



Omurga Cerrahisinde
Olgu Çözümlerleri

26-29 Eylül 2013

Çeşme Sheraton Kongre Merkezi, İzmir

Omurga Biyomekaniği; Deneysel Modeller

Dr.Hakan BOZKUŞ



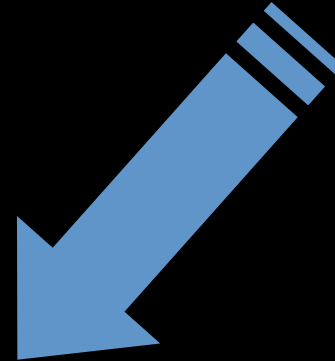
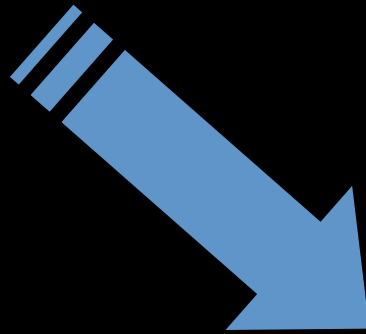
Omurga Sorunları Çözümü ?

1. Deneysel uygulama sonuçları
2. Klinik uygulama sonuçları

Deneyisel Çözüm

MÜHENDİSLİK

TIP

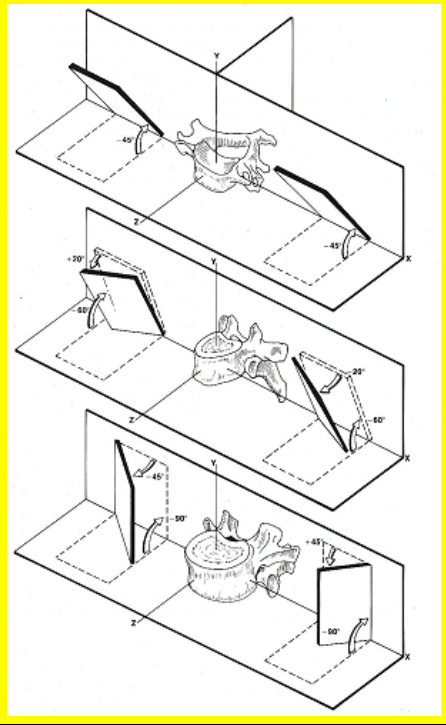


BİYOMEKANİK

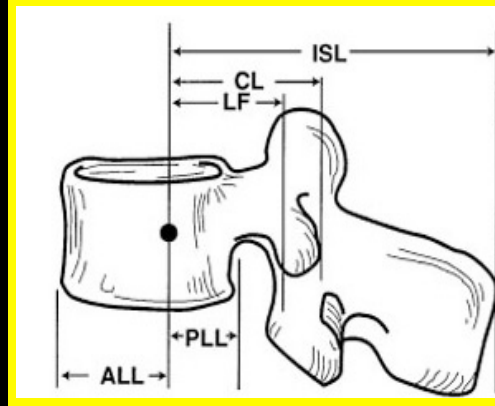
Omurga Biyomekaniği

- Hareket aralığı (ROM)
- Rotasyonun anlık eksenini (IAR)
- Yük/Deformasyon Eğrisi
- Stabilite
 - Cerrahi
 - Stabilizasyon

Hareketi Saęlayan Yapılar



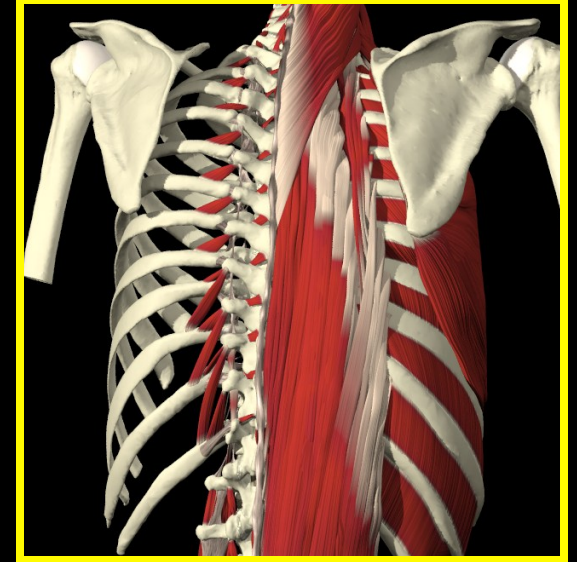
Fasetler



Ligamanlar

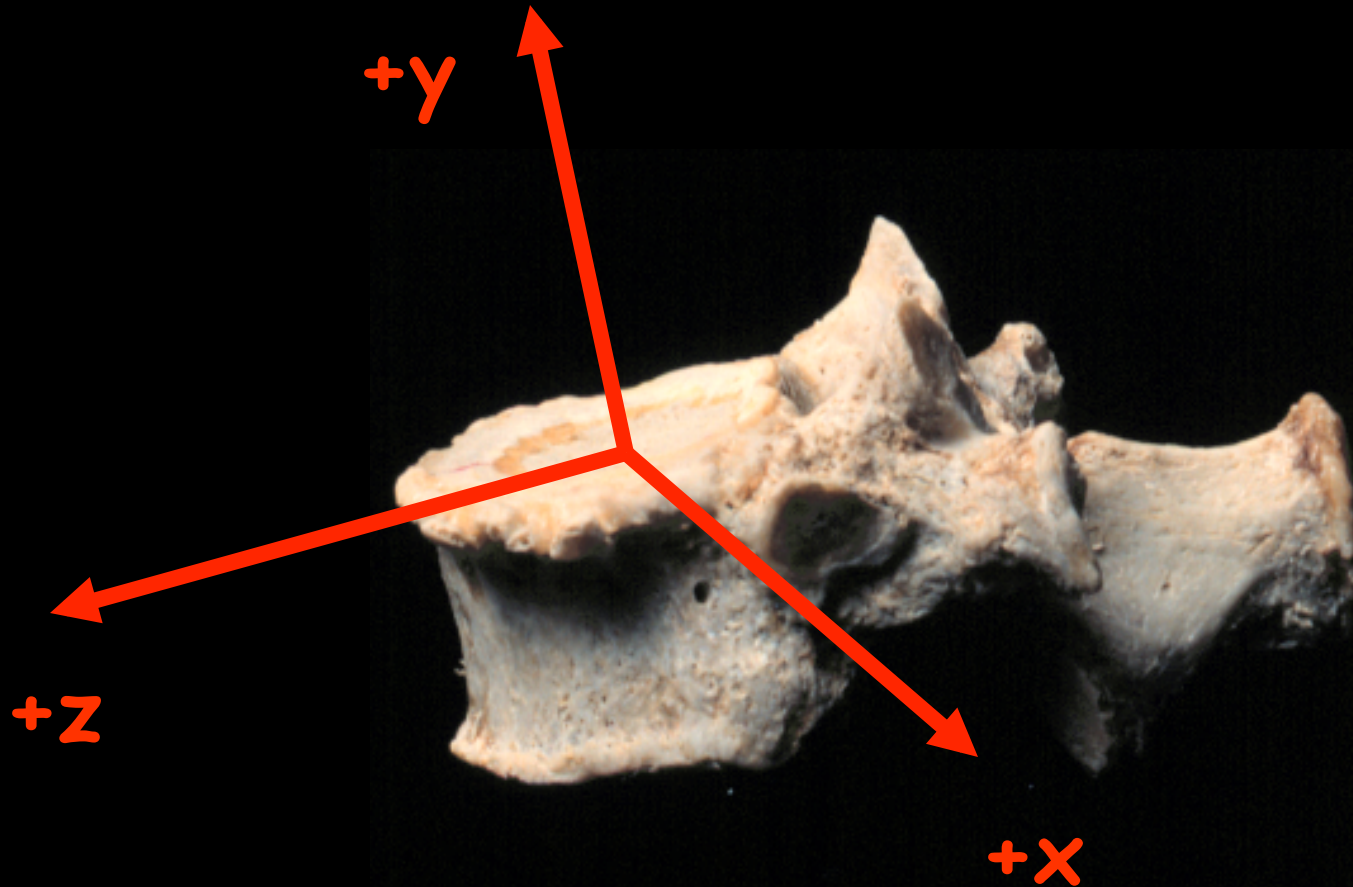


İntervertebral disk



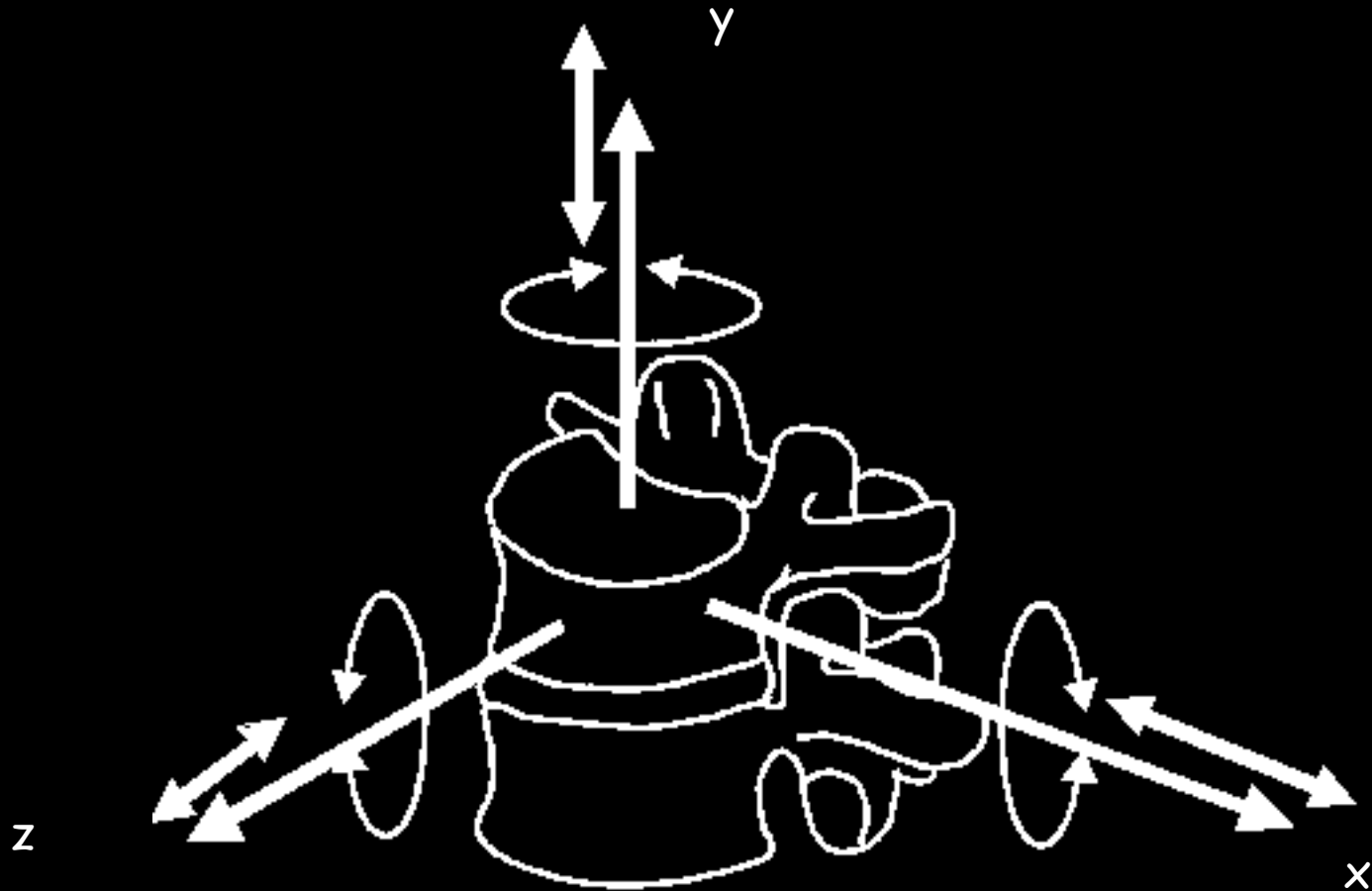
Adaleler

Pozitif Eksen Takımı



Hareket Serbestliđi

6 yönde hareket serbestliđi





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.

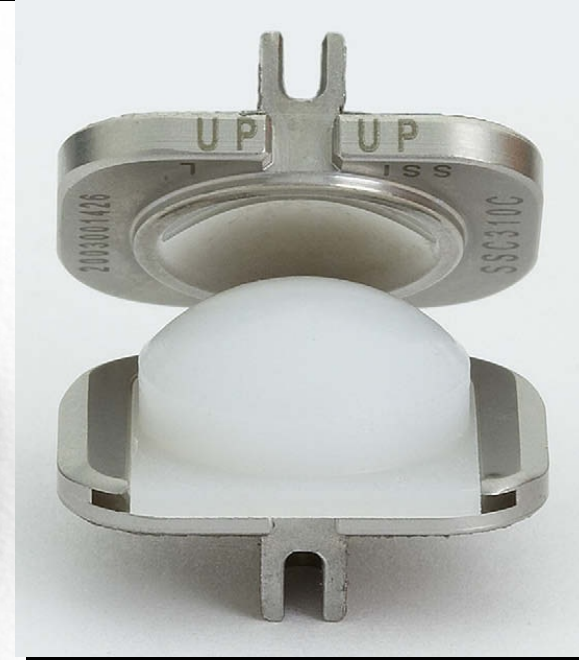
YAKINSAMA OLABİLİR !

Gerçekçi RAE Çözümü ?

- En az 3 noktanın,
- Translasyon vektörü ve rotasyon matrisinin bilinmesi
(röntgen sterofotogrametri)

ÜÇ BOYUTLU RAE !

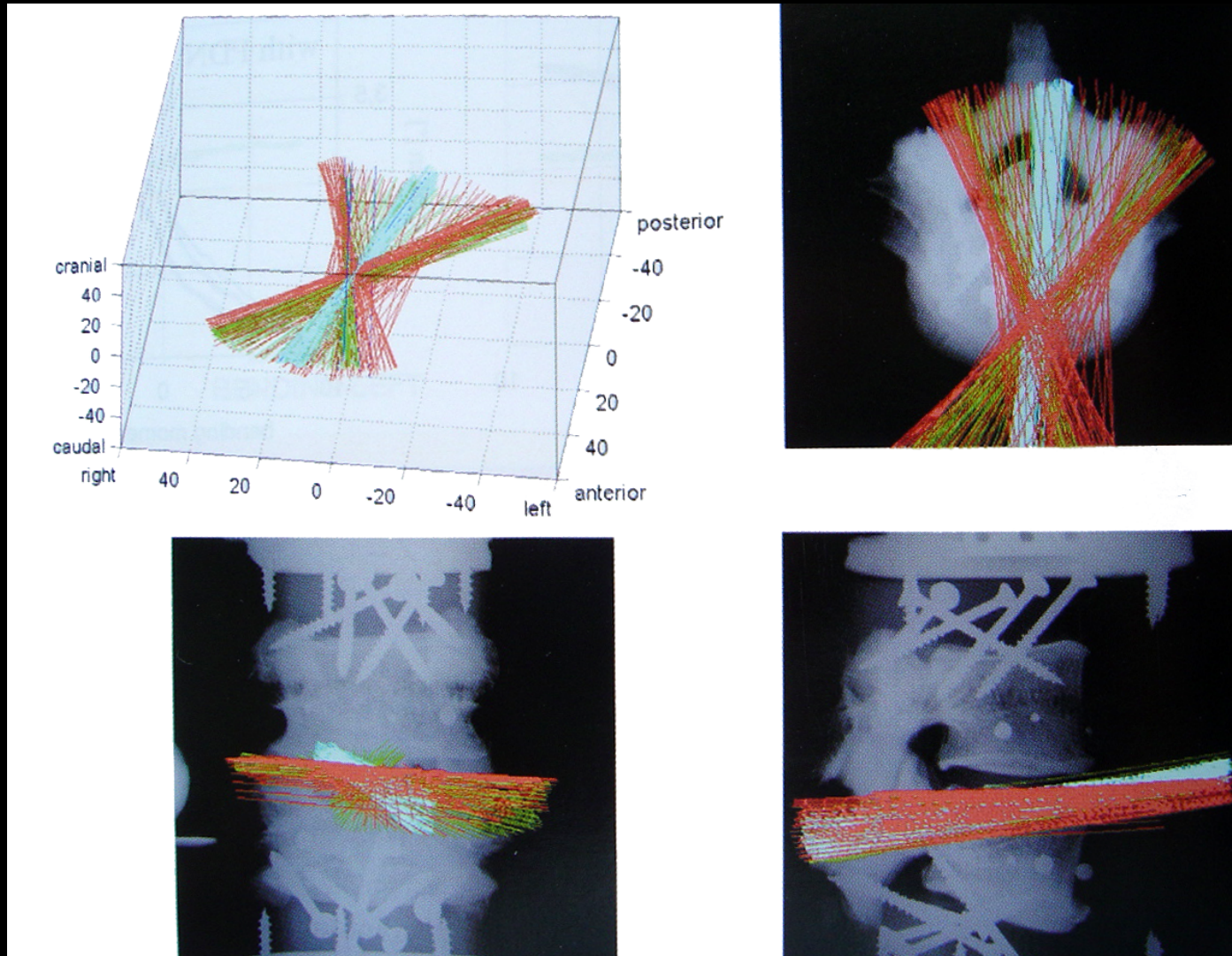
Helikal Rotasyon Ekseni



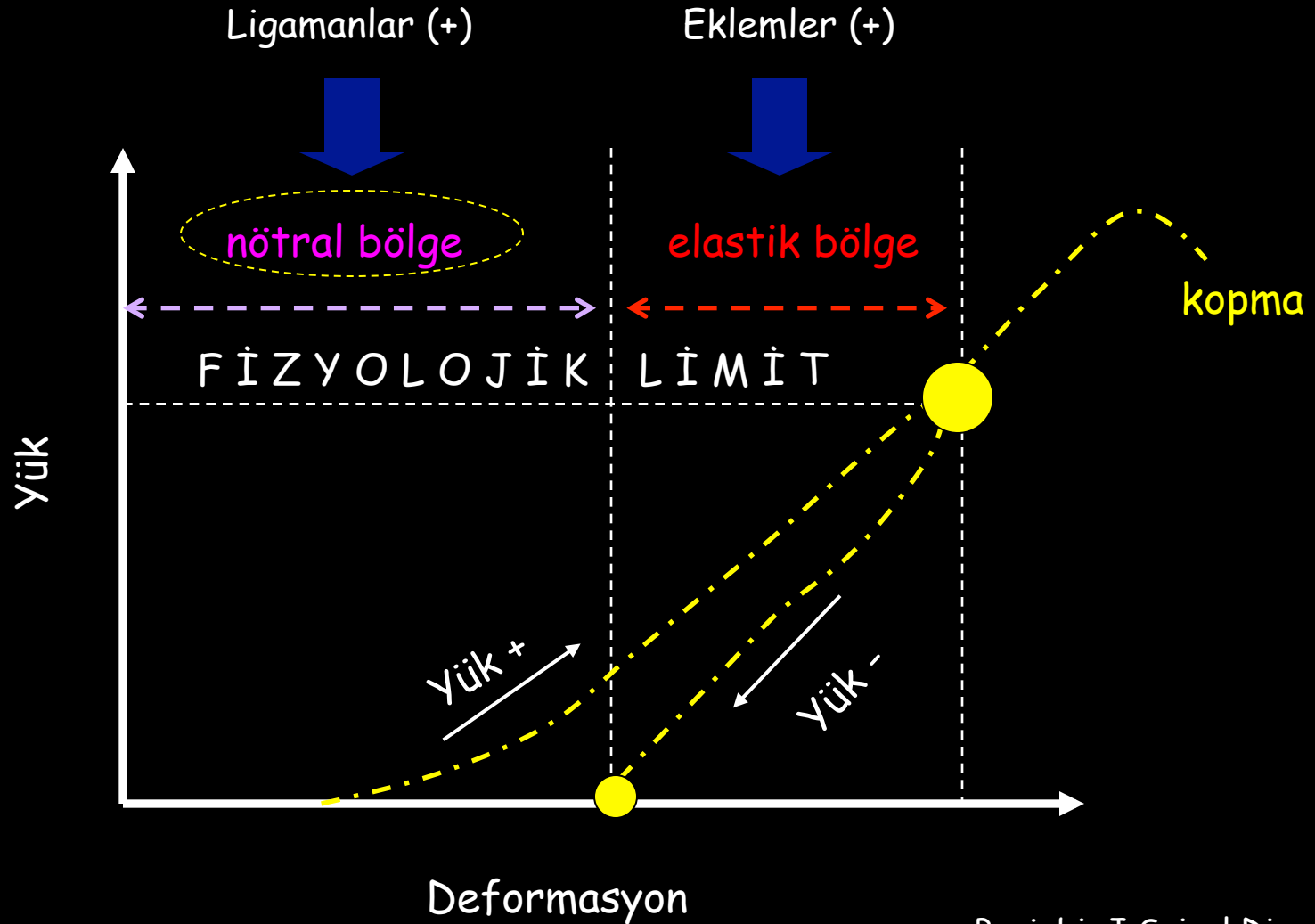
Helikal eksen

Spoor ve Veldpaus, J Biomech 1980

Helikal eksen hareketi (HAM)



Hareket Aralığı (ROM)



Omurgada Biyomekanik Çalışmalar

1. Deneysel modeller (in vitro)

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

2. Deneysel testler

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

Kadavra Model Hazırlanması

Fizyolojik Yükleme Testleri

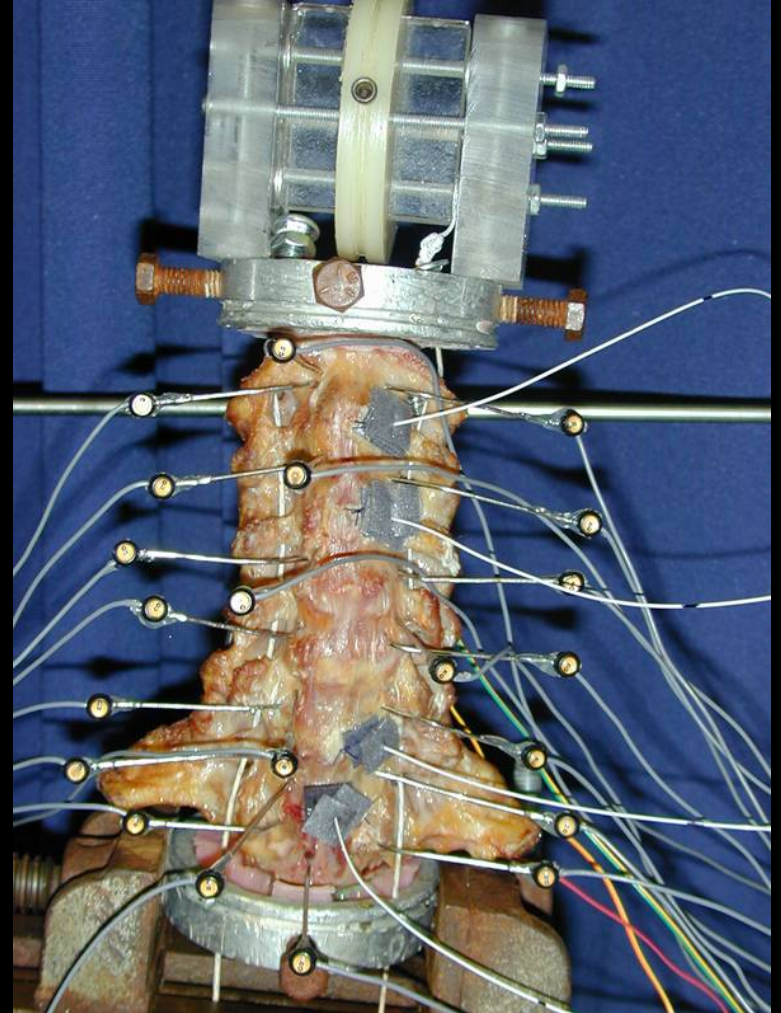
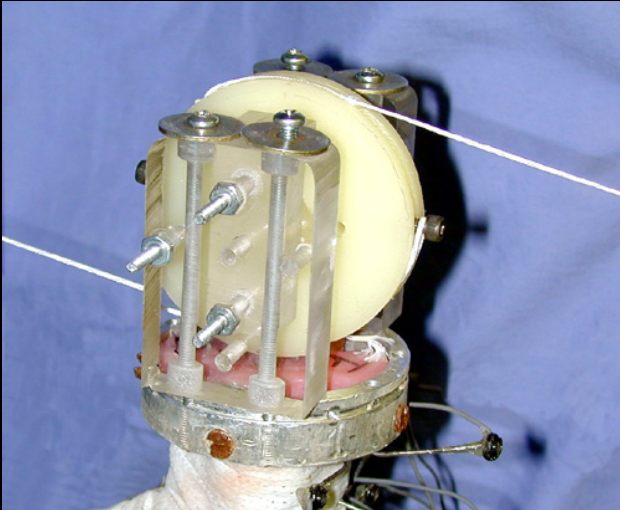
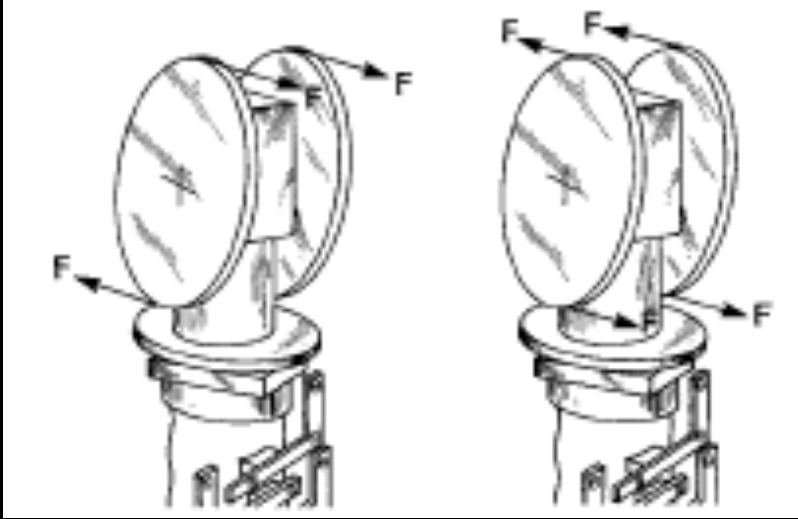
- Taze donmuş kadavra (-20° de muhafaza)
- Oda şartlarında ısıtılması
- Deney sırasında nemli tutulması
- Denek modelinin üst ve altında en az bir FSU olması
- Yükleme şartları
- En az 3 test ve bekleme süresi (sönümlleme etkisi)
- Cerrahi yapılacaksa tekniği
- Stabilizasyon yapılacaksa tekniği

İn Vitro Model Hazırlanması

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

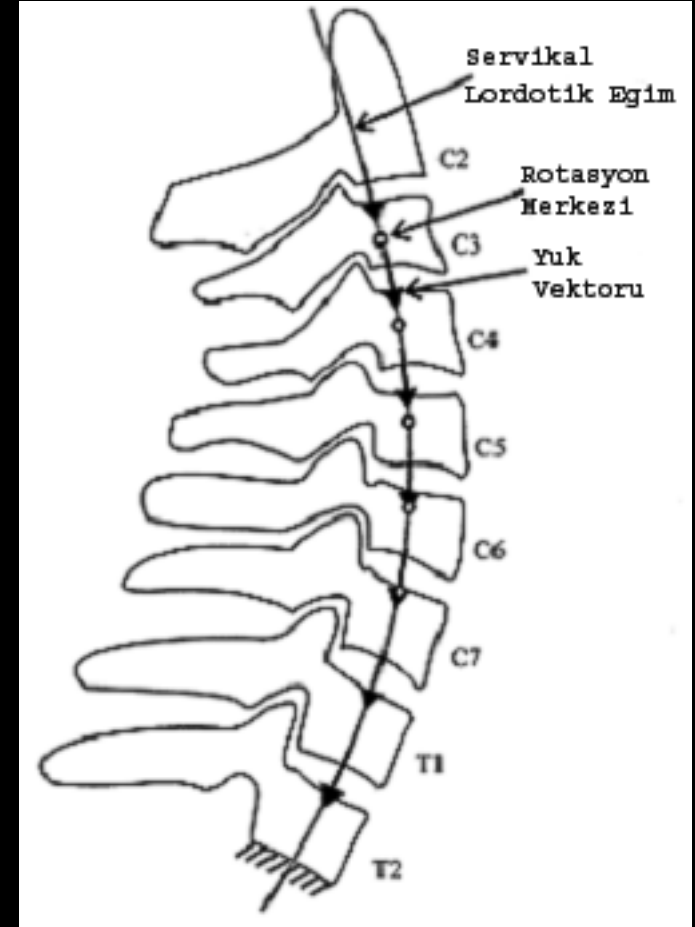
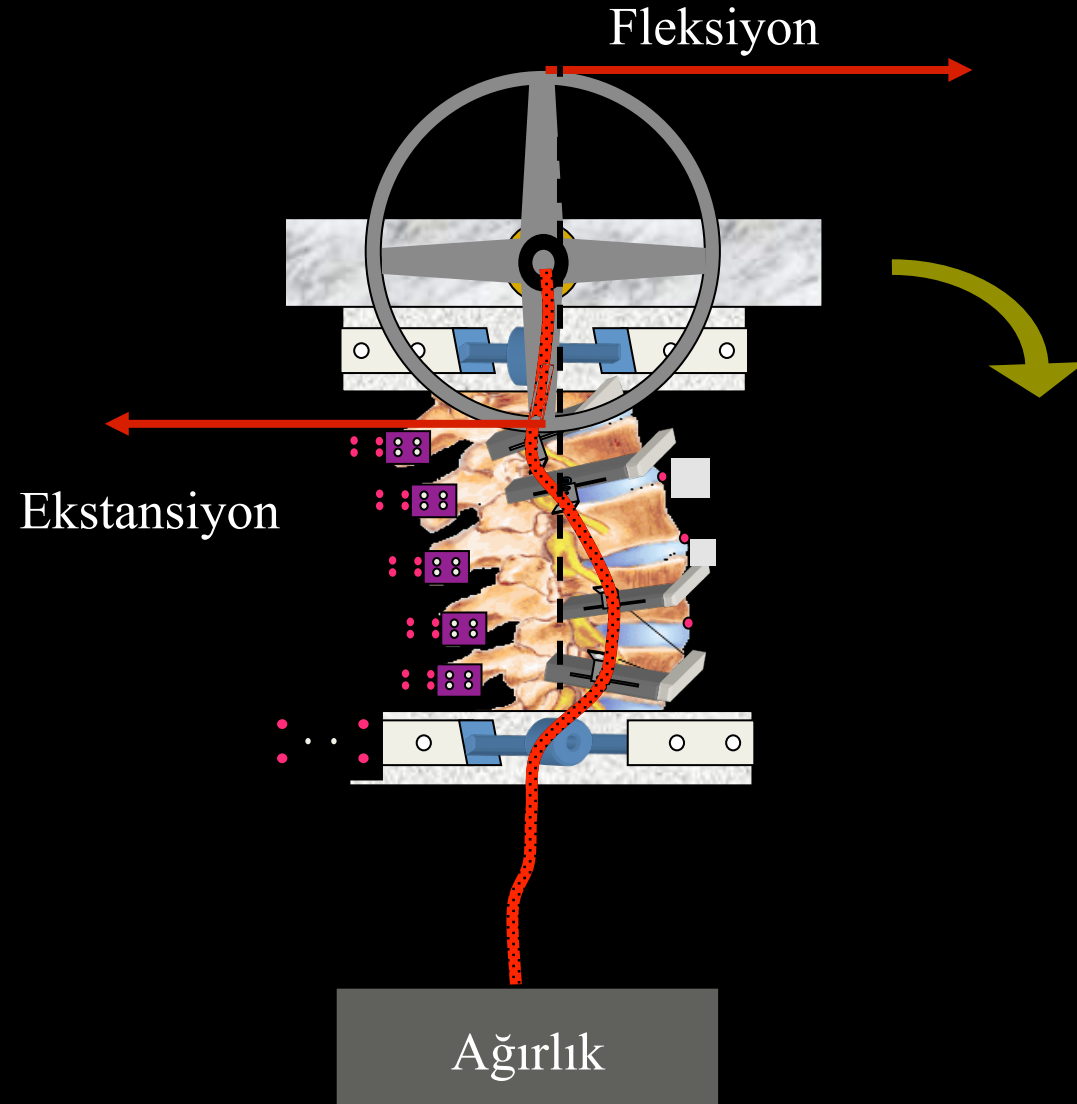


Moment yükleme

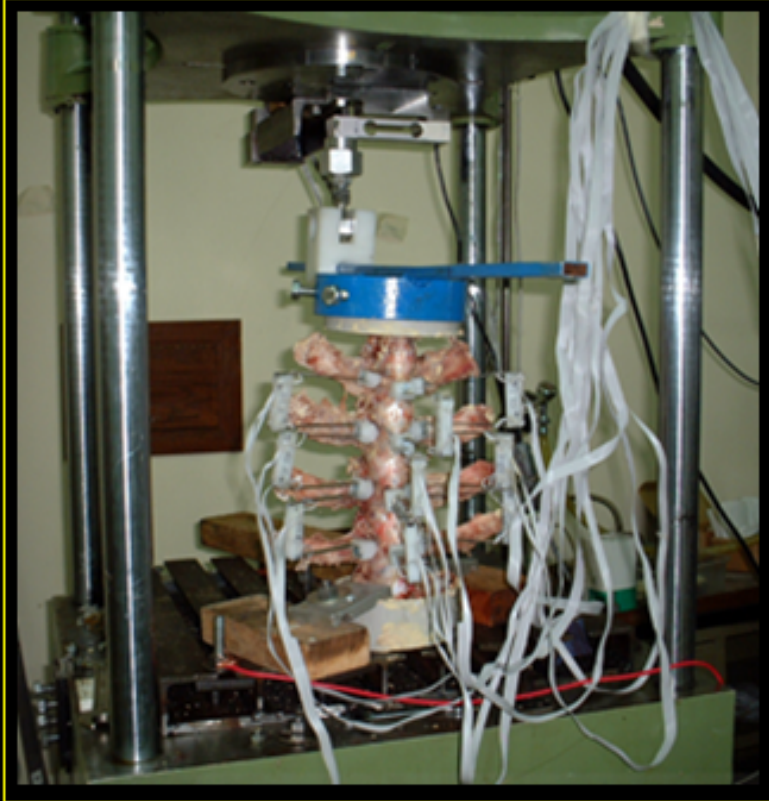


Panjabi ve ark. Spine, 2001

Tanjansiyel aksiyal yükleme



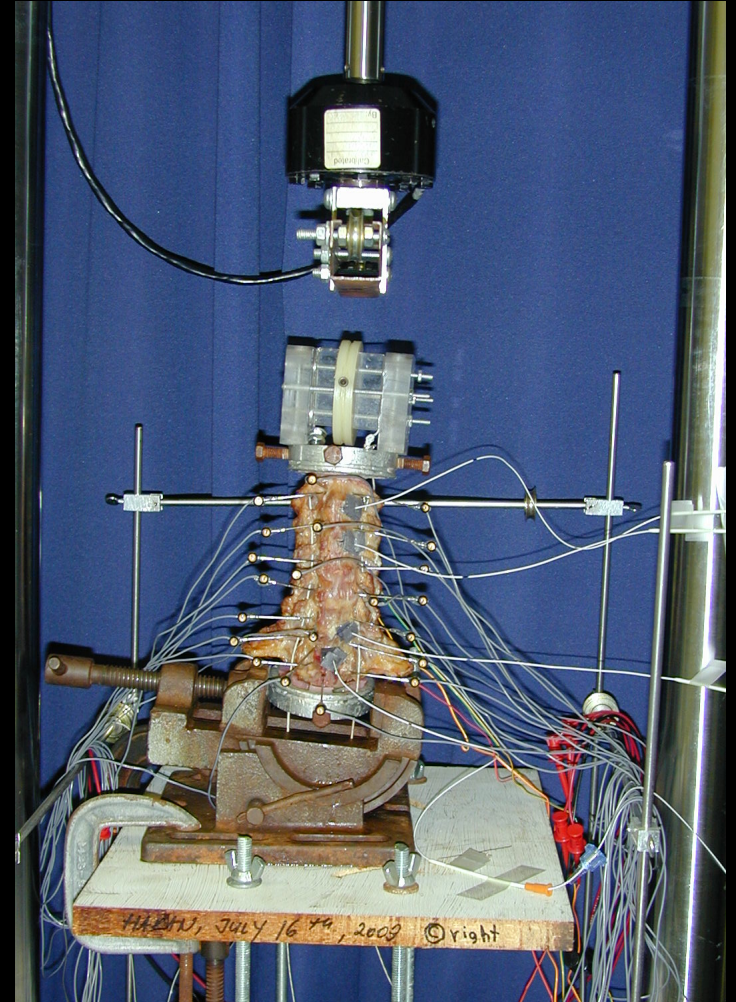
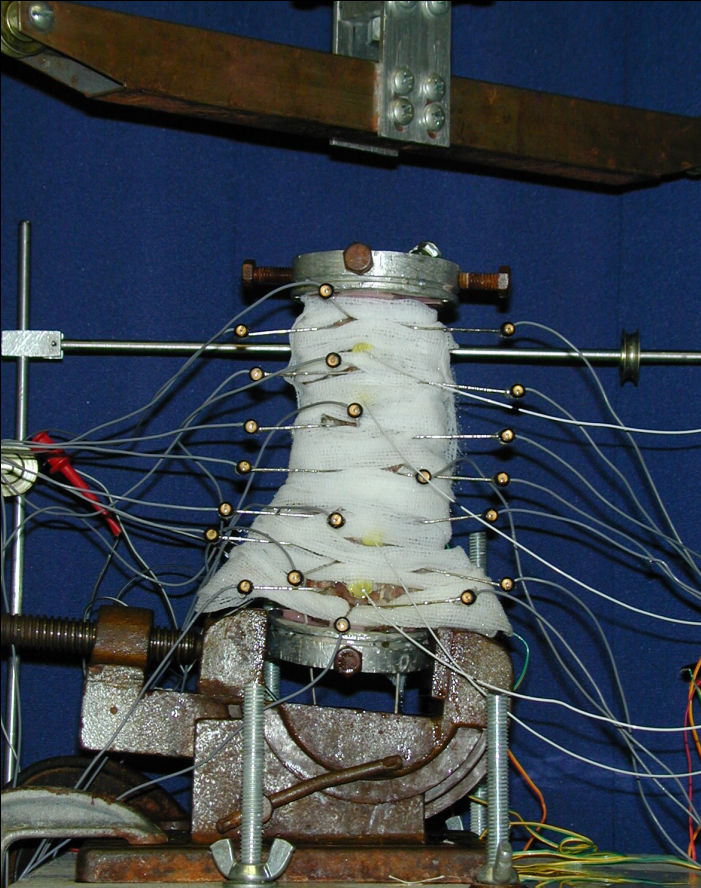
Hareket Aralığı Ölçümü



Ekstansometre

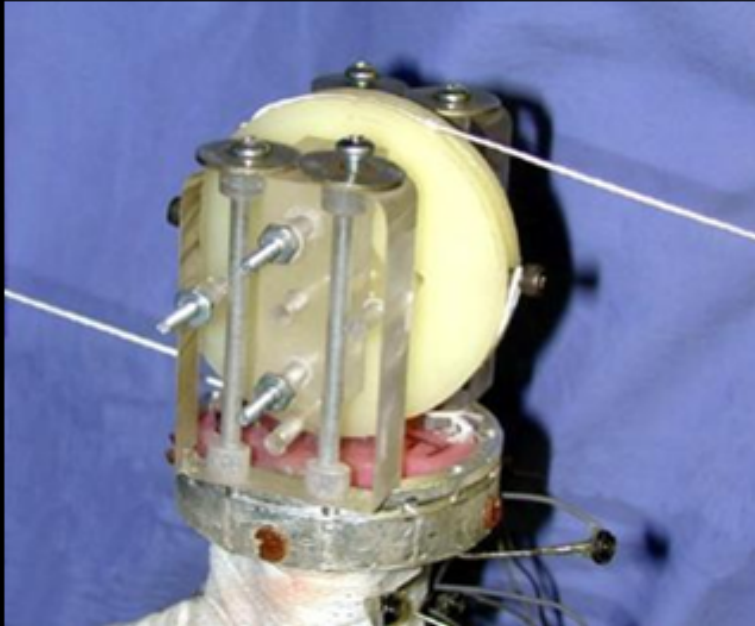
Deney düzeneđi

İnfrared ışaretlerin yerleřtirilmesi



Mekanik test düzeneđi

0.5, 1.0, 1.5 Nm tork yükleme



Flexion - Extension



Sterofotogrametrik ölçüm

Hareket Aralığı Ölçümü



Sterofotogrametri

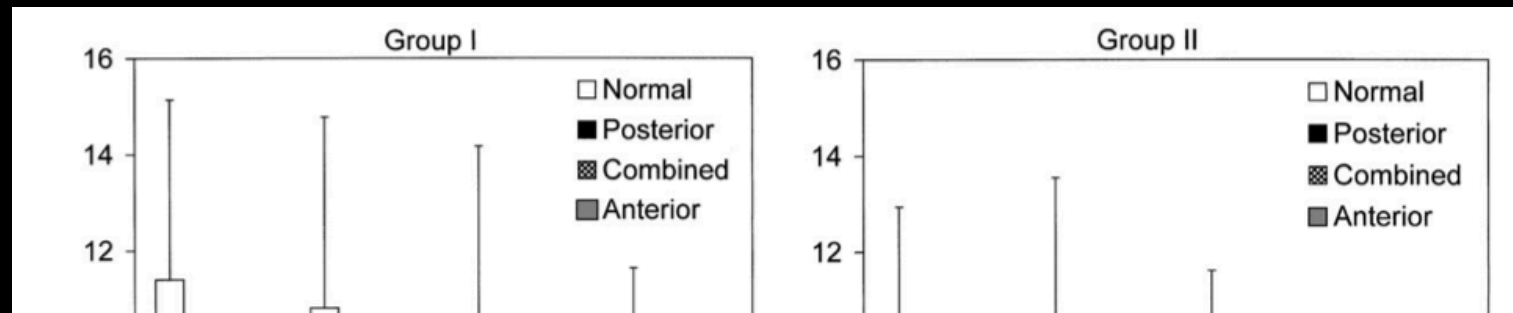


Table 2. Group II: Biomechanical Parameters and Their Percent Change Relative to Normal (mean $\pm$ SD)

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

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

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

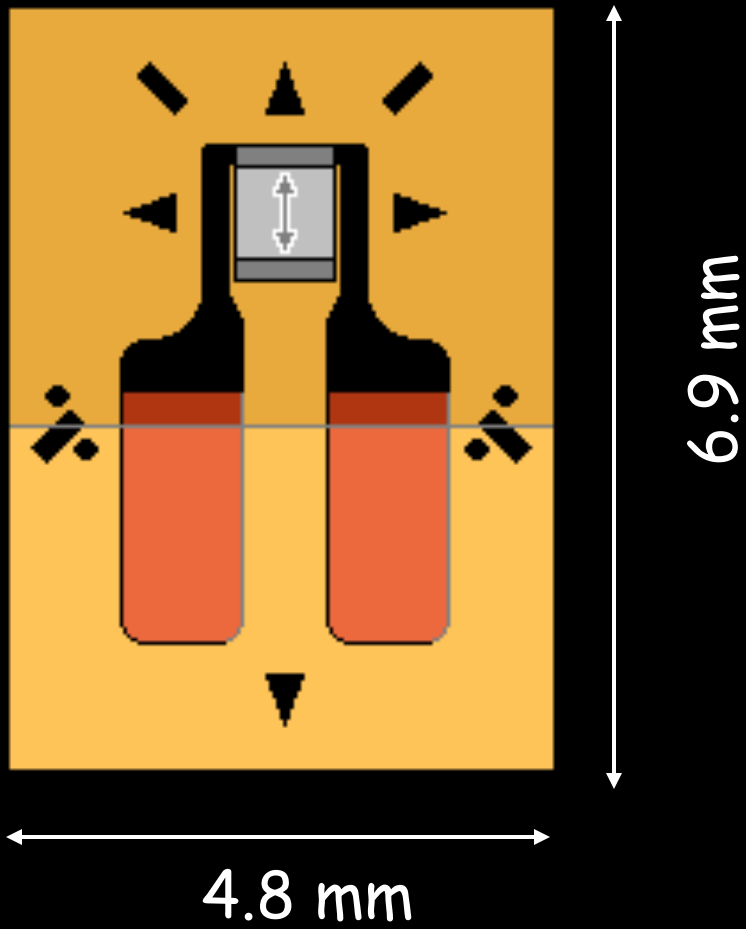
Mühendislik Teknolojilerinin Kullanımı

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

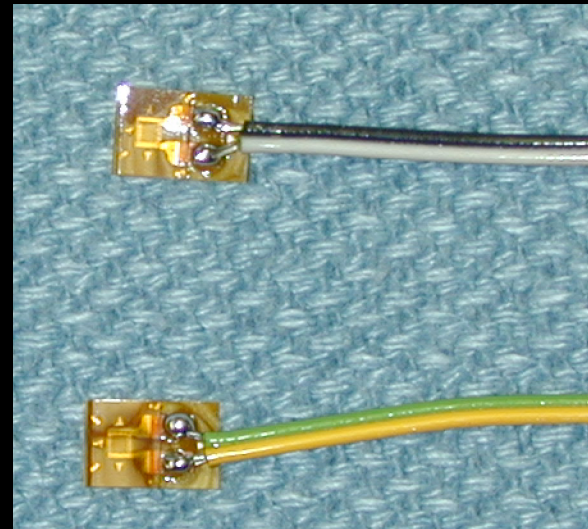
Strain (birim şekil değiştirme) ölçüm teknikleri

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

Strain gage



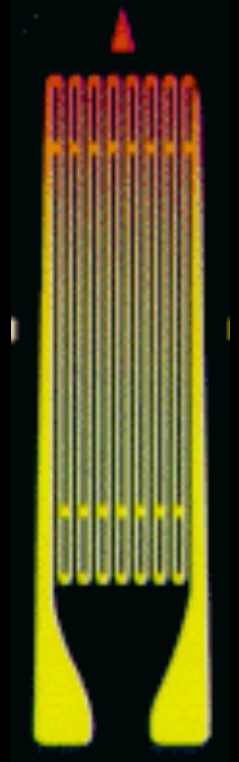
- Tek eksenli strain gage
- Statik ve dinamik gerilme analizi.



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.

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

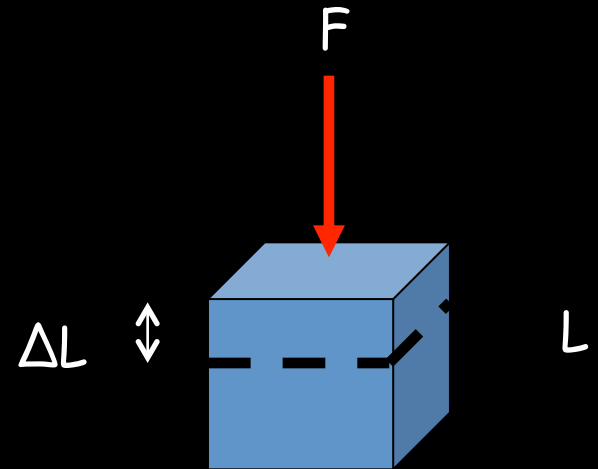


Birim Şekil Değiştirme (strain, ϵ)

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

Birim şekil değiştirme = $(\Delta L / L)$

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

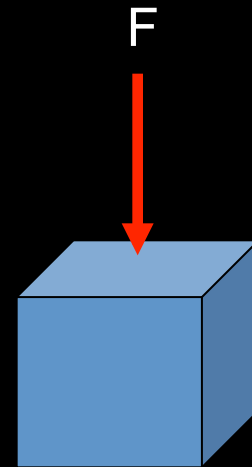


Gerilme (Stress, σ)

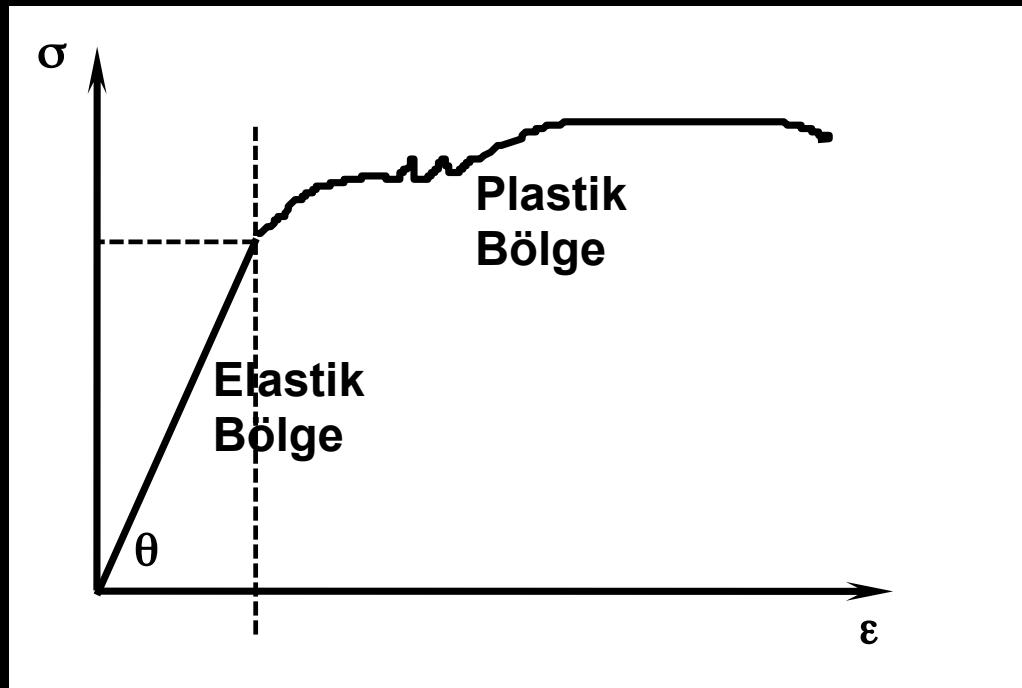
- Birim alana gelen kuvvet ($\text{Pa} = \text{N/m}^2$)

Gerilme = Kuvvet / Alan

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



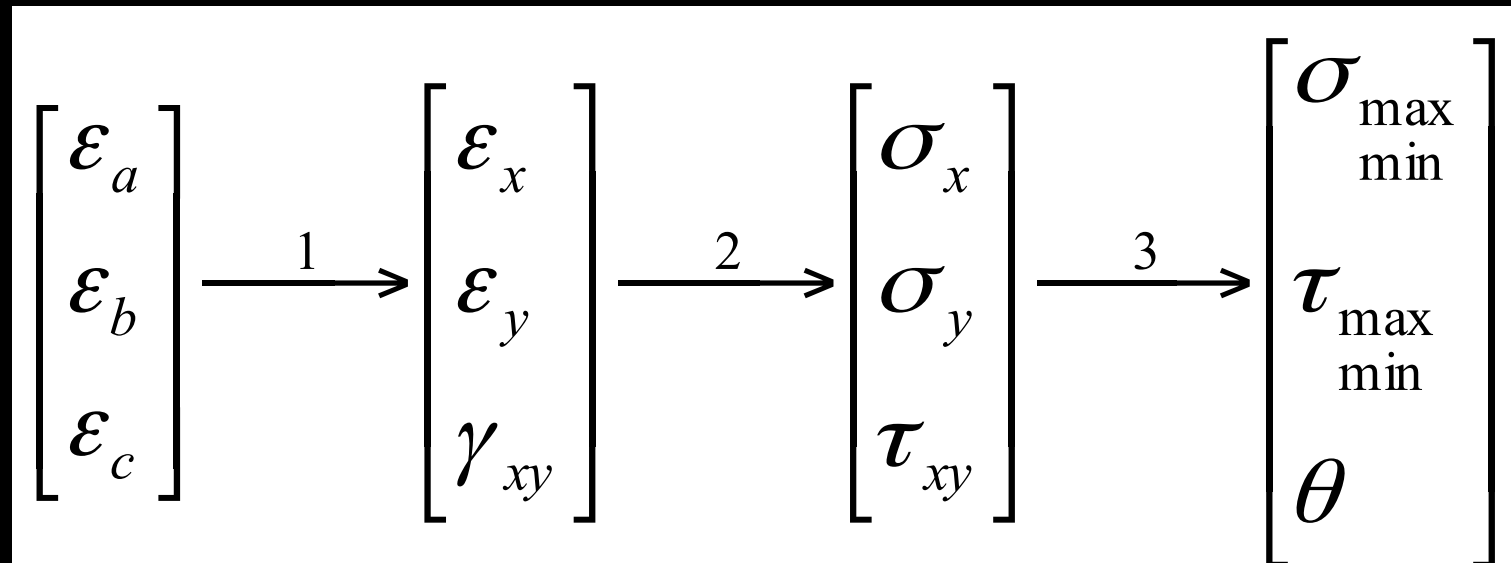
Elastik bölge, Hooke kanunu



$$\epsilon = \frac{\Delta l}{l}$$

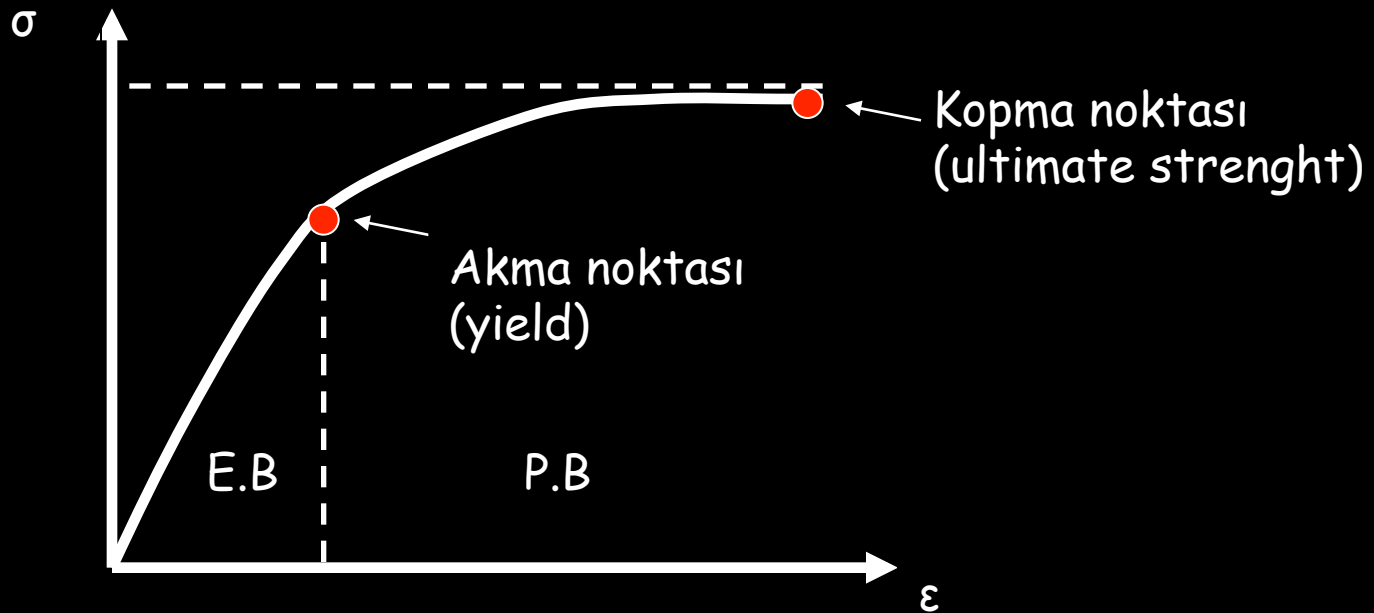
$$\sigma = E \cdot \epsilon$$

Strain' den stress (gerilme) hesaplanması

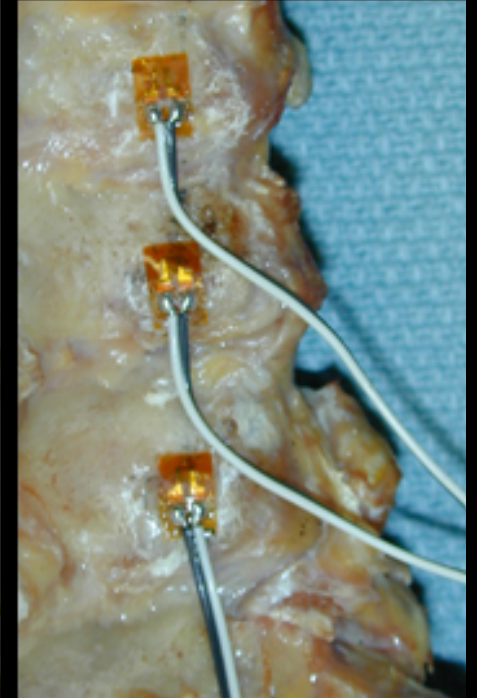
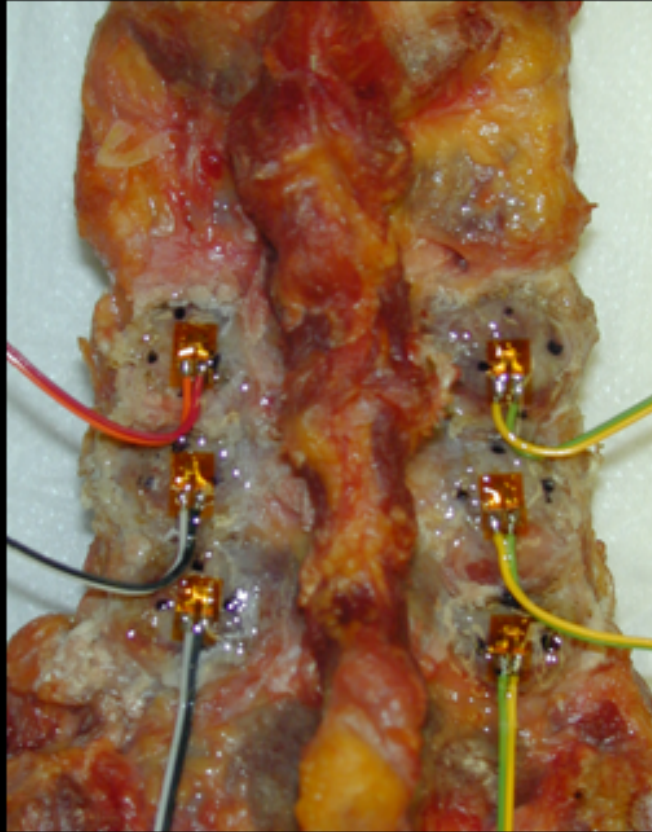


Stress/Strain Yük/Deformasyon

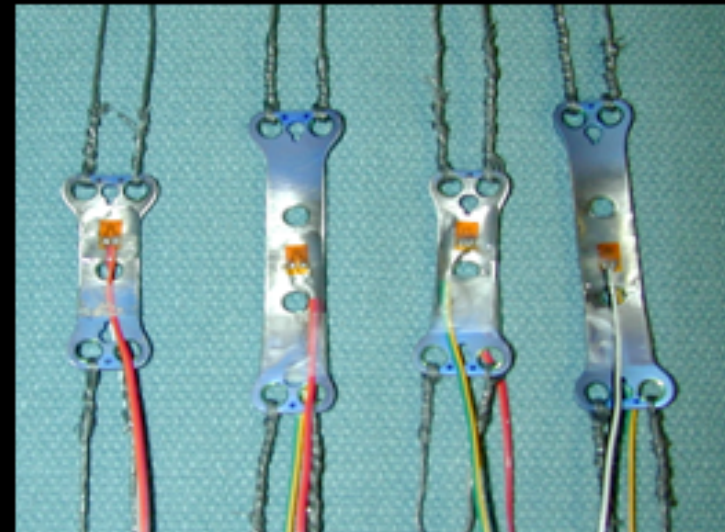
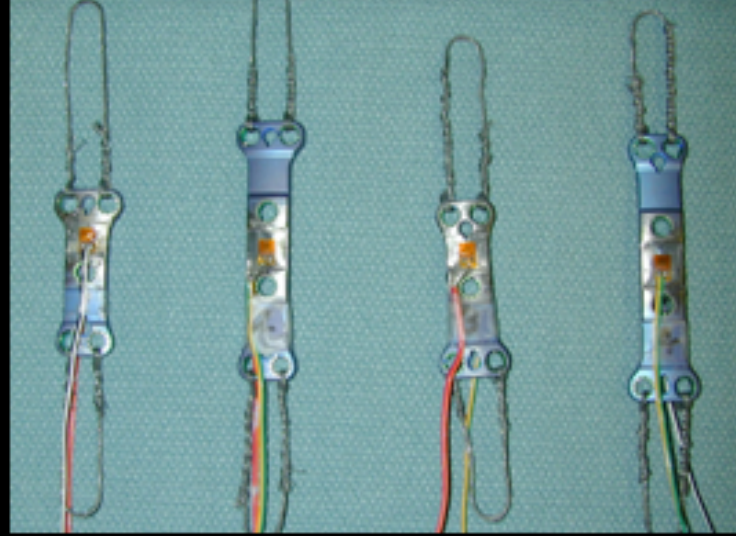
Elastisite modülü (Young Modülü) = (σ / ϵ)



Lateral mass' lara strain gage yapıştırılması



Plak için strain gage hazırlanması

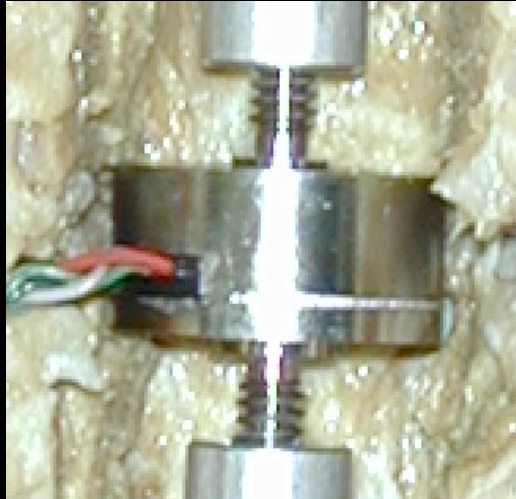


Load cell



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

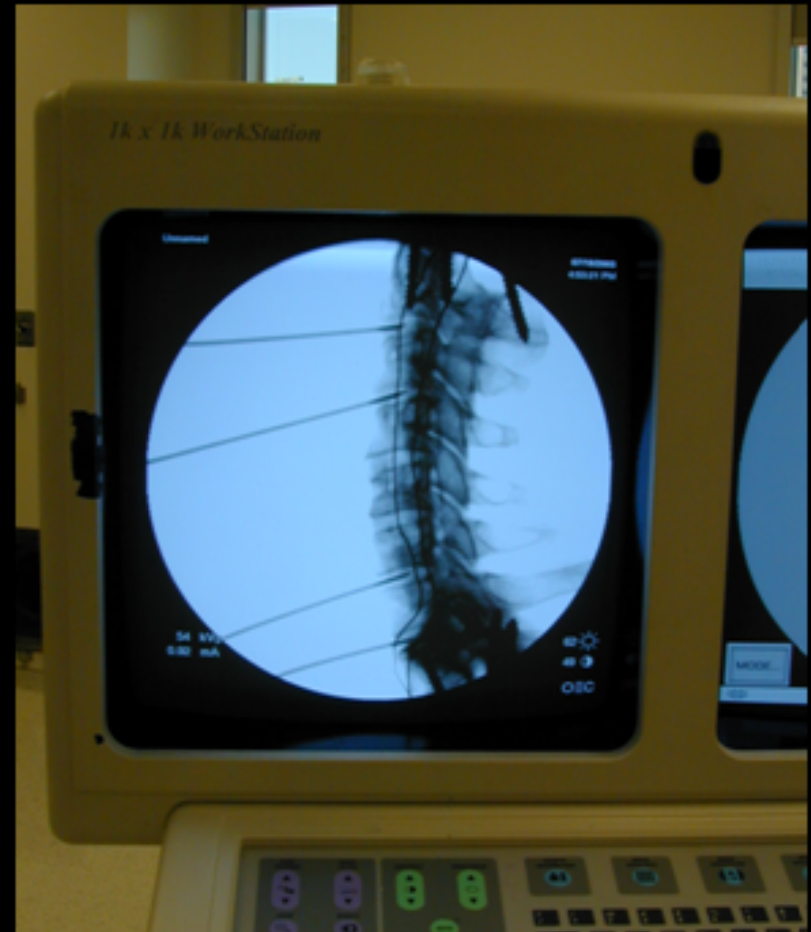
3.5 French (alıcı)

(3 French ~1 mm)



Bassınç kontrol ünitesi

Basınç transduserlerinin yerleştirilmesi



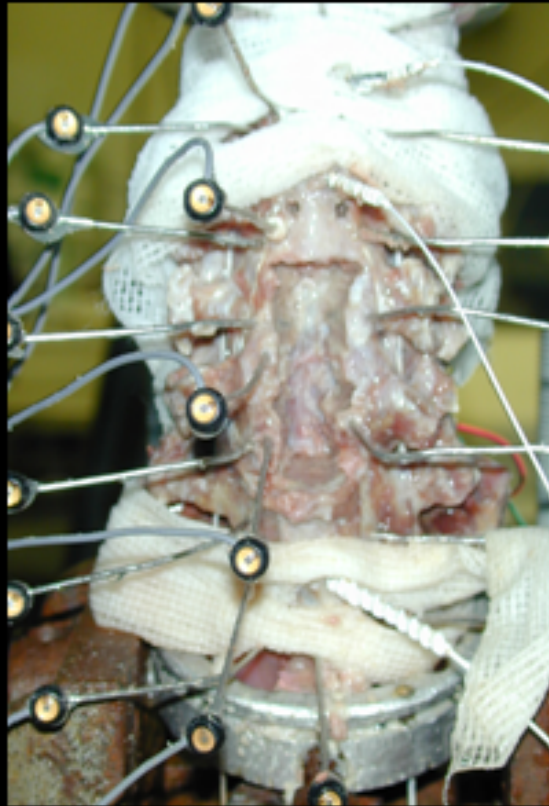
Basınç transduserlerinin yerleştirilmesi



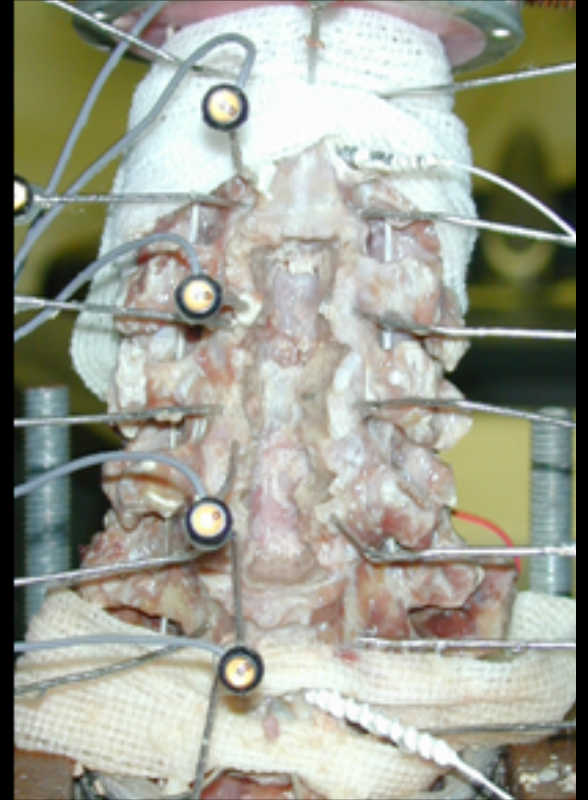
Korpektomi hazırlığı sonrası



C5 korpektomi

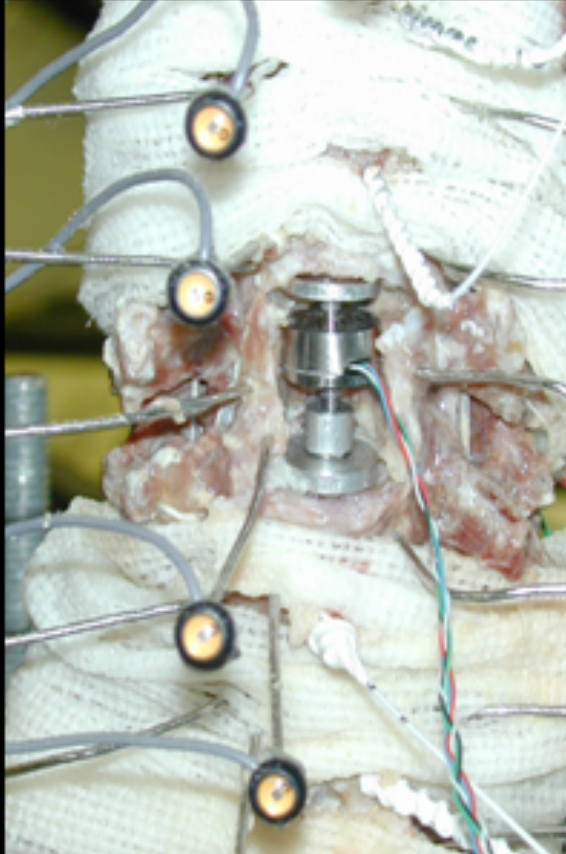


C5-6 korpektomi

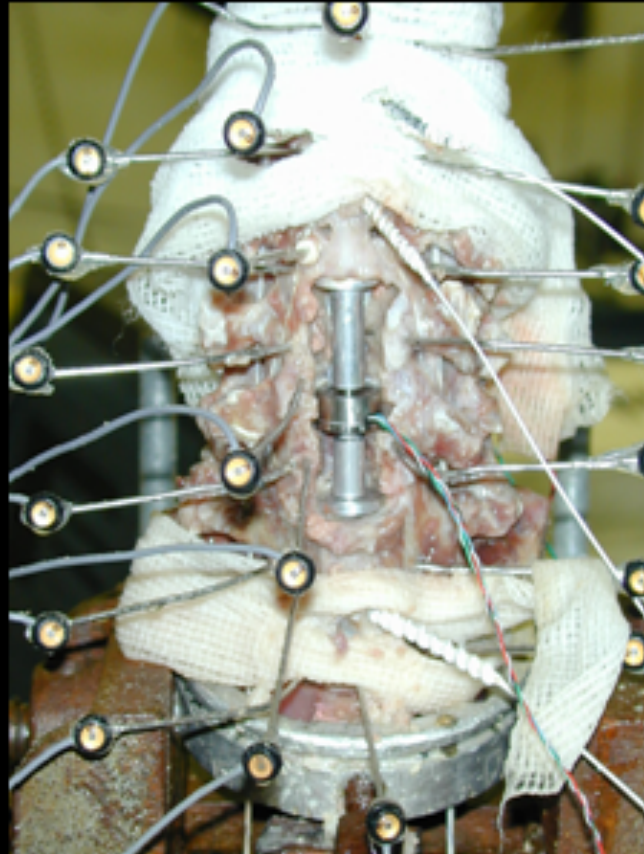


C4-5-6 korpektomi

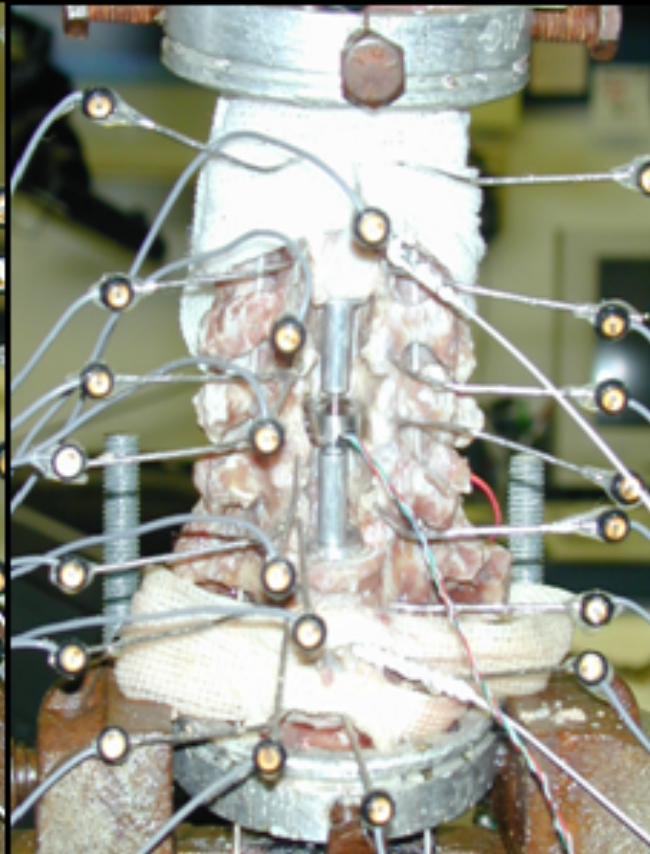
Load cell' lerin yerleştirilmesi



C5 load cell

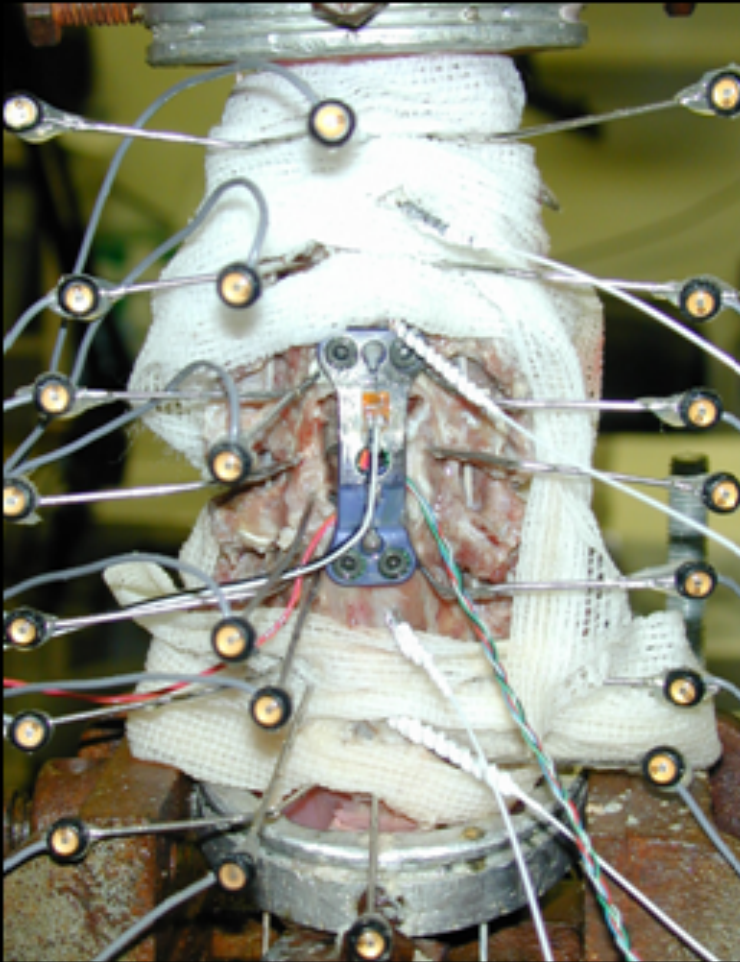


C5-6 load cell

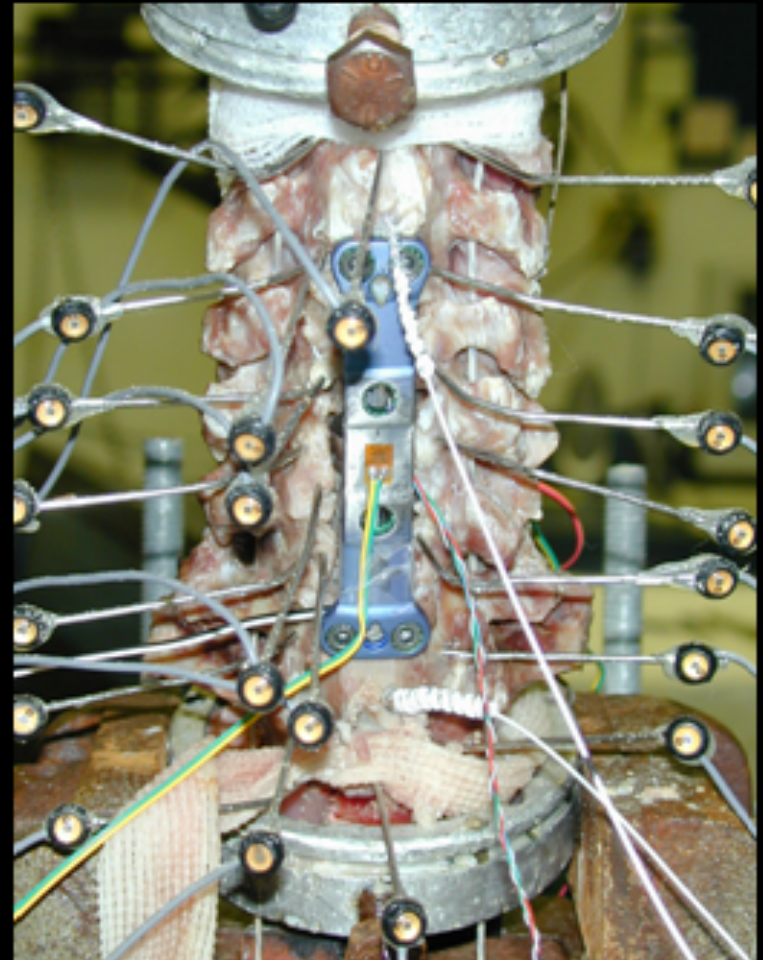


C4-5-6 load cell

Load cell ve plak yerleştirilmesi

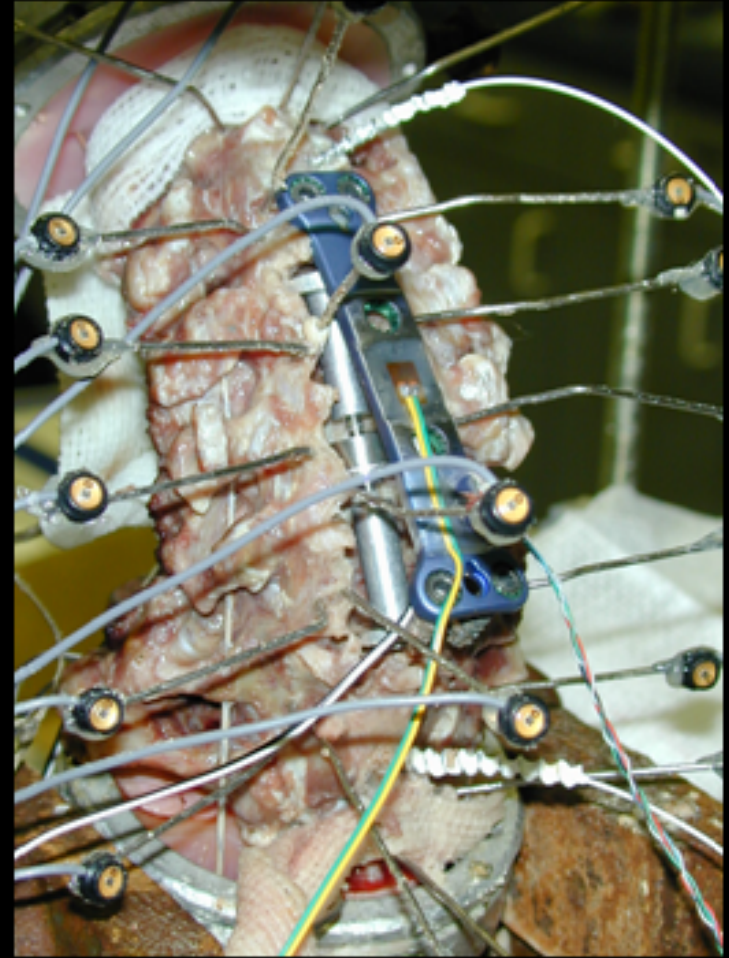
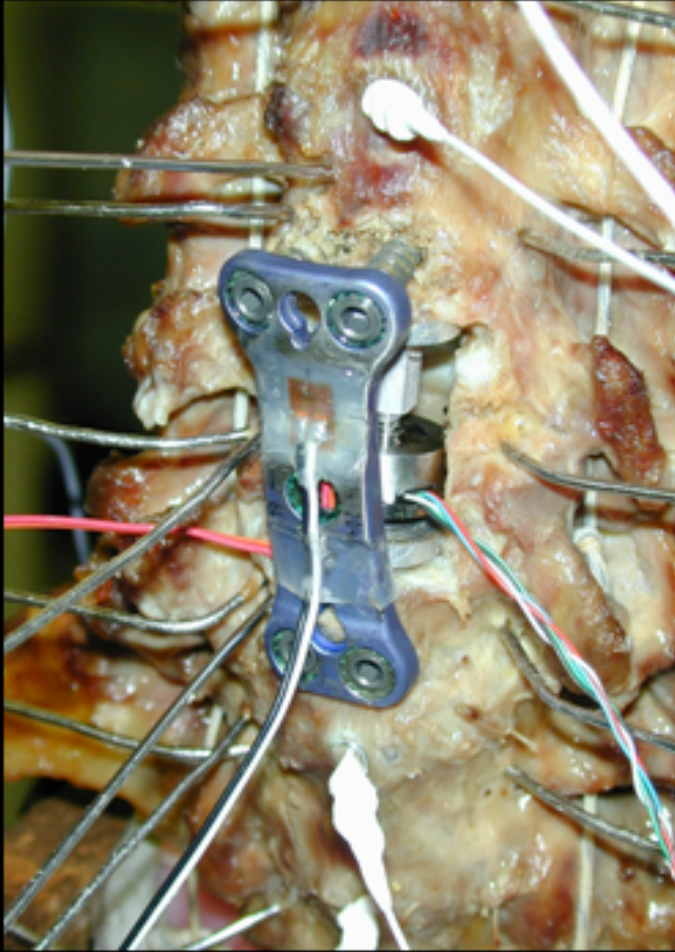


C5 anterior plak



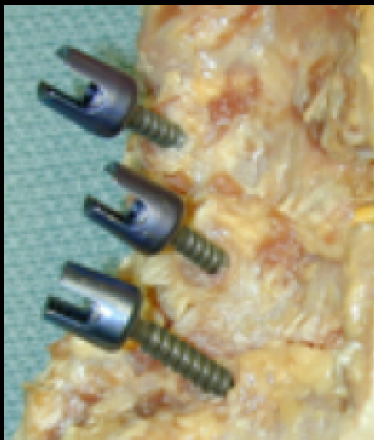
C4-5-6 anterior plak

Başarısız sonuçlar



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‡

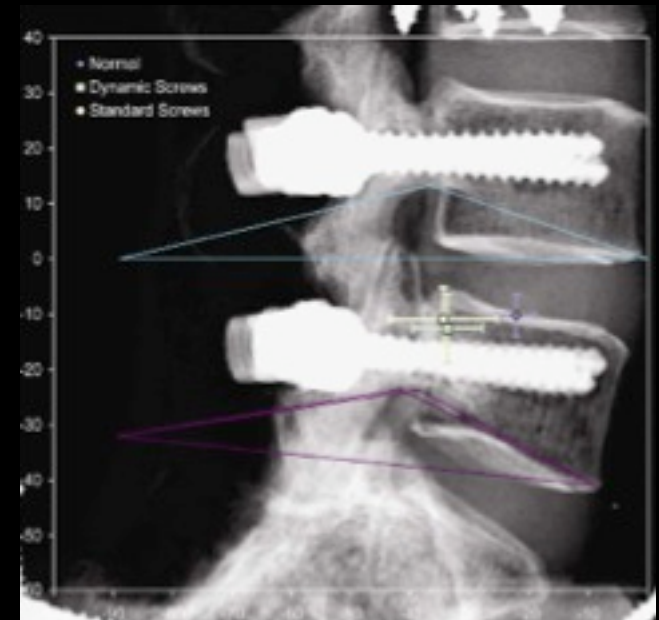
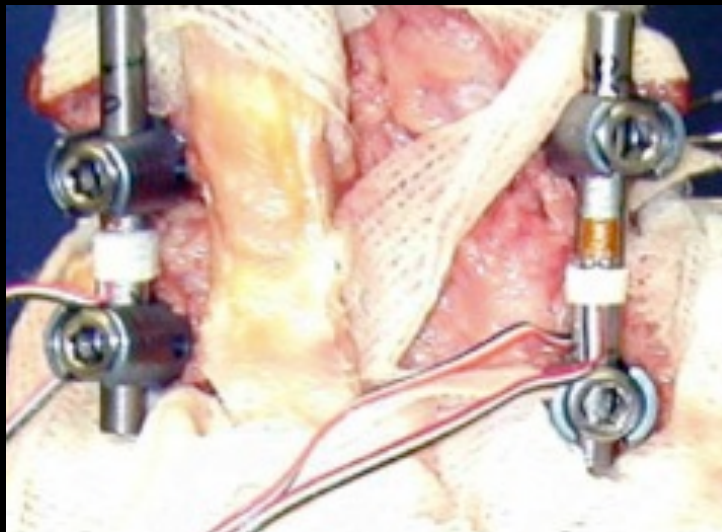
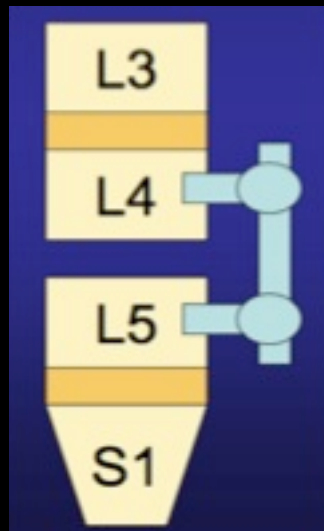


Dynamic lumbar pedicle screw-rod stabilization: in vitro biomechanical comparison with standard rigid pedicle screw-rod stabilization

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 FAHİR ÖZER, M.D.,¹ VOLKER K. H. SONNTAG, M.D.,²
AND NEIL R. CRAWFORD, PH.D.²**

¹Department of Neurosurgery, VKV Amerikan Hastanesi, Istanbul, Turkey; and ²Barrow 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](#)



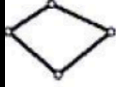
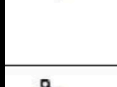
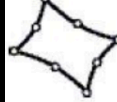
ISO 12189:2008

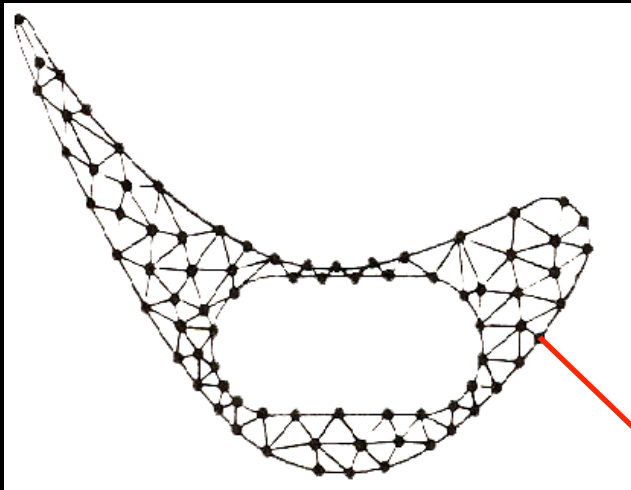
Implants for surgery -- Mechanical testing of implantable spinal devices -- Fatigue test method for spinal implant assemblies using an anterior support

Sonlu Eleman Yöntemi

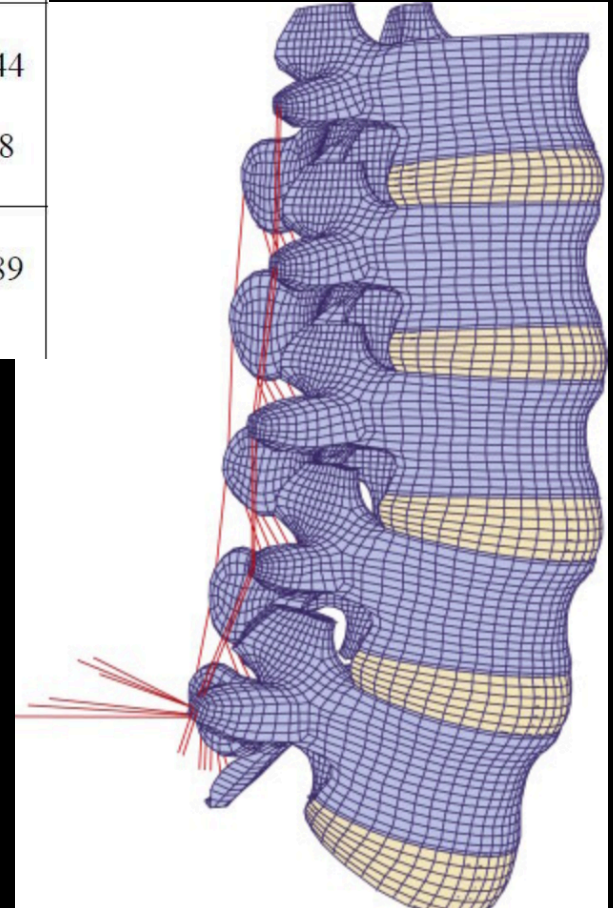
- Bir bütünün parçalara ayrılarak incelenmesi
- Uygun geometri (model)
- Mesh yapılması
- Materyel özellikleri
- Sınır şartlarının belirlenmesi
- Yükleme
- Sonuçların deneysel modeller ile kanıtlanması

Model ve Mesh

2D Solid	3D Solid	3D Shell	Line Elements
 PLANE42  PLANE182	 SOLID45  SOLID185	 SHELL63  SHELL181	 BEAM3/44  BEAM188
 PLANE82/183  PLANE2	 SOLID95/186  SOLID92/187	 SHELL93	 BEAM189



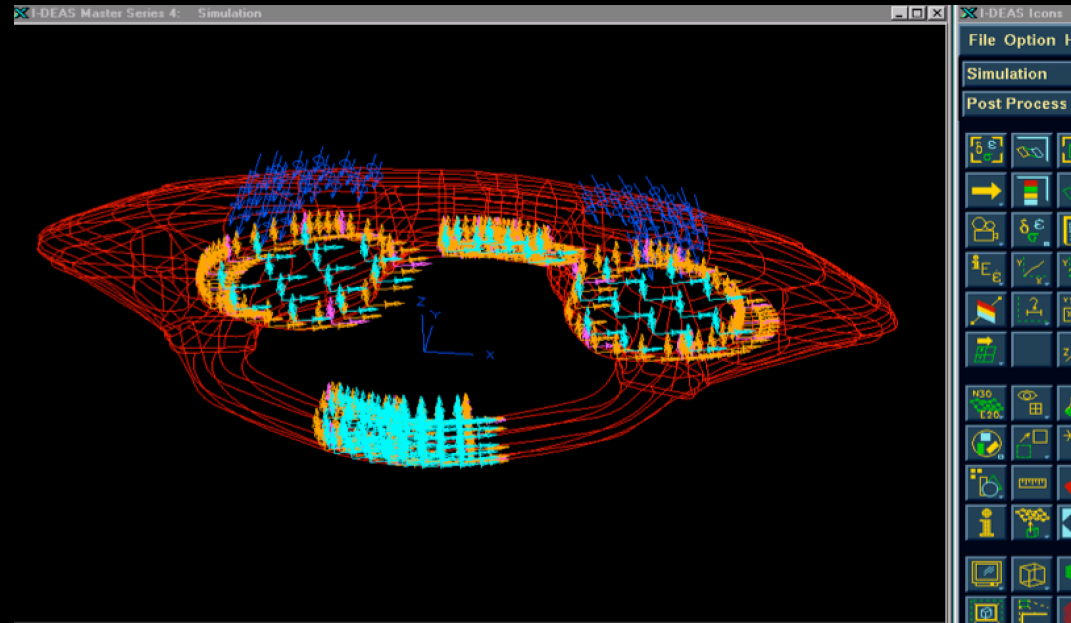
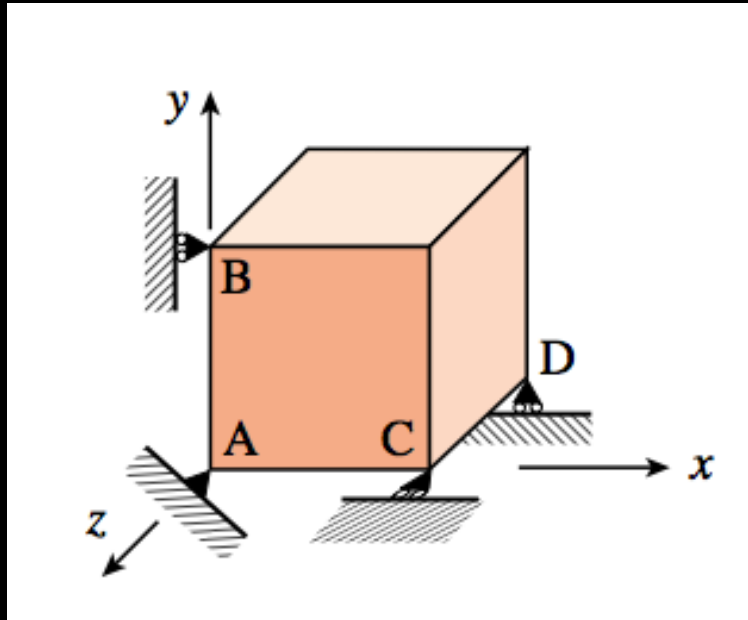
nod



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
Ligamentum flavum	2.4	0.39
Kapsular ligaman	7.7	0.39

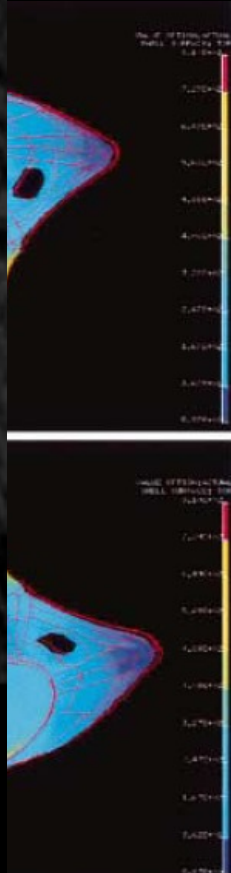
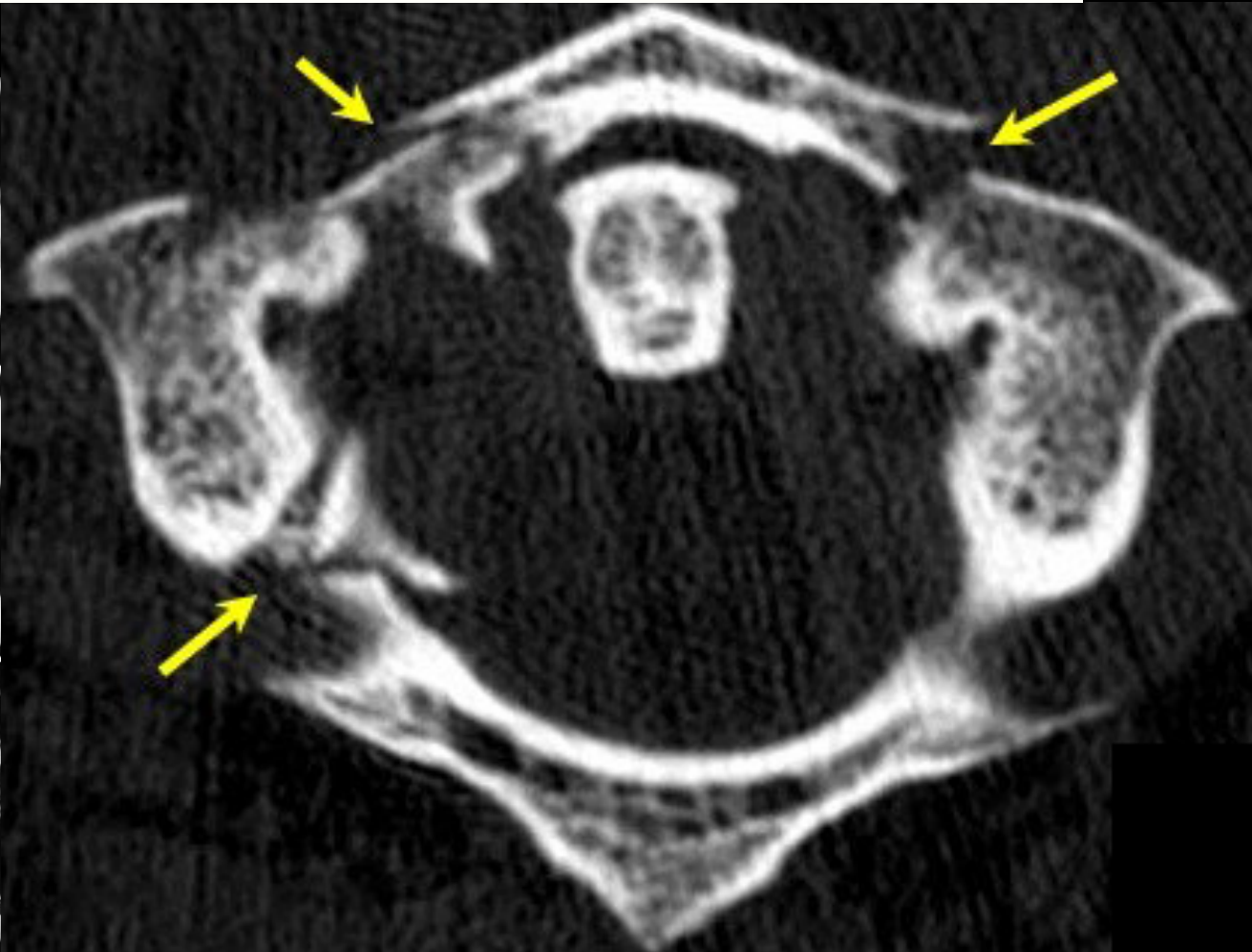
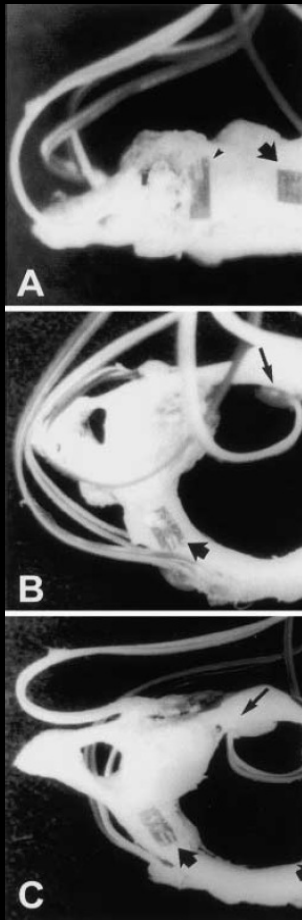
Sınır Şartları ve Yükleme



Deneysel Model ile Geçerlilik ?

Hakan Bozkus
Askin Karakas
Murat Hanci
Mustafa Uzan
Ergun Bozdag
Ali Cetin Sarioglu

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



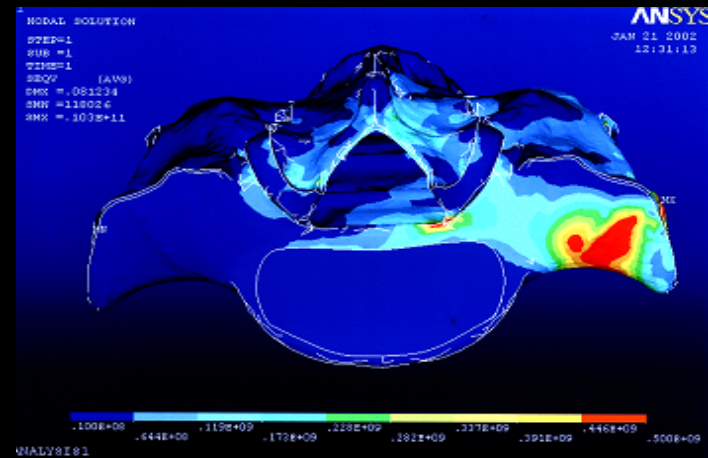
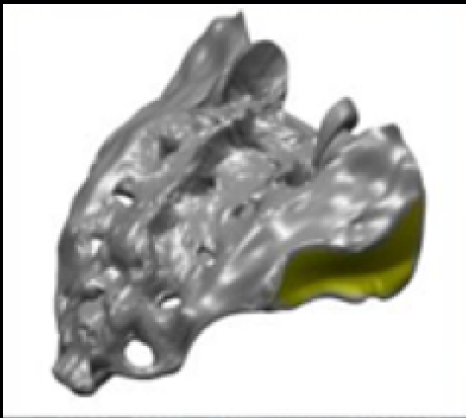
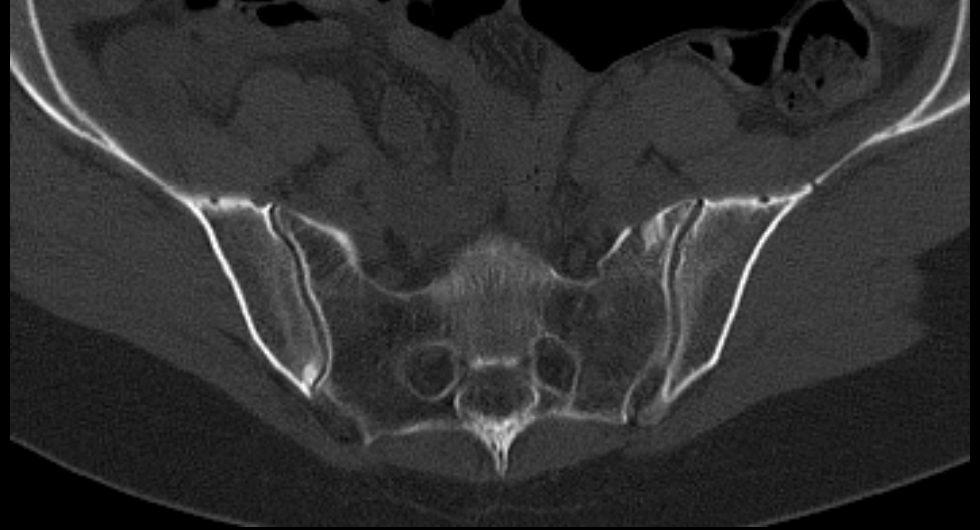
Finite element method based stress analysis of zone I and zone II sacral fractures

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

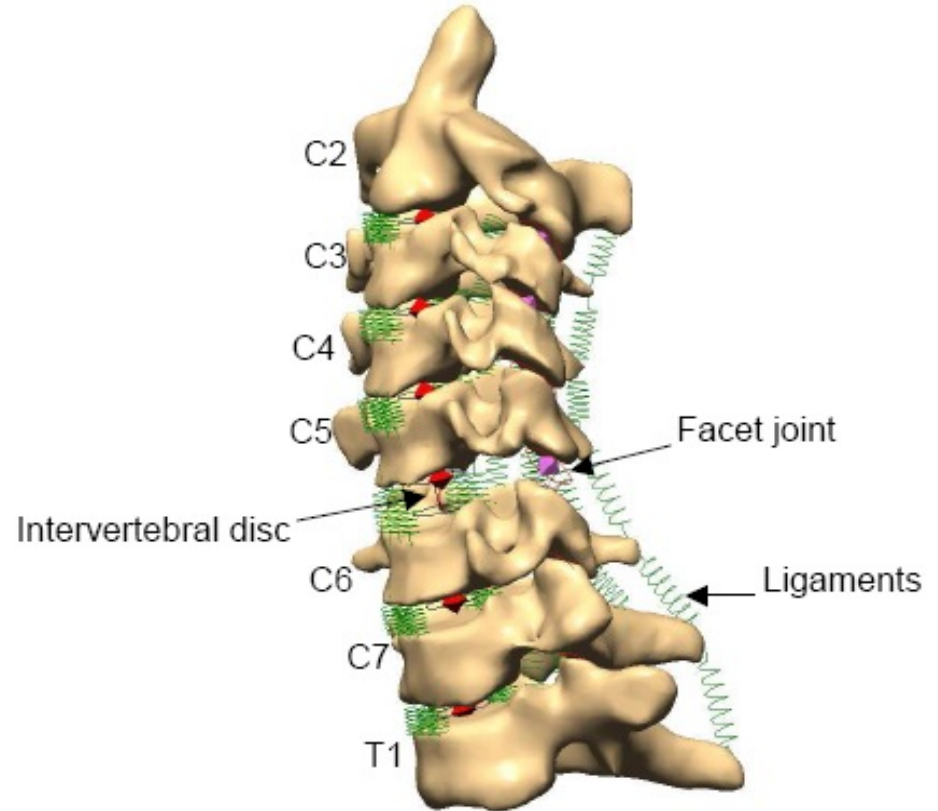
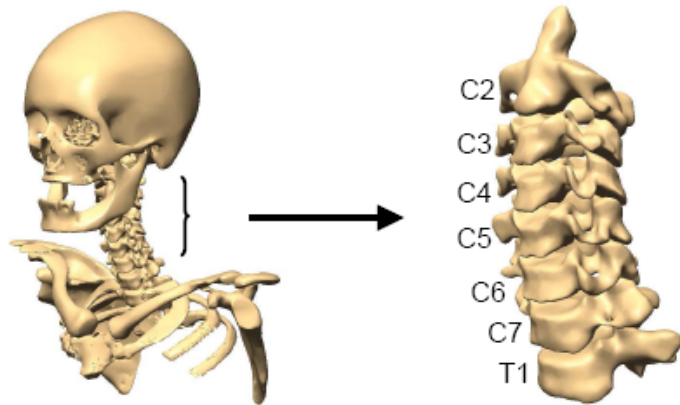
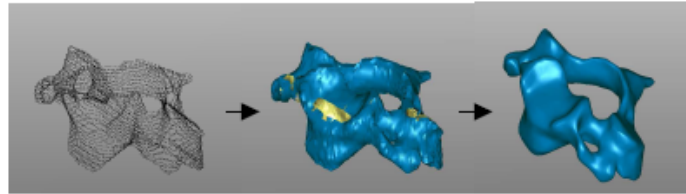
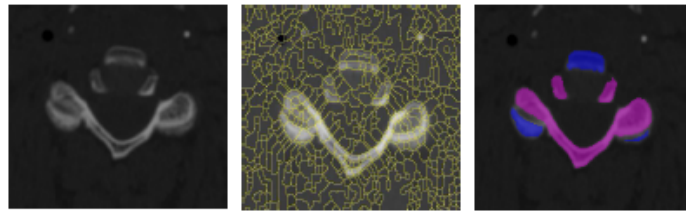
Hakan BOZKUŞ^{1,5}, Murat HANCI², M.Emin SÜNBÜLOĞLU³, M.Ali TUNALI³,
S.Ergun BOZDAĞ³, Önder AYDINGÖZ⁴, Alaattin ARPACI³

Turkish Journal of Trauma & Emergency Surgery

Ulus Travma Derg 2005

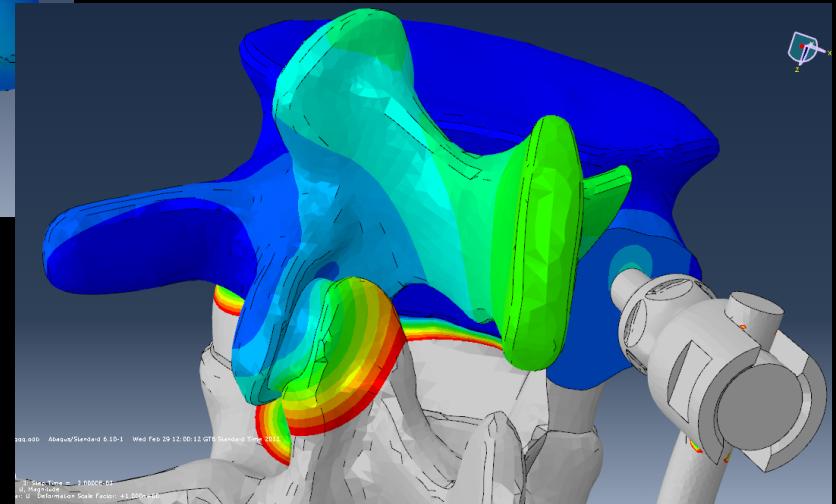
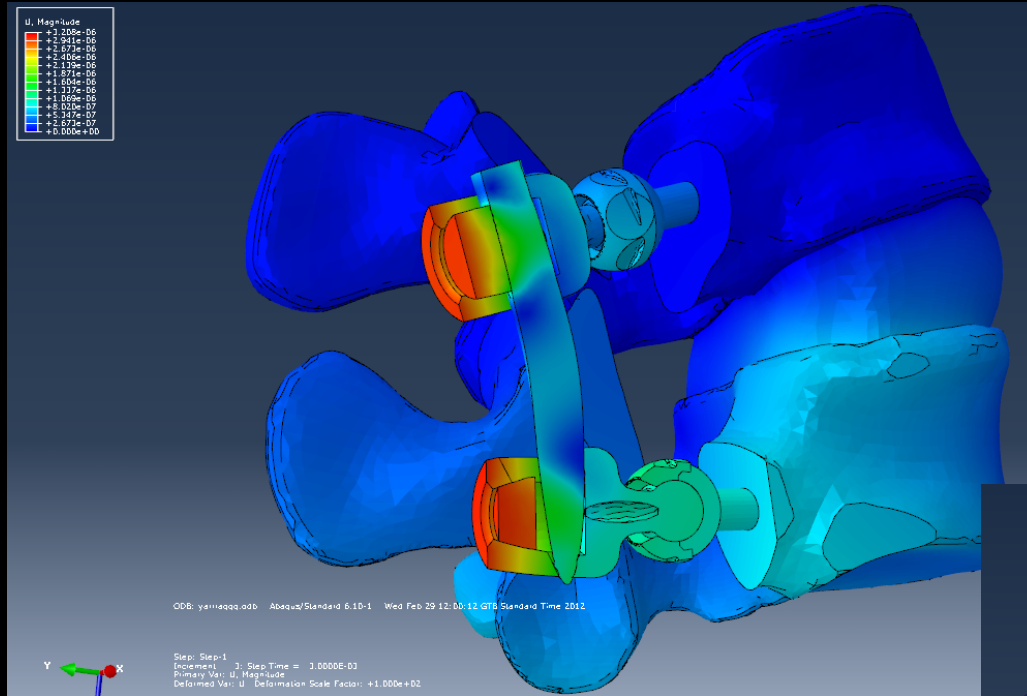


Sonlu eleman yöntemi (FEM)



FEM Kesitsel Von Mises Stress

Dinamik Pedikül Vida+ Rijit Rod



Stereolithography Model

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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

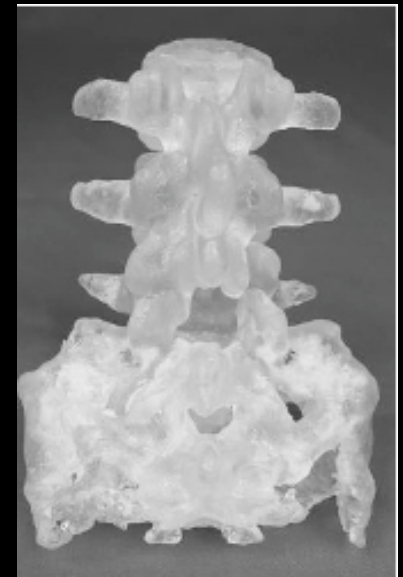
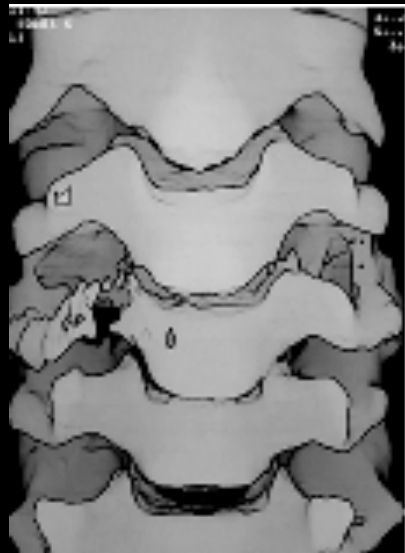
APPLICATION OF THE STEREOLITHOGRAPHY TECHNIQUE IN COMPLEX SPINE SURGERY

Wellington Silva Paiva¹, Robson Amorim¹,
Douglas Alexandre França Bezerra¹, Marcos Masini²

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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‡



Konuřmanın Slaytları

sunumlar@
hakanbozkus.com.tr

Teřekkür Ederim