Spinal Anatomik ve Biyomekanik Çalışma İlkeleri

Dr.Hakan BOZKUŞ

Omurga Sorunları Çözümü ?

1. Deneysel uygulama sonuçları

2. Klinik uygulama sonuçları

Deneysel Omurga Çalışmaları

Anatomik Modeller

1. Canlı Modeller
   1. Anatomi
   2. Travma
   3. Füzyon, Dejenerasyon, Rejenerasyon
   4. Medikal uygulama
   5. Cerrahi uygulama, Biyomateryel uygulama
   6. v.b……

2. Kadavra Modelleri
   1. Anatomi
   2. Cerrahi uygulama

Eur Spine J (2010) 19:46–56
DOI 10.1007/s00586-009-1192-5

REVIEW ARTICLE

Anatomy of large animal spines and its comparison to the human spine: a systematic review

Sun-Ren Sheng · Xiang-Yang Wang ·
Hua-Zi Xu · Guo-Qing Zhu · Yi-Fei Zhou

1980-2008 literatür taraması

Toplam 644 yayın

7 yayın kriterlere uygun

Table 2 Characteristics of the included studies

Authors	Year of publication	Animal names	Number of animals	Anatomical segments	Specimen properties	Measurement tools	Comparison of anatomical differences	Conclusions
Tominaga et al. [20]	1995	Baboon (mean age 16.7 years)	9	Cervical spine	Fresh	Digitized caliper	Comparison with the values of six adult cadaver cervical spines	The geometry and anatomy of the baboon cervical spine closely resemble that of the human cervical spine
Kandziora et al. [8]	2001	Sheep (mean age 2 years; average weight, 64.6 ± 3.7 kg)	20	Cervical spine	Fresh	Digitized ruler	Comparison with 20 fresh human cadaver cervical spines	The small intergroup standard deviations and the good comparability with the human spine encourage the use of the sheep cervical spine as a model for cervical spine research
Wilke et al. [23]	1997	Sheep (age 3–4 years; average weight, 72.1 ± 7.3 kg)	5	Cervical, thoracic and lumbar spines	Fresh	Hand-held micrometer	Comparison with reported values of the human spine	Sheep spine may be a useful model for experiments related to the gross structure of the thoracic or lumbar spine, with certain limitations for the cervical spine
Bozkus et al. [2]	2005	Pig (age 6 months; average weight, 30 kg)	10	Thoracic spine	Fresh	Digitized caliper and ruler	Comparison with the values of ten human cadaver Thoracic spines	Thoracic spine from T6 toT10 probably is most similar to that in the human anatomically
Dath et al. [6]	2007	Pig (age 18–24 months; weight, 60–80 kg)	6	Lumbar spine	Fresh	Digitized caliper	Comparison with the values of six human lumbar spine specimens	Porcine lumbar vertebrae may be used as an alternative to human specimen if the anatomical differences are taken into account
Cotterill et al. [4]	1986	Calf (age 6–8 weeks)	10	Thoracic (T6 and T12) and lumbar (L3) spines	Fresh	Hand-held micrometer	Comparison with the values of ten human thoracic lumbar spine specimens'	Differences in column length and curvature were observed. These significantly different measurements were considered important factors that influence experimental results when using the bovine spine as a model
Kumar et al. [9]	2000	Deer (age 20–27 months; weight, 46–52 kg)	6	Cervical, thoracic and lumbar spines	Fresh	Hand-held micrometer	Comparison with reported values of the human spine	The deer and human vertebrae show many similarities in the lower thoracic and upper lumbar spine, although they show substantial differences in certain dimensions. The cervical spine was markedly different in comparison

Spinal Cord (2017) 55, 714–721

www.nature.com/sc

REVIEW

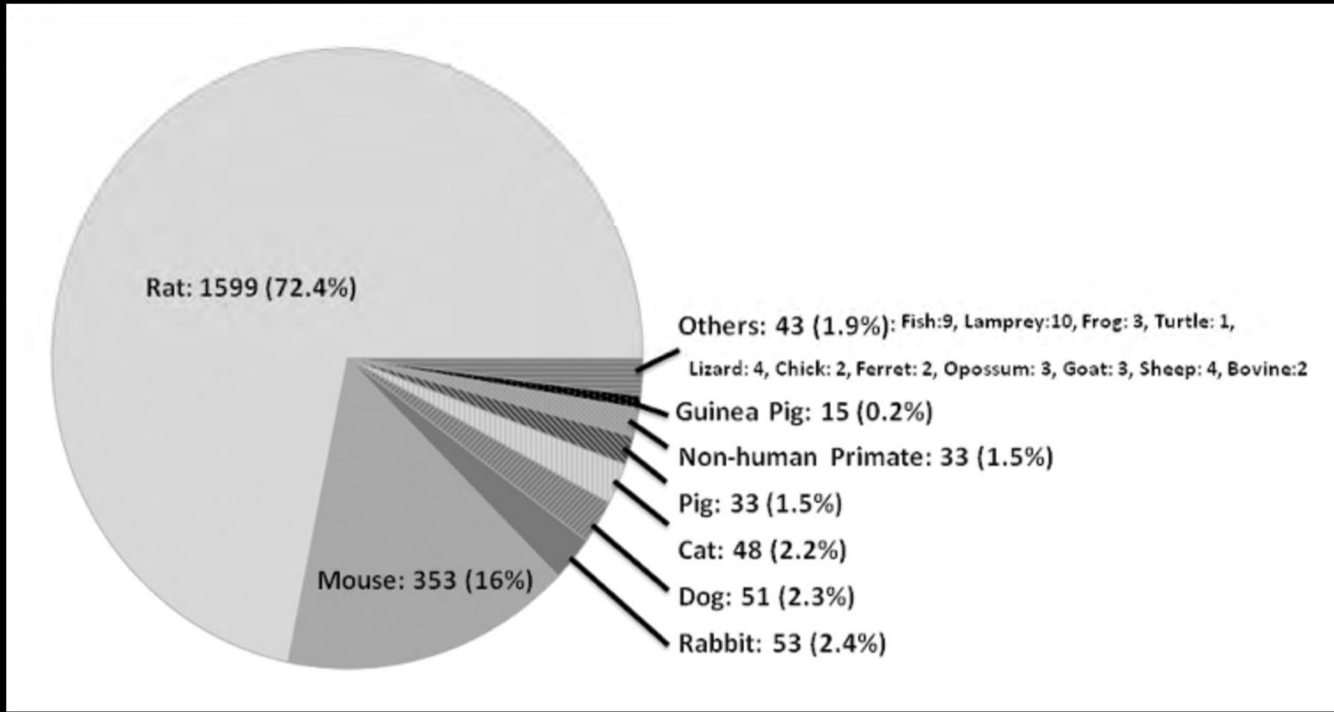
Animal models of spinal cord injury: a systematic review

M Sharif-Alhoseini[1], M Khormali[1,2], M Rezaei[1,2], M Safdarian[1], A Hajighadery[1,2], MM Khalatbari[1], M Safdarian[1], S Meknatkhah[3], M Rezvan[1], M Chalangari[1], P Derakhshan[1] and V Rahimi-Movaghar[1]

1946-2016 literatür taraması

Toplam 2870 yayın

2209 yayın uygun

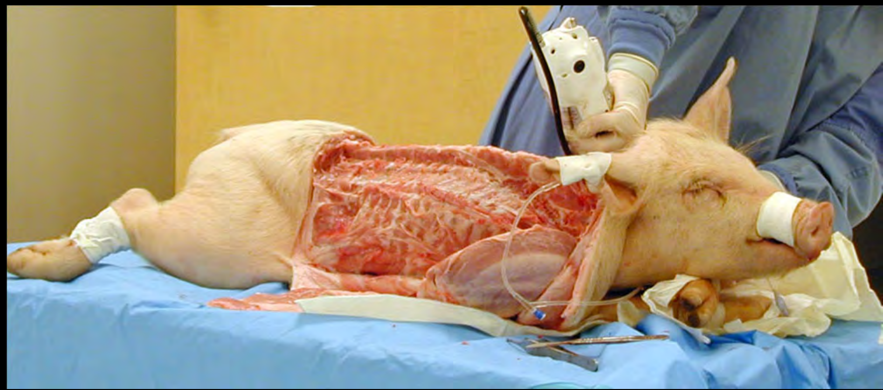


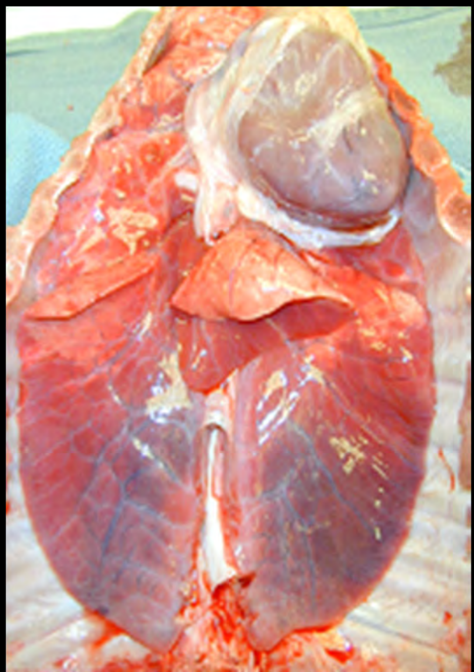
Results: Among the 2209 included studies, testing the effects of drug's or growth factor's interventions was the most common aim (36.6%) followed by surveying pathophysiologic changes (30.2%). The most common spinal region involved was thoracic (81%). Contusion was the most common pattern of injury (41%) followed by transection (32.5%) and compression (19.4%). The most common species involved in animal models of SCI was the rat (72.4%). Two or more types of outcome assessments were used in the majority of the studies, and the most common assessment method was biological plus behavioral (50.8%).

Conclusions: Prior to choosing an animal model, the objectives of the proposed study must precisely be defined. Contusion and compression models better simulate the biomechanics and neuropathology of human injury, whereas transection models are valuable to study anatomic regeneration. Rodents are the most common and probably best-suited species for preliminary SCI studies.

Spinal Cord (2017) **55,** 714–721; doi:10.1038/sc.2016.187; published online 24 January 2017

Torakatomi

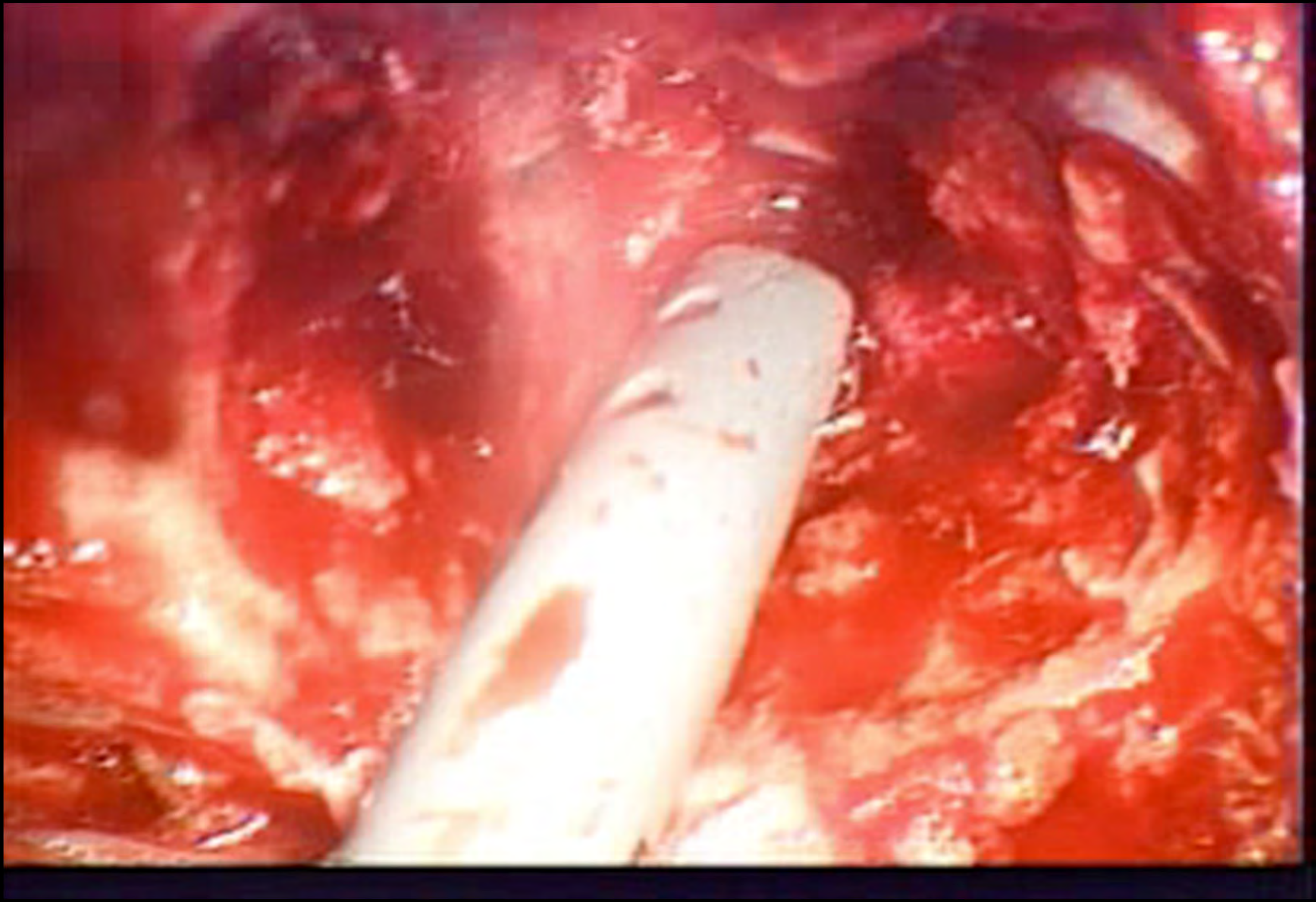




Torakoskopi

İnterkostal Anatomi

Torakoskopik Diskektomi



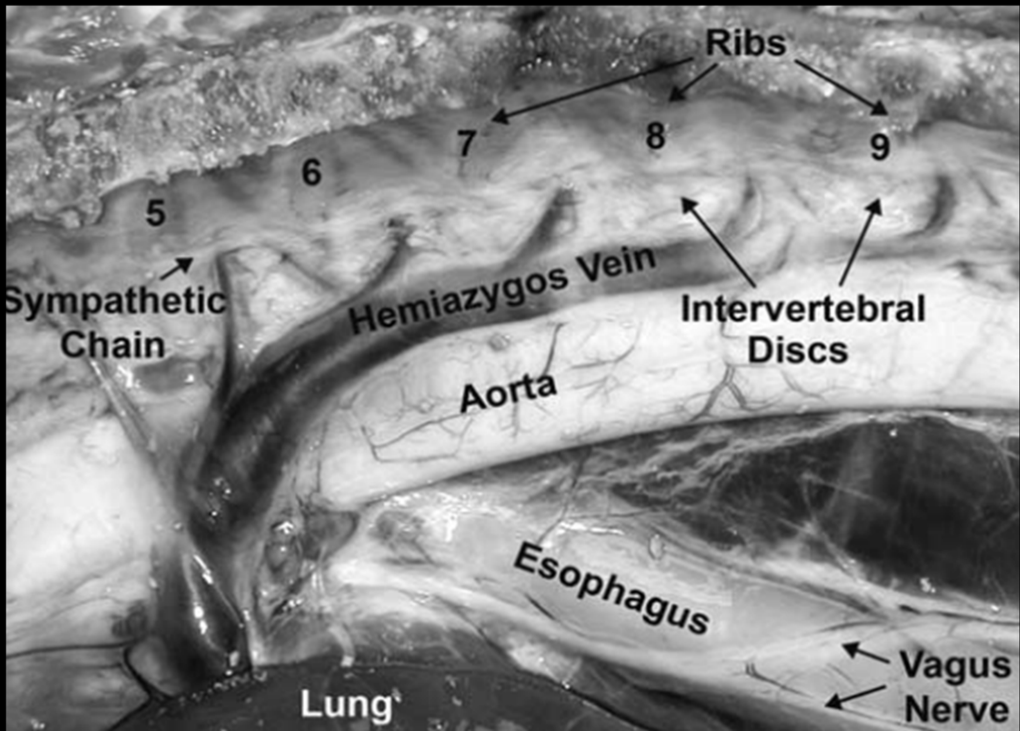
Surg Endosc (2005) 19: 1652–1665
DOI: 10.1007/s00464-005-0159-9

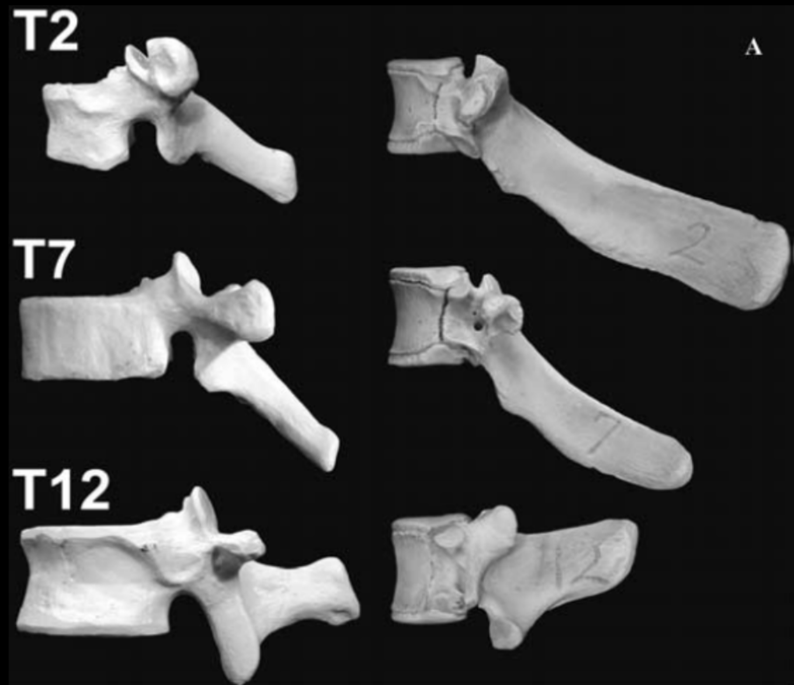
SURGICAL ENDOSCOPY
and Other Interventional Techniques

Comparative anatomy of the porcine and human thoracic spines with reference to thoracoscopic surgical techniques

H. Bozkus,[1] N. R. Crawford,[2] R. H. Chamberlain,[2] T. D. Valenzuela,[2] A. Espinoza,[2] Z. Yüksel,[2] C. A. Dickman[2]

[1] Department of Neurosurgery, VKV American Hospital, Güzelbahçe Sk. No. 20, 80200, Nisantasi, Istanbul, Turkey
[2] Spinal Biomechanics Research Laboratory, Barrow Neurological Institute, 350 West Thomas Road, Phoenix, AZ 85013, USA

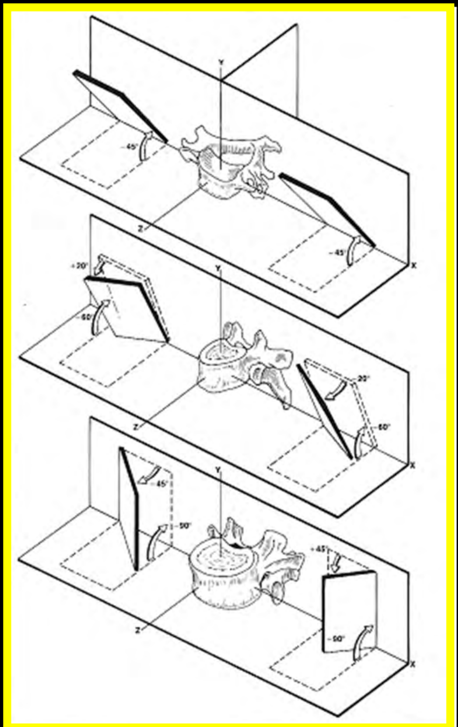




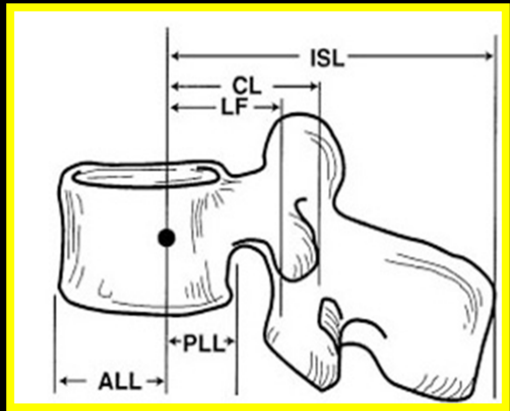
Omurga Biyomekanik Davranışı

- Hareket aralığı (ROM)
- Rotasyonun anlık ekseni (IAR)
- Yük/Deformasyon Eğrisi
- Stabilite
  - Cerrahi
  - Fiksasyon

Hareketi Sağlayan Yapılar



Fasetler



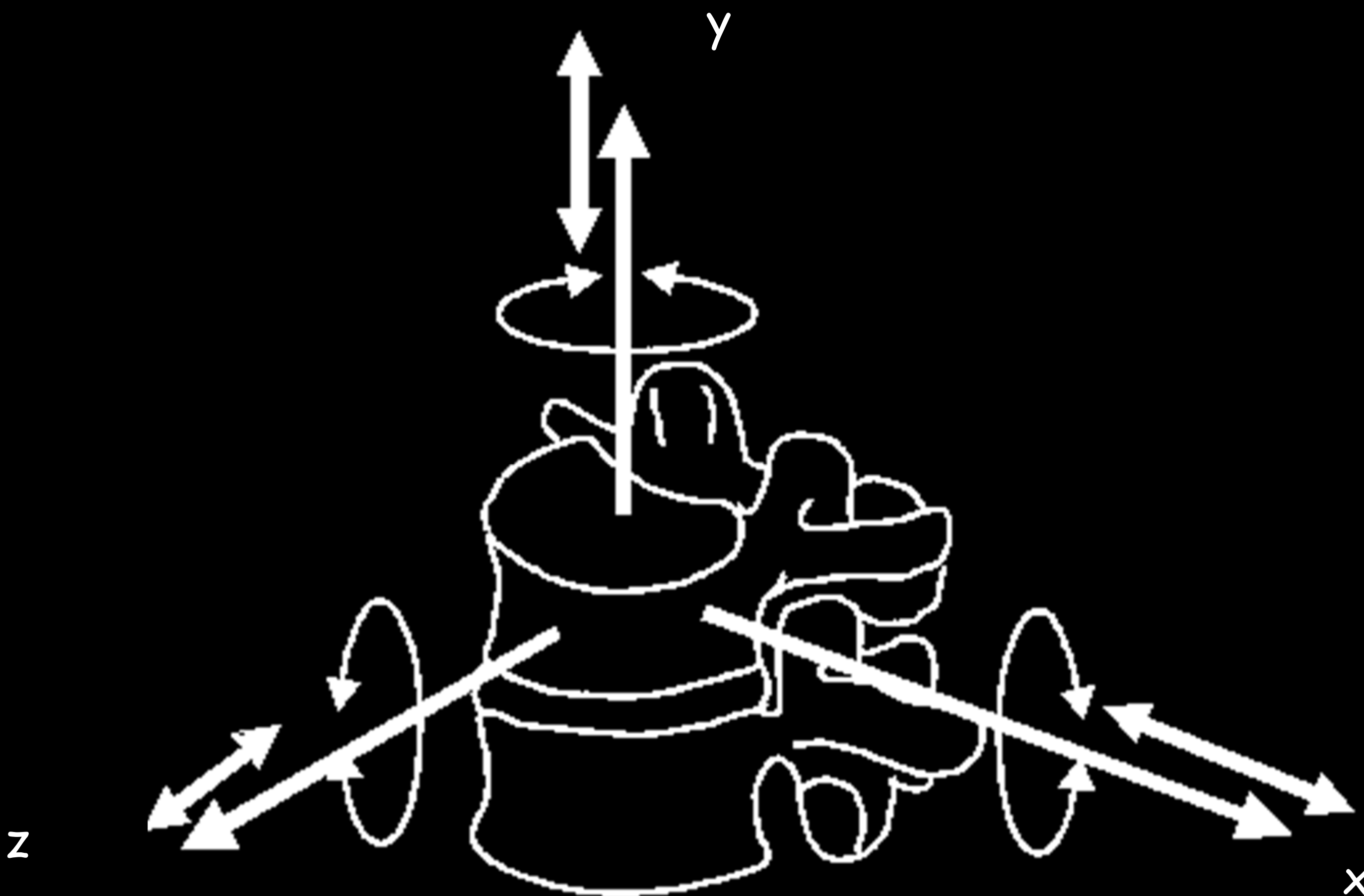
Ligamanlar

Adaleler

İntervertebral disk

Hareket Serbestliği

6 yönde hareket serbestliği



Panjabi, 1978

Tek Planda RAE Doğruluğu ?

GERÇEK KATI CİSİM HAREKETİNİ GÖSTERMİYOR !

A1A2 ve B1B2 noktalarının translasyonu tek bir doğrultuda olmayabilir.

İstatistiksel olarak aynı translasyon vektörlerinin kullanılması gerçekçi değil.

YAKINSAMA OLABİLİR !

Woltring ve ark., J Biomech 1985

Gerçekçi RAE Çözümü ?

- En az 3 noktanın,
- Translasyon vektörü ve rotasyon matriksinin bilinmesi

(röntgen sterofotogrametri)

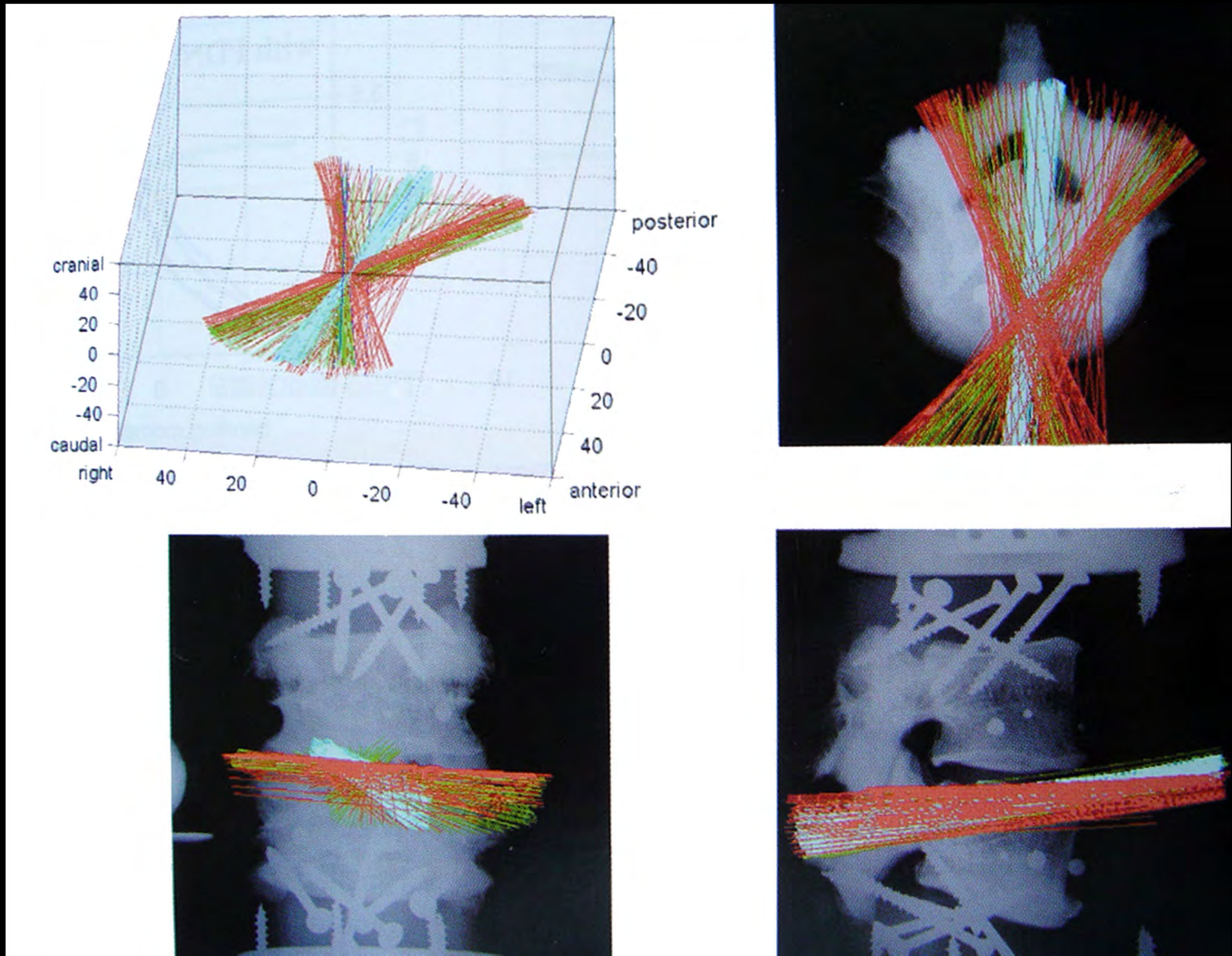
ÜÇ BOYUTLU RAE !

Helikal Rotasyon Ekseni

likal eksen

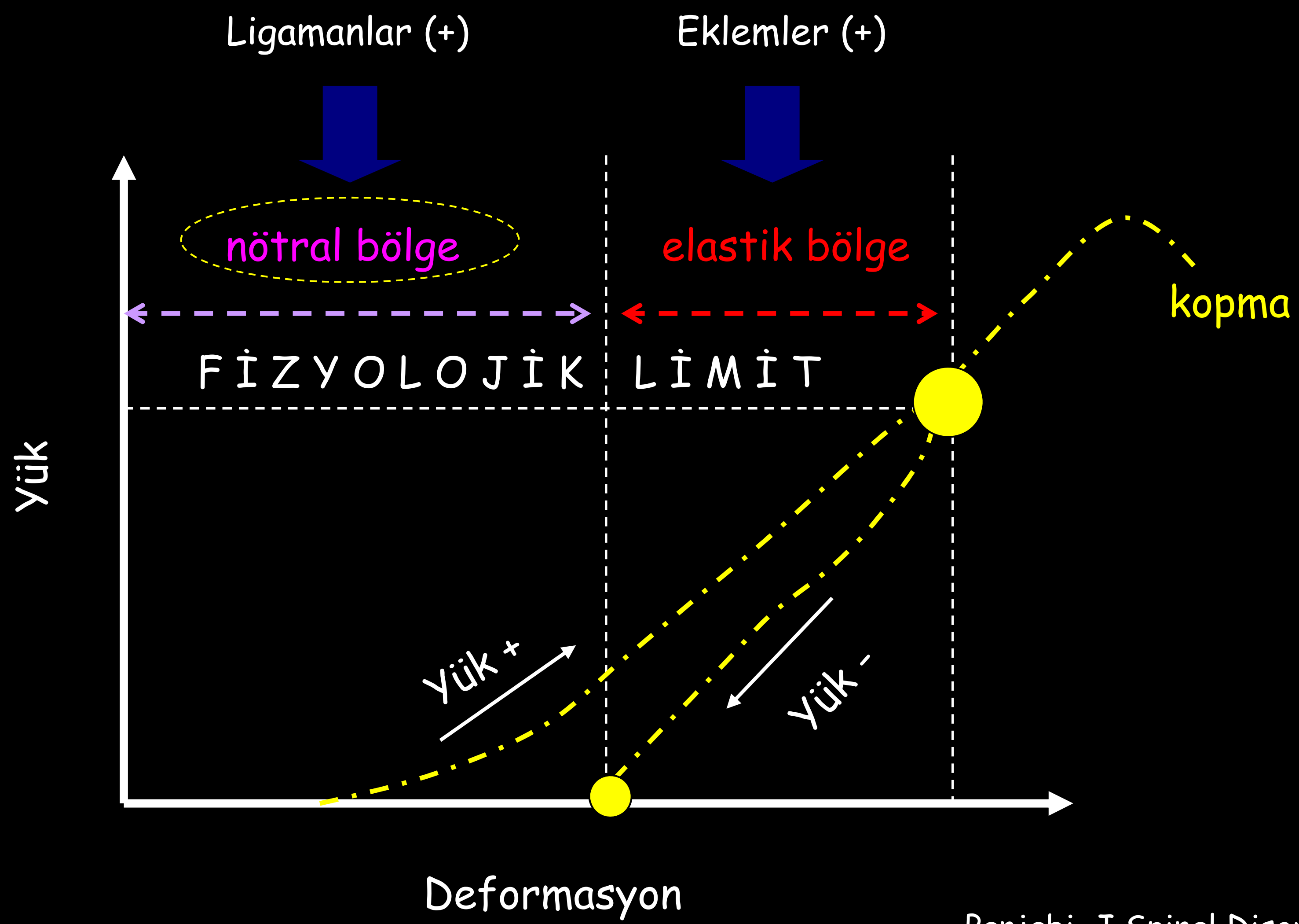
Spoor ve Veldpaus, J Biomech 1980

Helikal eksen hareketi (HAM)



Roundtables in Spine Surgery, 1; 1, 2005

Hareket Aralığı (ROM)



Panjabi, J Spinal Disord 1992

Omurgada Biyomekanik Çalışmalar

- Deneysel modeller (in vitro)

  1. Kadavra (insan, hayvan)
  2. Bilgisayar modelleri

- Deneysel testler

  1. Fizyolojik yükleme (flexibility test)
  2. Hasar oluşturan yükleme (failure test)
  3. Yorulma (fatigue)

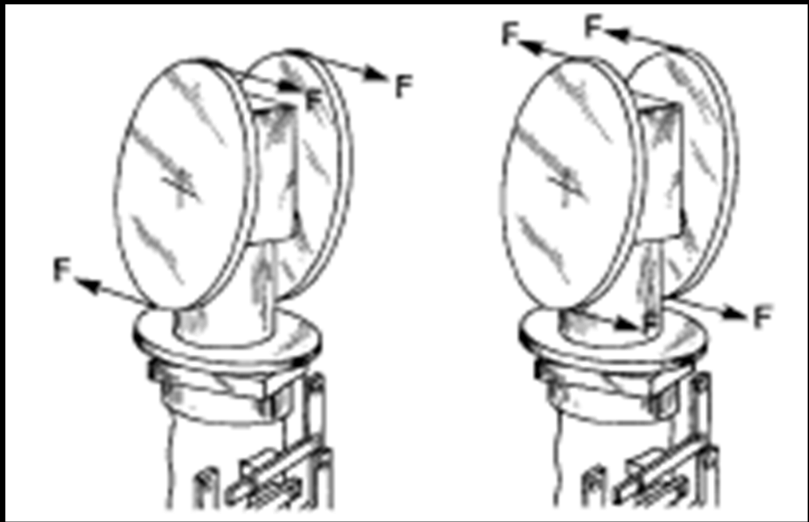
Kadavra Model Hazırlanması

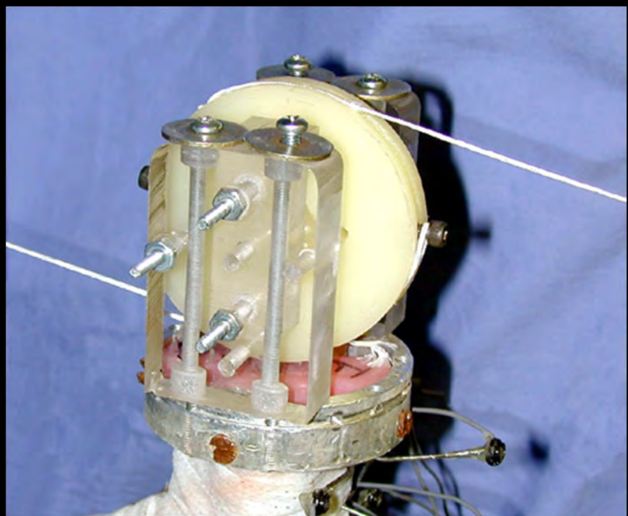
- Taze donmuş kadavra (-20° de muhafaza)
- Oda şartlarında ısıtılması
- Deney sırasında nemli tutulması
- Denek modelinin üst ve altında en az bir FSU olması
- Yükleme şartları
- En az 3 test ve bekleme süresi (sönümleme etkisi)
- Cerrahi yapılacaksa tekniği
- Stabilizasyon yapılacaksa tekniği

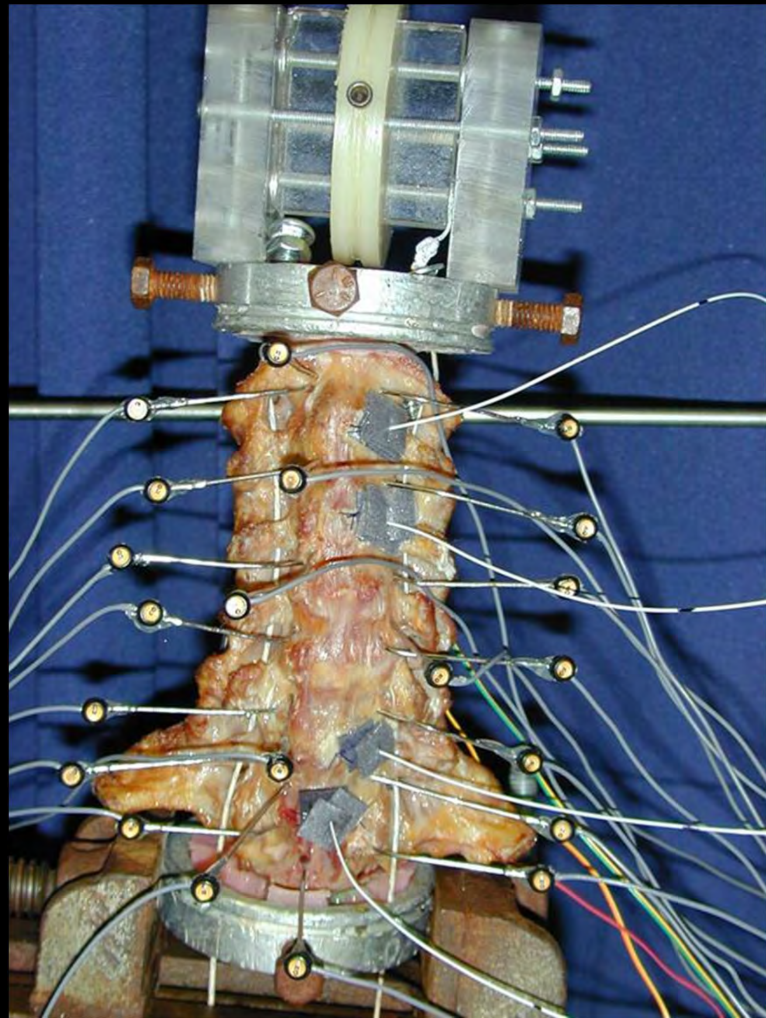
İn Vitro Model Hazırlanması

Taze insan kadavrası (C2-T1 segmentleri), disk ve ligamanlara zarar verilmeksizin adale dokularından temizlenmesi.

Moment yüklemesi

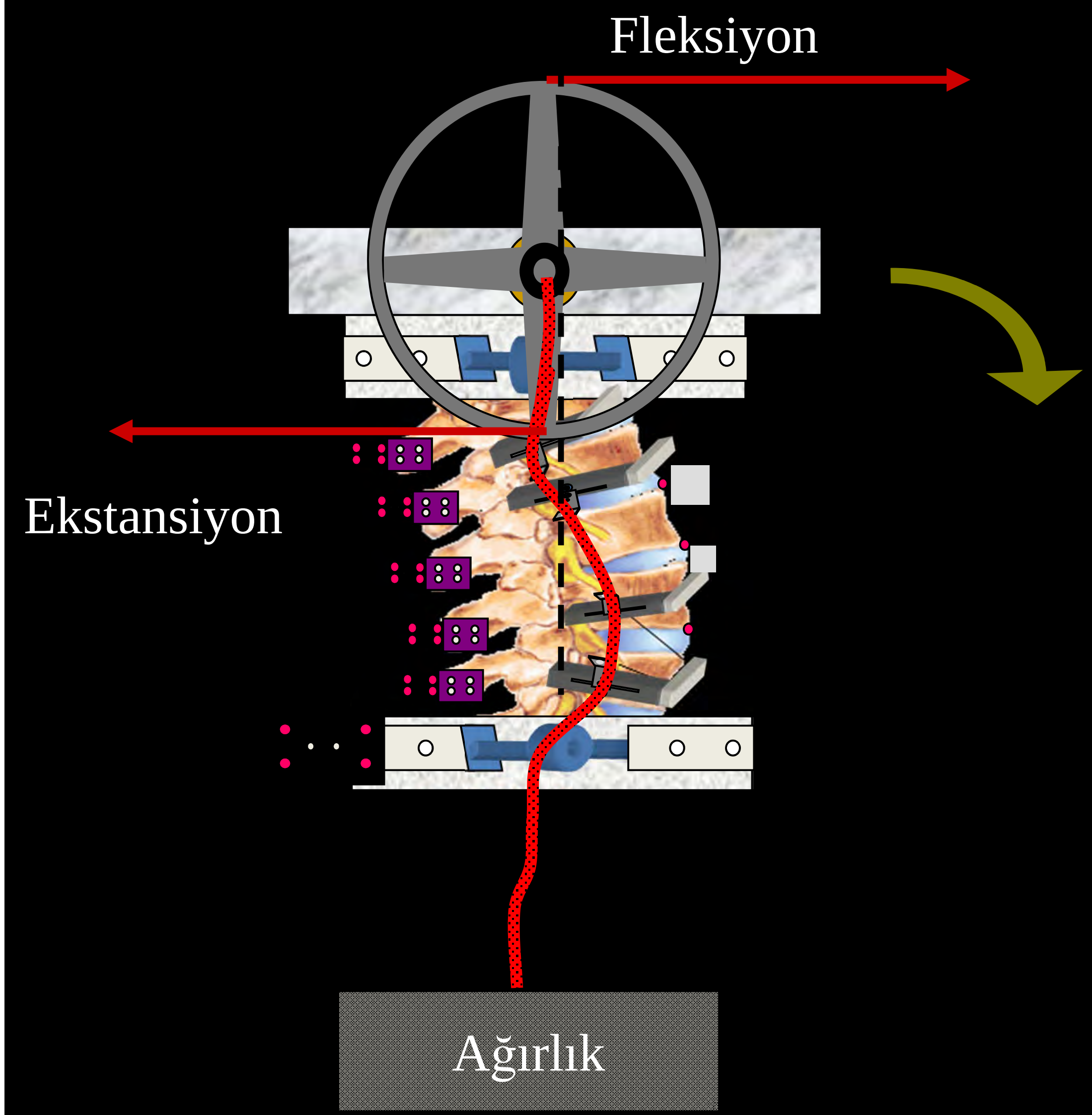


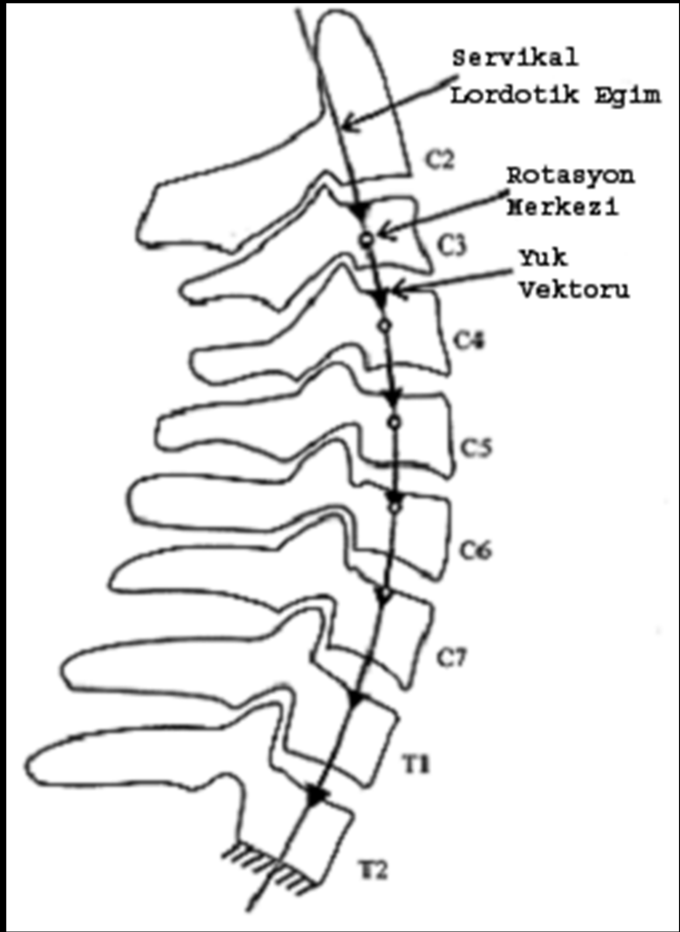




Panjabi ve ark. Spine, 2001

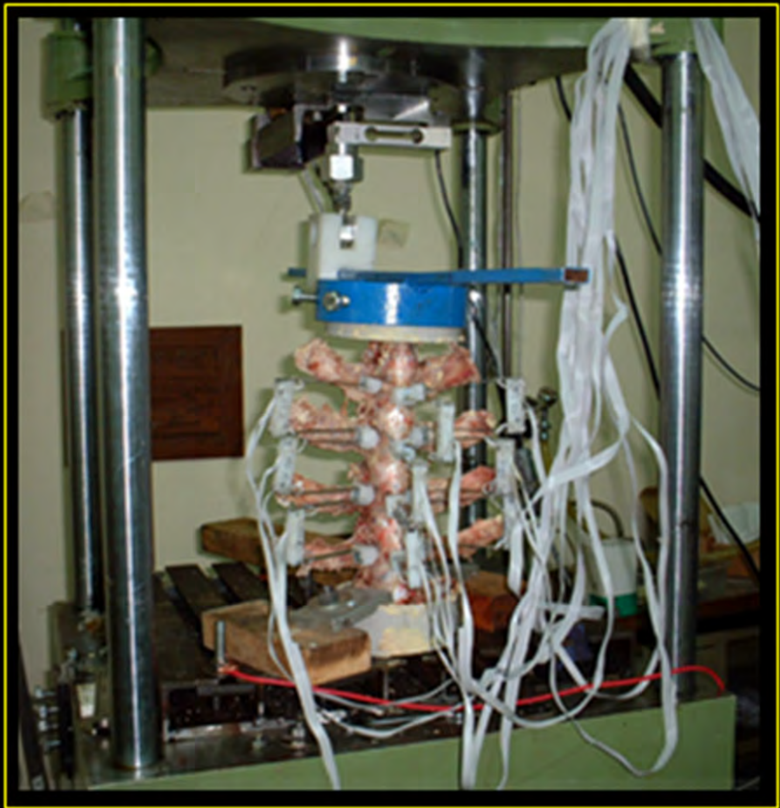
Tanjansiyel aksiyal yükleme





Patwardhan ve ark. Spine, 2000

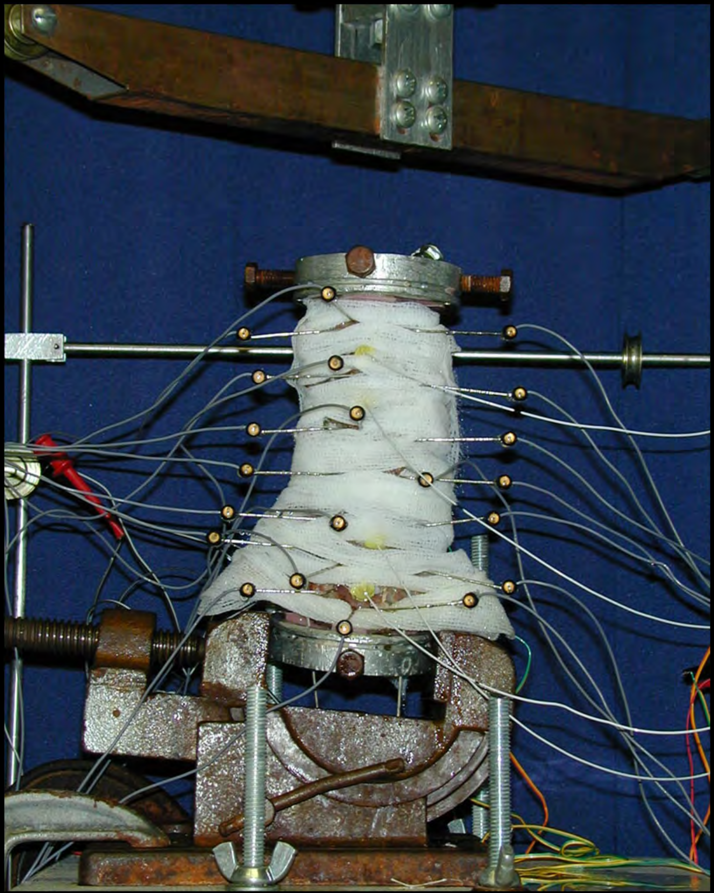
Hareket Aralığı Ölçümü

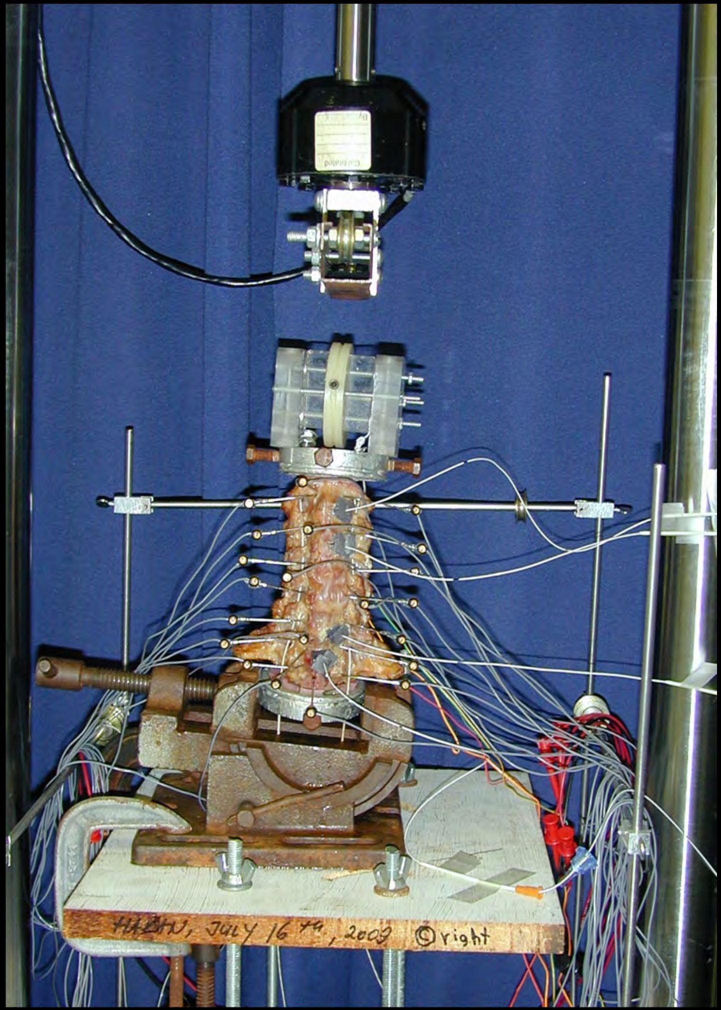


Ekstansometre

Deney düzeneği

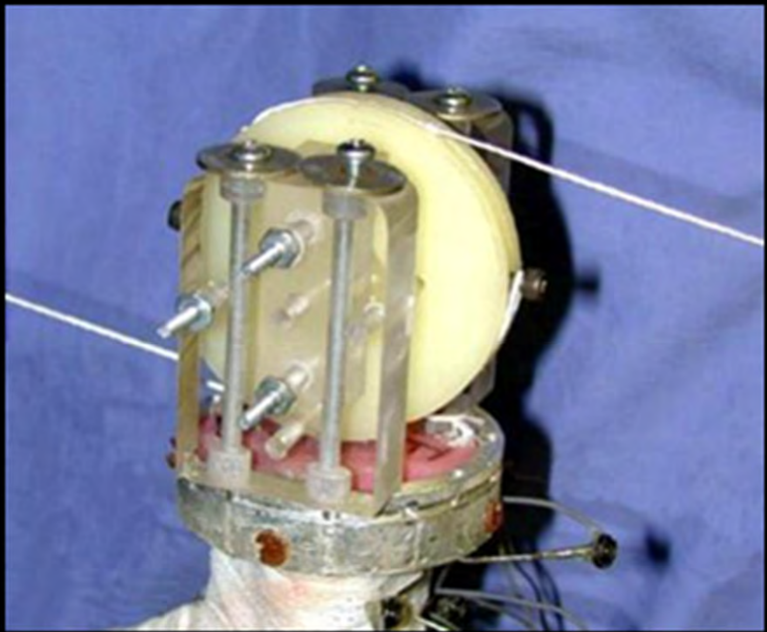
İnfrared işaretlerin yerleştirilmesi





Mekanik test düzeneği

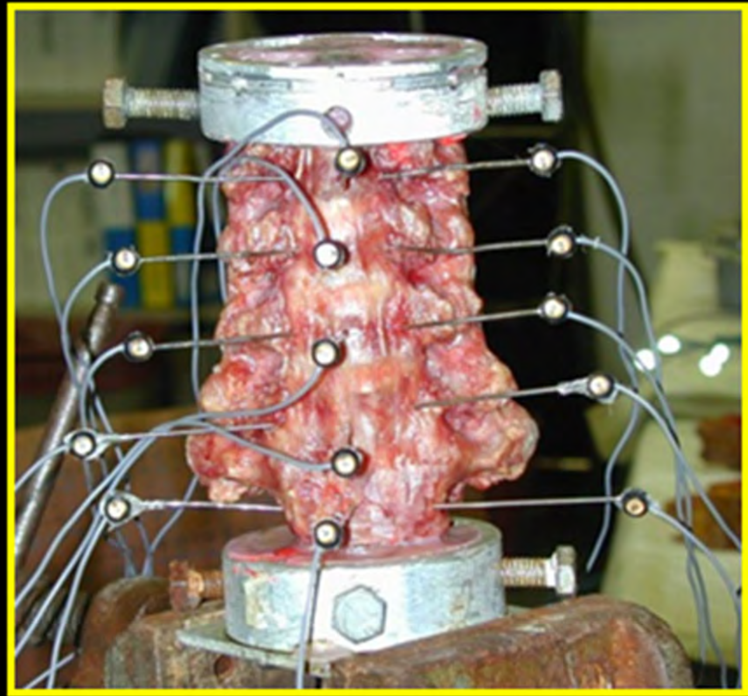
0.5, 1.0, 1.5 Nm tork yüklemesi



Flexion - Extension

Sterofotogrametrik ölçüm

Hareket Aralığı Ölçümü



Sterofotogrametri

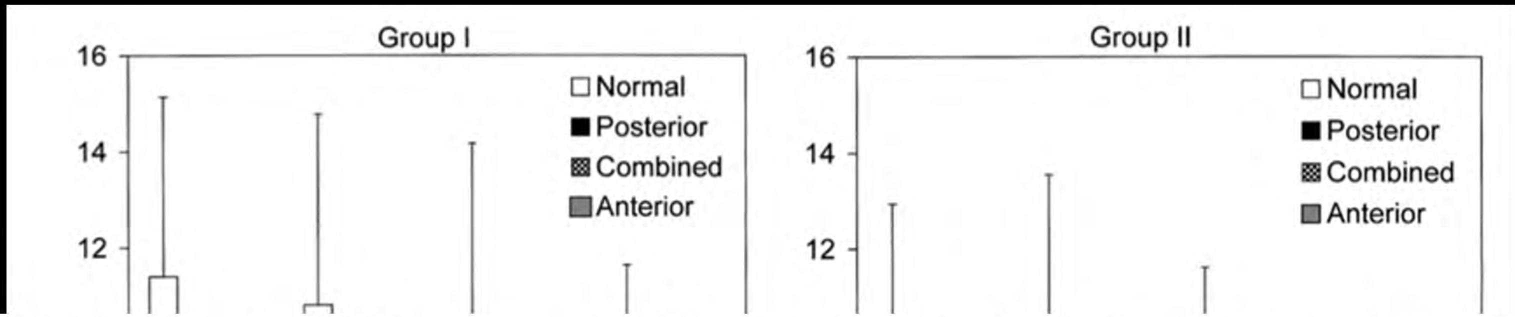


Table 2. Group II: Biomechanical Parameters and Their Percent Change Relative to Normal (mean ± SD)

Parameter	Loading Mode	Normal (° or Nm/°)	Posterior Fixation (° or Nm/°)	Percent Reduction *vs.* Normal	Combined Fixation (° or Nm/°)	Percent Reduction *vs.* Normal	Anterior Fixation (° or Nm/°)	Percent Reduction *vs.* Normal
Range of motion	Flexion	10.3 ± 2.6	2.5 ± 1.7*	74 ± 22†	0.3 ± 0.3	97 ± 2†	4.1 ± 2.2*	62 ± 12†
	Extension	10.2 ± 3.4	3.5 ± 1.8*	65 ± 19†	0.5 ± 0.4	95 ± 2†	2.4 ± 2.3*	79 ± 11†
	Lateral bending	8.4 ± 3.2	0.4 ± 0.2*	95 ± 2†	0.2 ± 0.2	97 ± 1†	2.8 ± 2.4*	69 ± 19†
	Axial rotation	6.9 ± 2.5	0.8 ± 0.4*	87 ± 6†	0.5 ± 0.4	92 ± 6†	3.6 ± 2.6*	42 ± 48
Lax zone	Flexion-extension	11.6 ± 4.1	1.1 ± 1.0*	90 ± 12†	0.3 ± 0.3	98 ± 1†	2.1 ± 2.8	83 ± 17†
	Lateral bending	11.2 ± 5.6	0.1 ± 0.1	99 ± 1†	0.1 ± 0.1	99 ± 1†	2.3 ± 2.9*	82 ± 18†
	Axial rotation	8.7 ± 4.7	0.2 ± 0.2	98 ± 1†	0.2 ± 0.3	97 ± 3†	2.6 ± 2.8*	64 ± 44†
Stiff zone	Flexion	4.5 ± 1.0	2.0 ± 1.2*	54 ± 32†	0.2 ± 0.2	96 ± 3†	3.1 ± 1.3*	32 ± 24†
	Extension	4.4 ± 1.6	2.9 ± 1.5*	30 ± 41†	0.4 ± 0.3	91 ± 4†	1.5 ± 0.9*	68 ± 8†
	Lateral bending	2.8 ± 0.5	0.3 ± 0.1*	89 ± 4†	0.2 ± 0.1	93 ± 3†	1.7 ± 1.0*	44 ± 24†
	Axial rotation	2.5 ± 0.4	0.8 ± 0.3*	70 ± 12†	0.4 ± 0.3	84 ± 10†	2.3 ± 1.2*	8 ± 52
Stiffness	Flexion	0.34 ± 0.07	1.03 ± 0.61*	−209 ± 182†	11.54 ± 6.73	−3368 ± 2261†	0.62 ± 0.38*	−76 ± 90
	Extension	0.37 ± 0.12	0.69 ± 0.48*	−81 ± 80	5.02 ± 2.56	−1240 ± 629†	1.40 ± 0.77*	−275 ± 200†
	Lateral bending	0.54 ± 0.10	5.31 ± 1.92*	−878 ± 322†	10.21 ± 4.46	−1731 ± 592†	1.20 ± 0.69*	−112 ± 89†
	Axial rotation	0.61 ± 0.09	2.37 ± 1.01*	−290 ± 152†	5.51 ± 4.04	−782 ± 549†	0.85 ± 0.42*	−39 ± 60

*Significant difference from combined fixation ($P < 0.05$).
†Significant difference from normal ($P < 0.05$).

Mühendislik Teknolojilerinin Kullanımı

1. Kolonlar arasındaki yük dağılımı analizi
   Arka kolon --------------- strain gage
   Ön ve orta kolon ----------- load cell

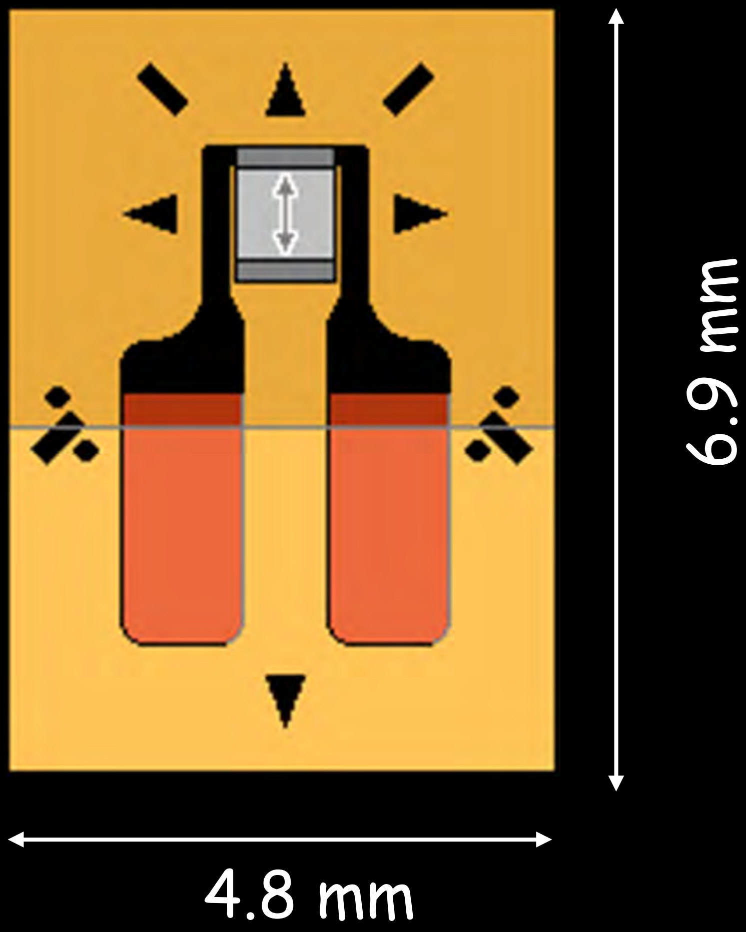
2. Komşu disk mesafesindeki basınç değişimi
   Basınç transduserler

3. Omur segmentleri arasındaki hareket
   Sterofotogrametri

Strain (birim şekil değiştirme) ölçüm teknikleri

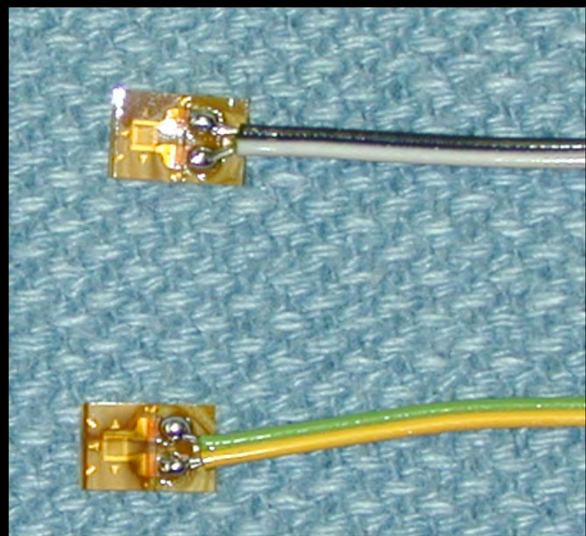
- Gevrek kaplama
- Fotoelastisite
- Termografi
- Elektrik rezistans strain gage tekniği
- Sonlu eleman yöntemi

Strain gage



- Tek eksenli strain gage

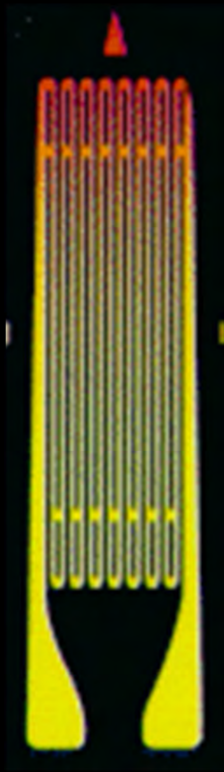
- Statik ve dinamik gerilme analizi.



Strain gage ölçüm mekanizması

- Bir tele kuvvet uygulanması ile telin boyunda oluşan şekil değişimi sırasında telin kesit alanının değişimi nedeniyle tel malzemesinin elektrik akımına karşı gösterdiği direnç değişikliğinin ölçülmesidir.

$$R = \rho \frac{\ell}{A}$$

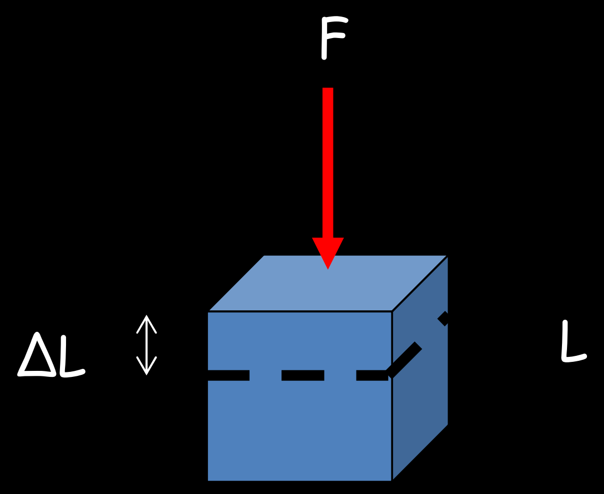


Birim Şekil Değiştirme (strain, ε)

- Geometride oluşan şekil değiştirmenin (uzama, kısalma, kayma) ilk duruma oranı (BİRİMSİZDİR!)

Birim şekil değiştirme= (ΔL/ L)

- Basma (compressive)
- Çekme (tensile)
- Kayma (shear)

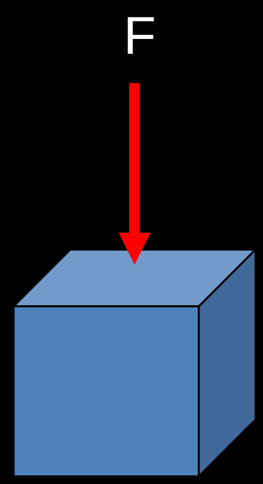


Gerilme (Stress, σ)

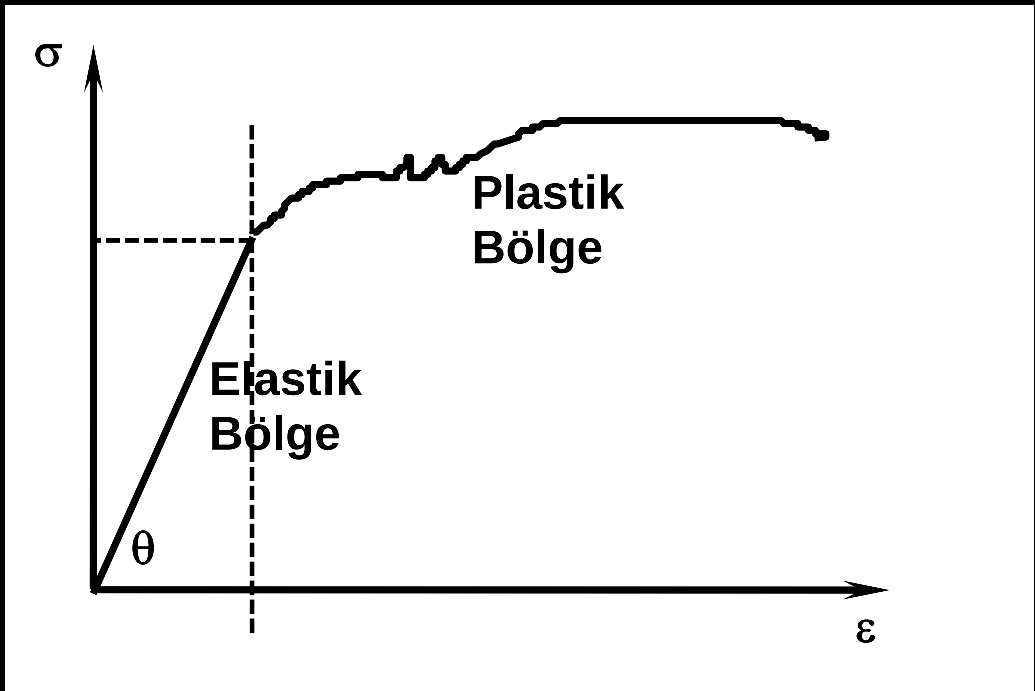
- Birim alana gelen kuvvet (Pa= N/m^2)

Gerilme= Kuvvet/Alan

- Basma (compressive)
- Çekme (tensile)
- Kayma (shear)



Elastik bölge, Hooke kanunu



$$\varepsilon = \frac{\Delta \ell}{\ell}$$

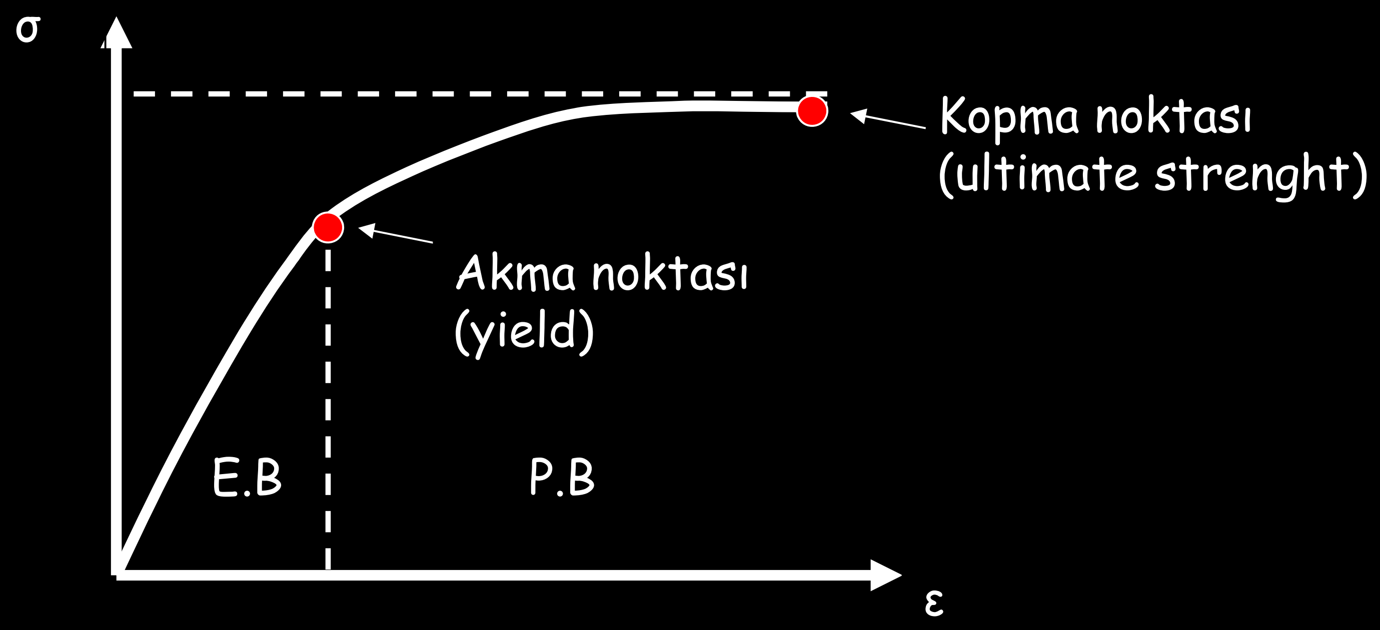
$$\sigma = E.\varepsilon$$

Strain' den stress (gerilme) hesaplanması

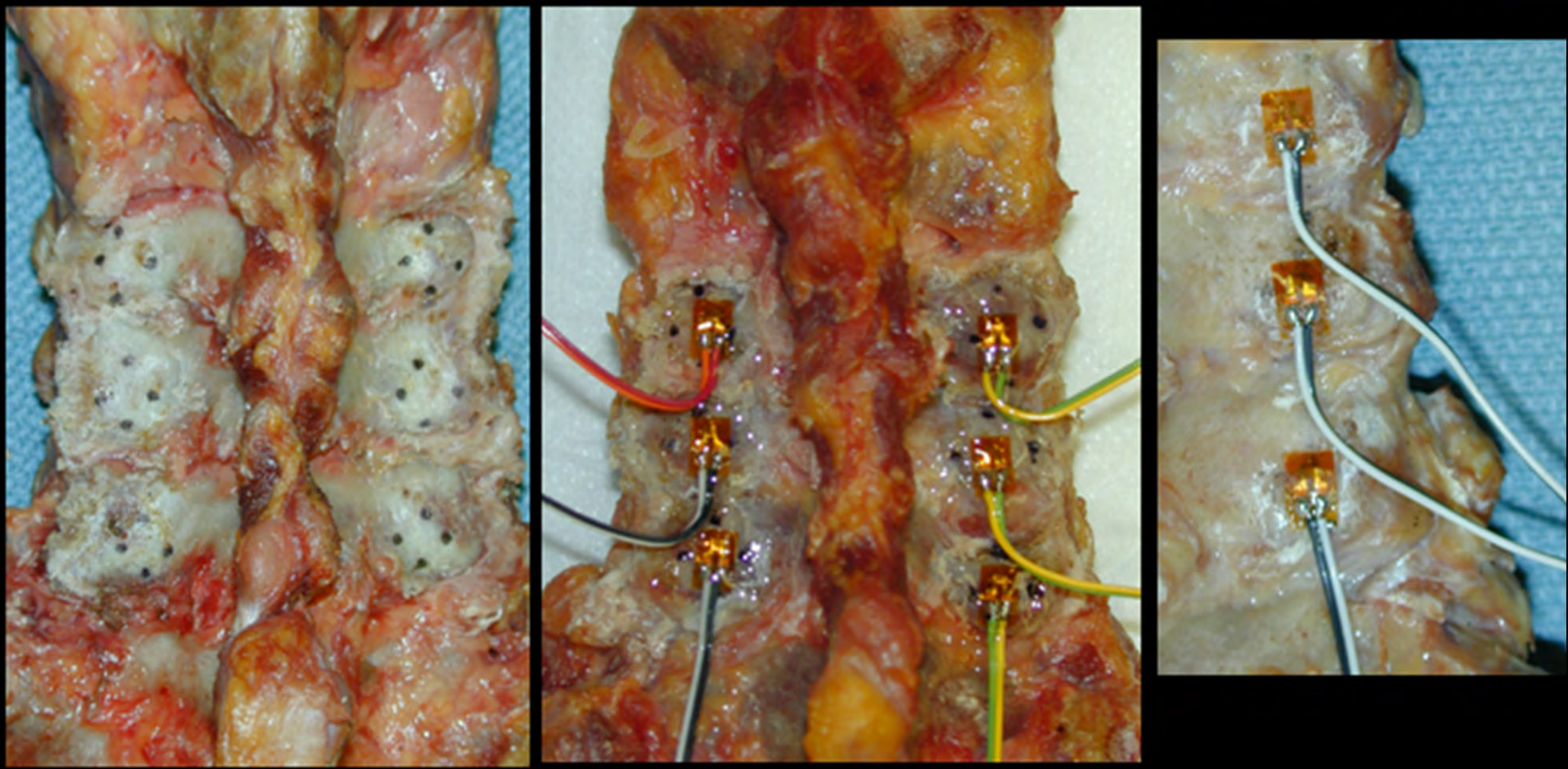
$$\begin{bmatrix} \varepsilon_a \\ \varepsilon_b \\ \varepsilon_c \end{bmatrix} \xrightarrow{\;1\;} \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix} \xrightarrow{\;2\;} \begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{bmatrix} \xrightarrow{\;3\;} \begin{bmatrix} \sigma_{\substack{\max \\ \min}} \\ \tau_{\substack{\max \\ \min}} \\ \theta \end{bmatrix}$$

Stress/Strain
Yük/Deformasyon

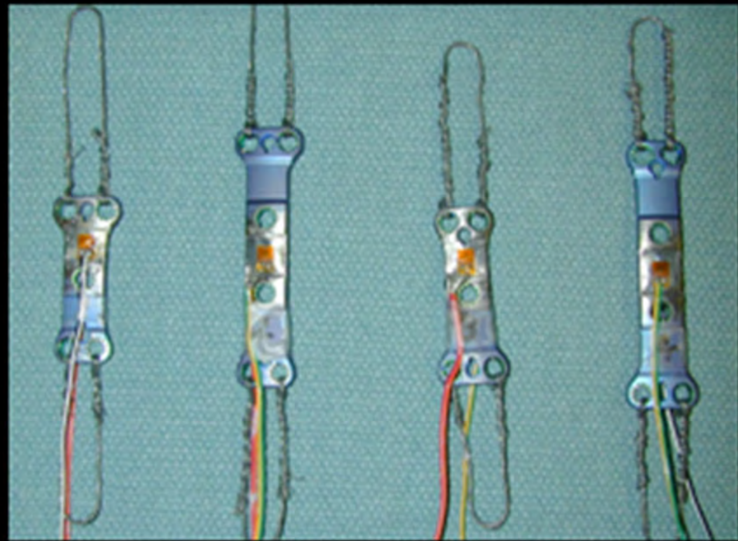
Elastisite modülü (Young Modülü) = (σ / ε)

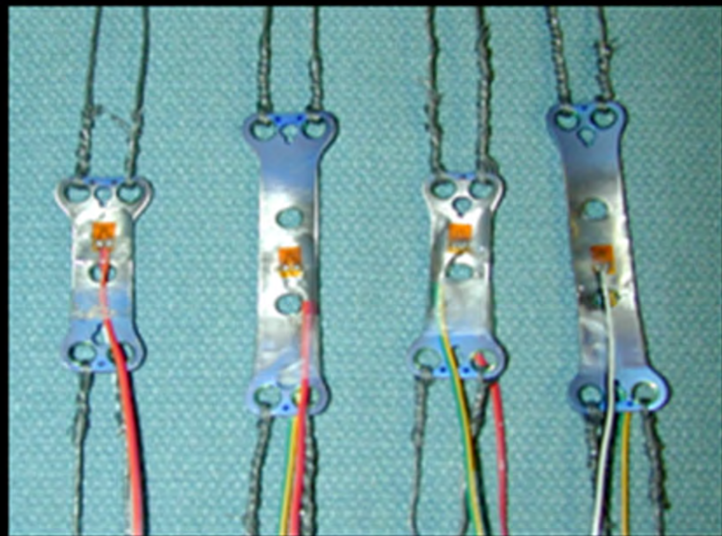


Lateral mass' lara strain gage yapıştırılması



Plak için strain gage hazırlanması

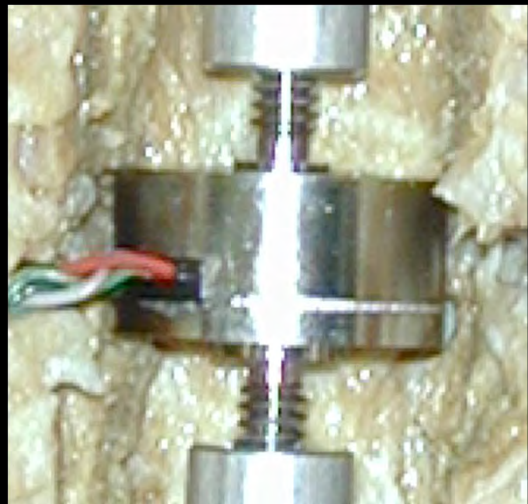




Load cell

17.35 mm

12.7 mm



Yükseltici

- Load cell boyutu; 17.35 x 12.7 mm,
- Tek mesafe korpektomi için yeterli.

Ultra-minyatür tek alıcılı mikro basınç transduseri

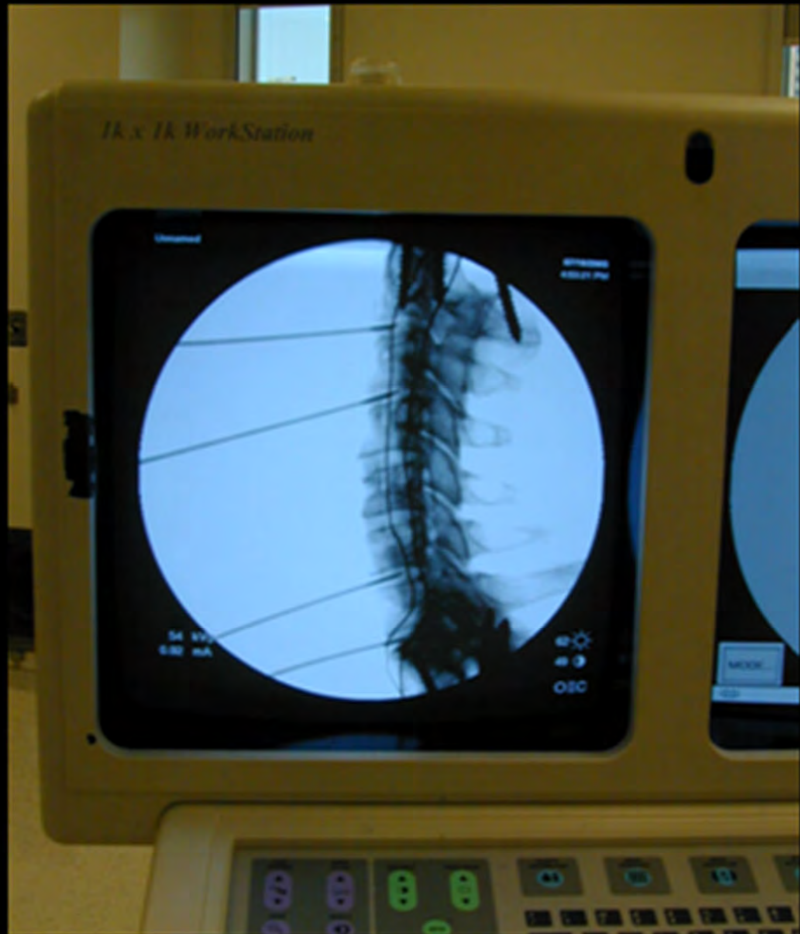
SPR-524

3.5 French (alıcı)

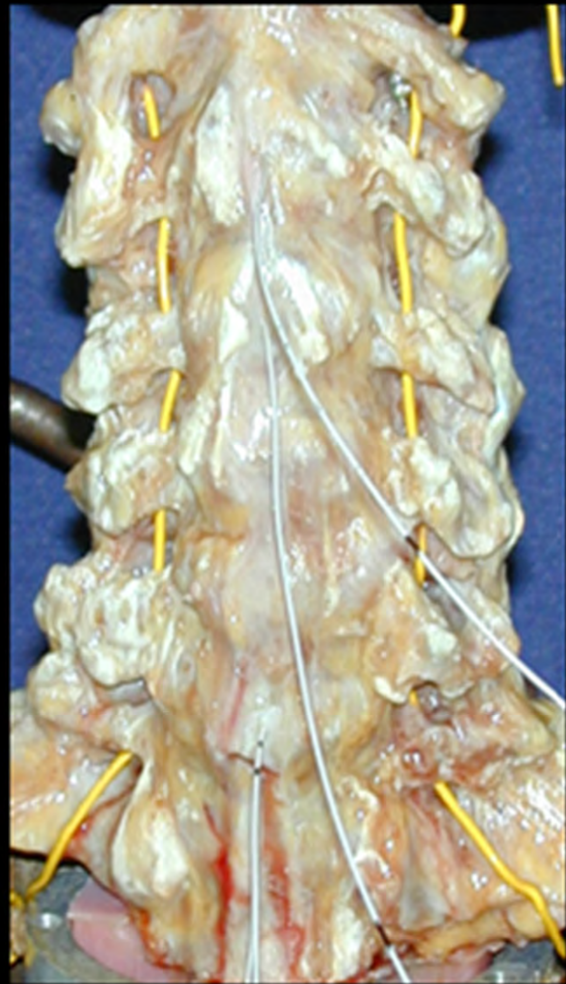
(3 French ~1 mm)

Basınç kontrol ünitesi

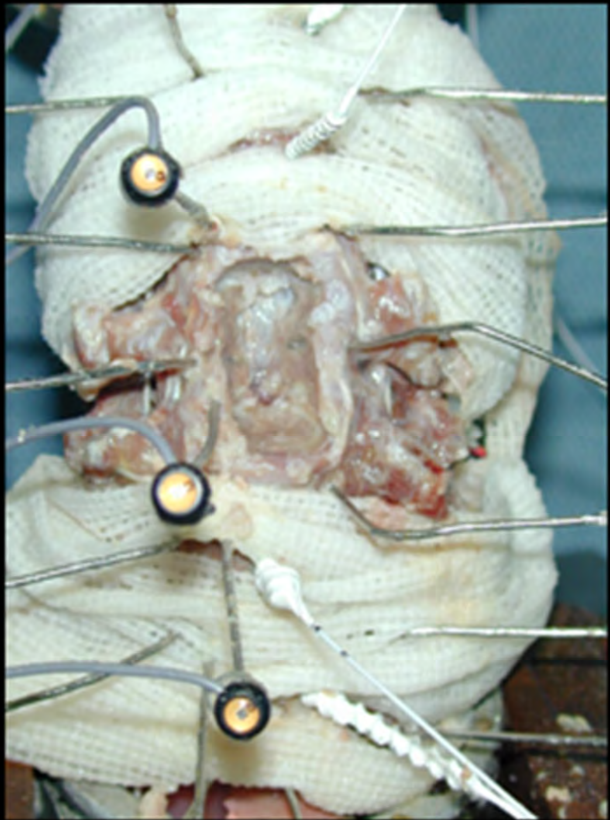
Basınç transduserlerinin yerleştirilmesi



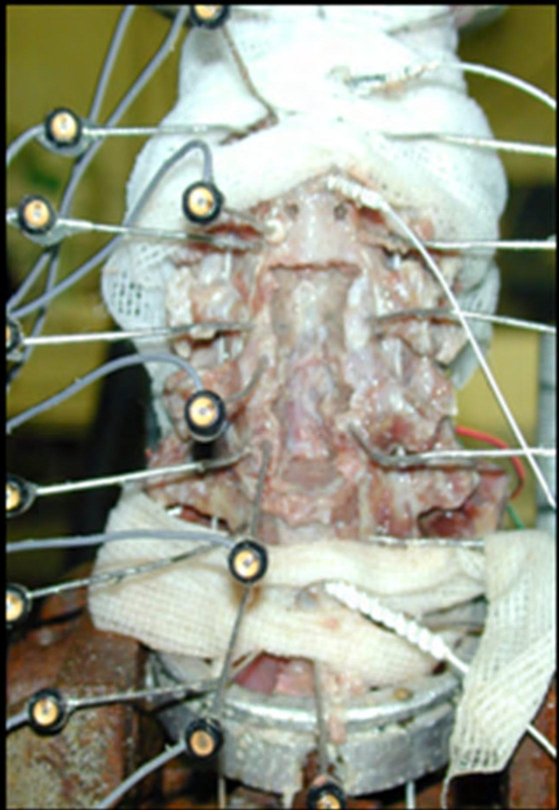
Basınç transduserlerinin yerleştirilmesi



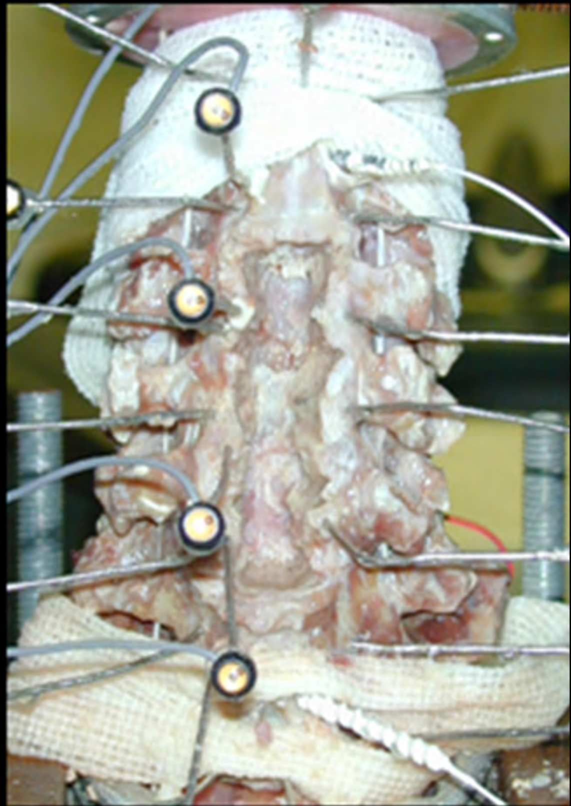
Korpektomi hazırlığı sonrası



C5 korpektomi

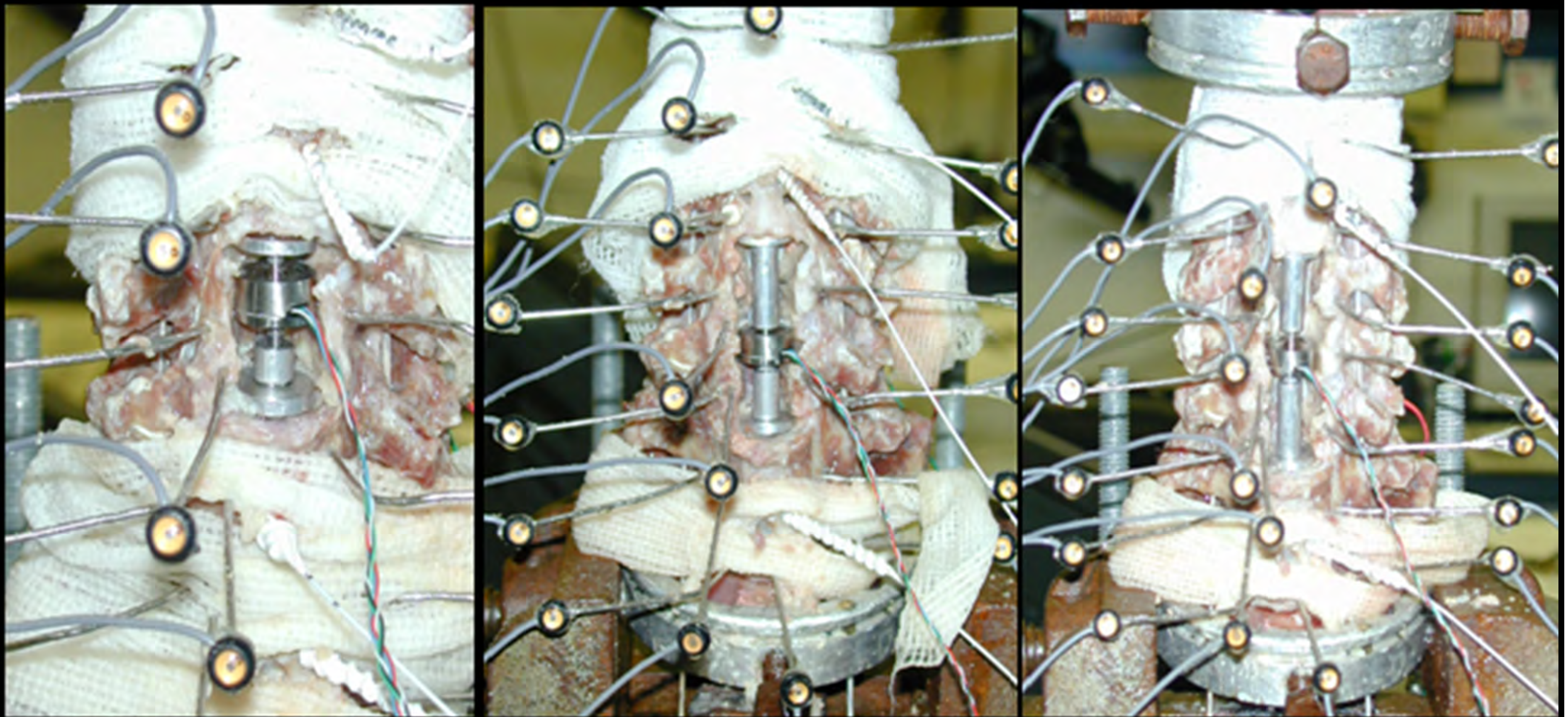


C5-6 korpektomi



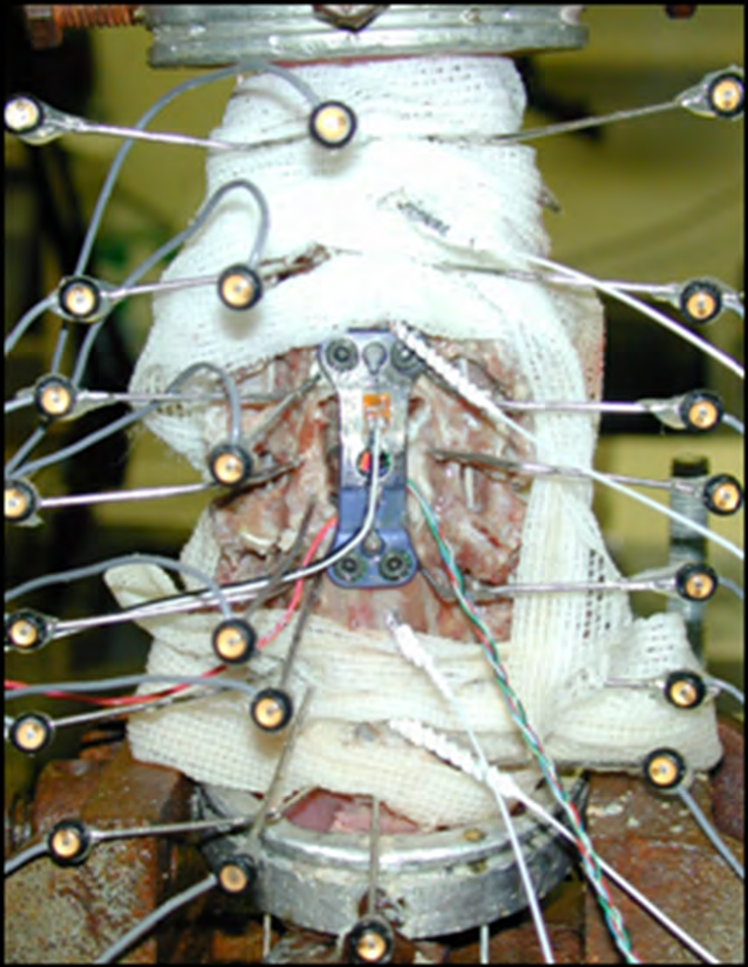
C4-5-6 korpektomi

Load cell' lerin yerleştirilmesi

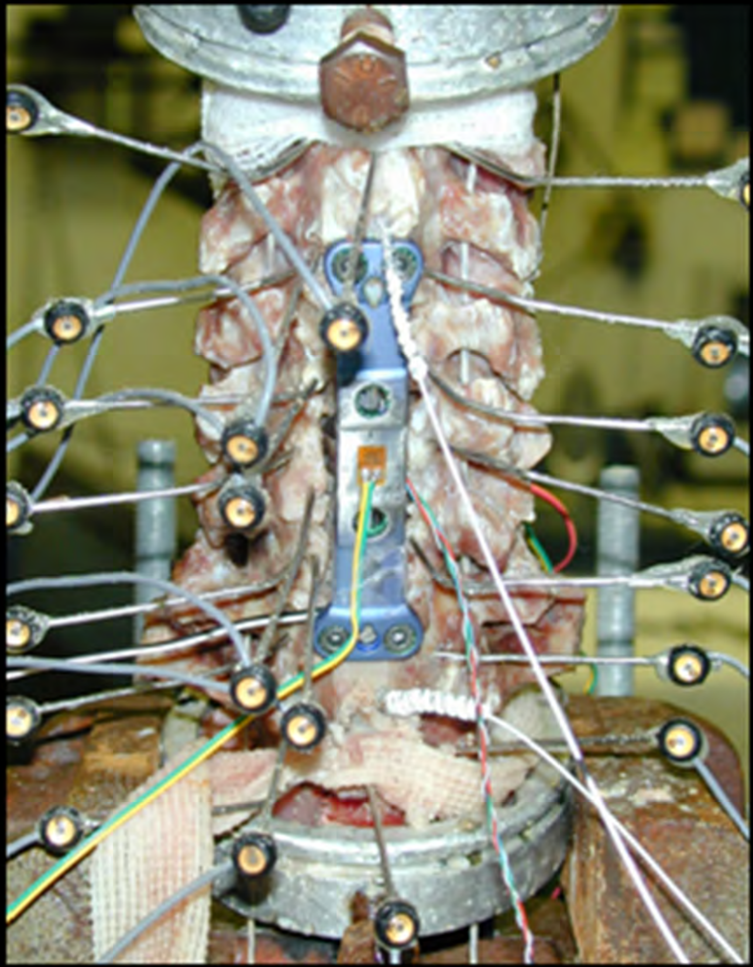


C5 load cell | C5-6 load cell | C4-5-6 load cell

Load cell ve plak yerleştirilmesi

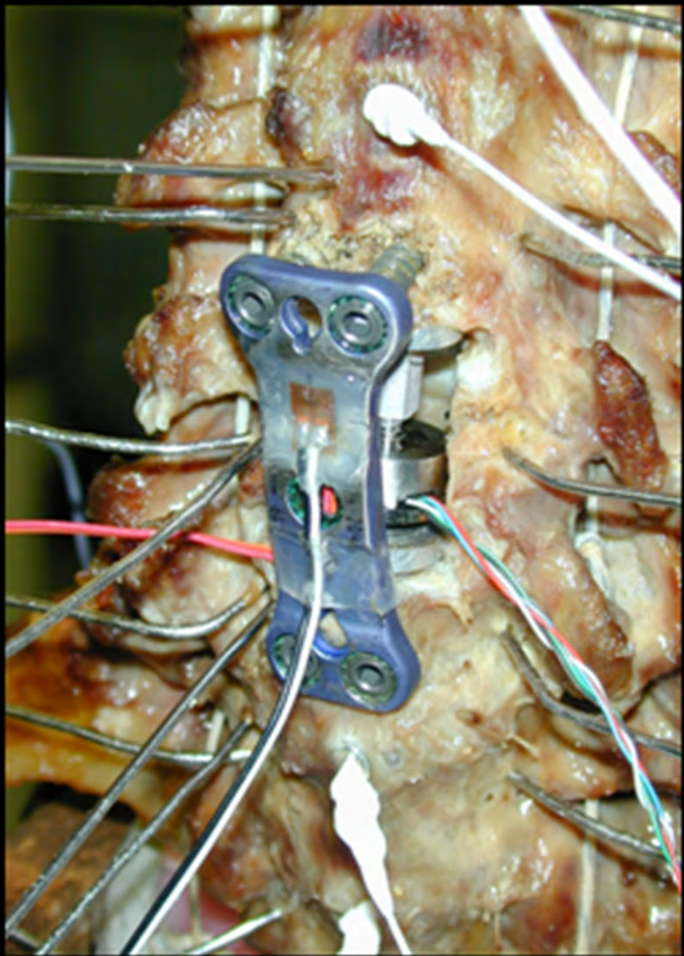


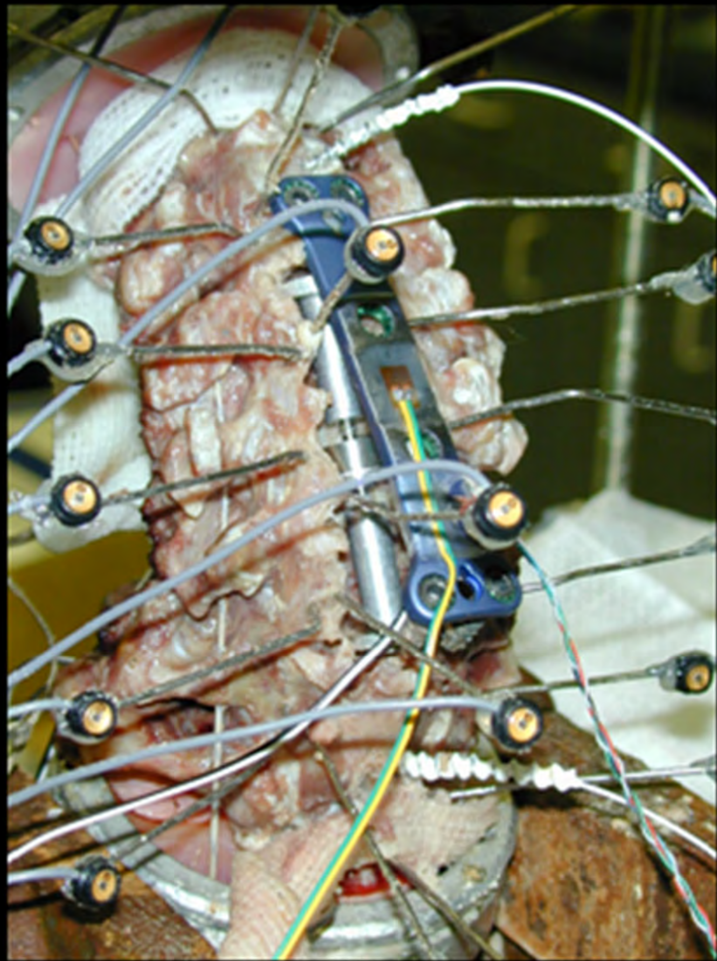
C5 anterior plak



C4-5-6 anterior plak

Başarısız sonuçlar

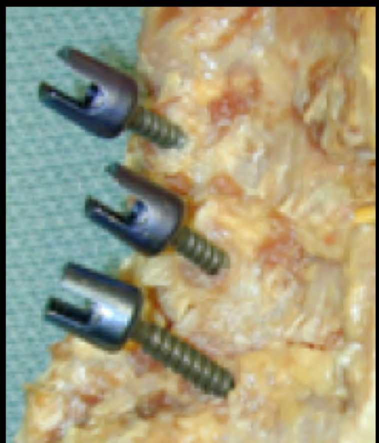




SPINE Volume 30, Number 8, pp 915–922

Biomechanical Analysis of Rigid Stabilization Techniques for Three-Column Injury in the Lower Cervical Spine

Hakan Bozkus, MD,* Christopher P. Ames, MD,† Robert H. Chamberlain, MS,‡
Eric W. Nottmeier, MD,§ Volker K. H. Sonntag, MD,‡ Stephen M. Papadopoulos, MD,‡ and
Neil R. Crawford, PhD‡



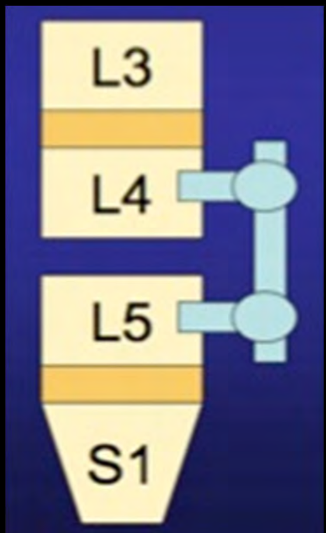
J Neurosurg Spine 12:183–189, 2010

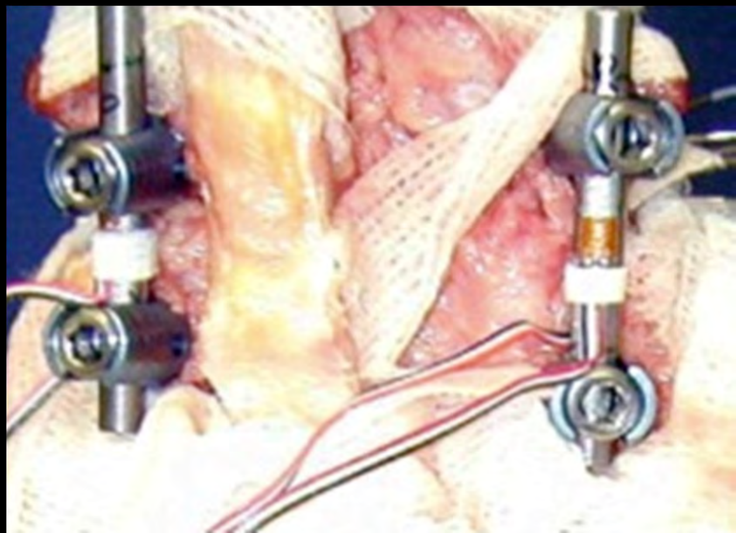
Dynamic lumbar pedicle screw-rod stabilization: in vitro biomechanical comparison with standard rigid pedicle screw-rod stabilization

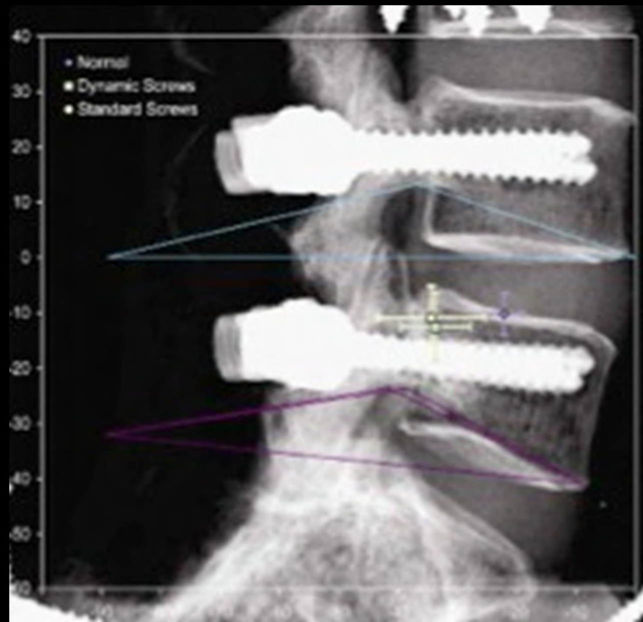
Laboratory investigation

HAKAN BOZKUŞ, M.D.,[1] MEHMET ŞENOĞLU, M.D.,[2] SEUNGWON BAEK, M.S.,[2] ANNA G. U. SAWA, M.S.,[2] ALI FAHIR ÖZER, M.D.,[1] VOLKER K. H. SONNTAG, M.D.,[2] AND NEIL R. CRAWFORD, PH.D.[2]

[1]Department of Neurosurgery, VKV Amerikan Hastanesi, Istanbul, Turkey; and [2]Barrow Neurological Institute, Spinal Biomechanics Research Laboratory, Phoenix, Arizona







Pedikül Vida-Rod Sistemi Yorulması

Standartlar

ASTM F1717 - 13

Standard Test Methods for Spinal Implant Constructs in a Vertebrectomy Model

Active Standard ASTM F1717 | Developed by Subcommittee: F04.25

Book of Standards Volume: 13.01

ISO 12189:2008

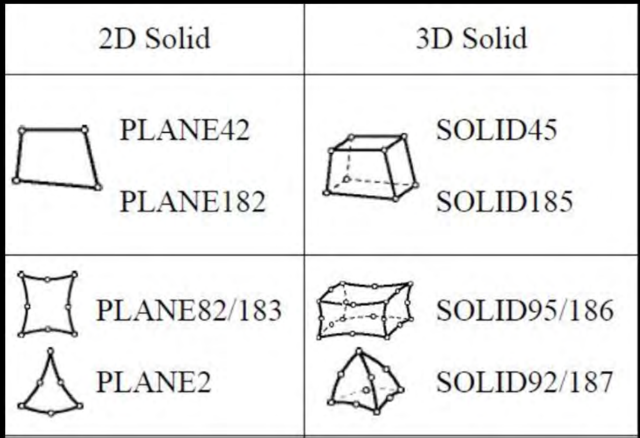
Implants for surgery -- Mechanical testing of implantable spinal devices -- Fatigue test method for spinal implant assemblies using an anterior support

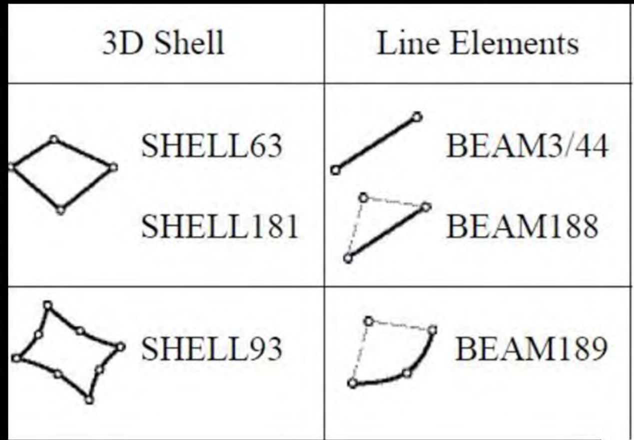
Sonlu Eleman Yöntemi

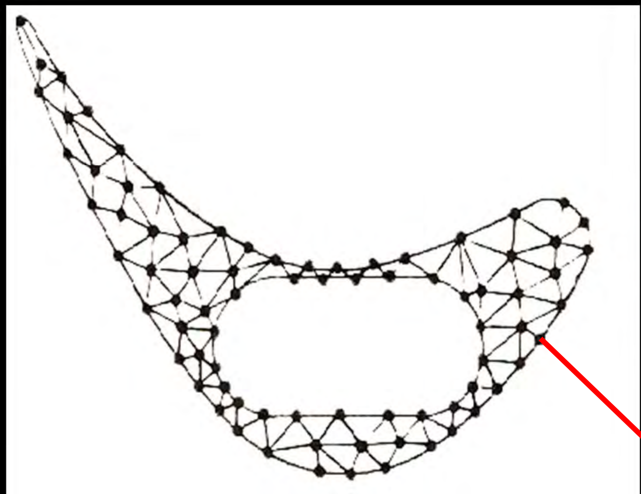
- Bir bütünün parçalara ayrılarak incelenmesi

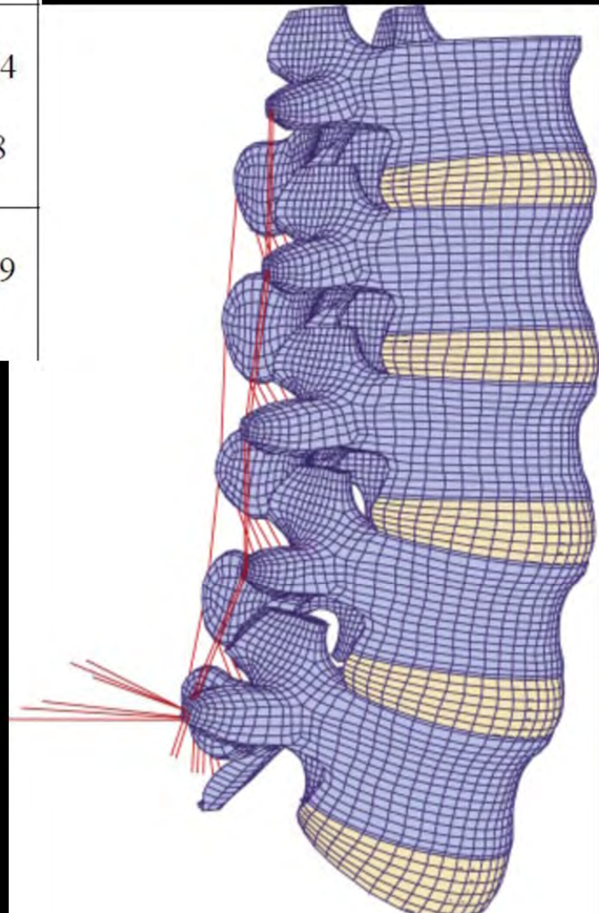
- Uygun geometri (model)
- Mesh yapılması
- Materyel özellikleri
- Sınır şartlarının belirlenmesi
- Yükleme
- Sonuçların deneysel modeller ile kanıtlanması

Model ve Mesh







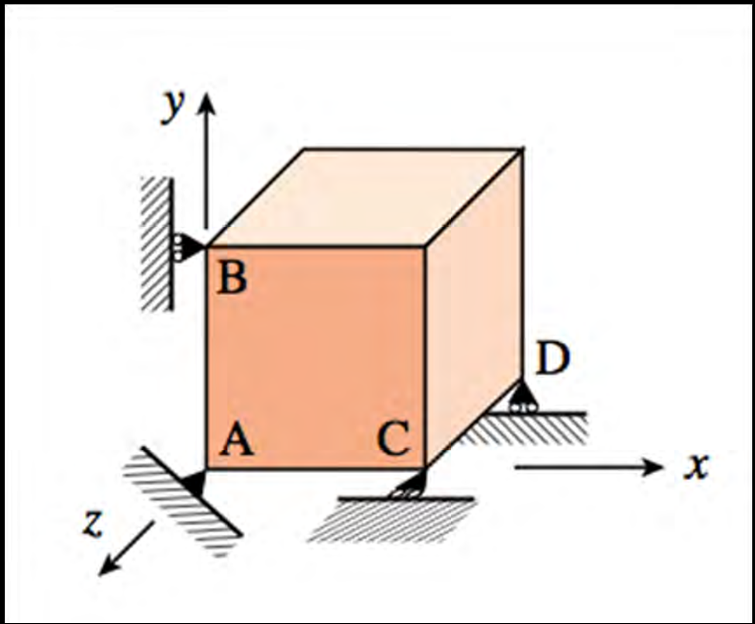


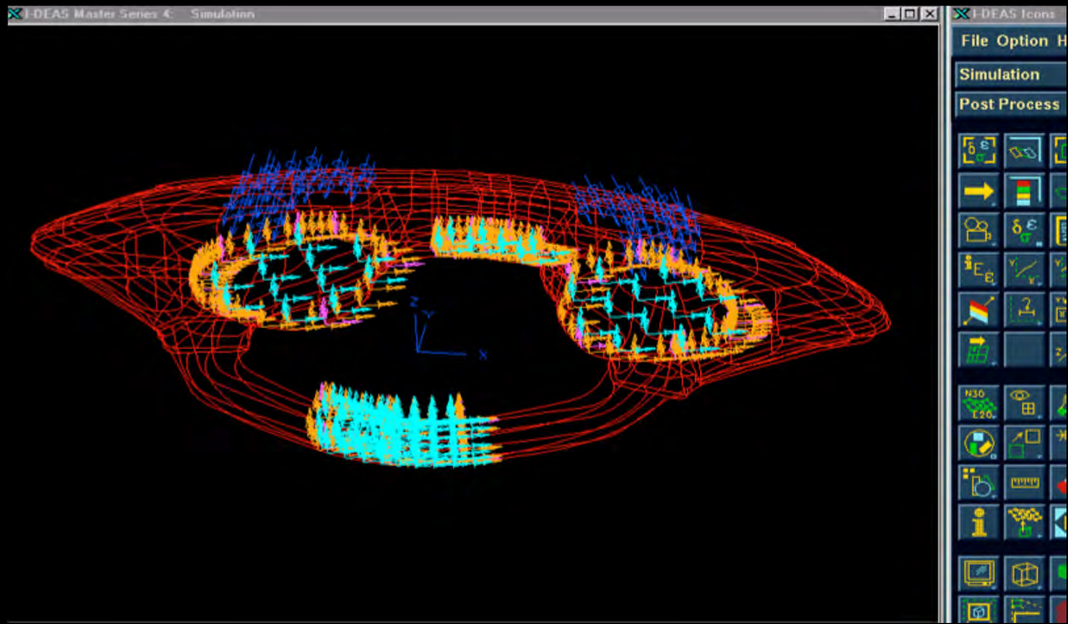
nod

Materyel Özellikleri

Anatomik bölge	Young's modülü (Mpa)	Poisson's oranı
Kortikal kemik	10000	0.29
Trabeküler kemik	100	0.29
Endplate	500	0.40
Lamina, spinoz proses	3500	0.29
Disk annulusu	3.4	0.40
Disk nukleusu	3.4	0.49
Anterior longitudinal ligaman	11.9	0.39
Posterior longitudinal ligaman	12.5	0.39
İnterspinoz ligaman	3.4	0.39
Ligamantum flavum	2.4	0.39
Kapsular ligaman	7.7	0.39

Sınır Şartları ve Yükleme





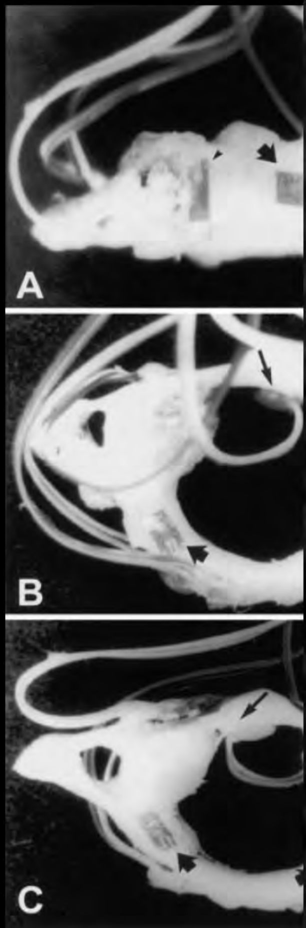
Deneysel Model ile Geçerlilik ?

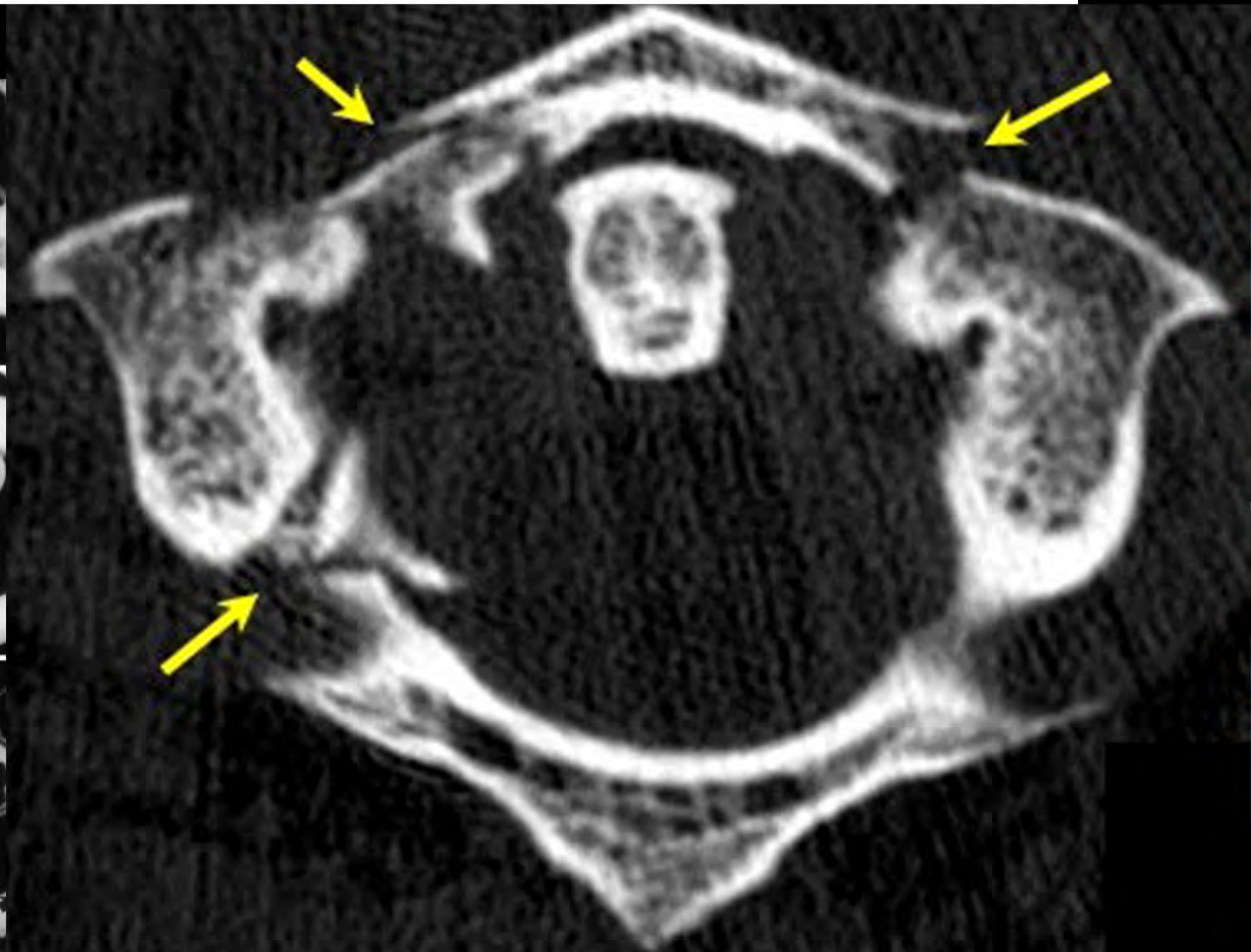
Eur Spine J (2001) 10:257–263
DOI 10.1007/s005860100256

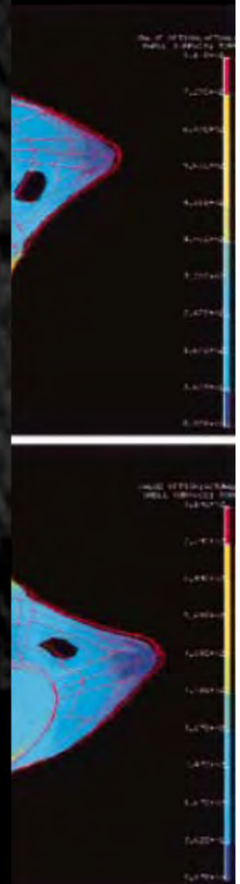
ORIGINAL ARTICLE

Hakan Bozkus
Askin Karakas
Murat Hancı
Mustafa Uzan
Ergun Bozdag
Ali Cetin Sarıoglu

Finite element model of the Jefferson fracture: comparison with a cadaver model







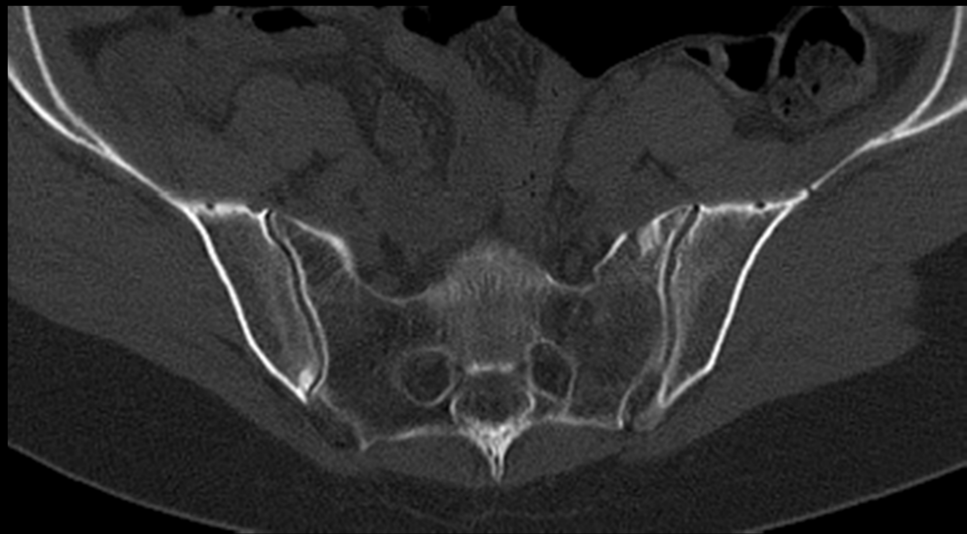
Finite element method based stress analysis of zone I and zone II sacral fractures

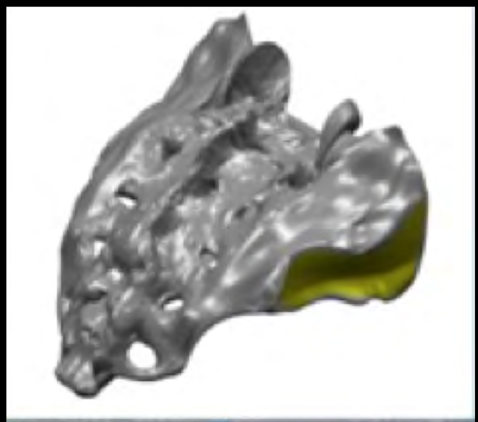
Birinci ve ikinci bölge sakrum kırıklarının sonlu eleman metoduna dayalı gerilme analizi

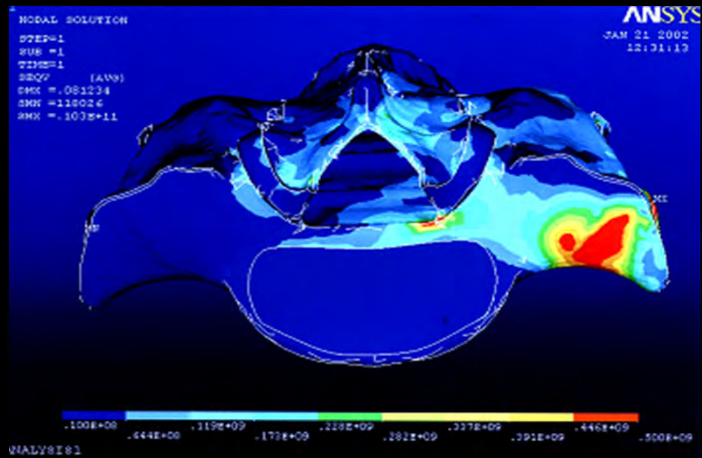
Hakan BOZKUŞ[1,5], Murat HANCI[2], M.Emin SÜNBÜLOĞLU[3], M.Ali TUNALI[3], S.Ergun BOZDAĞ[3], Önder AYDINGÖZ[4], Alaattin ARPACI[3]

Turkish Journal of Trauma & Emergency Surgery

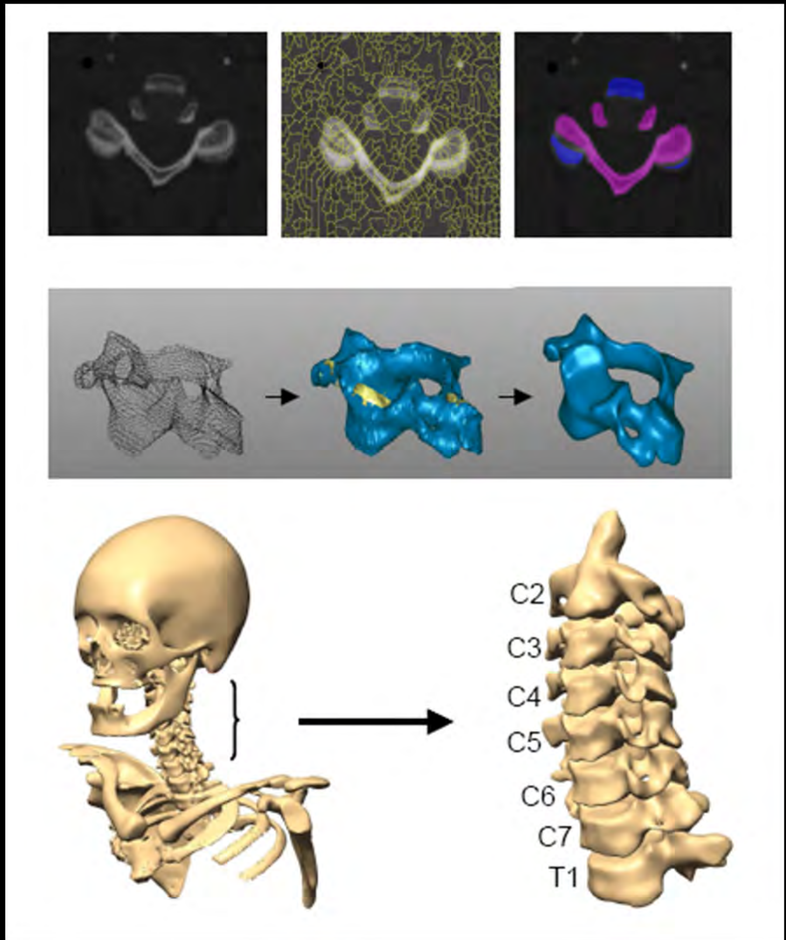
Ulus Travma Derg 2005

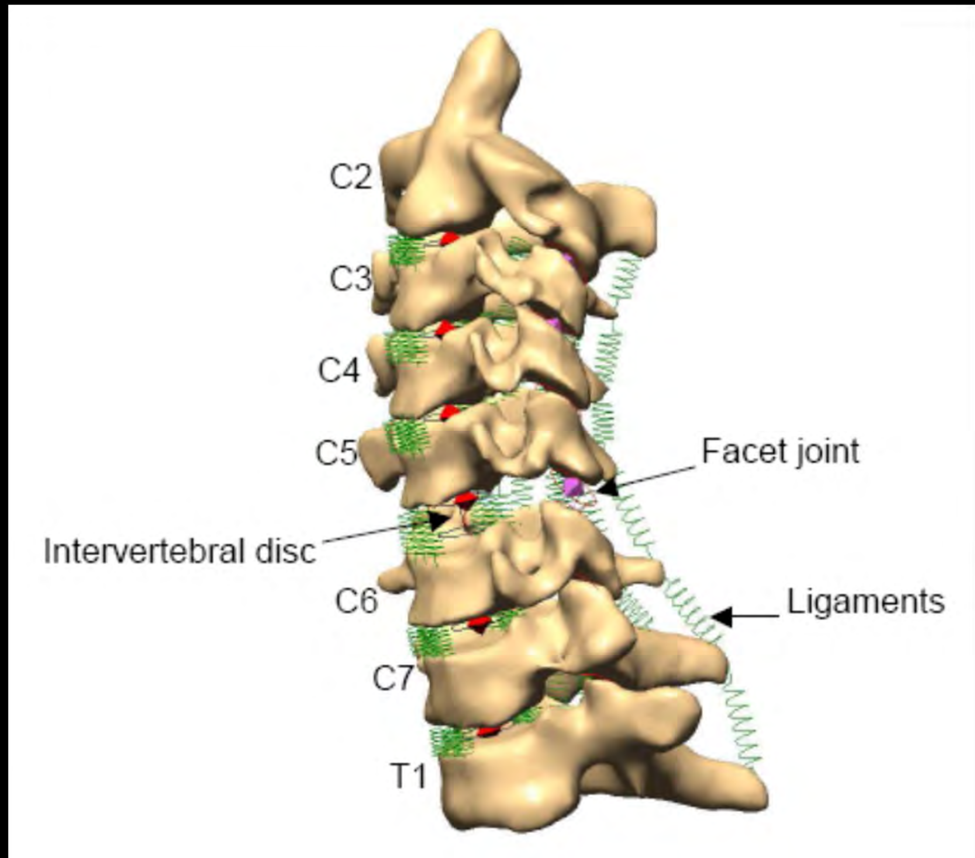






Sonlu eleman yöntemi (FEM)

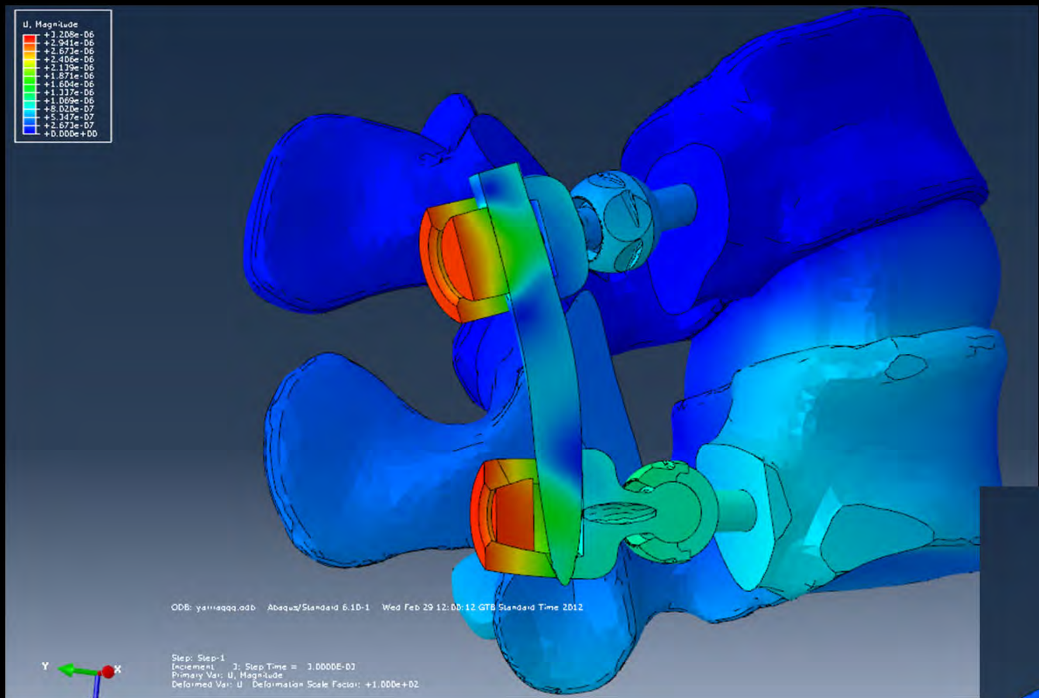


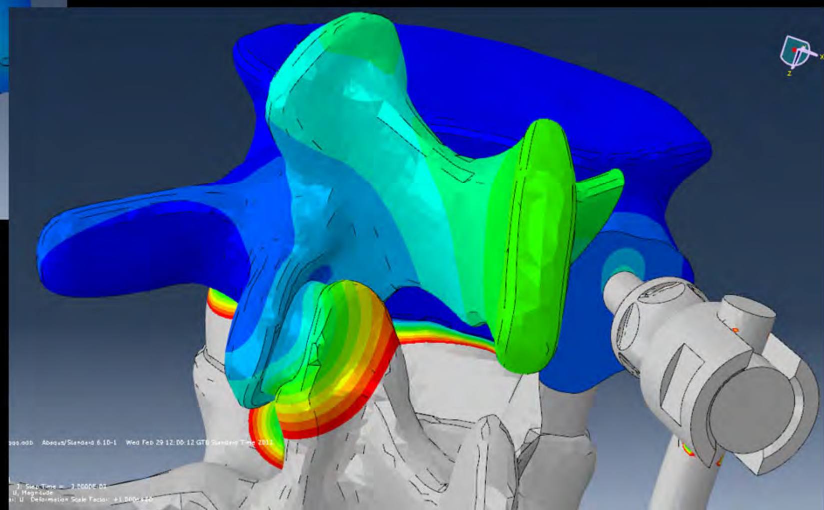


Ahn HS,
Univ. Memphis,
PhD 2005

FEM Kesitsel Von Misses Stress

Dinamik Pedikül Vida+ Rijit Rod



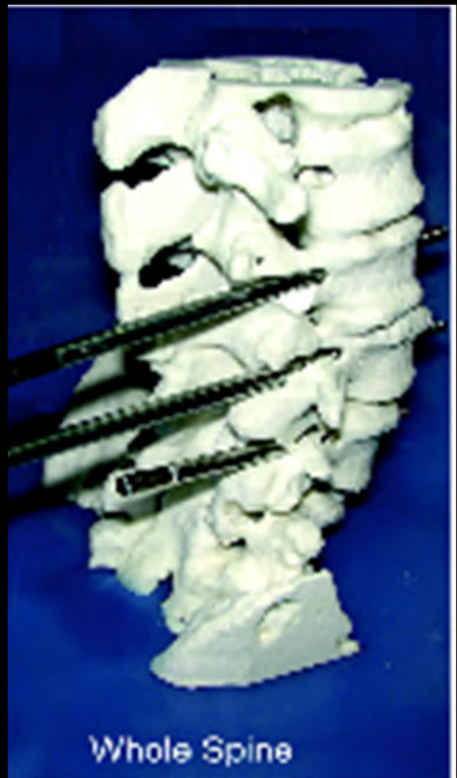


Stereolithography Model

49

Rapid Prototyping: The Future of Trauma Surgery?

By George A. Brown, MS, MD, Keikhosrow Firoozbakhsh, PhD,
Thomas A. DeCoster, MD, José R. Reyna Jr., MD, and Moheb Moneim, MD



Biyomodelleme (Stereolithography)

Arq Neuropsiquiatr 2007;65(2-B):443-445

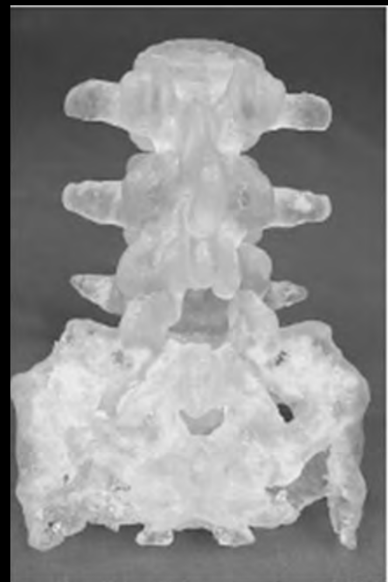
APLICATION OF THE STEREOLITHOGRAPHY TECHNIQUE IN COMPLEX SPINE SURGERY

Wellingson Silva Paiva[1], Robson Amorim[1], Douglas Alexandre França Bezerra[1], Marcos Masini[2]

SPINE Volume 30, Number 24, pp 2841–2845
©2005, Lippincott Williams & Wilkins, Inc.

Biomodeling as an Aid to Spinal Instrumentation

Paul S. D'Urso, MBBS, PhD, FRACS,* Owen D. Williamson, MB, BS, FRACS,† and Robert G. Thompson, BInfoTech‡



Konuşmanın Slaytları

sunumlar@
hakanbozkus.com.tr

Teşekkür Ederim