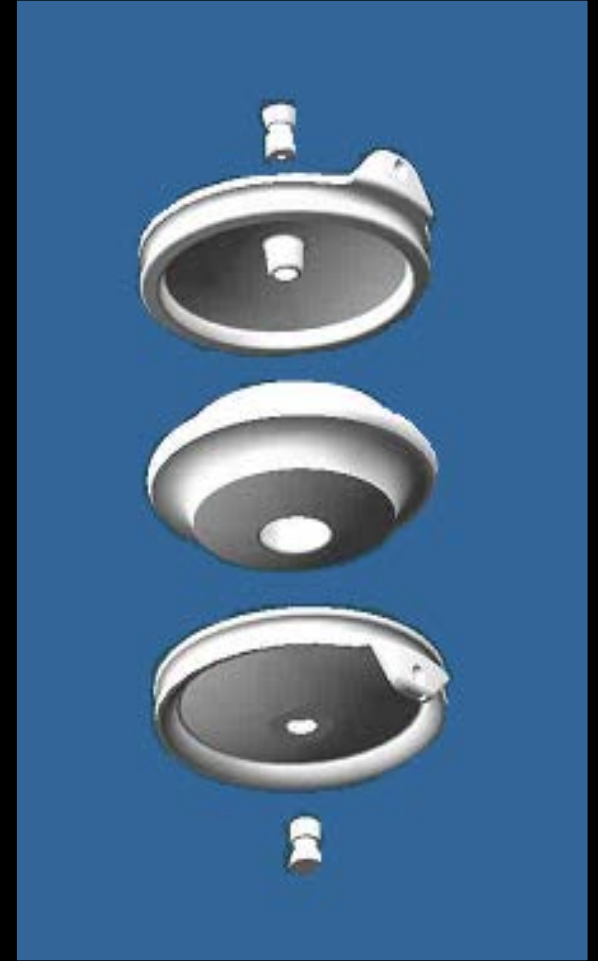
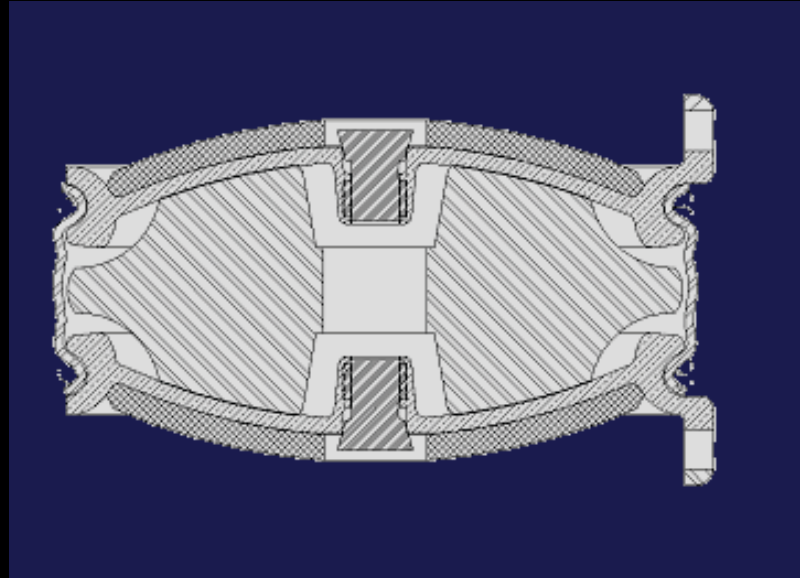
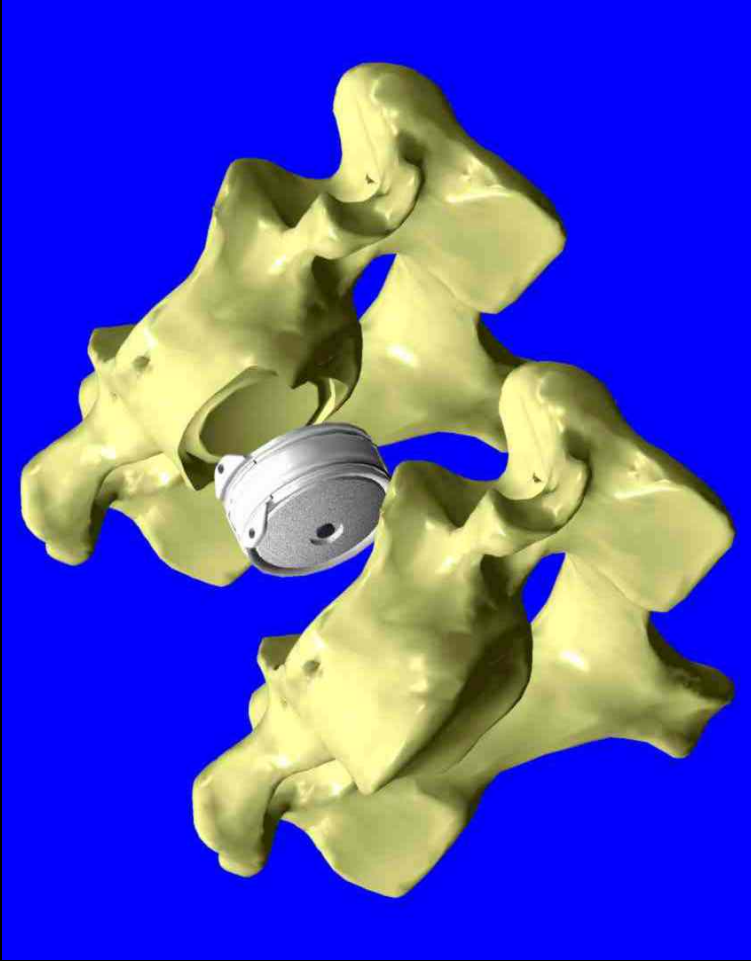


R.S.
47yrs
2001

Bryan Disc



Bryan Disc

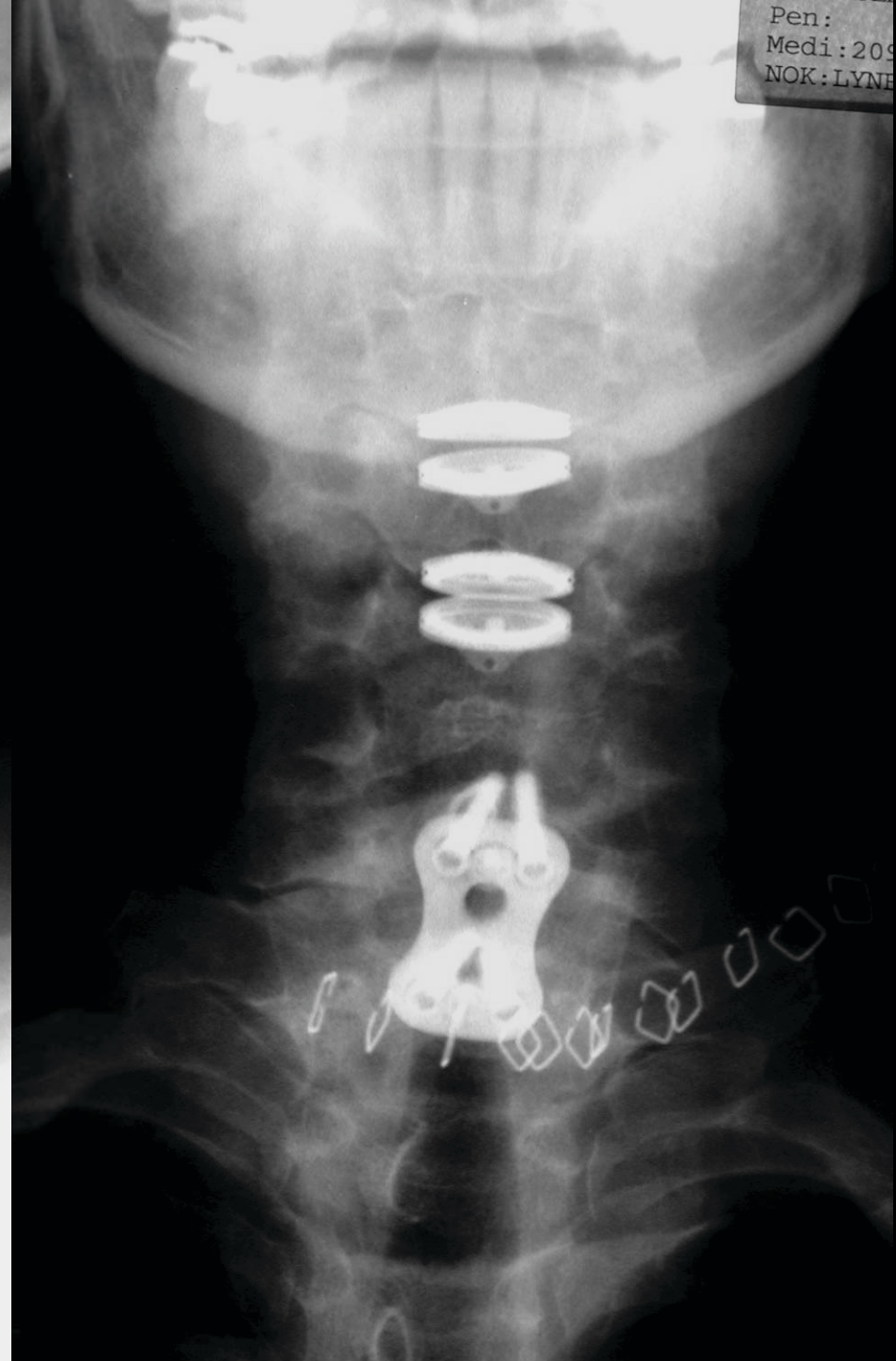


NOK:LYNETTE SLATTER
Medi:209231274



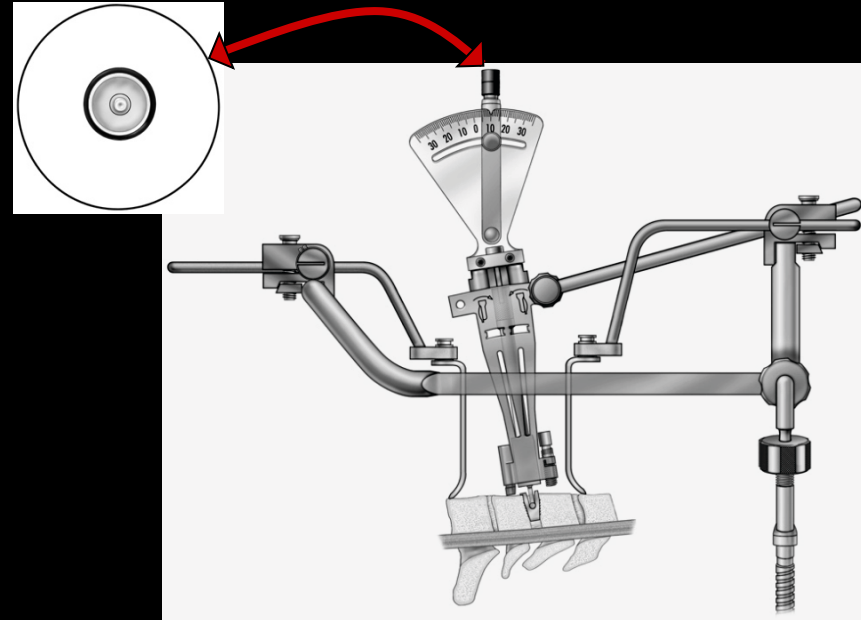
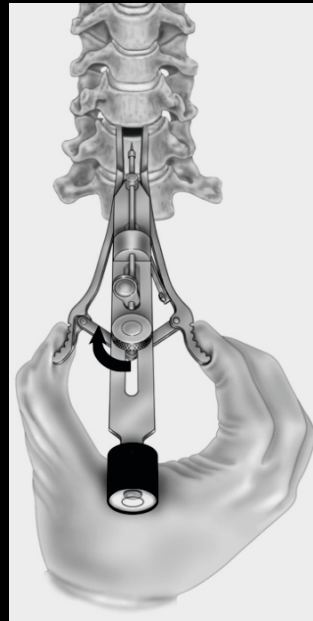
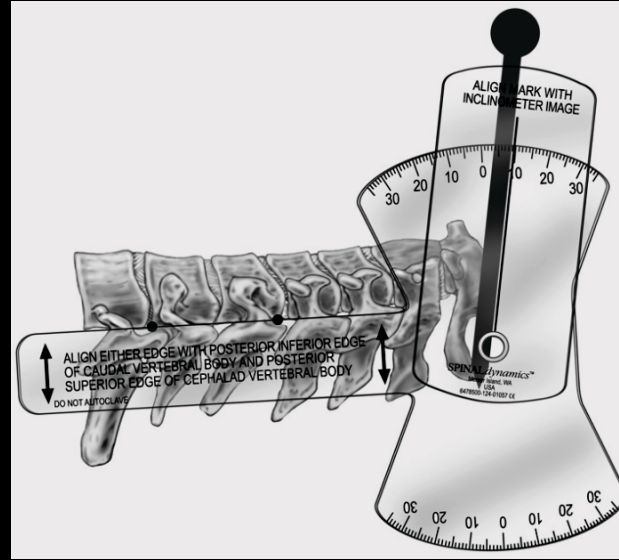
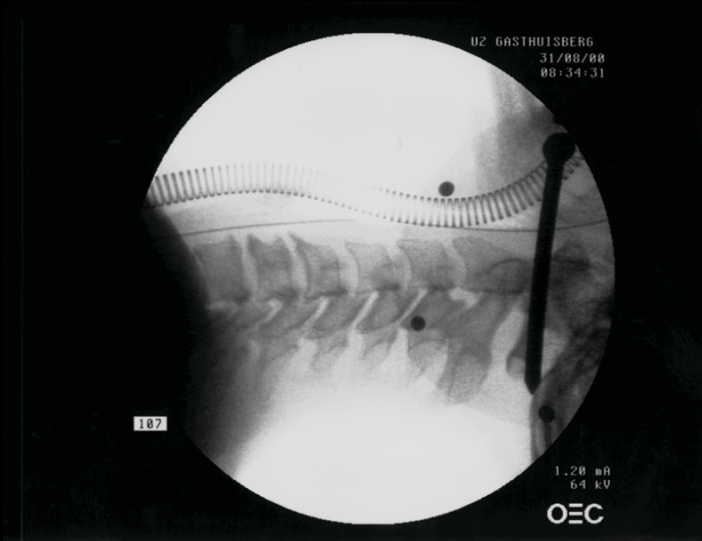
R.S.
47yrs
Surgery: July 2001

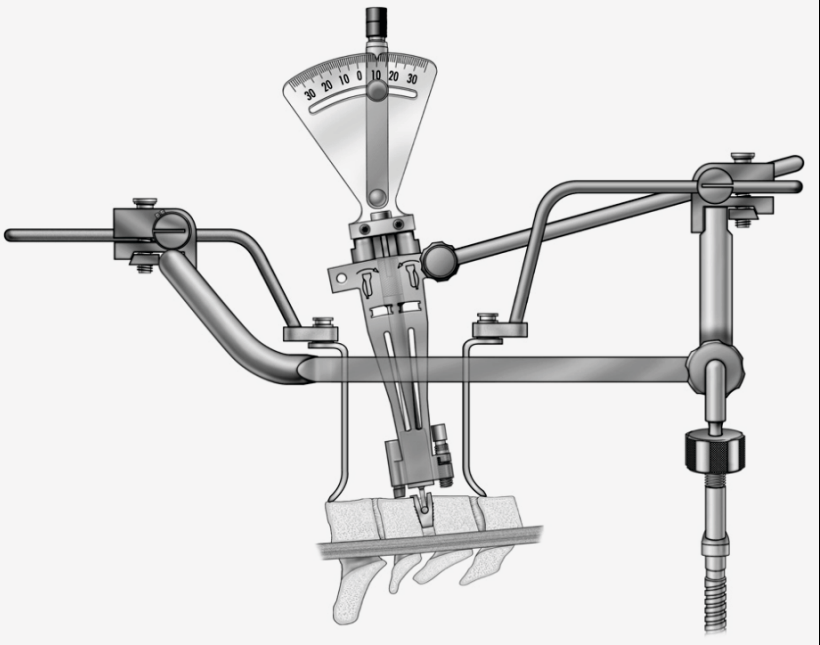
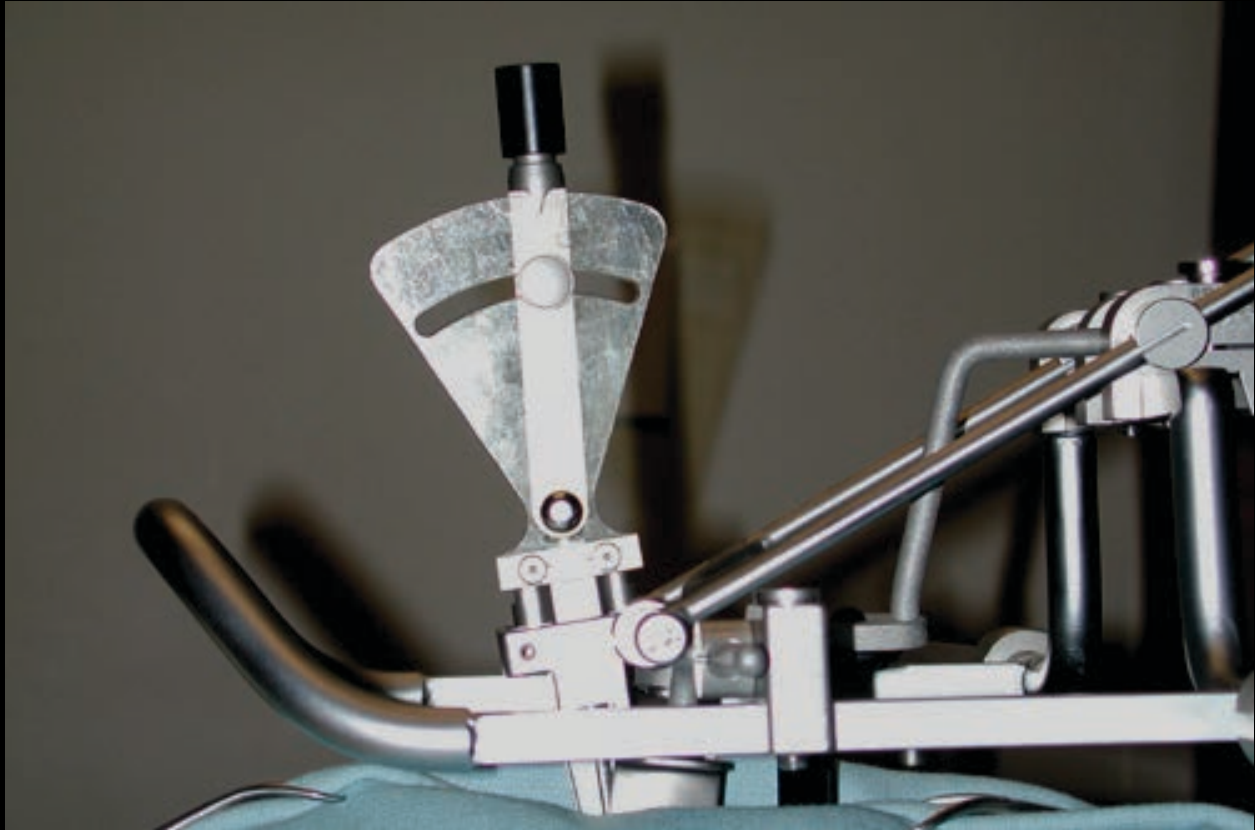
Pen:
Medi:209
NOK:LYNETTE



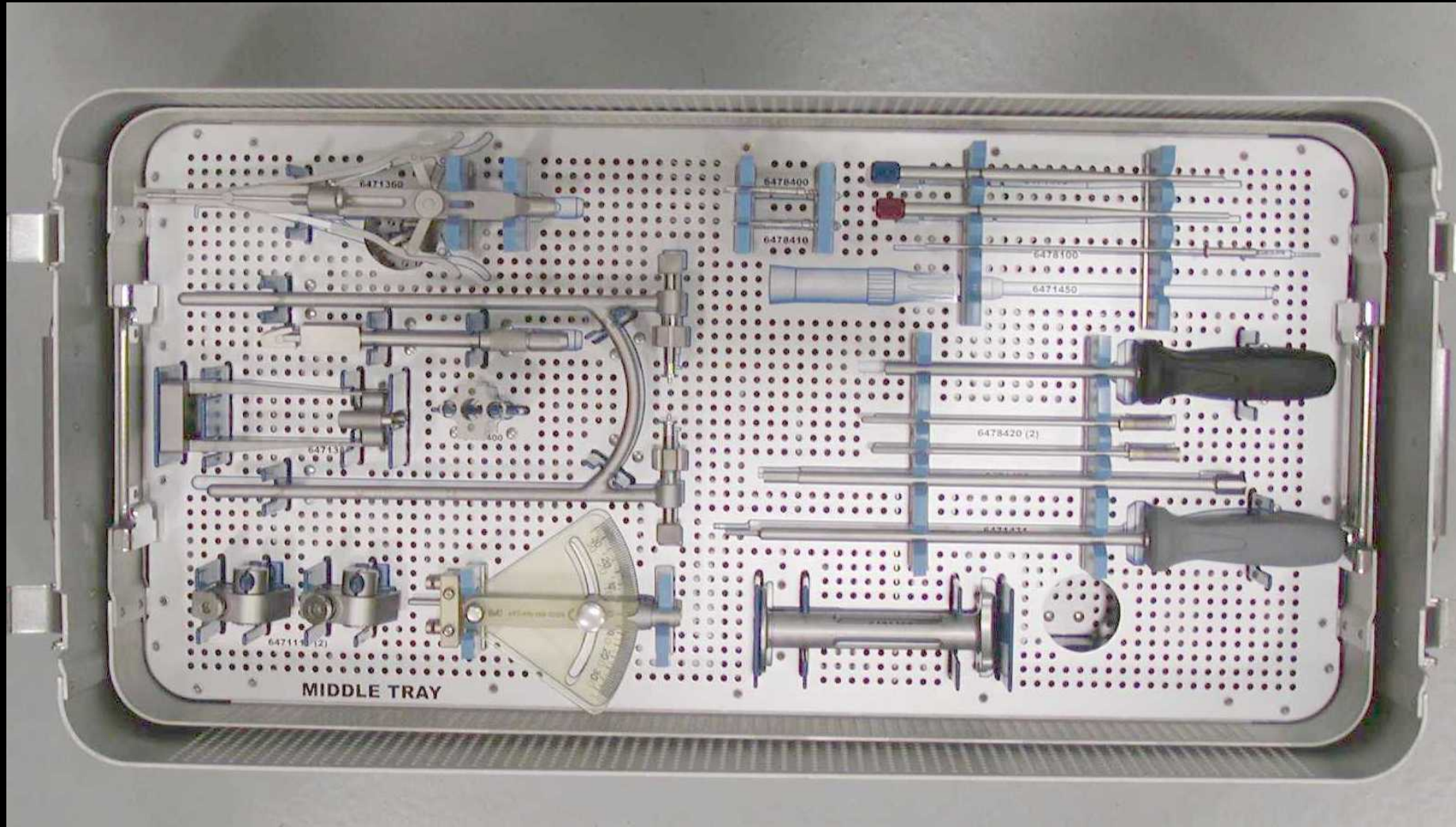
OPERATIVE SYSTEM

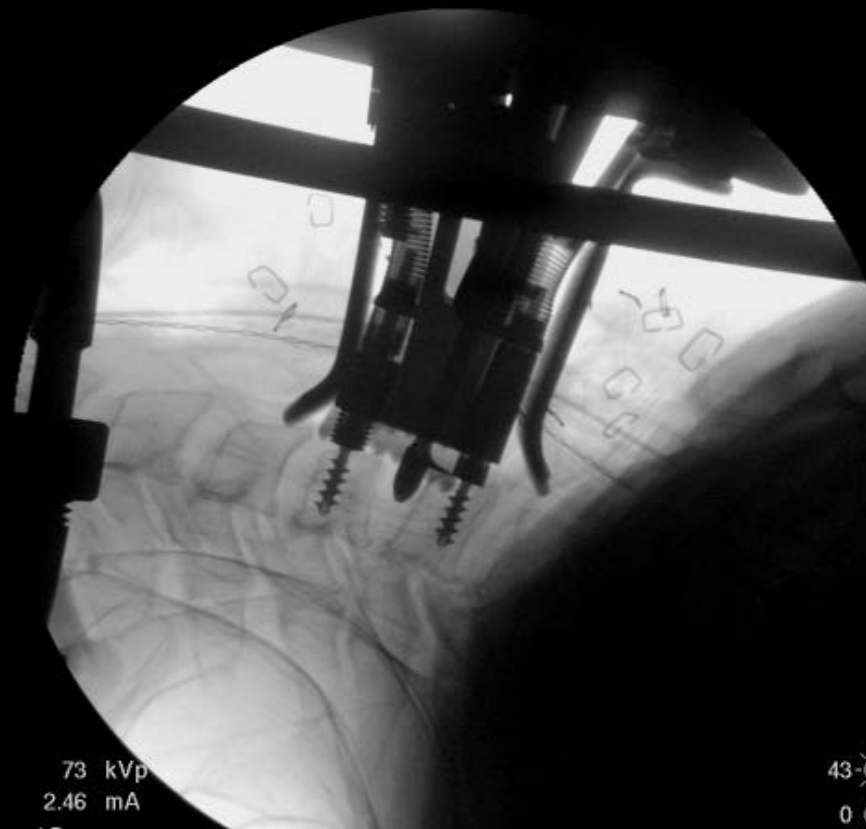
Gravity referenced stereotaxy





Bryan Cervical Disc Case 2 Alignment & Measurement Tools





73 kVp
2.46 mA



70 kVp
1.80 mA

43
0



71 kVp
1.80 mA

43 
0 



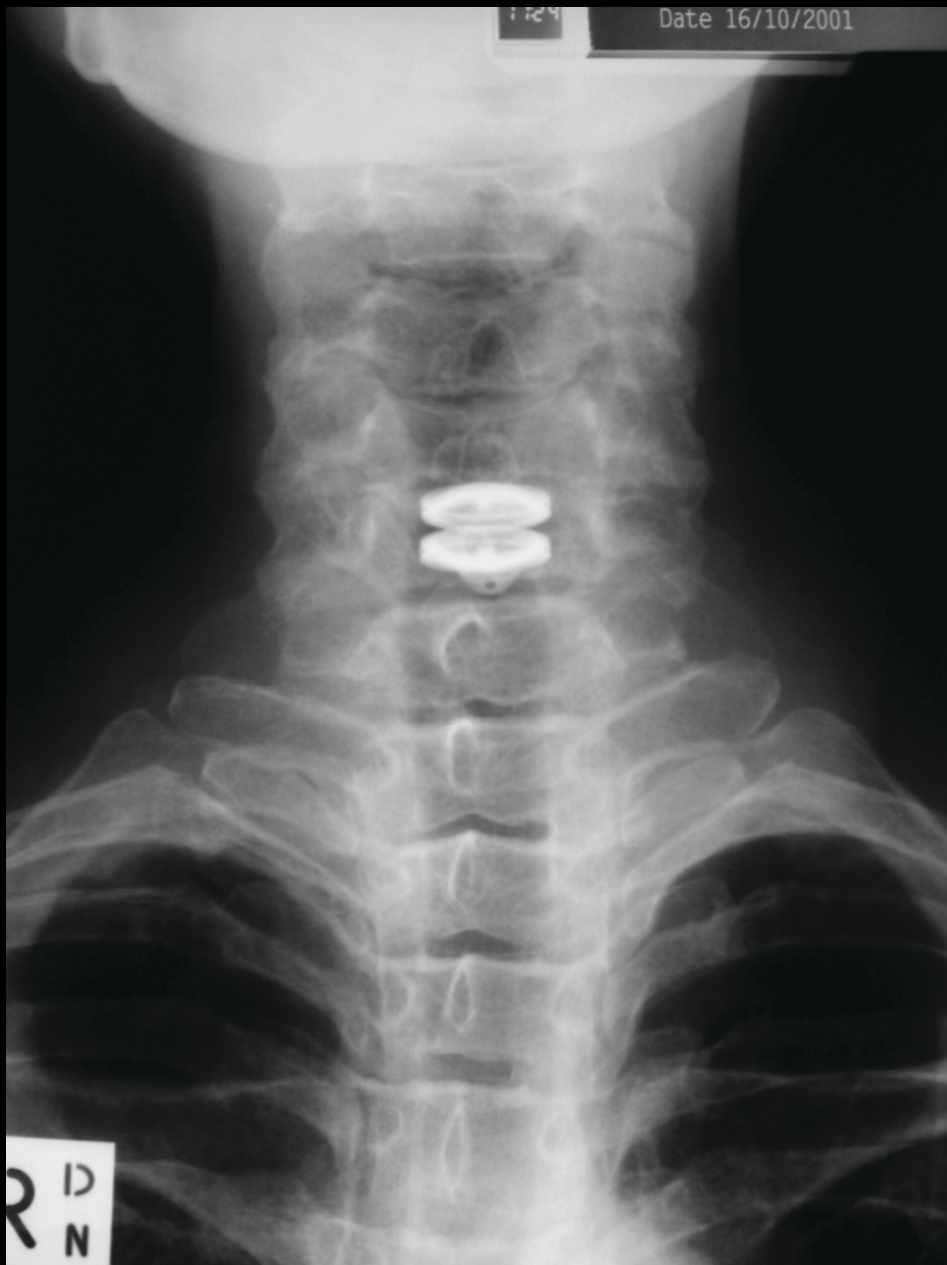
71 kVp
1.85 mA
24

Dalcross
18.09.2001
17:10:11

43 
0 
OEC

69 kVp
1.75 mA
26

43 
0 
OEC





Kyphosis

FLEXION

3 IN
A-P



000



000

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

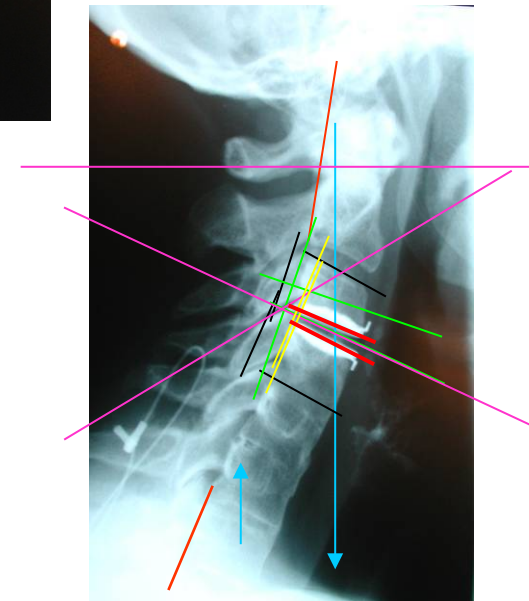
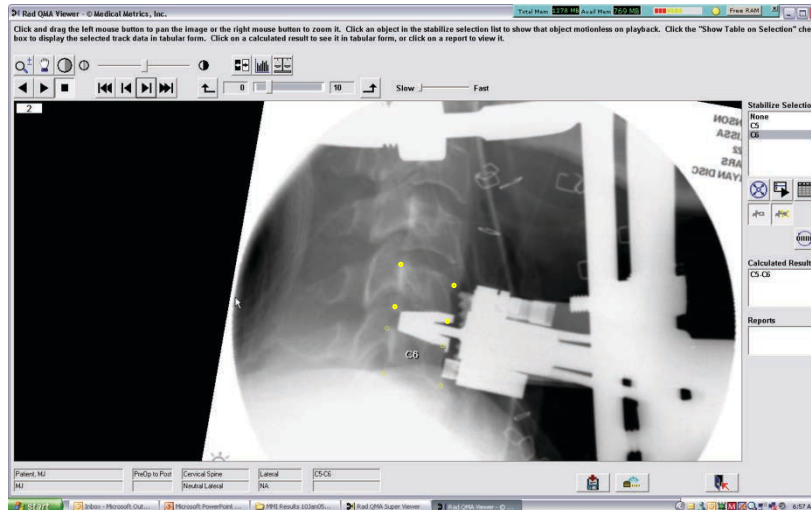
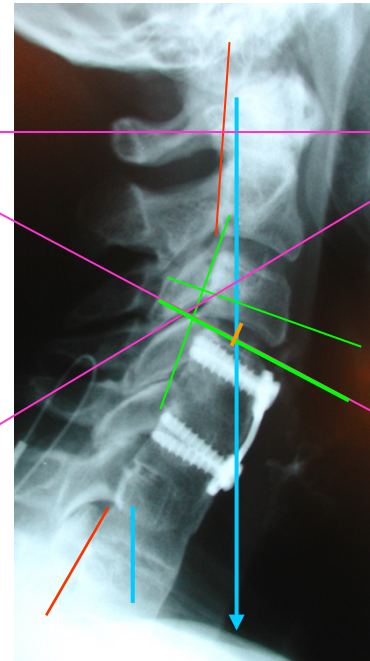
William R. Sears, MBBS, FRACS, Neil Duggal, MD, MSc, FRCS(C),†
Lali H. Sekhon, MBBS, PhD, FRACS,‡ and Owen D. Williamson, GradDipClinEpi, FRACS§*

Study Design

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

35 possible predictors studied

- Pre-Operative
- Operative
- Post-Operative

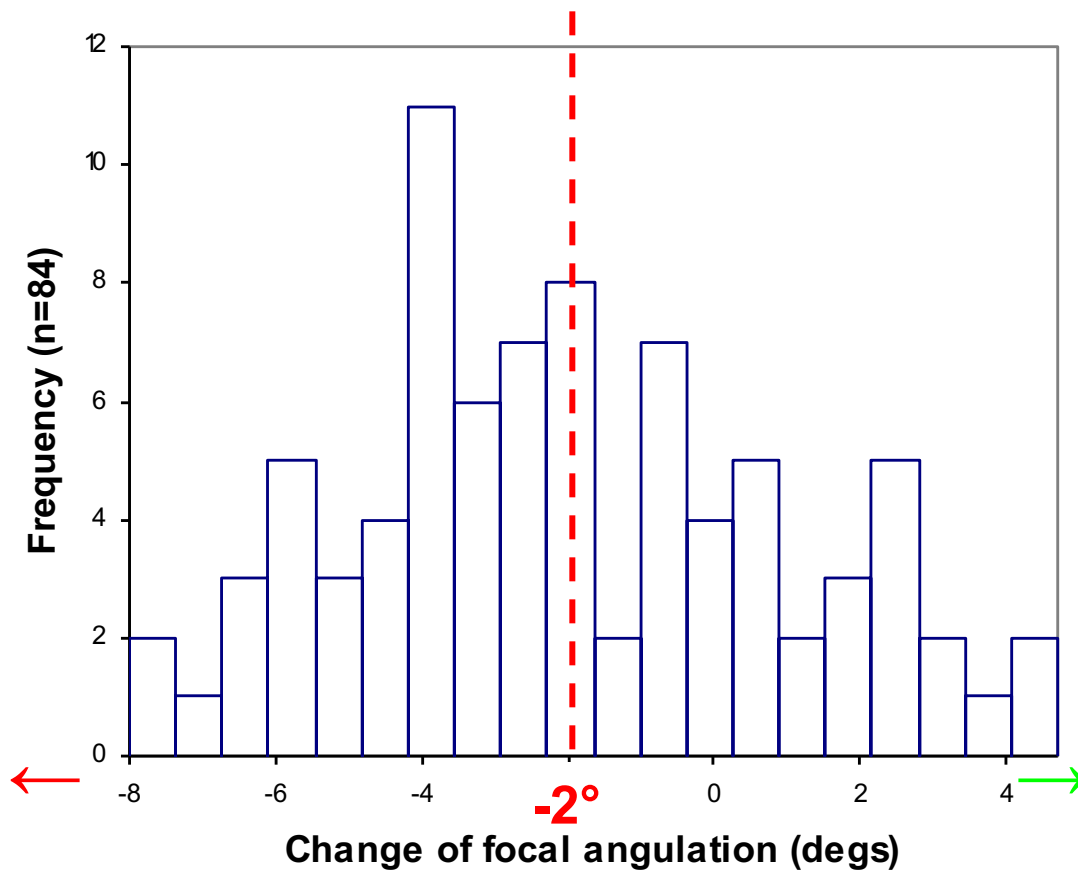


Outcome measures

Post-op FSU angulation (n = 84)



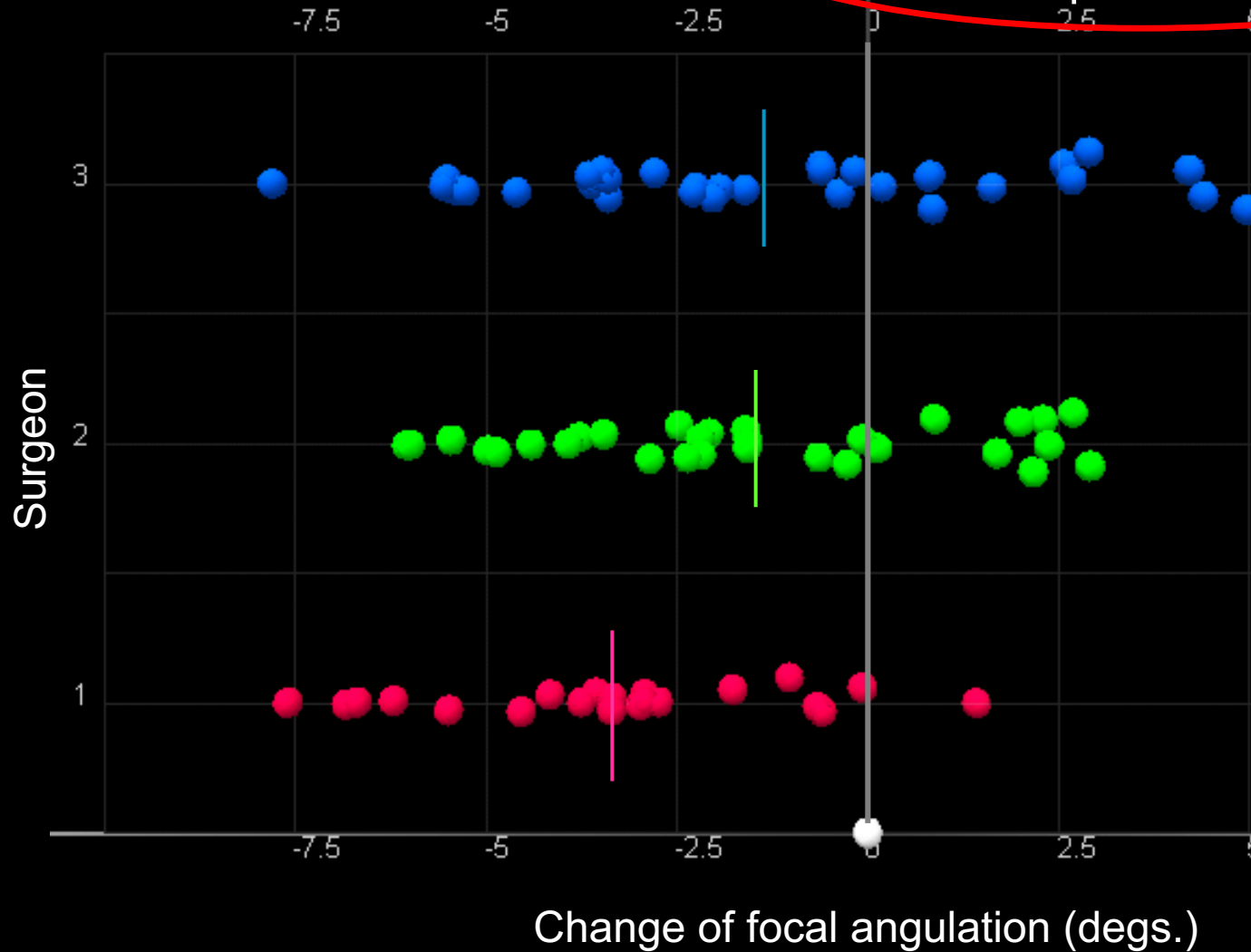
8° Kyphosis



5° Lordosis

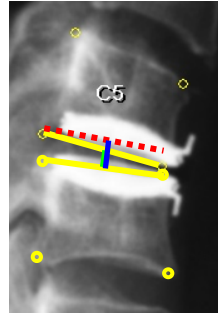
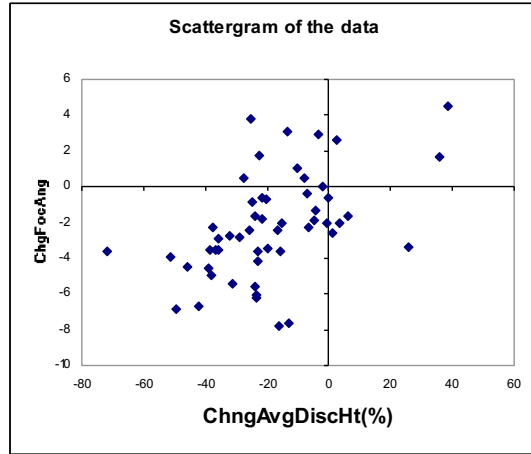
Change of FSU angulation 3 surgeons

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

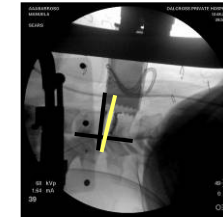
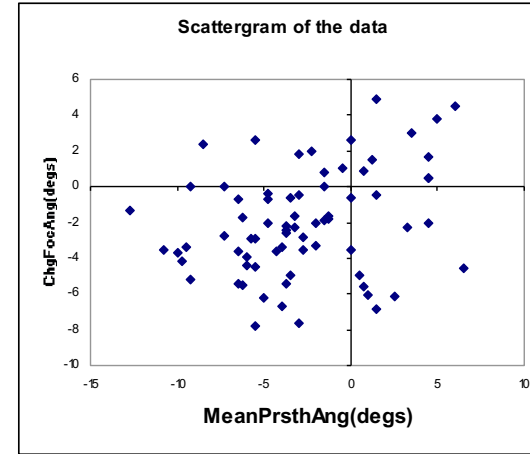


Change in Post-operative FSU angulation

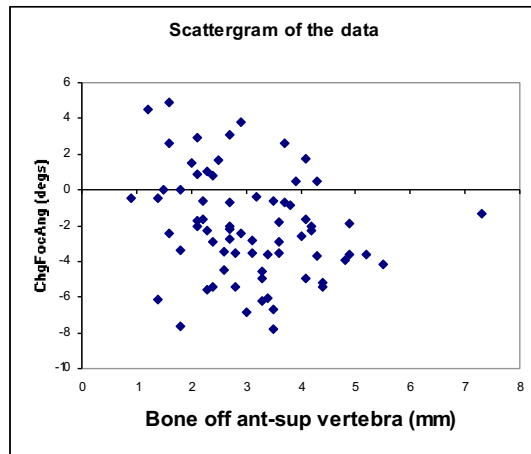
Significant uni-variate correlations



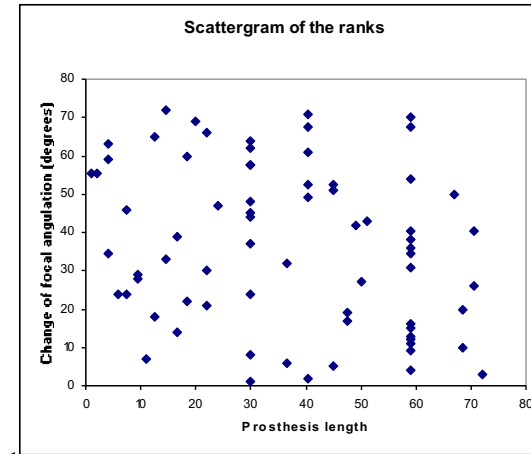
Change in avge. Disc Space height (%)
 $r_s = 0.54, p < 0.0001$



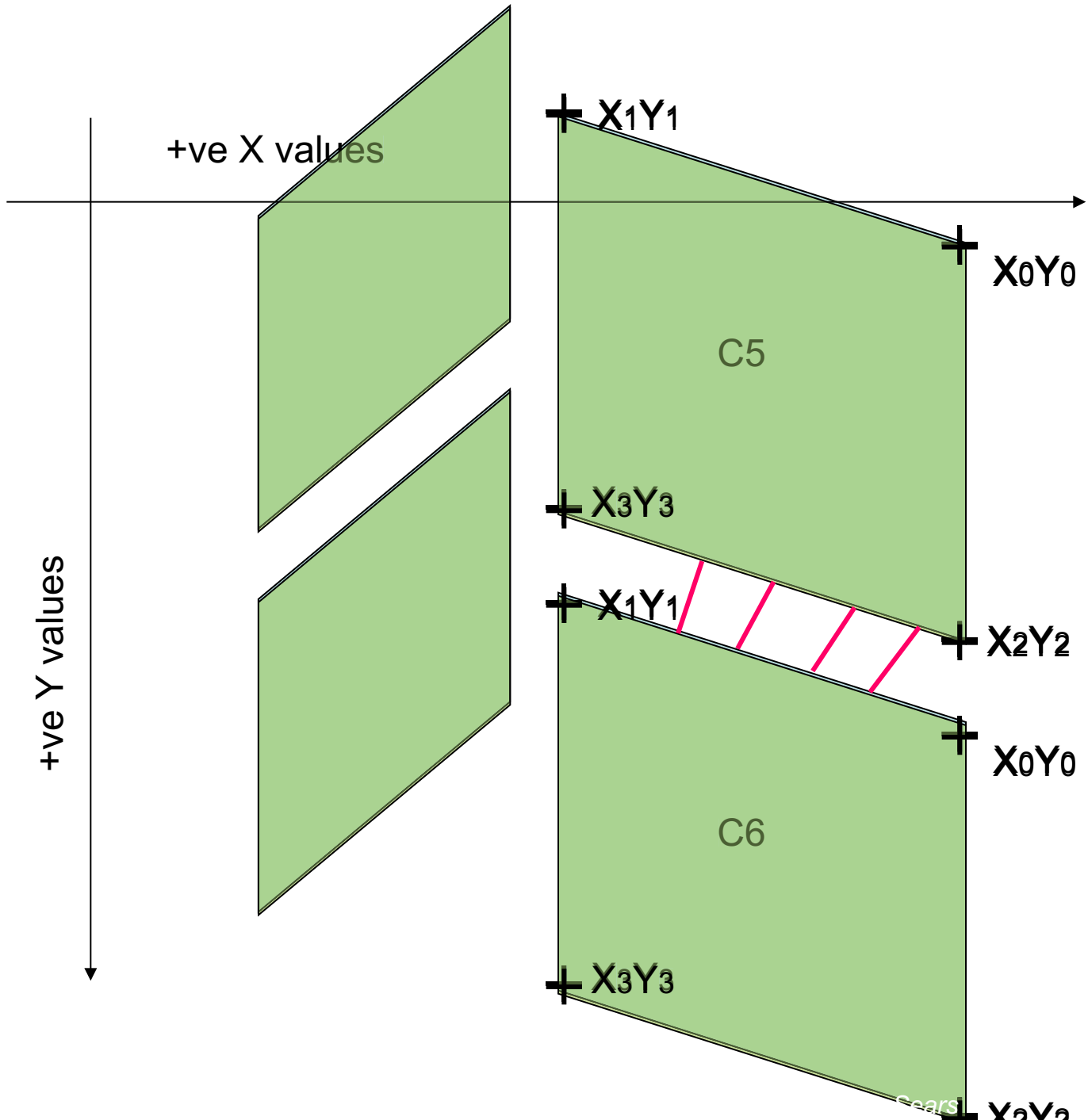
Angle of prosthesis insertion
 $r_s = 0.36, p = 0.003$

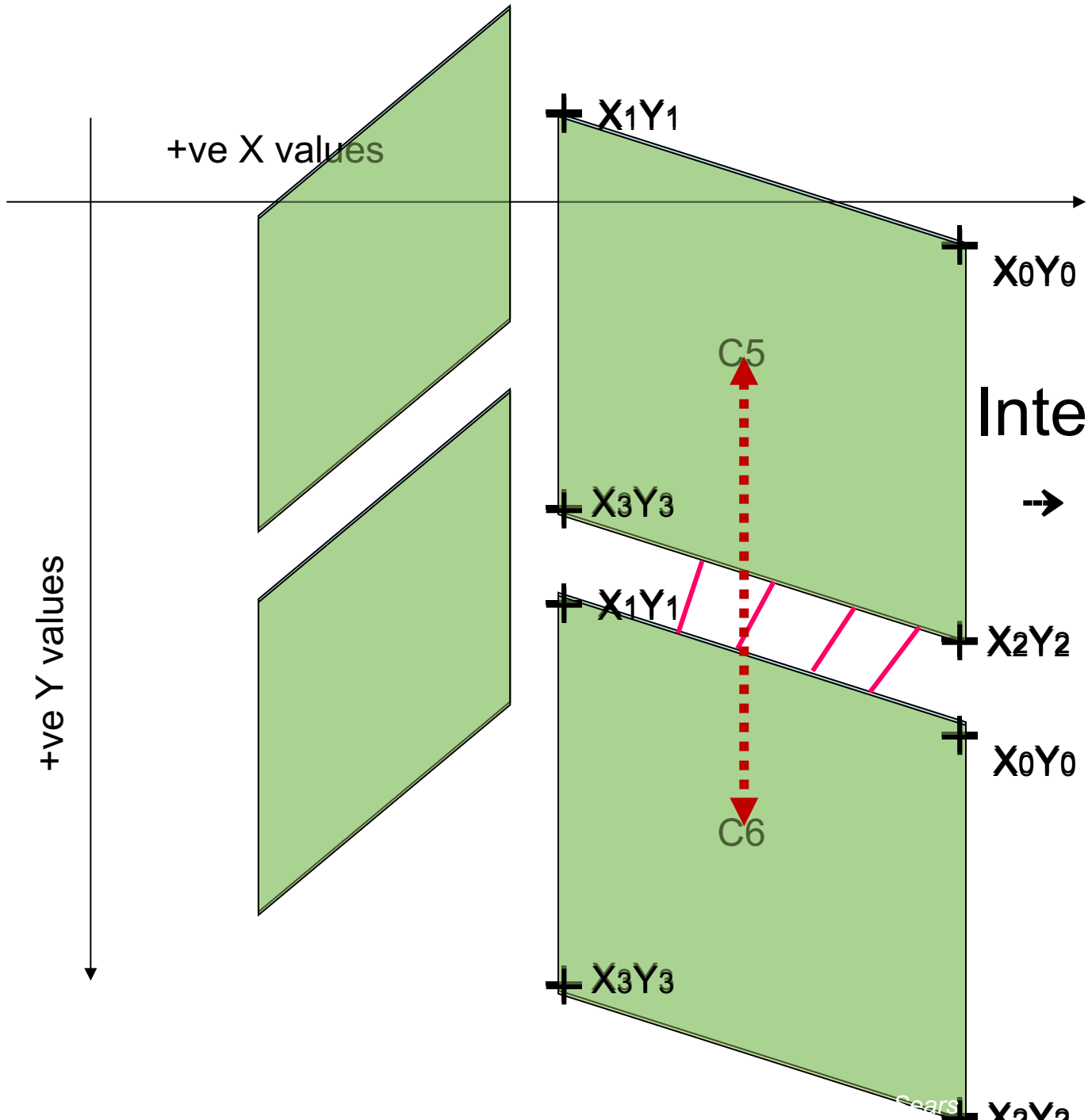


Bone removal ant-sup vertebra
 $r_s = -0.28, p = 0.02$



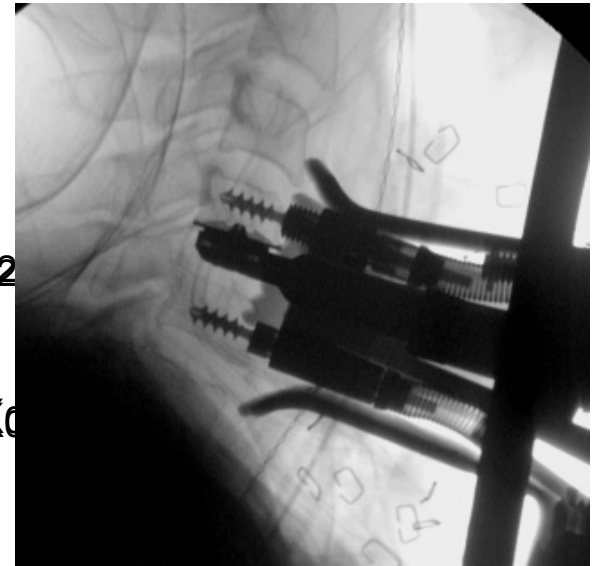
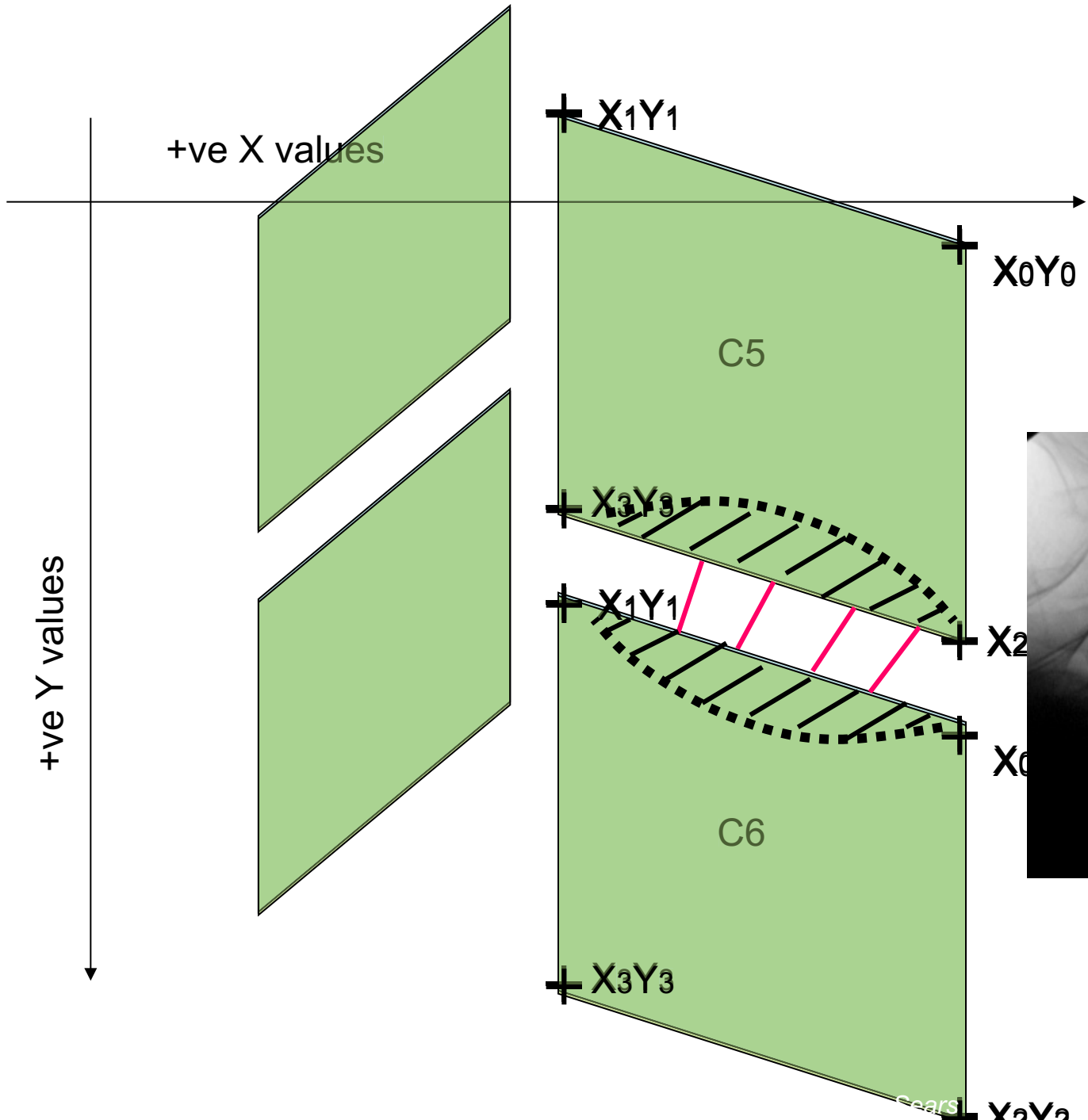
Prosthesis length
 $r_s = -0.25, p = 0.04$

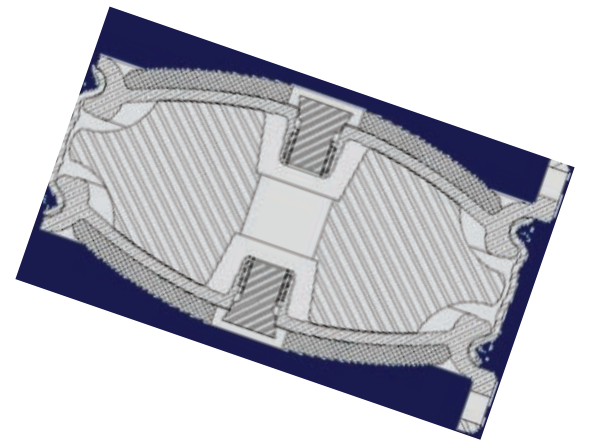
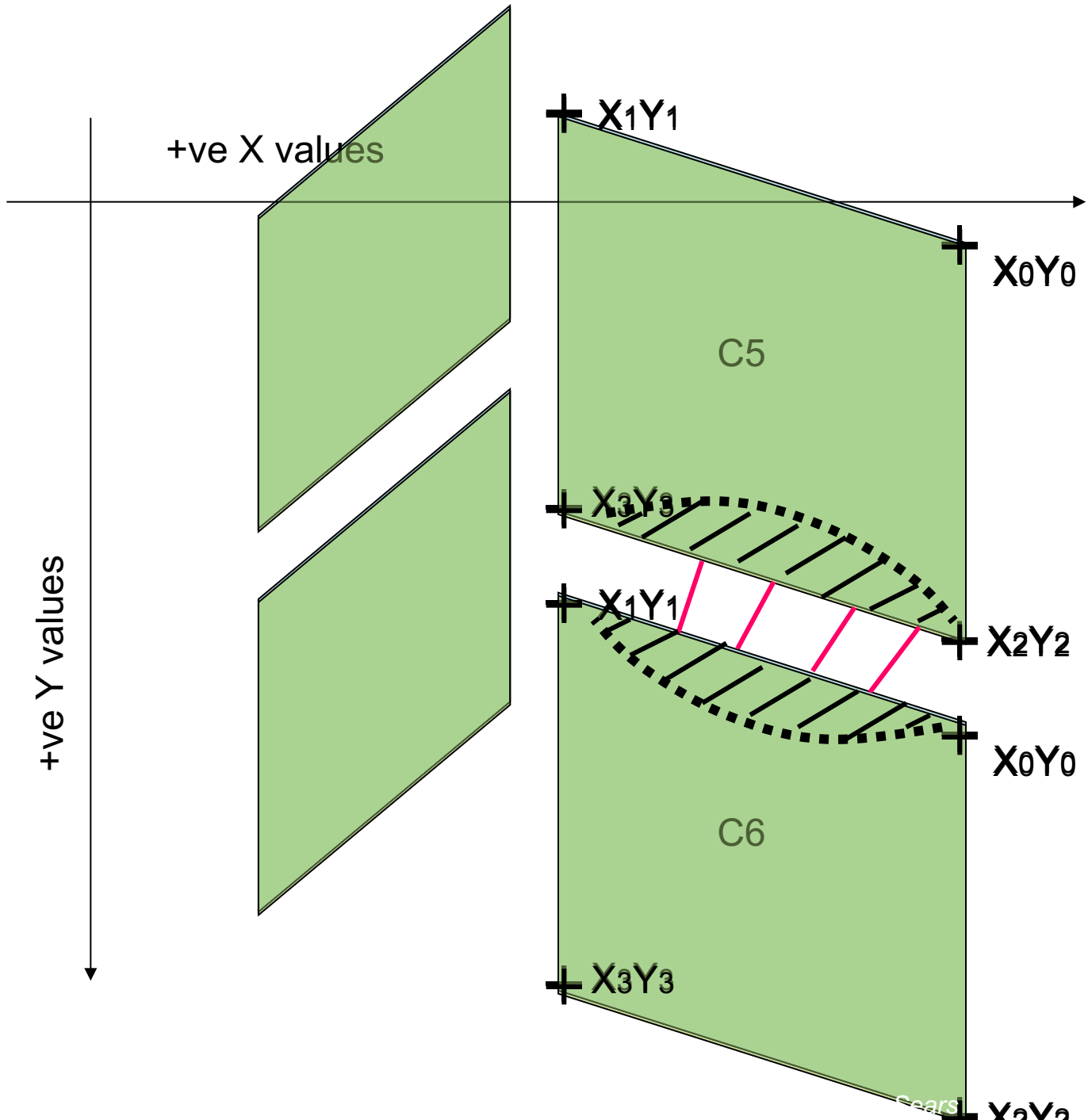


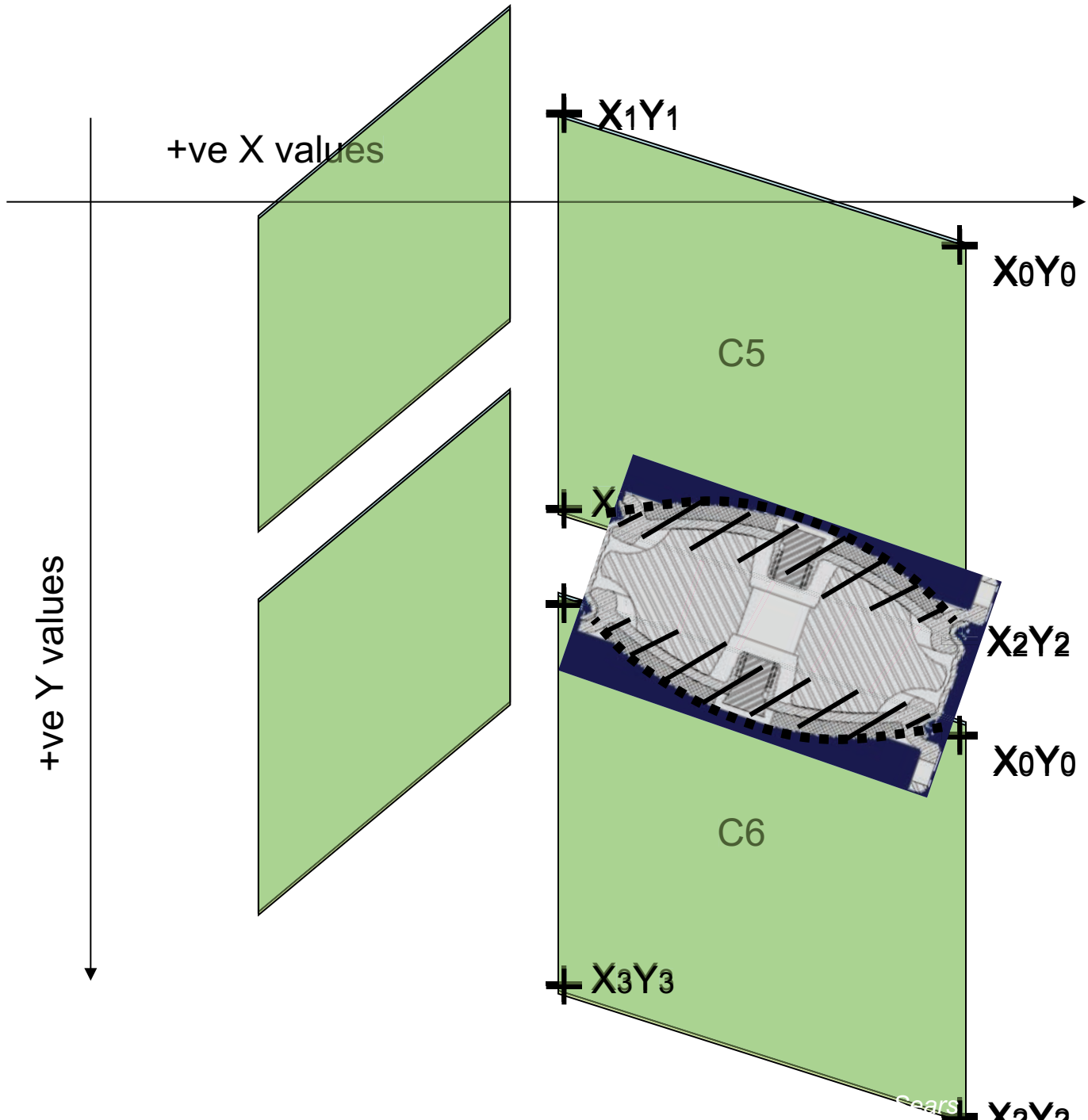


Intervertebral distance
 → 'Disc-space height'

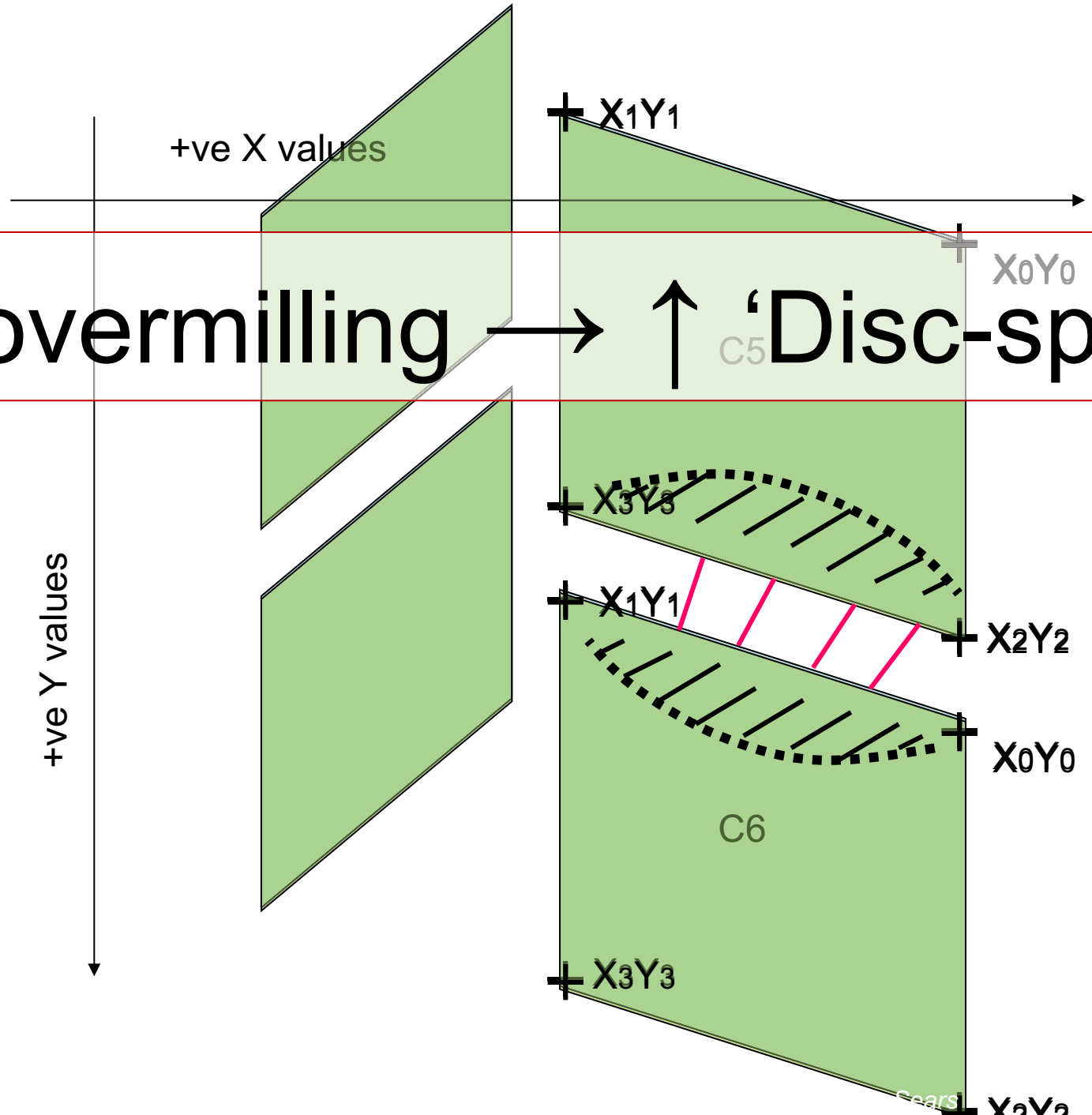
Sears X_2Y_2



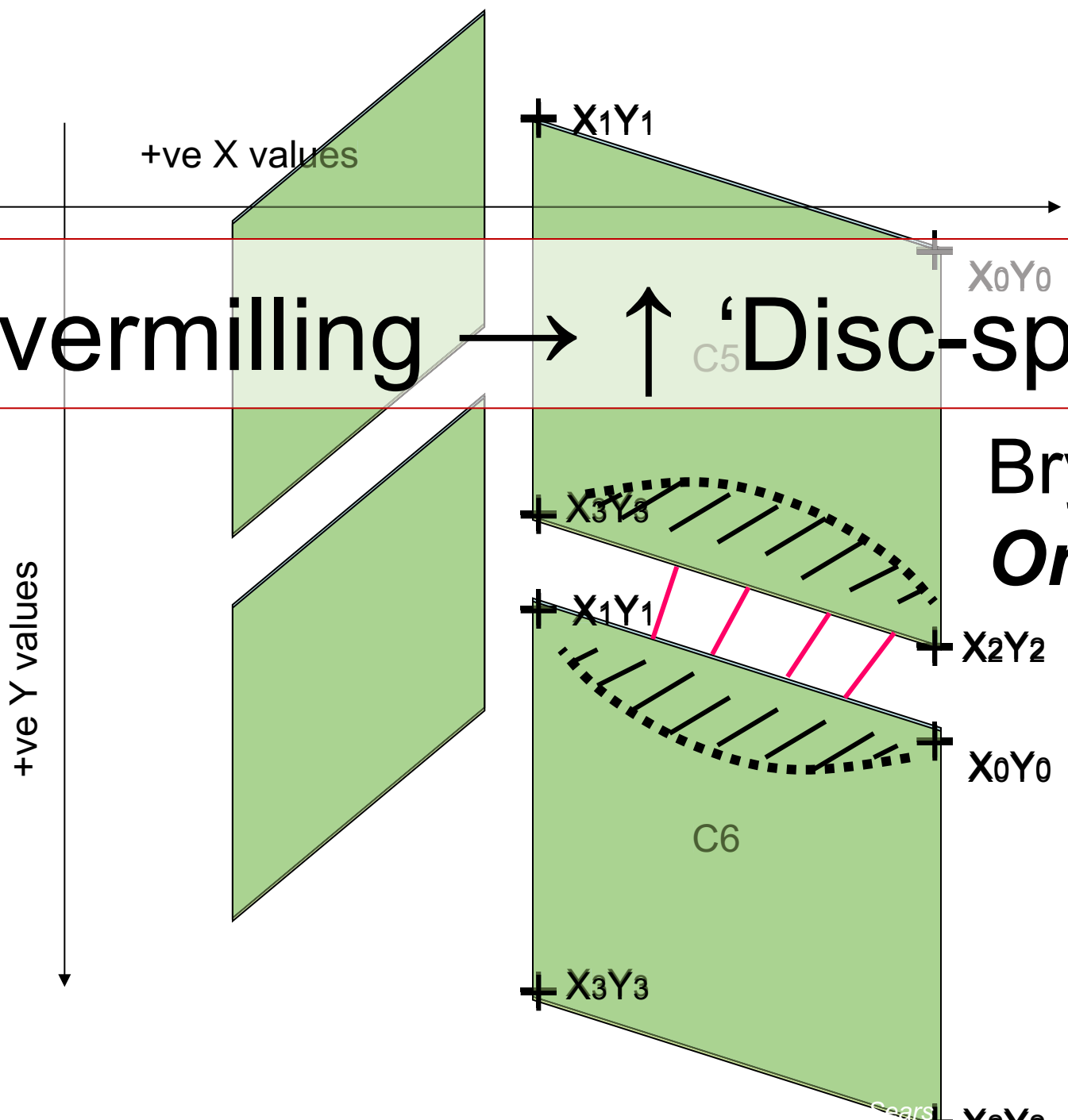




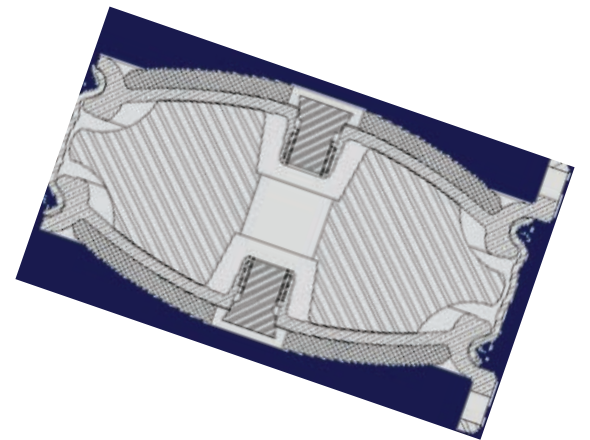
If overmilling → ↑ 'Disc-space height'



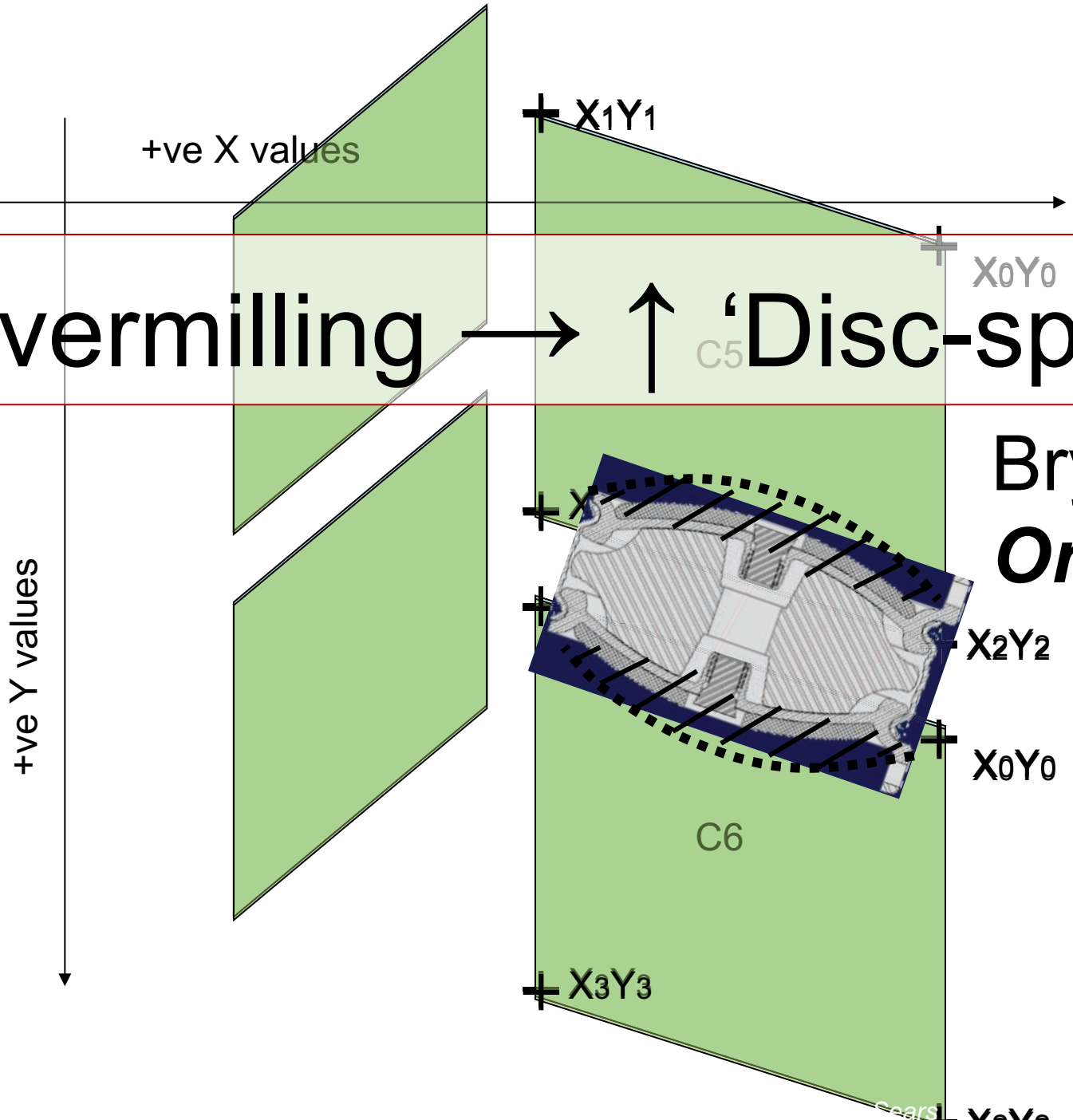
If overmilling → ↑ 'Disc-space height'



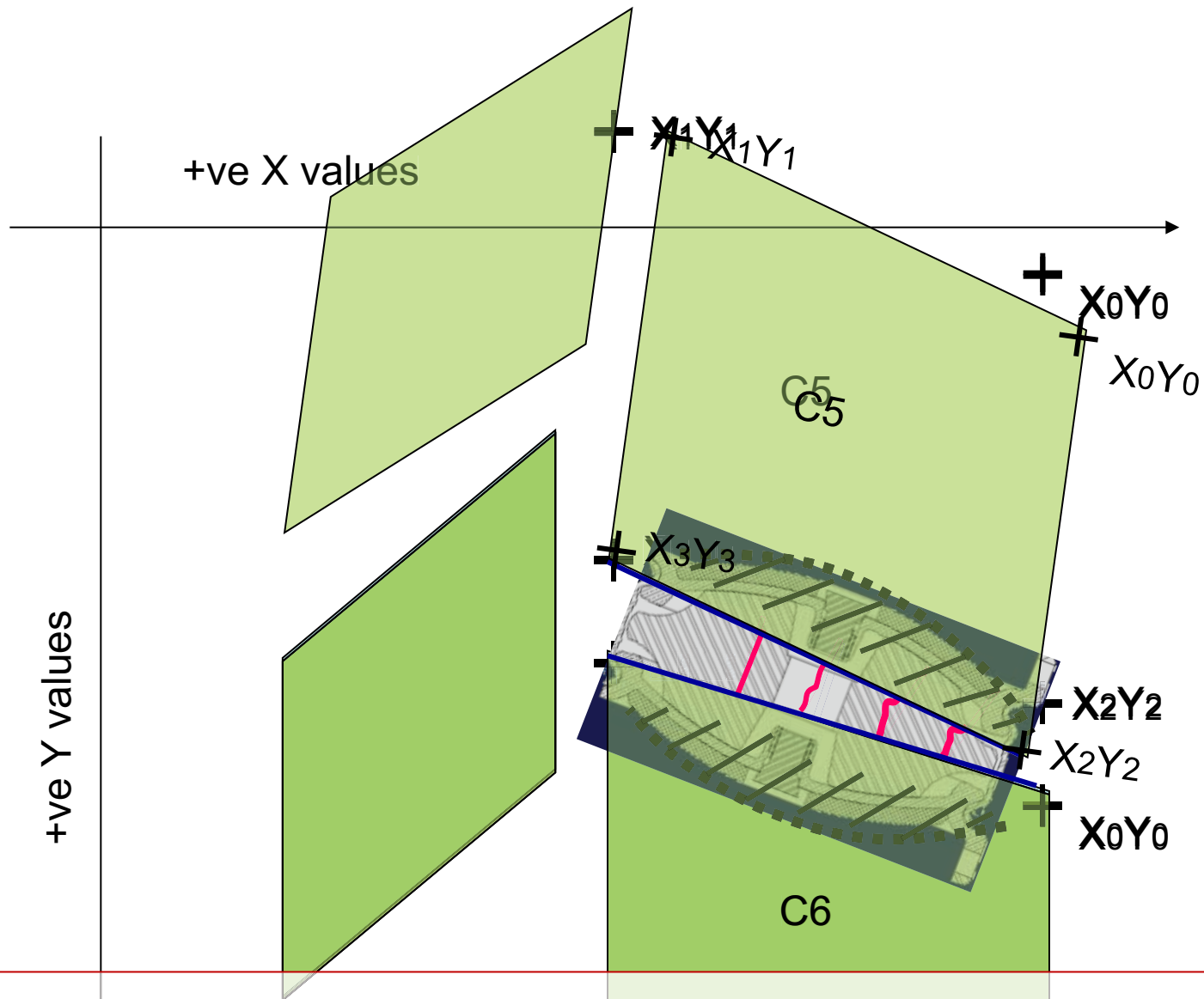
Bryan prosthesis:
One height only



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	89.41	61.14	87.61



C4
C5
C6
C7

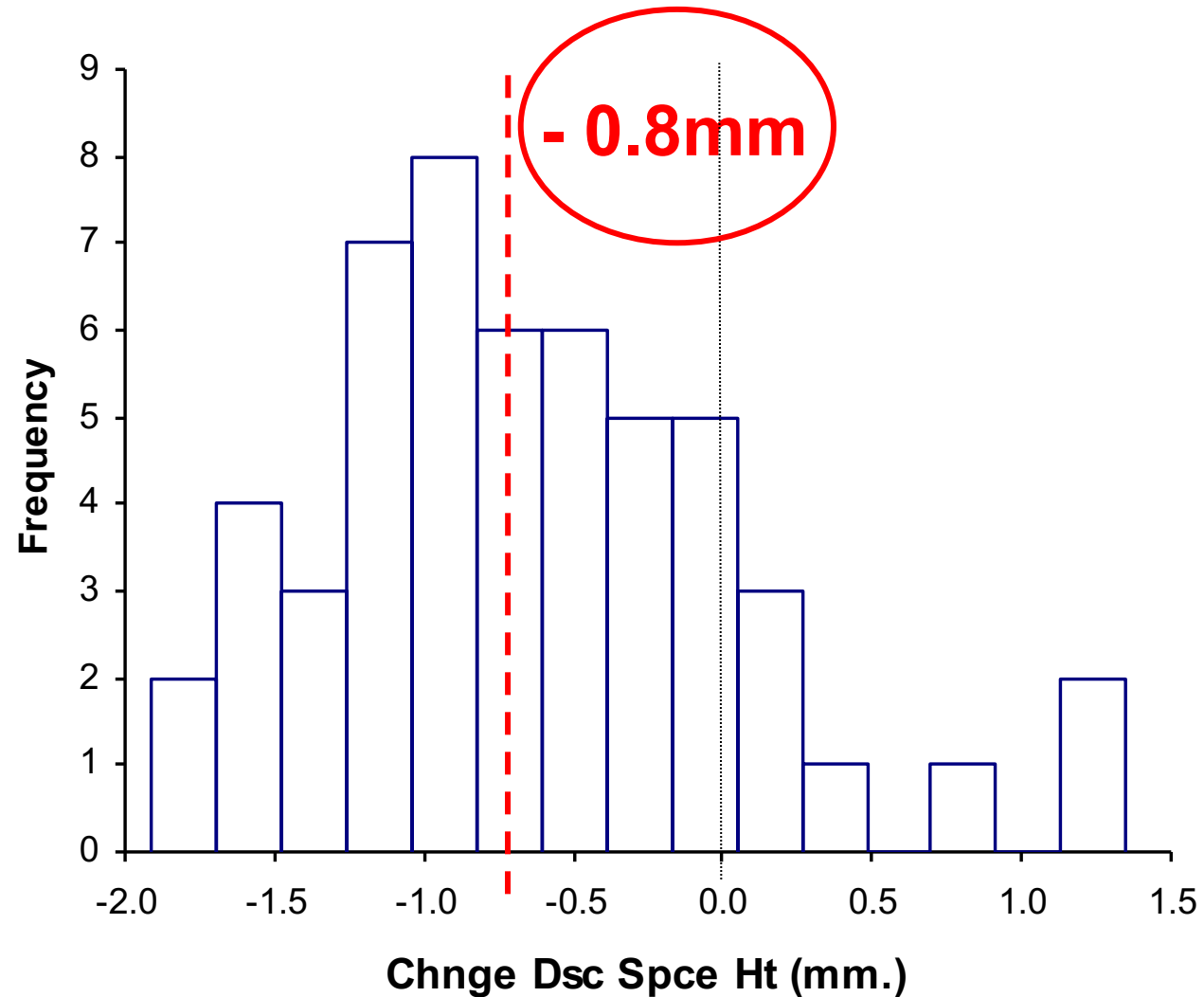


Calcula

C4-C5
C5-C6
C6-C7

Corrected change of disc space height (mm.)

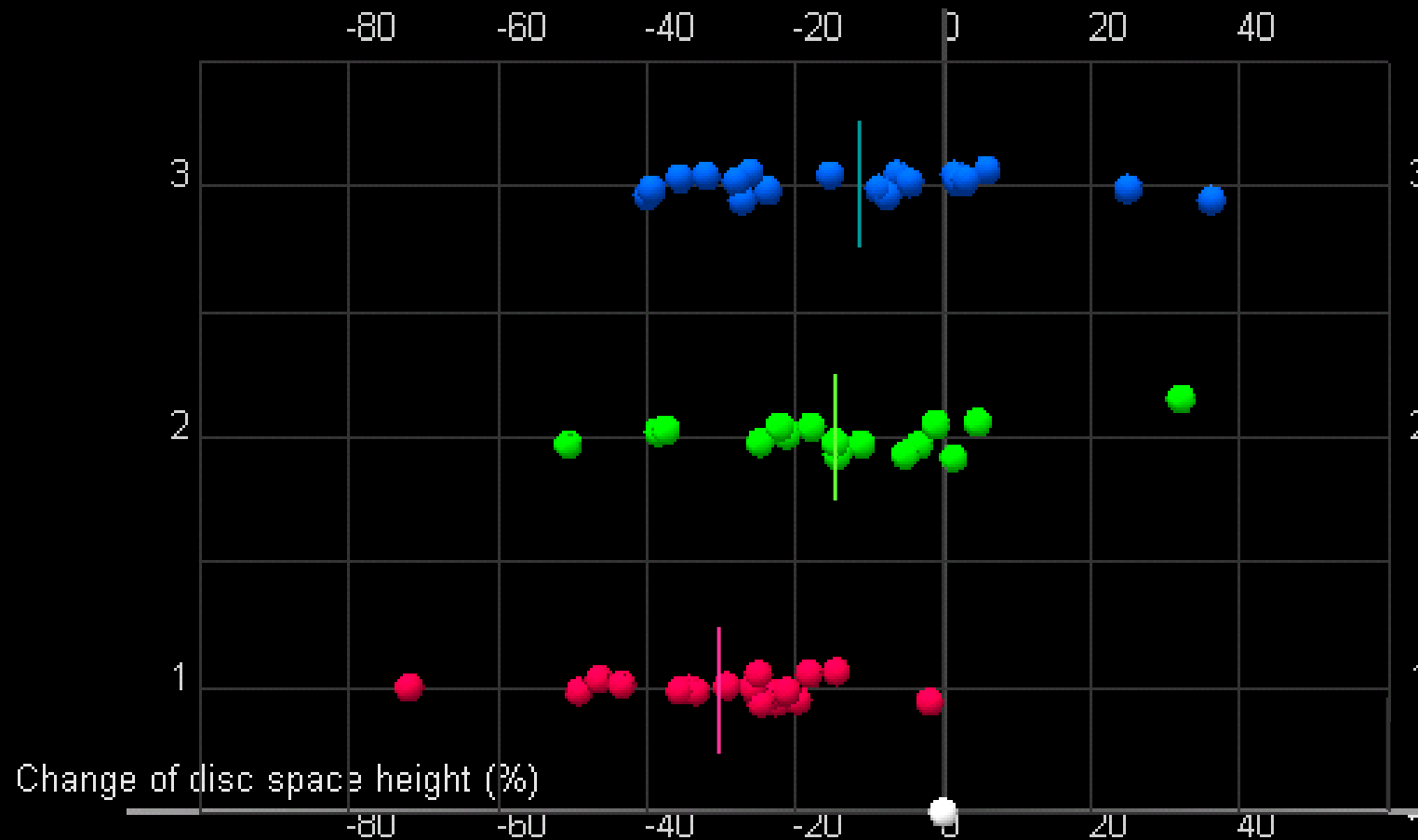
$n = 53$



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





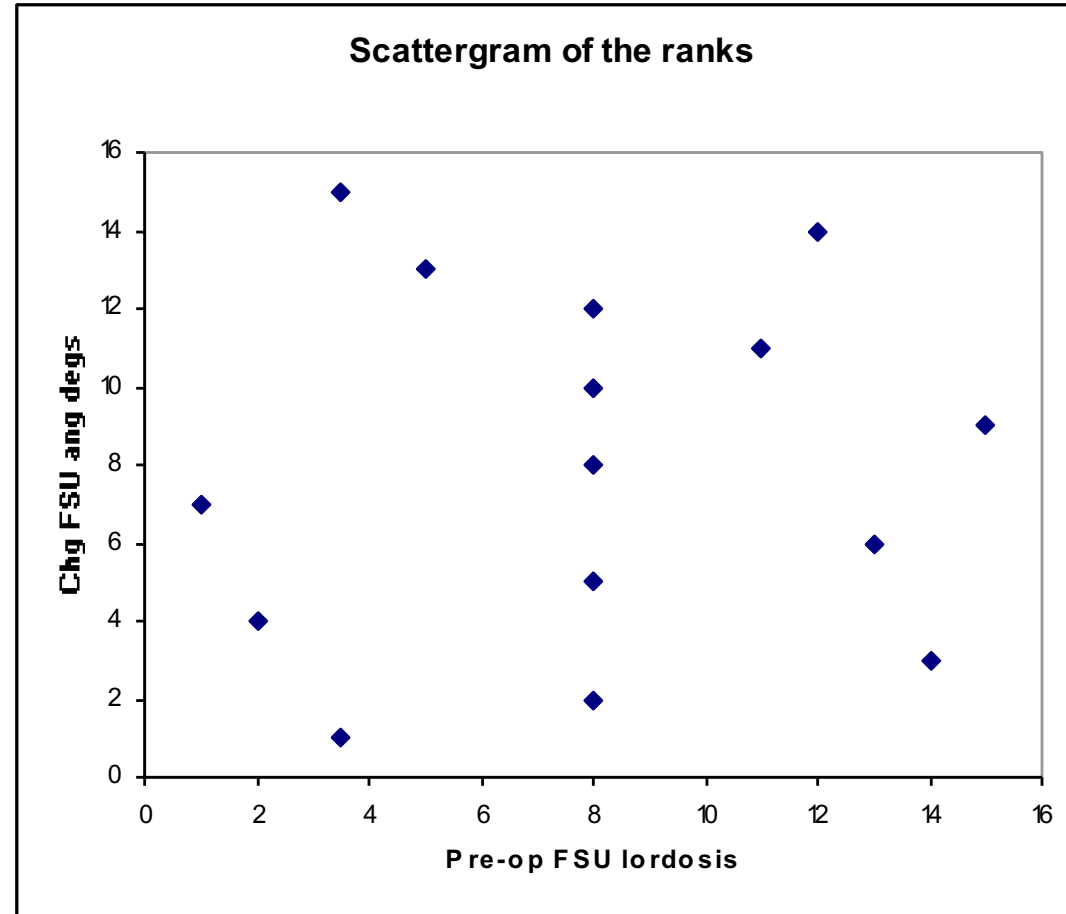
Neutral Pre and Post-ops (Revision surgery March 2, 2004)

Subsequent unpublished Study

Sears *et al*

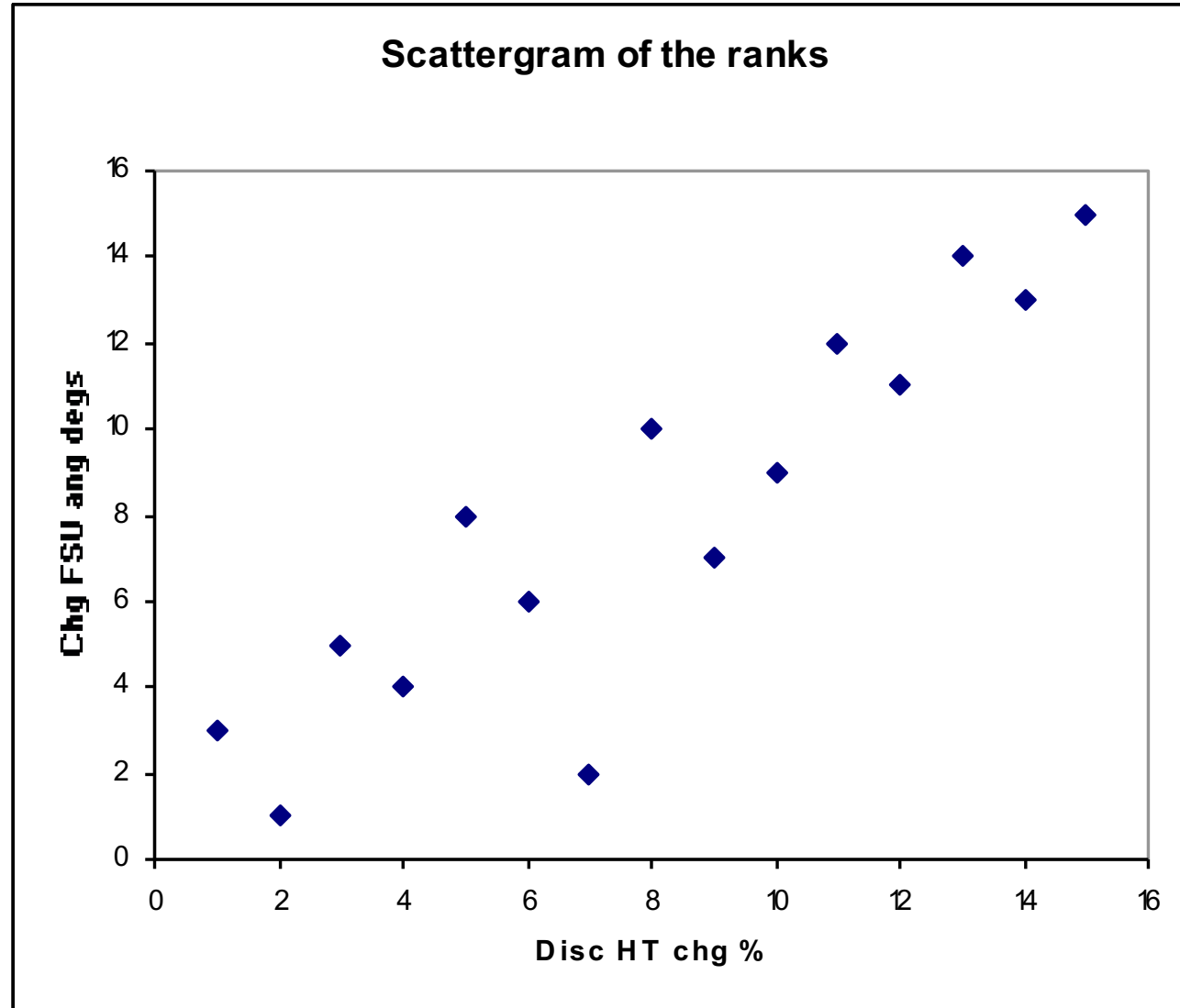
- 9 patients, 15 disc prostheses,
- September 2005 – September 2006
 - Care to avoid subsidence during disc space distraction,
 - PLL preserved where possible,
 - Deliberate undermilling

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



$$r_s = 0.058, p = 0.84$$

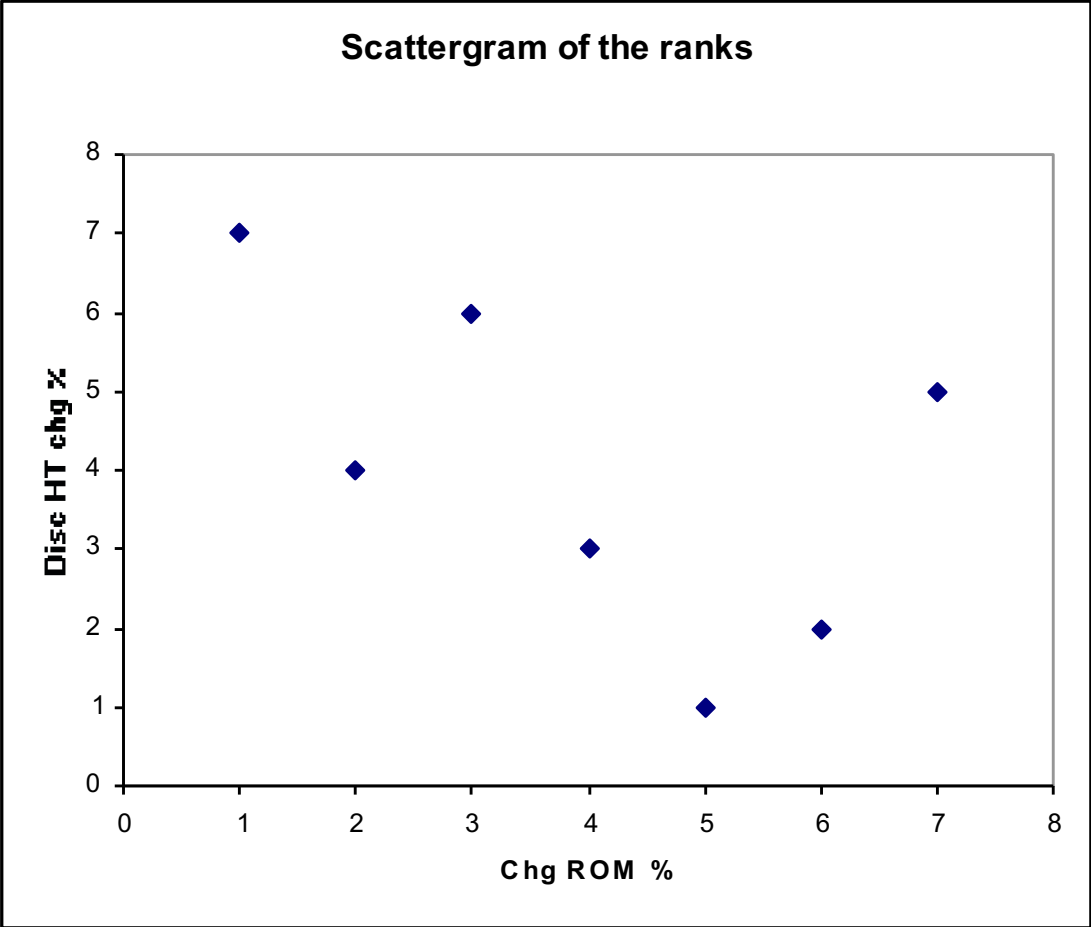
Change in FSU lordosis vs. Change in Disc Space Height (n=15)



$$r_s = 0.90$$

$$p < 0.0001$$

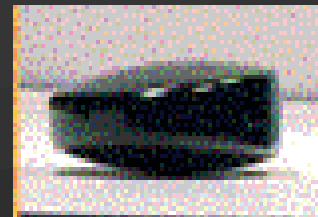
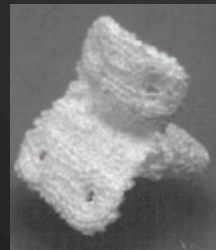
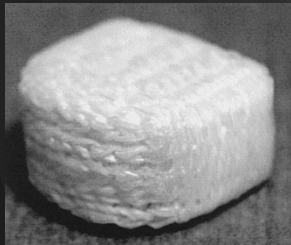
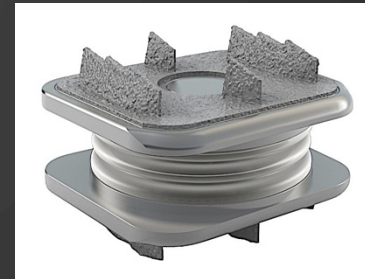
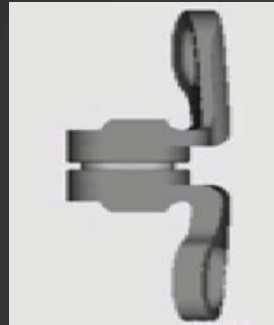
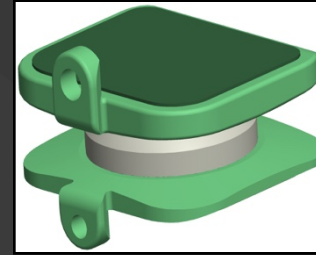
Change in Range-of-motion vs. Change in Disc Space Height (n=7)



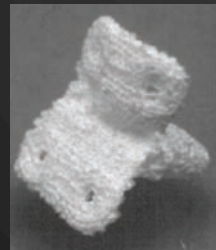
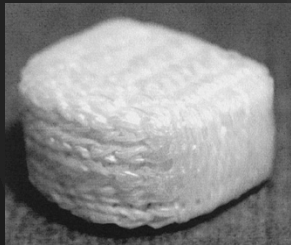
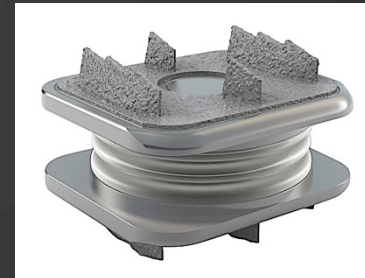
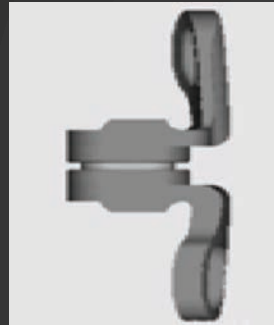
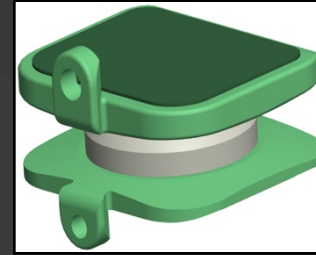
$$r_s = -0.5$$

$$p = 0.21$$

Disc prosthesis kinematics

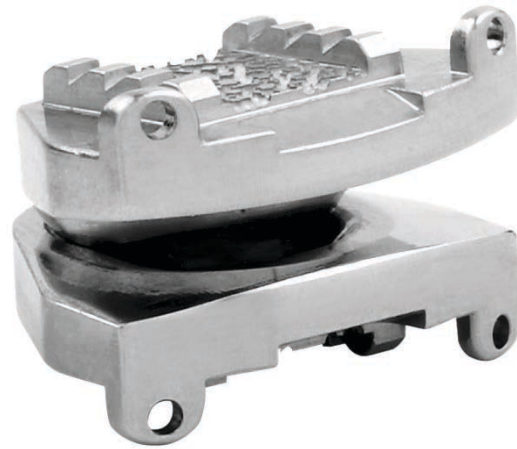


Do they matter... *clinically*?





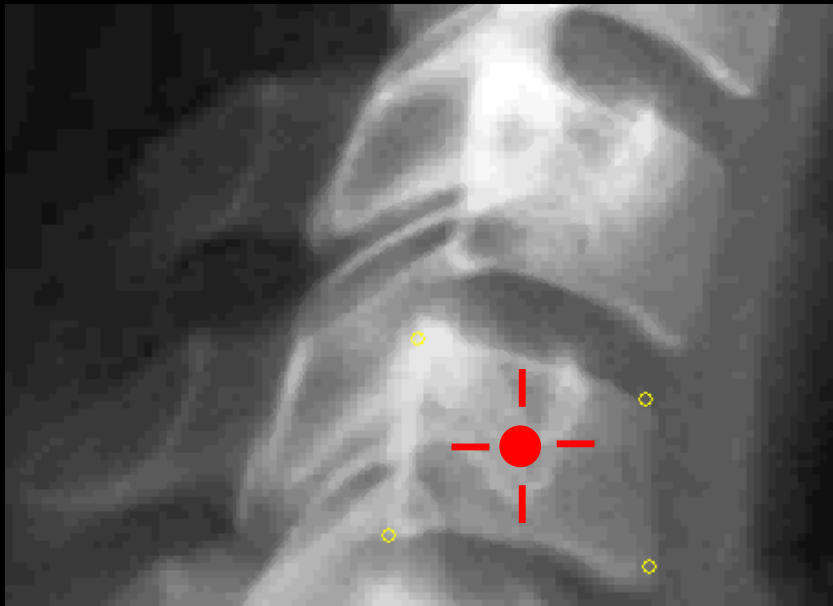
Mobile core devices
5/6 degrees-of-freedom



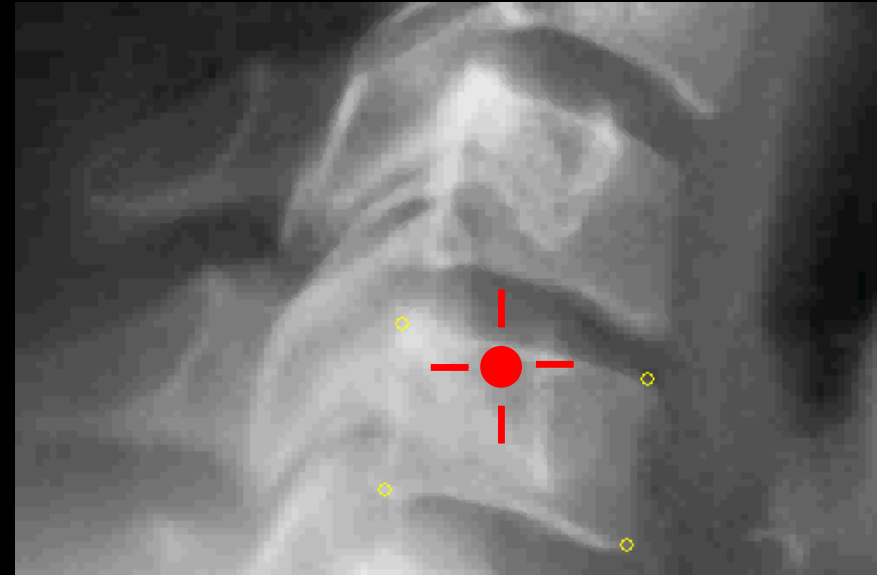
Other
5 degrees-of-freedom



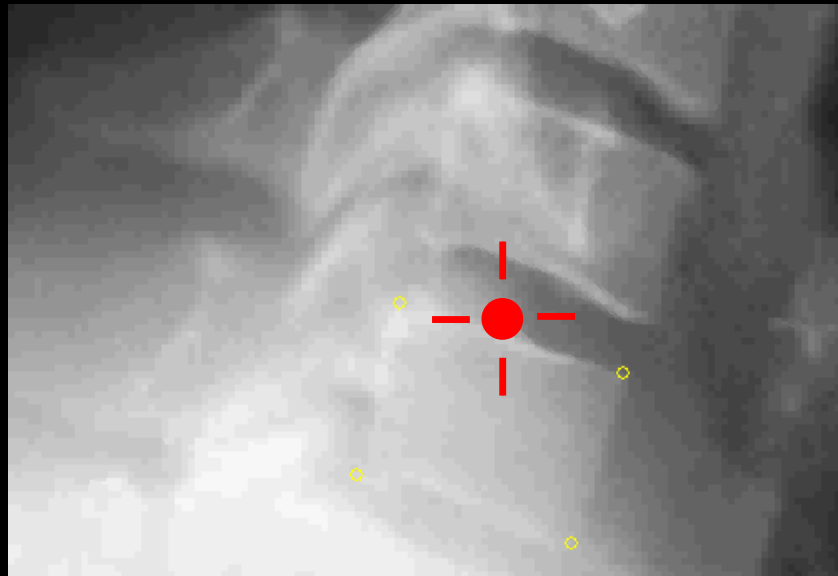
Ball & socket devices
3 degrees-of-freedom



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***



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.
Semin Spine Surg 18:117-129 © 2006 Elsevier Inc. All rights reserved.

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.

*Sydney NeuroSpine Clinic and Departments of Neurosurgery, Royal North Shore, and Dalgross Private Hospitals, Sydney, Australia.

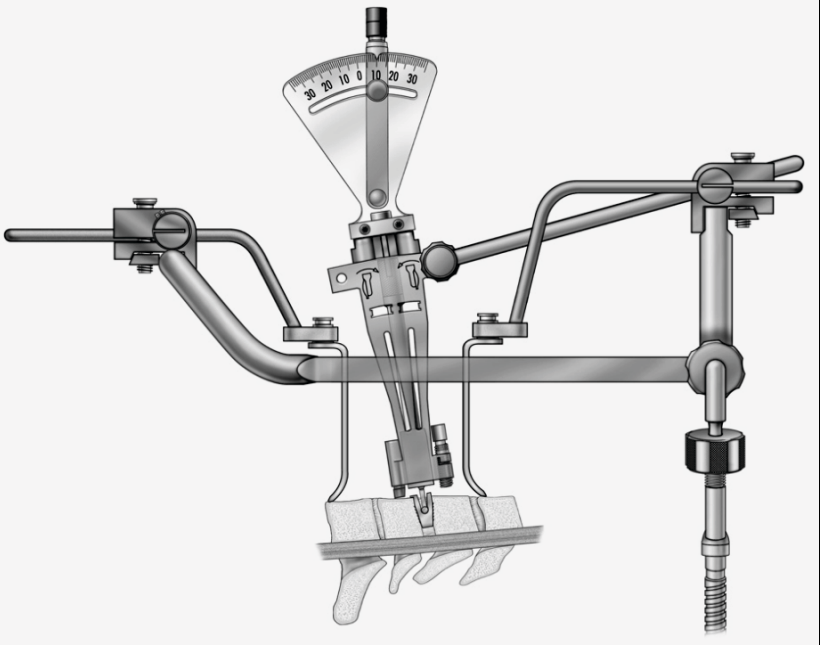
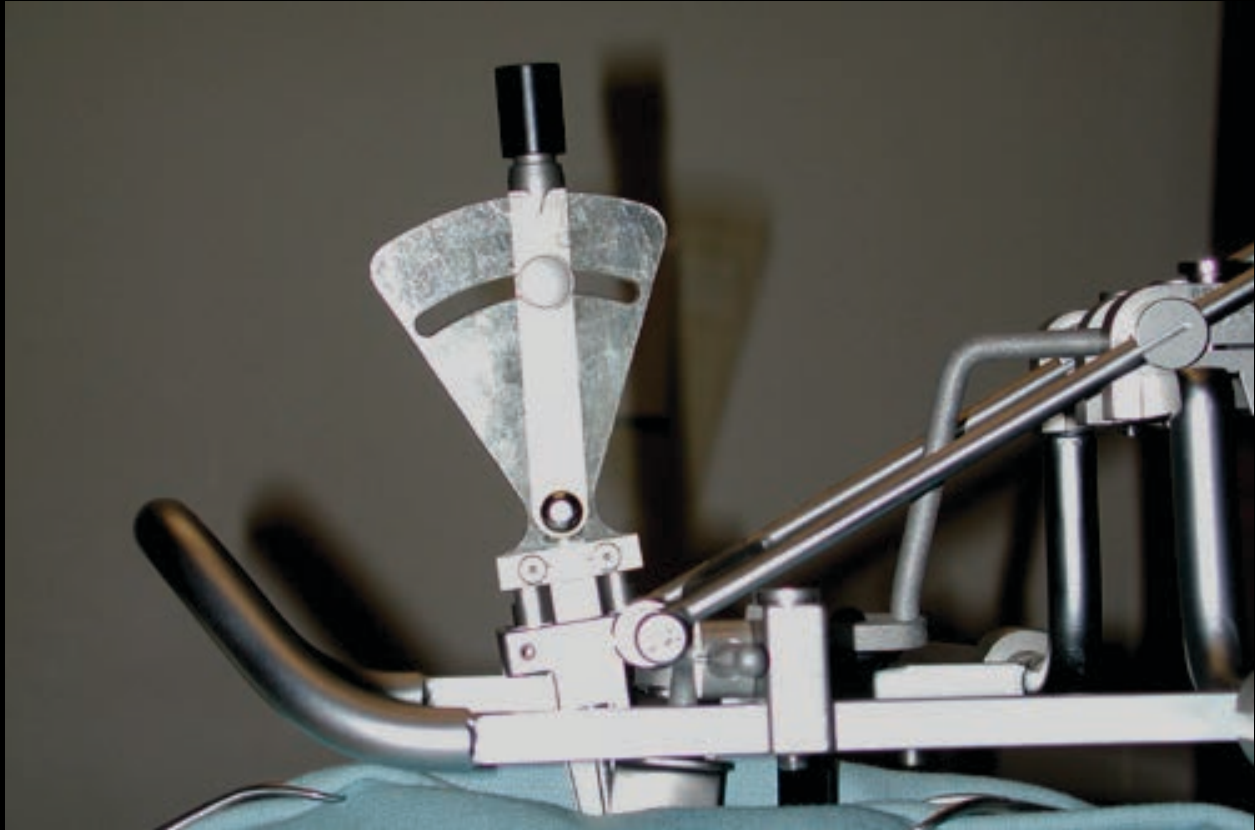
†Department of Orthopedics, Royal Brisbane Hospital, Brisbane, Australia.

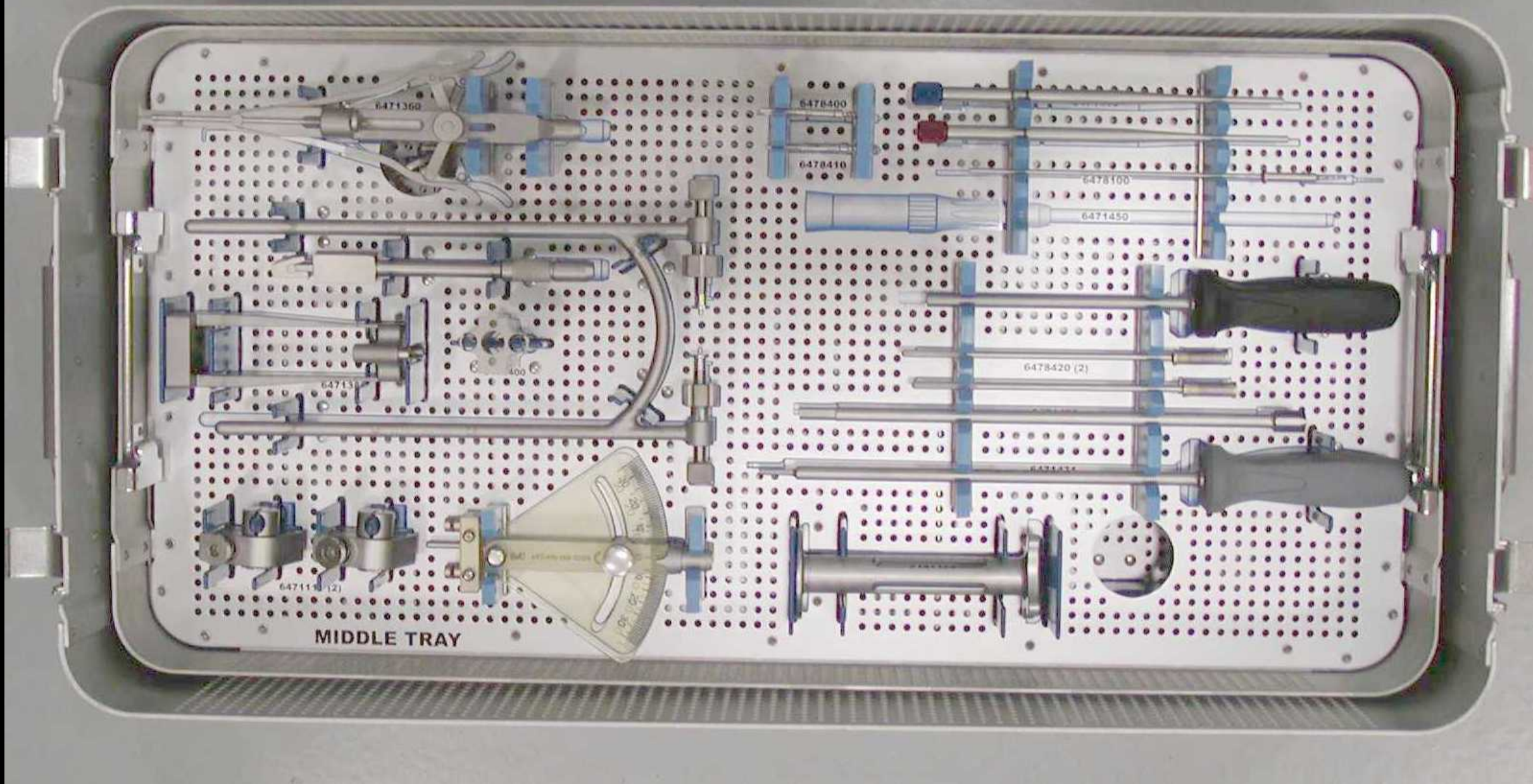
‡Indiana Spine Group, Indiana University School of Medicine, Indianapolis, IN.

Financial Disclosure: The authors are consultants to the Medtronic Sofamor Danek Company, Memphis, TN. Financial support was provided by Medtronic Sofamor Danek in the form of a research assistant, Gavin White, whose help is gratefully acknowledged.

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.

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





MIDDLE TRAY

6471360

6478400

6478410

6478100

6471450

64713

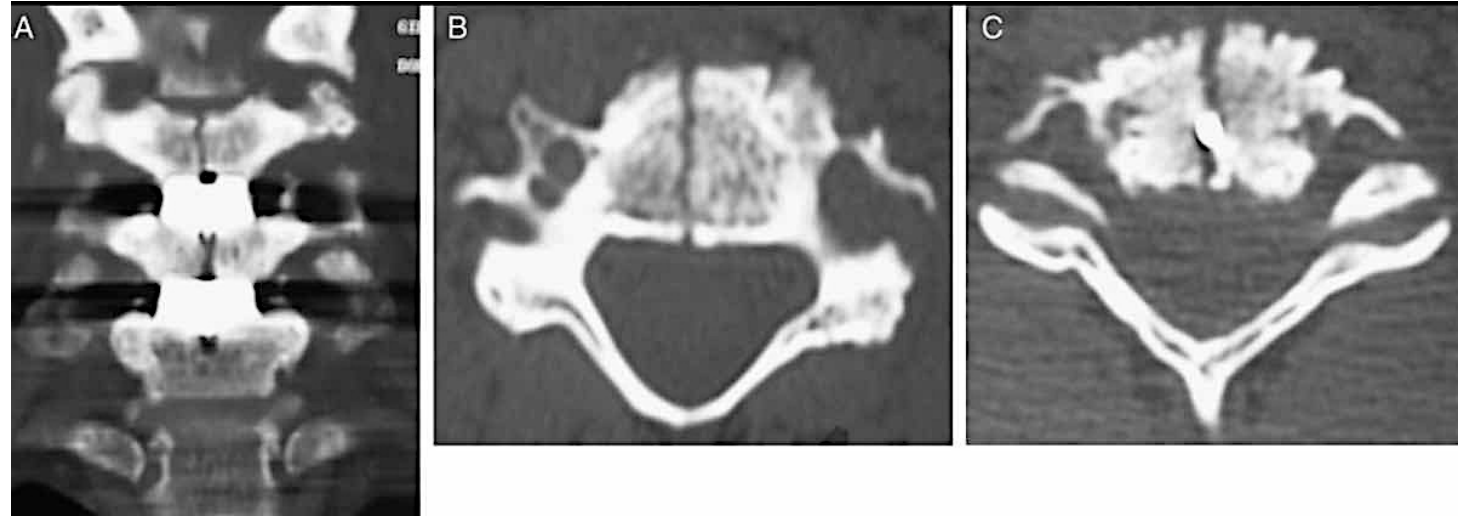
400

6478420 (2)

647110 (2)

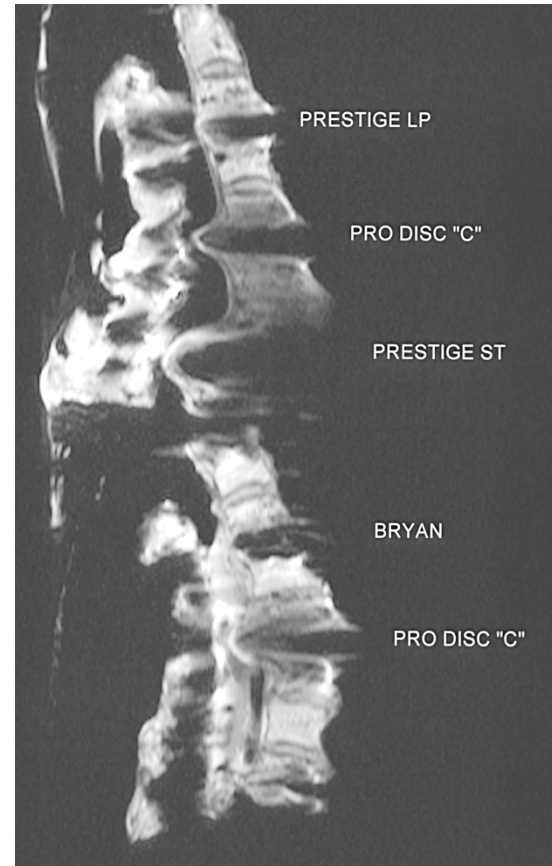
Clinical Goals of Cervical Disc Arthroplasty

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

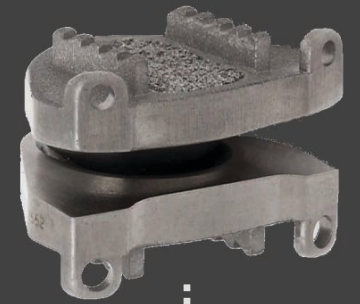


Clinical Goals of Cervical Disc Arthroplasty

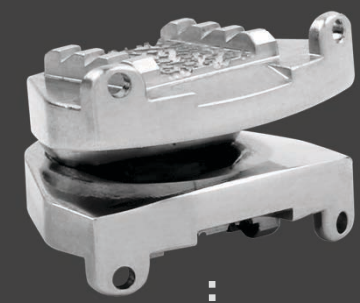
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Prestige LP



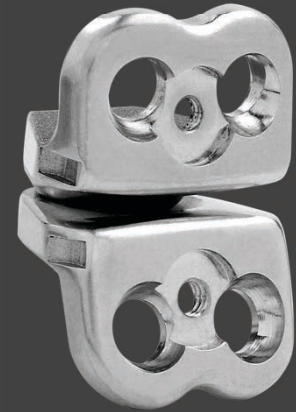
Prestige STLP



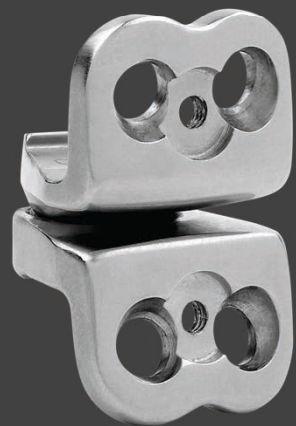
Prestige ST



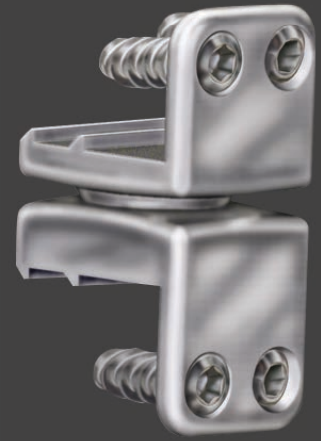
Prestige II



Prestige I



Bristol/Cummins



1991

1998

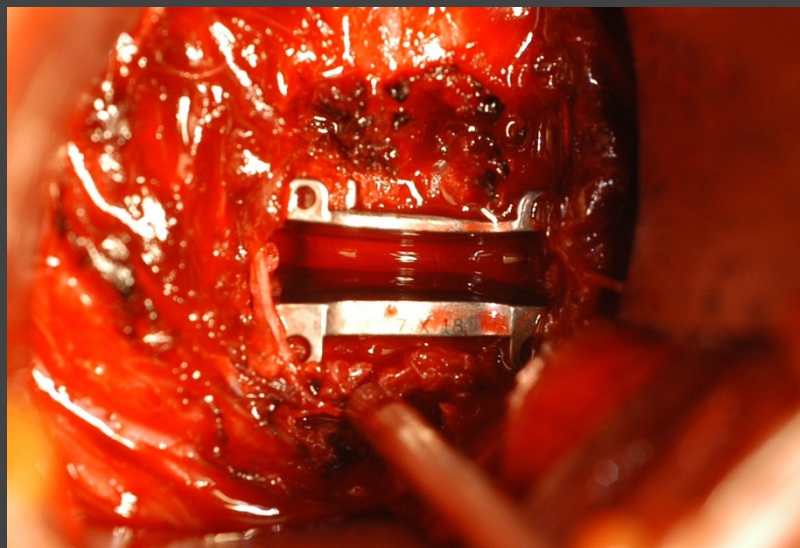
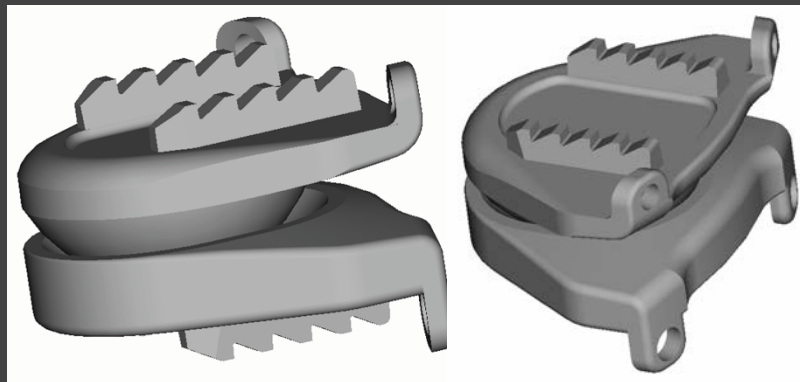
1999

2002

2003

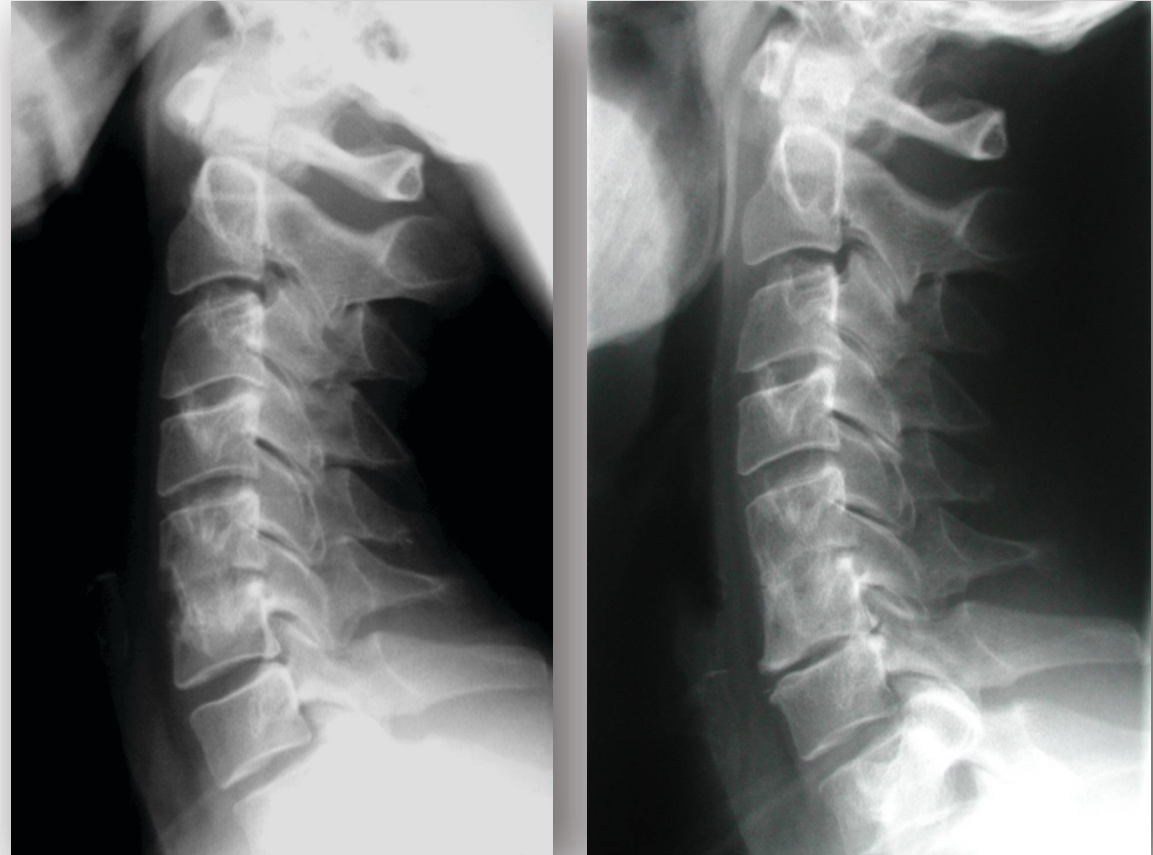
2004

Prestige LP



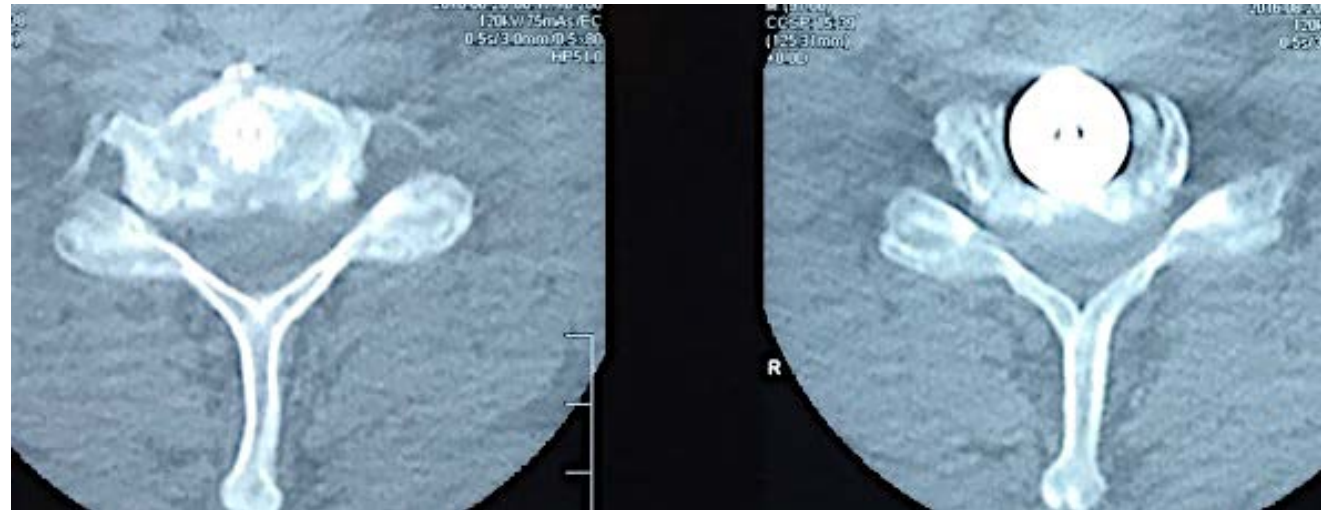
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Clinical Goals of Cervical Disc Arthroplasty

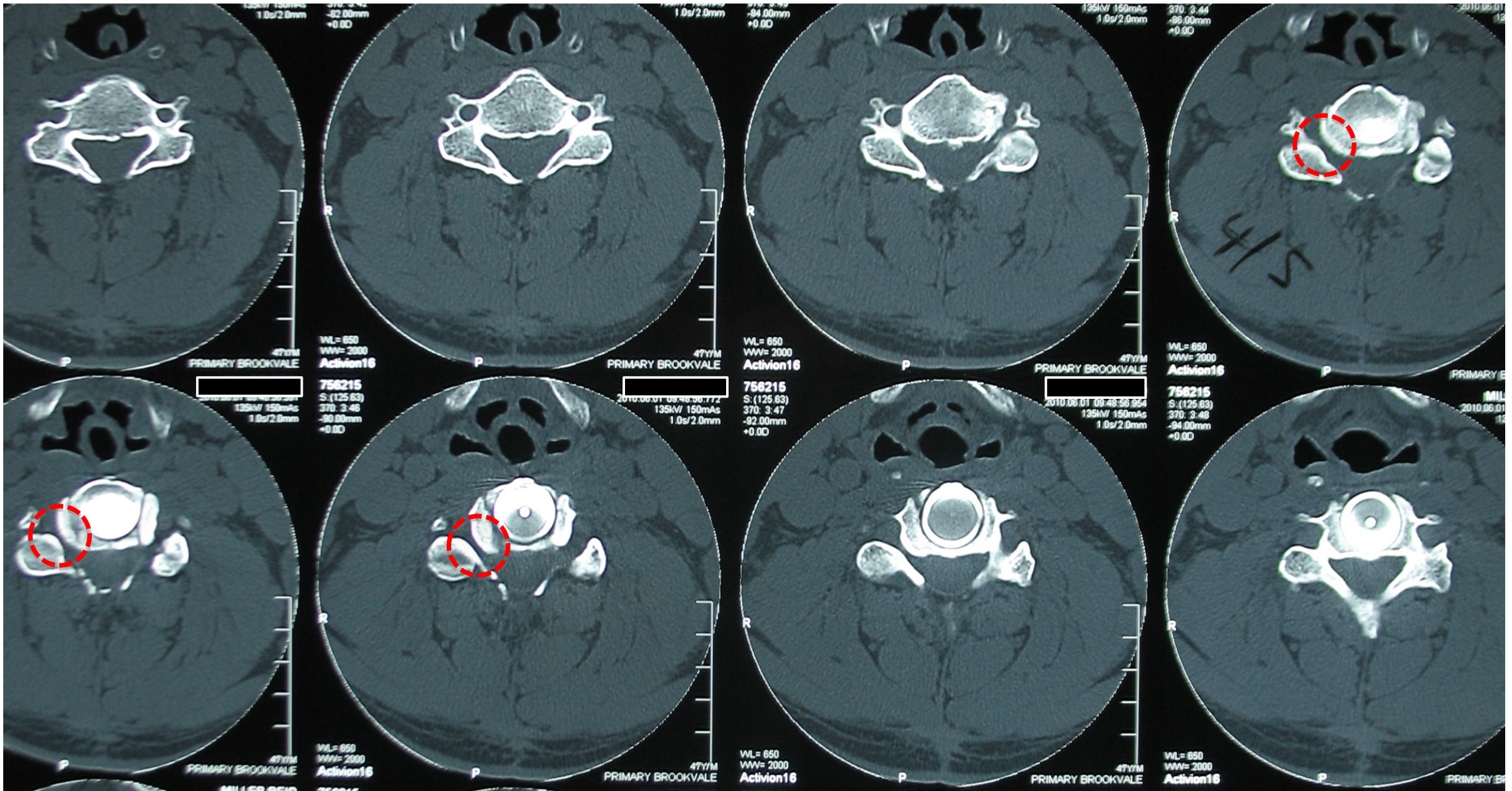
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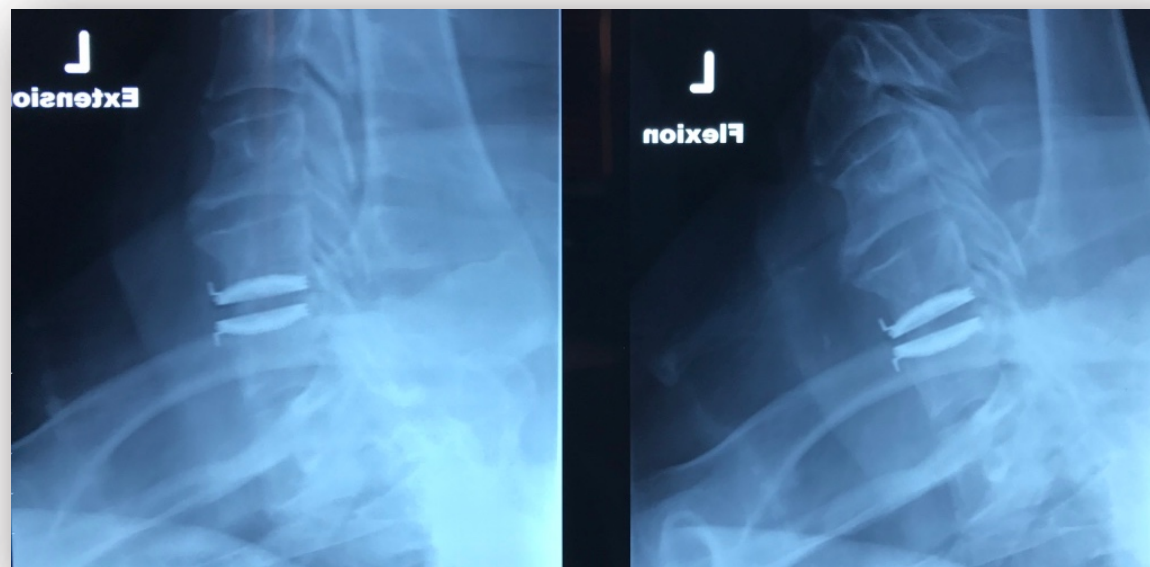
Same segment disease?

Male 47yrs, 7 years post Bryan TDR





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

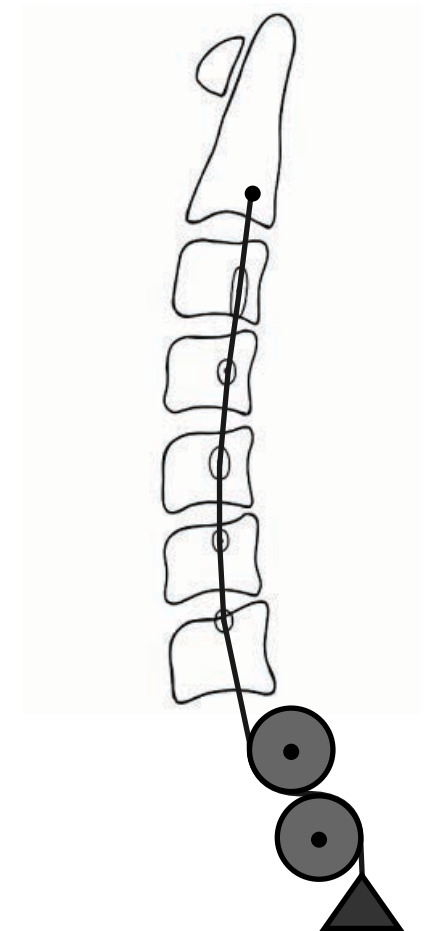
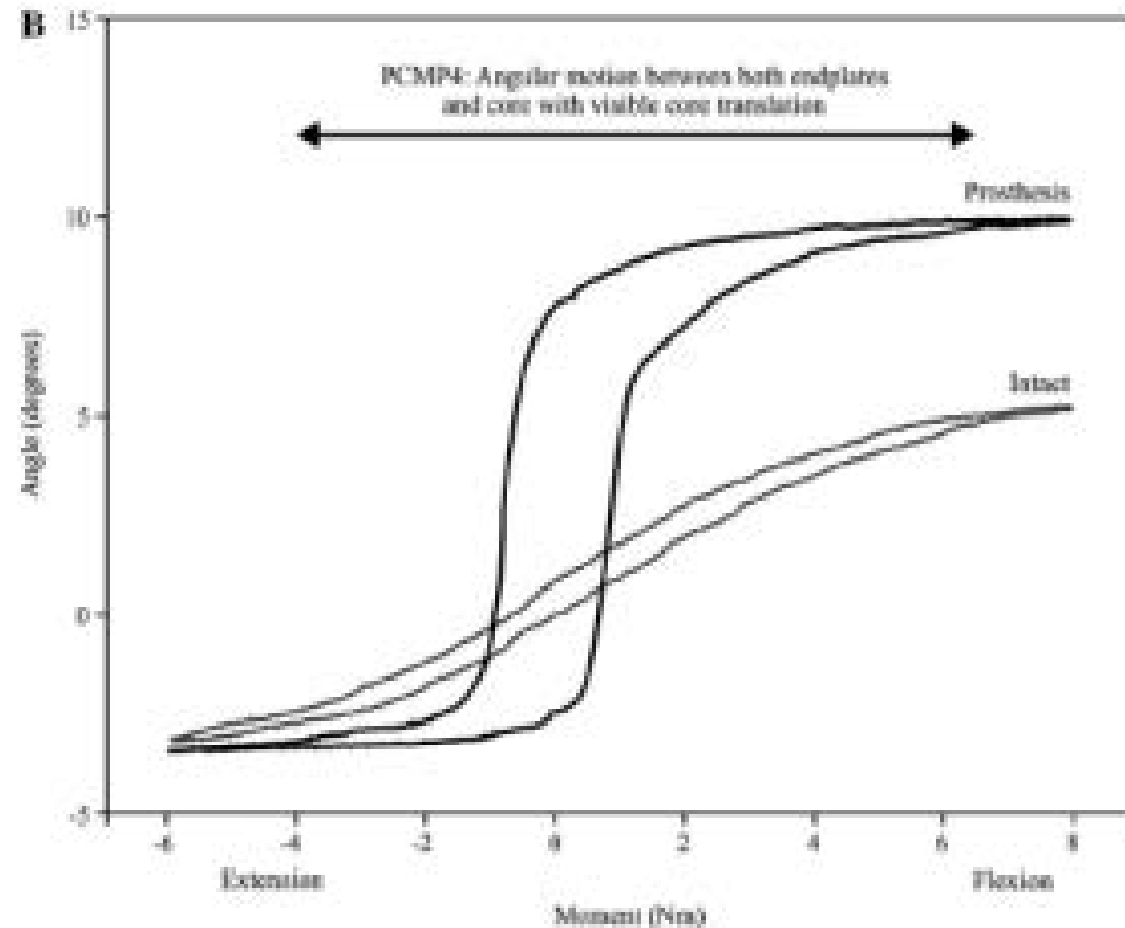


Fig. 3. Load versus angular displacement graphs. (A) An L3-S1 motion segment. (B) An L4-L5 motion segment.

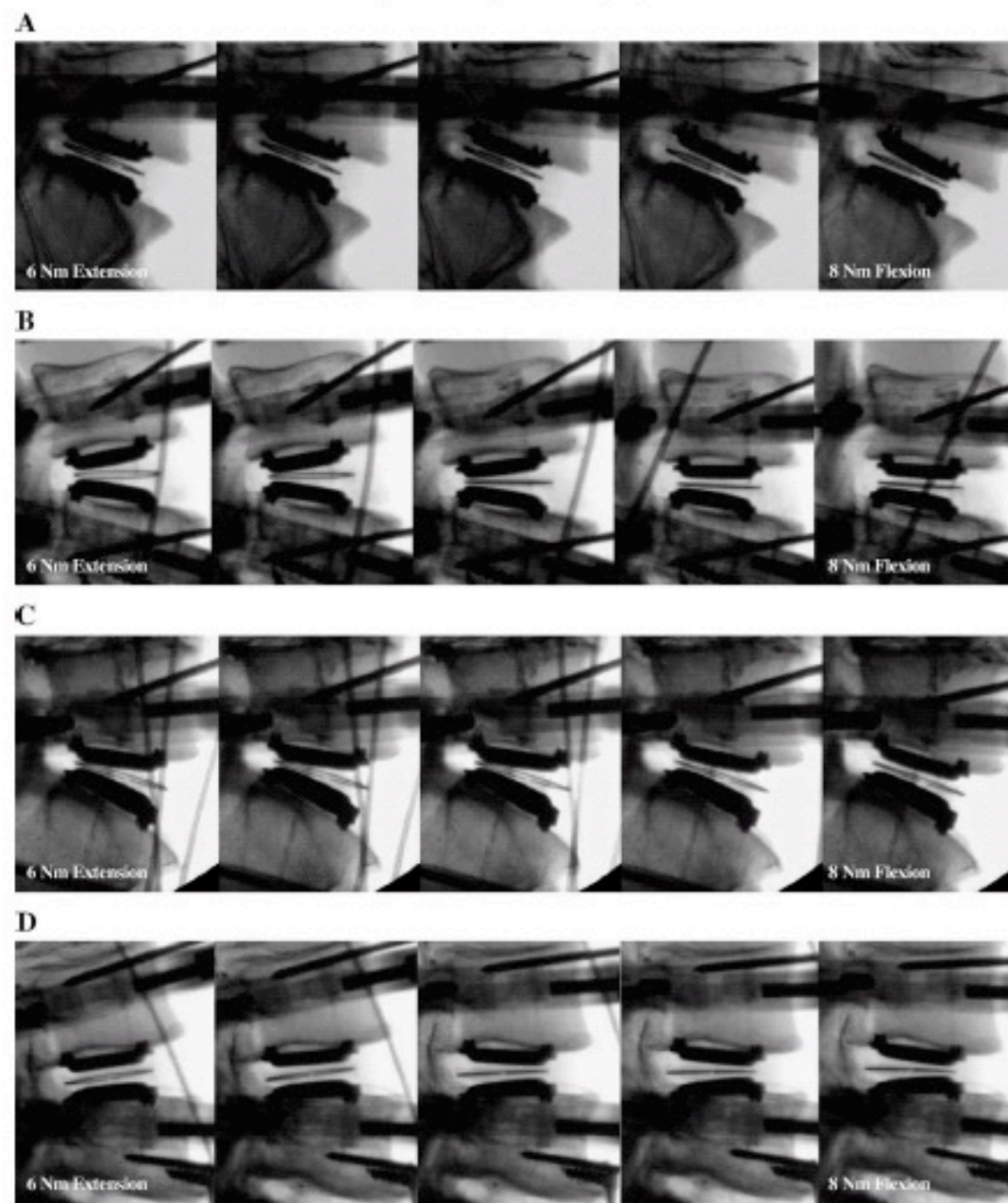
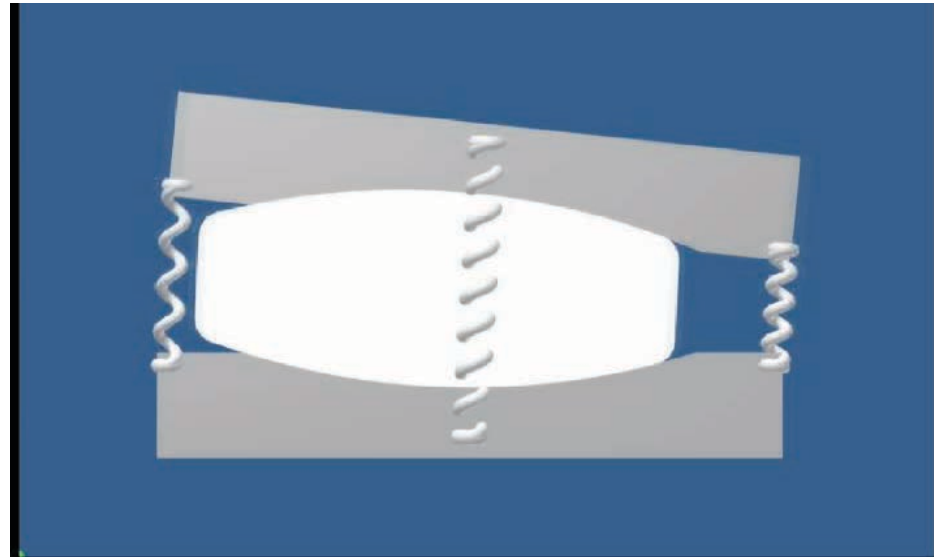


Fig. 2. Prosthesis component motion patterns (PCMPs). (A) Angular motion predominantly between the upper end plate and core, with little or no visible core translation (PCMP1). (B) Lift-off of upper prosthesis end plate from core or of core from lower end plate (PCMP2). (C) Core entrapment, resulting 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/‘ballistic’ movement



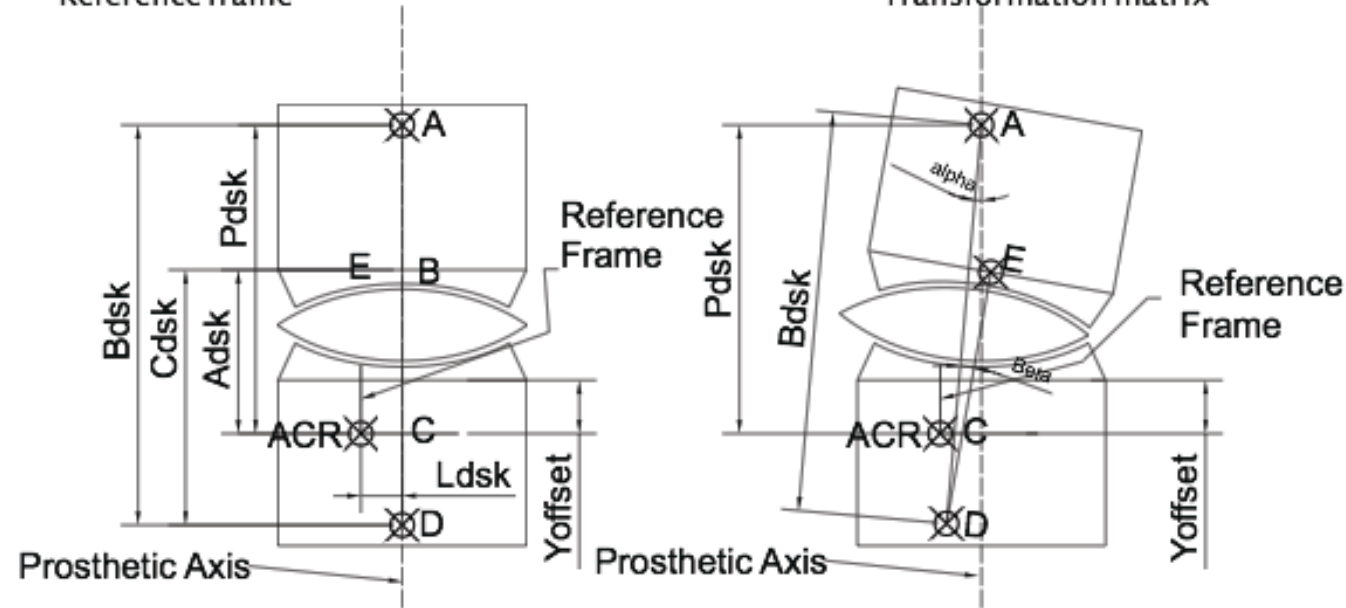
Courtesy of Dr Peter McCombe

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

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

Reference frame

Transformation matrix



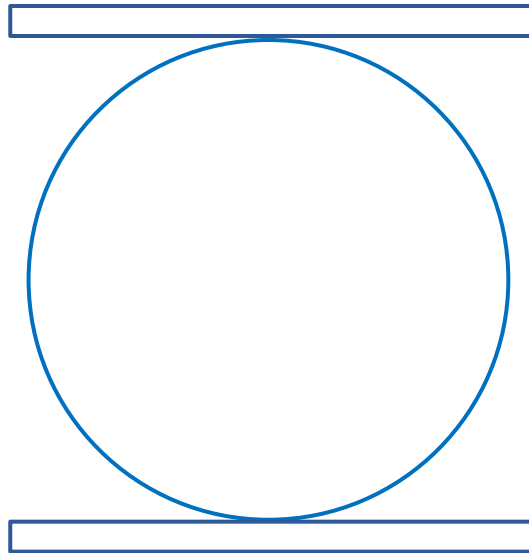
$$AFR2 = \begin{bmatrix} 1 & 0 & Ldsk \\ 0 & 1 & Pdsk \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} \cos \alpha & -\sin \alpha & 0 \\ \sin \alpha & \cos \alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & -Bdsk \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} \cos \beta & -\sin \beta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

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

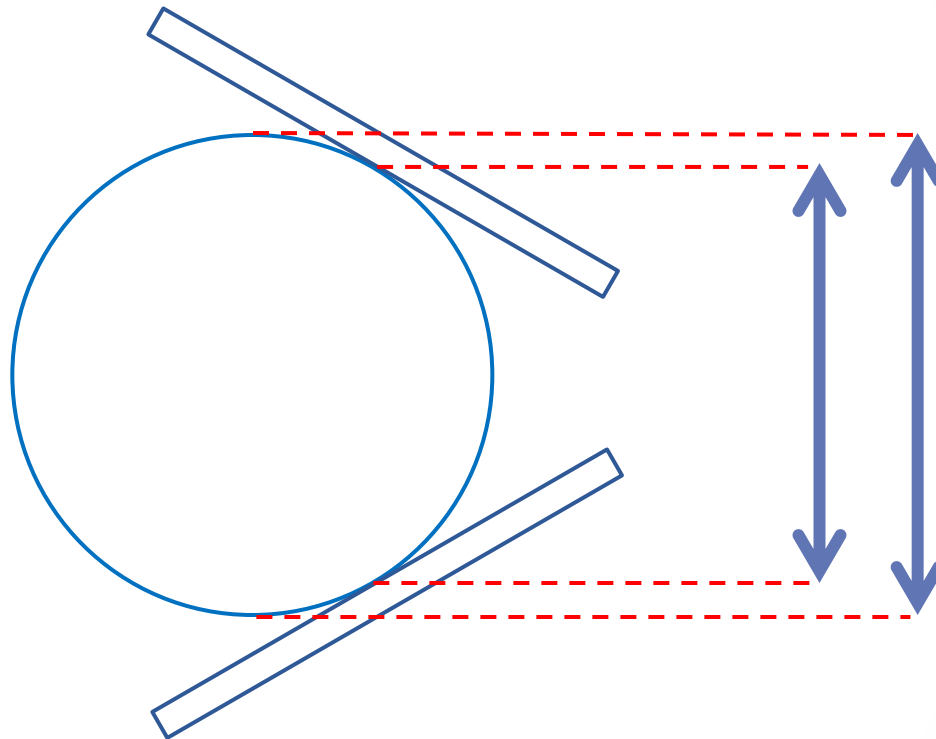
$$g(\alpha, \beta) = -(\sin \alpha \cdot \cos \beta + \cos \alpha \cdot \sin \beta) \cdot Ldsk + (\cos \alpha \cdot \cos \beta - \sin \alpha \cdot \sin \beta) \cdot Cdsk - \cos \alpha \cdot Bdsk + Pdsk$$

Courtesy of Dr Peter McCombe

Higher potential energy position



Lower potential energy position



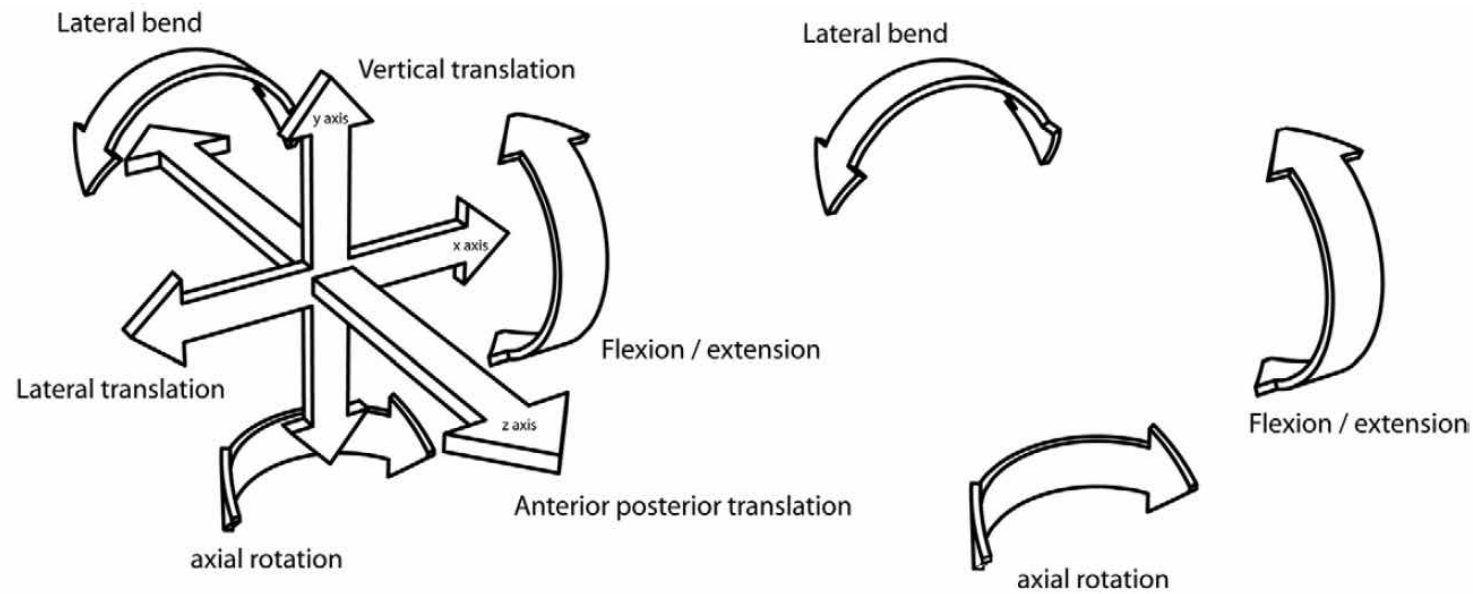
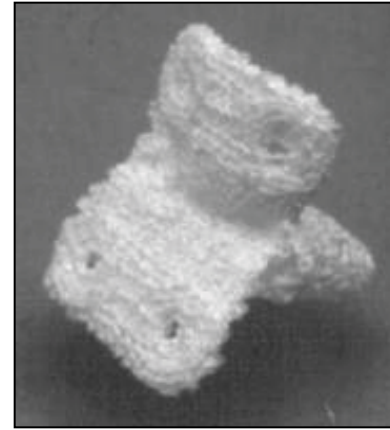


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Bryan	Unconstrained	Unrestrained	Limited	Compressible	6	3	Y
eDISC	Unconstrained	Restrained	Unlimited	Compressible	6	3	Y
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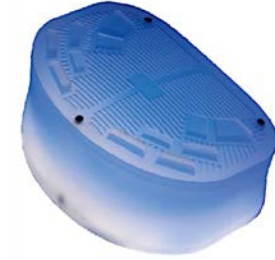
*Two in the sagittal plane and one in each of the coronal and axial planes.

Visco-elastic, polymer discs



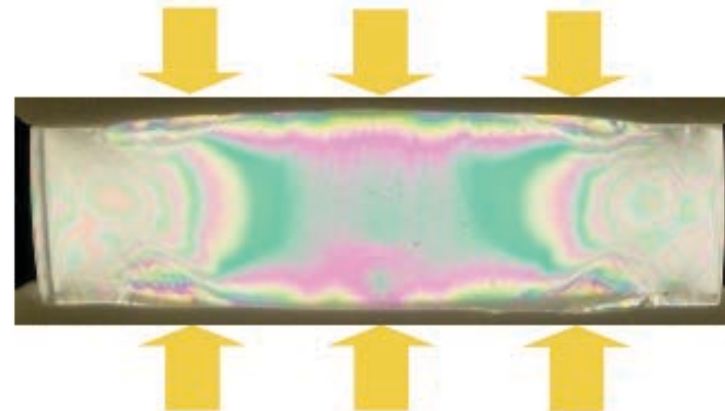


Visco-elastic prostheses Cadisc™-L



 Cadisc™-L Graduated Modulus Technology

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



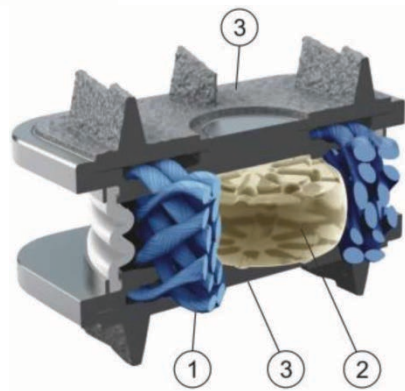
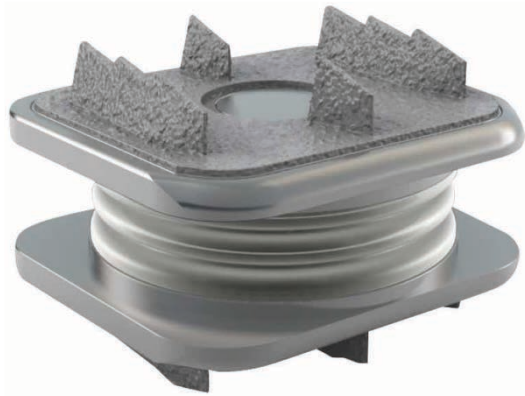
Polarised light image of Cadisc™-L under axial load.
Courtesy of Dr. J. Gwynne, University of Cambridge

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







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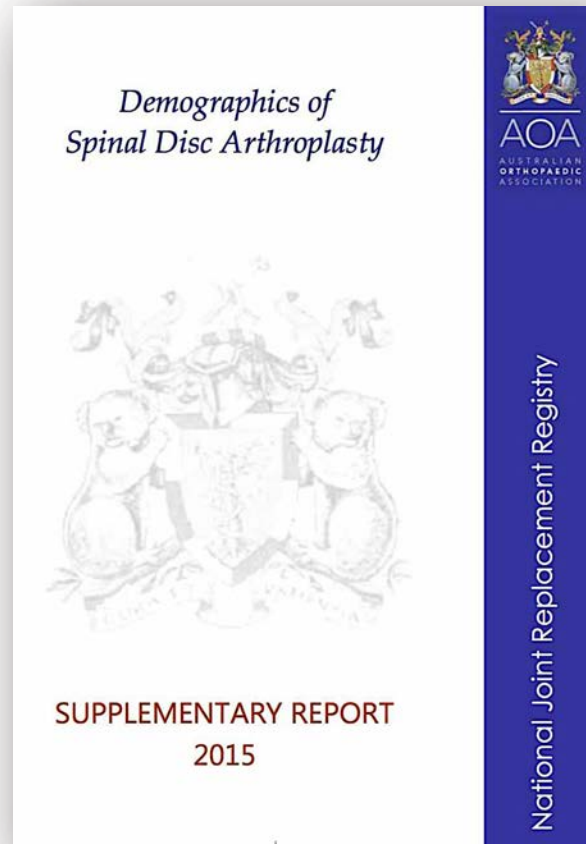


Table SD12 Most Used Ball Trough Prostheses in Primary Spinal Ball Trough Replacement

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