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CENTER FOR DISRUPTIVE MUSCULOSKELETAL INNOVATIONS

Lumbar Disc Geometry Affects the Risk for Rod Fracture in Adult Spinal Deformity (ASD) Surgery

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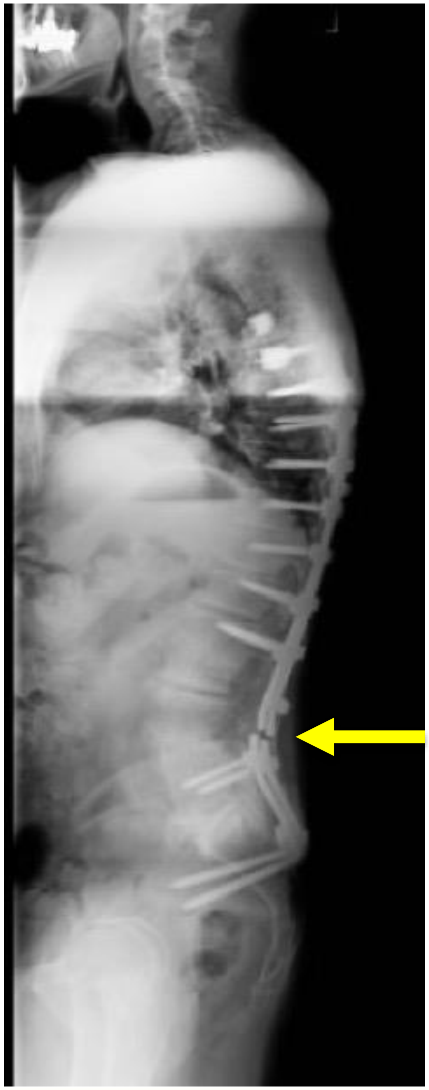
Background

- Risk factors associated with rod fracture In ASD
    - Age
    - Previous spine surgery
    - Insufficient sagittal plane correction
    - Intrinsic
        - Rod material → Stainless steel, Titanium and CoCr alloys
        - Diameter (5.5-6.35 mm)
    - Extrinsic
        - Contouring and bending
            - Fatigue strength
        - Notch sensitivity
        - Cyclic loading
            - Repeated metal strain

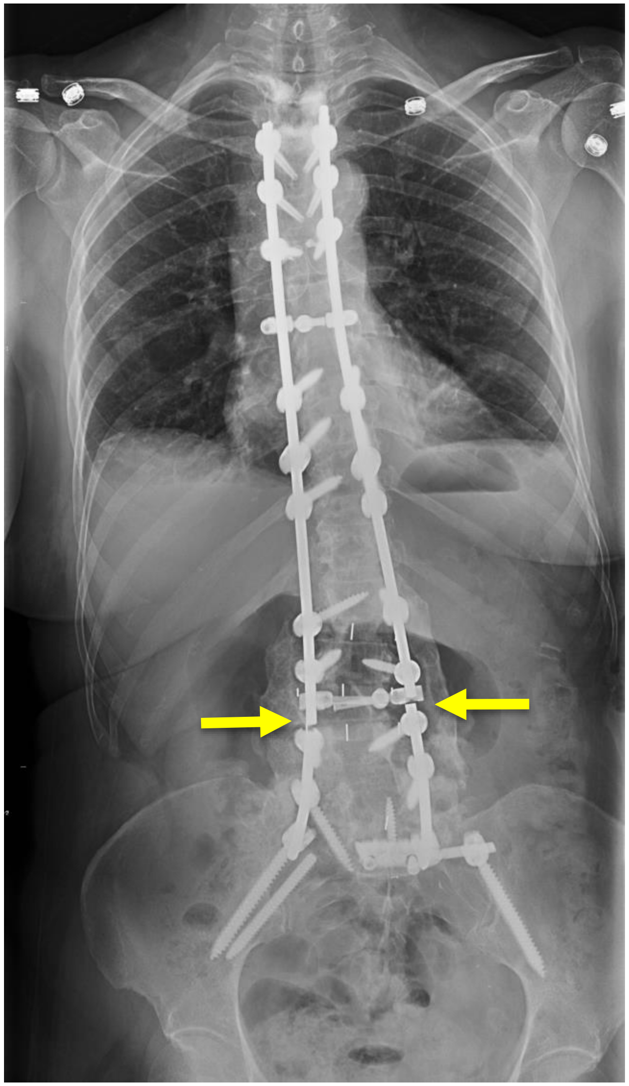


Background

- Superior rod fracture in Lumbar region
  - Lumbar Spine mobility
  - Increased weight-bearing capabilities

- Patients with rod fracture
  - Larger non-fused disc heights
  - Larger diameters
  - Higher volumes adjacent to the PSO or apical lumbar vertebra

- Interbody grafts
  - Provide additional stiffness



Project Aims/ Hypotheses

- Increased stresses result at the PSO site

- Larger discs adjacent to PSO
  - Higher motion in a posteriorly instrumented construct
  - Increased loads / stresses on the instrumentation

- Alternative instrumentation including interbody grafts (IBGs) in larger discs adjacent to PSO
  - Improve stability
  - Decrease rod fracture rates

Methods

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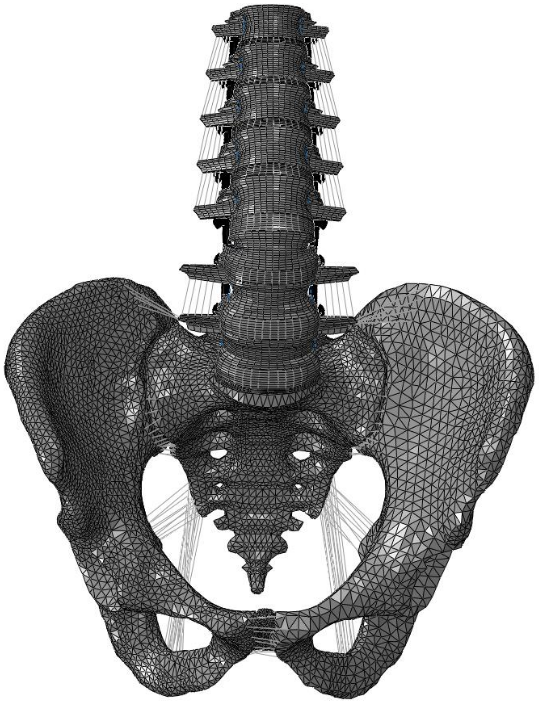
- Modify in house T10-Sacrum Finite Element Model
  - Intact Ligamentous Model - INT
  - Simulate 35^0 PSO at L3 and stabilized (PSO) with normal disc heights L1 to S1
  - Simulate PSO + IBGs in all discs from L1 to S1
  - Simulate PSO + No IBGs but reduced disc heights (80%, 50% and 20% normal disc height)
  - Simulate PSO + different locations and length of second rod (Dual rod (inward), Dual rod (outward), Dual rod (ouward-long)

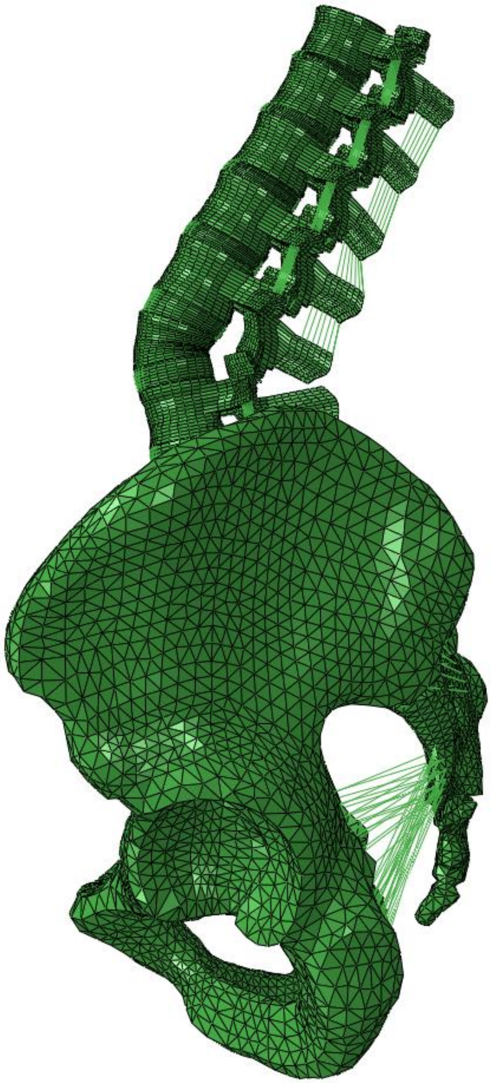


- Maximum von Mises Stress in Various Simulation Groups (Flex, Ext, LB and AR with 7.5 N.m moment and Pre-load)

- Compare Data for Hypotheses Evaluations

Methods: Pedicle Subtraction Osteotomy

- Wedged shape resection of 35 Degrees at L3
- Posterior arch of L3 removal
- Removal of posterior ligaments (L2/3, L3/4)
- Removal of transverse ligaments (L2/3, L3/4)
- Removal of interspinous and supraspinous ligaments
- Removal of pedicles and transverse processes of L3



Methods: Instrumentation

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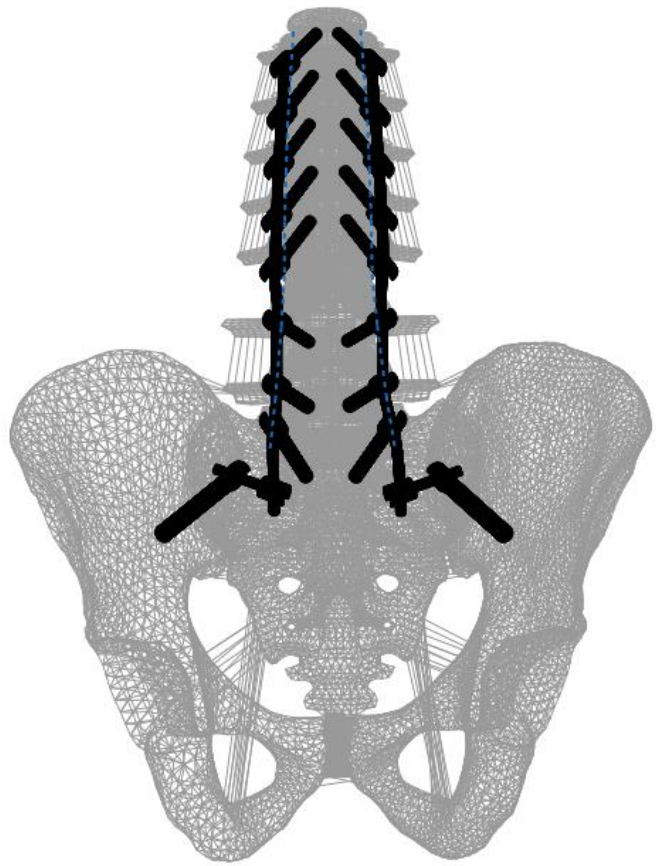
- Rod diameter is 5.5mm Cobalt Chrome

Vertebra Level	Screw Diameter (mm)	Screw Length (mm)	Screw Material
T10	4.5	40	Ti-6Al-4v
T11	4.5	40	Ti-6Al-4v
T12	4.5	40	Ti-6Al-4v
L1	5.5	45	Ti-6Al-4v
L2	5.5	45	Ti-6Al-4v
L4	5.5	45	Ti-6Al-4v
L5	6.5	45	Ti-6Al-4v
S1	6.5	55	Ti-6Al-4v
Iliac	8.5	80	Ti-6Al-4v

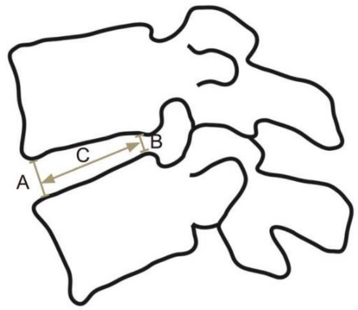


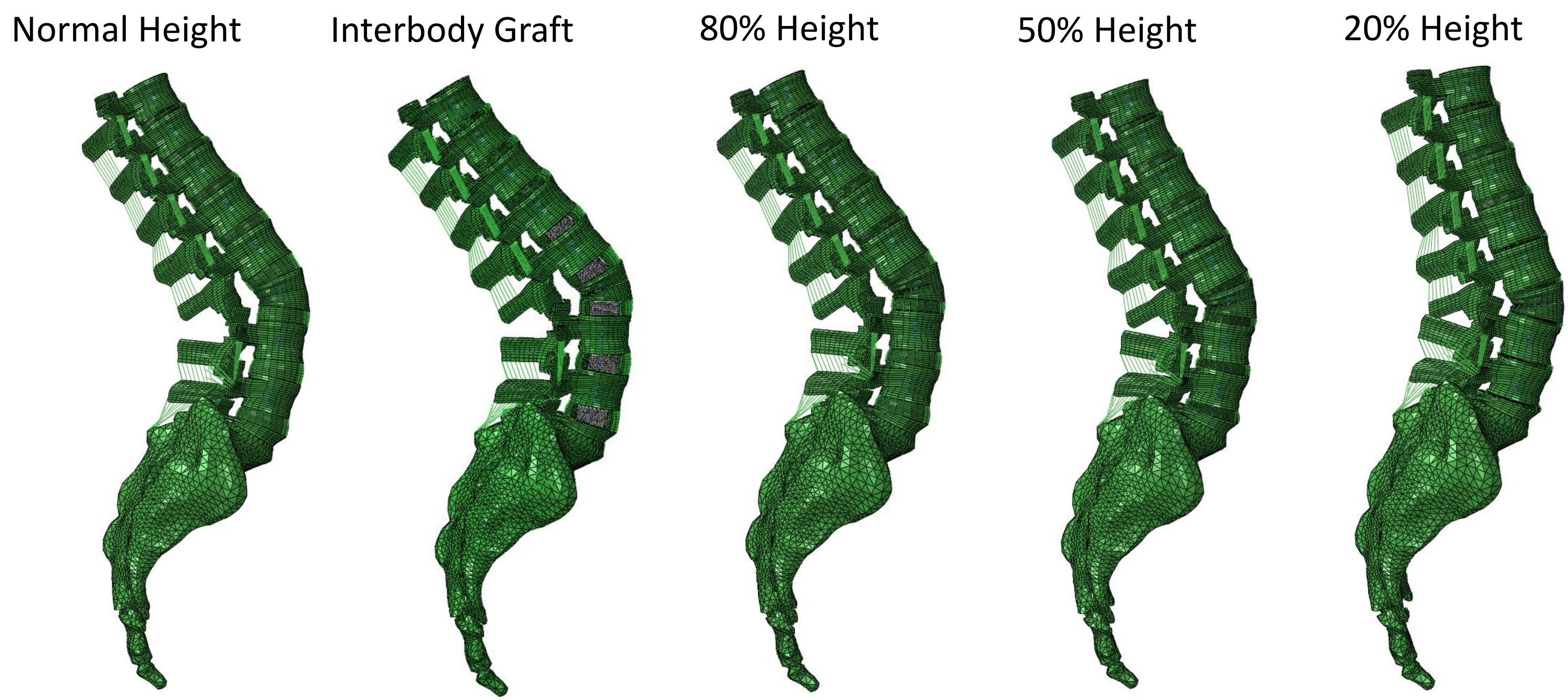
Methods: Disc Degenerated Models

- Farfan index

The sum of anterior disc height (A) and posterior disc height (B) is divided by sagittal disc width (C)

Disc space height
=(A+B)/C





Methods: Dual rod Models

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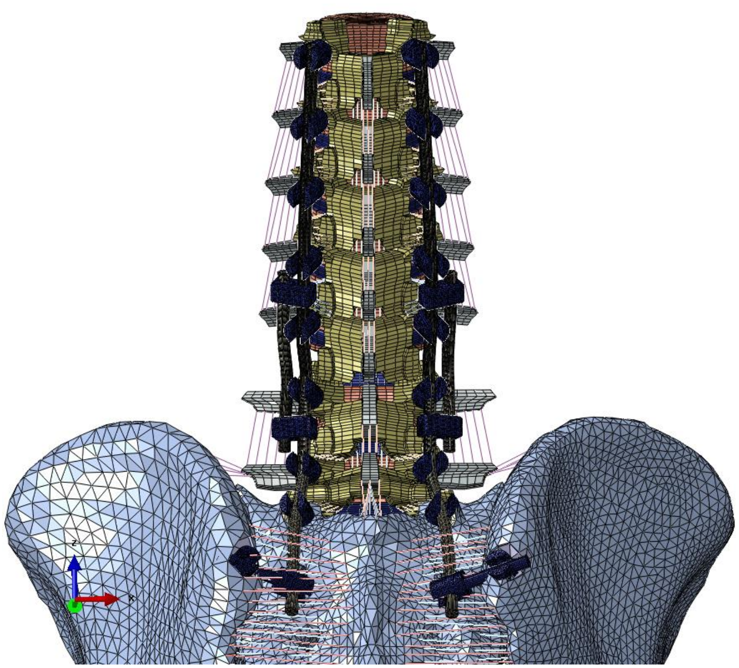
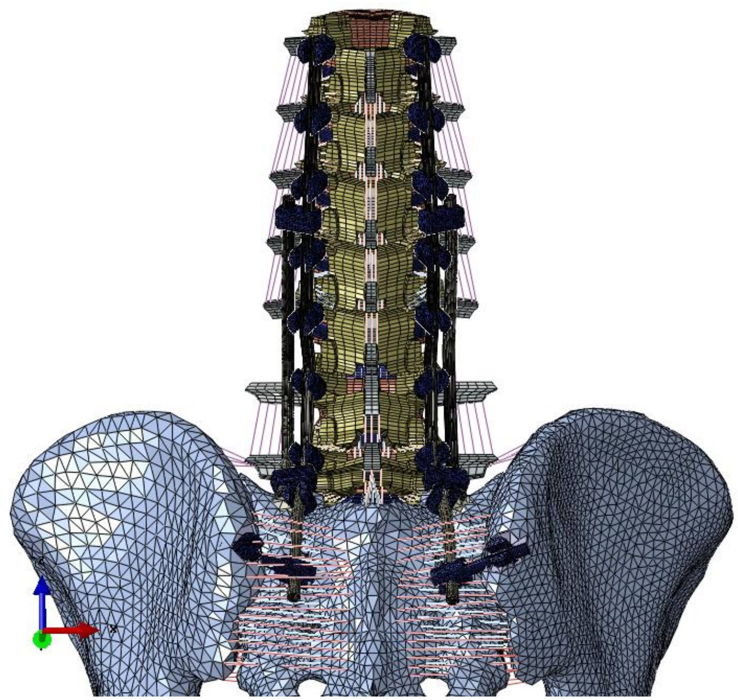
Dual Rods at the PSO region

- Second rod (Lateral): L2 to L4
- Second rod (Lateral Long): L1 to L5



Dual Rod (Lateral)



Dual Rod (Lateral Long)

Methods: Material Properties

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- Disc Degenerated Fibers and ligaments
  - Buckled fibers and ligaments
  - Offset non-linear force-deflection curves
- Nucleus Compressibility
  - Young's modulus increased from healthy nucleus to annulus ground substance value
  - 80% and 50% disc height Young's modulus → linearly interpolated
- Annulus ground substance
  - Based on Holzapfel et al. → Not changed

Nucleus				
Component/Material	Constitutive model	C1	C2	D1
Nucleus/Normal	Mooney Rivlin	0.12	0.03	0.0005
Nucleus/80 percent	Mooney Rivlin	0.135	0.03375	0.037875
Nucleus/50 percent	Mooney Rivlin	0.1575	0.039375	0.0939375
Nucleus/20 Percent	Mooney Rivlin	0.18	0.045	0.15
Annulus				
Annulus (Ground)	Neo Hookean	0.348	--	0.3

Methods: Material Properties

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Component/ Material	Element Formulation	Constitutive Model	Young's Modulus (Mpa)	Poisson's Ratio	Cross-sectional Area (mm2)
Bony Structure					
Vertebral Cortical Bone	Hexahedral	Elastic	12000	0.3	--
Vertebral Cancellous Bone	Hexahedral	Elastic	100	0.2	--
Posterior Cortical Bone	Hexahedral	Elastic	12000	0.3	--
Posterior Cancellous Bone	Hexahedral	Elastic	100	0.2	--
Ligaments					
Anterior Longitudinal	Truss	Non-linear Hypoelastic	7.8 (<12%), 20 (>12%)	0.3	74
Posterior Longitudinal	Truss	Non-linear Hypoelastic	10 (<11%), 20 (>11%)	0.3	14.4
Ligamentum Flavum	Truss	Non-linear Hypoelastic	15 (<6.2%), 19.5 (>6.2%)	0.3	40
Intertransverse	Truss	Non-linear Hypoelastic	10 (<18%), 58.7 (>18%)	0.3	1.8
Interspinous	Truss	Non-linear Hypoelastic	10 (<14%), 11.6 (>14%)	0.3	40
Supraspinous	Truss	Non-linear Hypoelastic	8 (<20%), 15 (>20%)	0.3	30
Capsular	Truss	Non-linear Hypoelastic	7.5 (<25%), 32.9 (>25%)	0.3	34

Results: Disc Degeneration Validation

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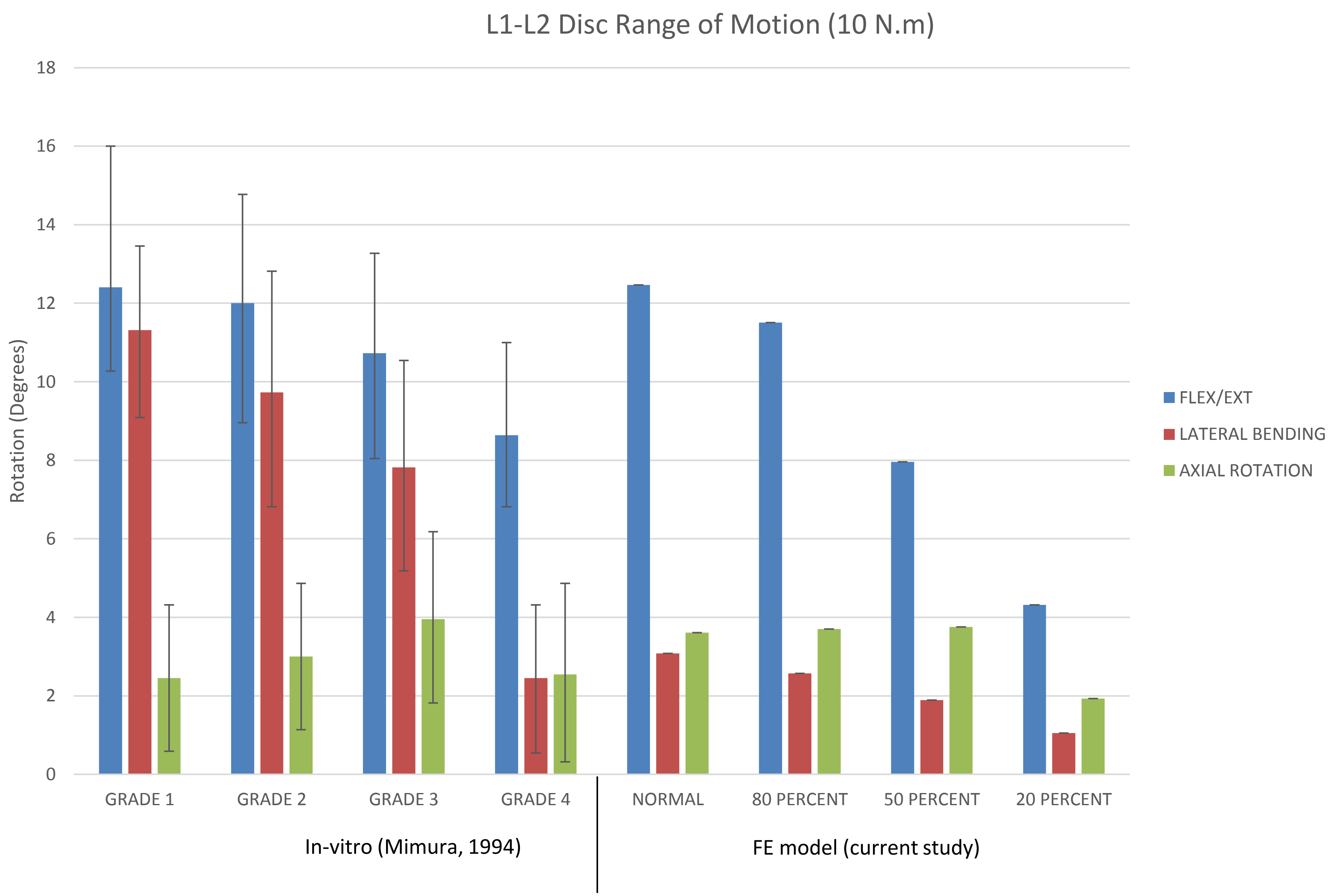
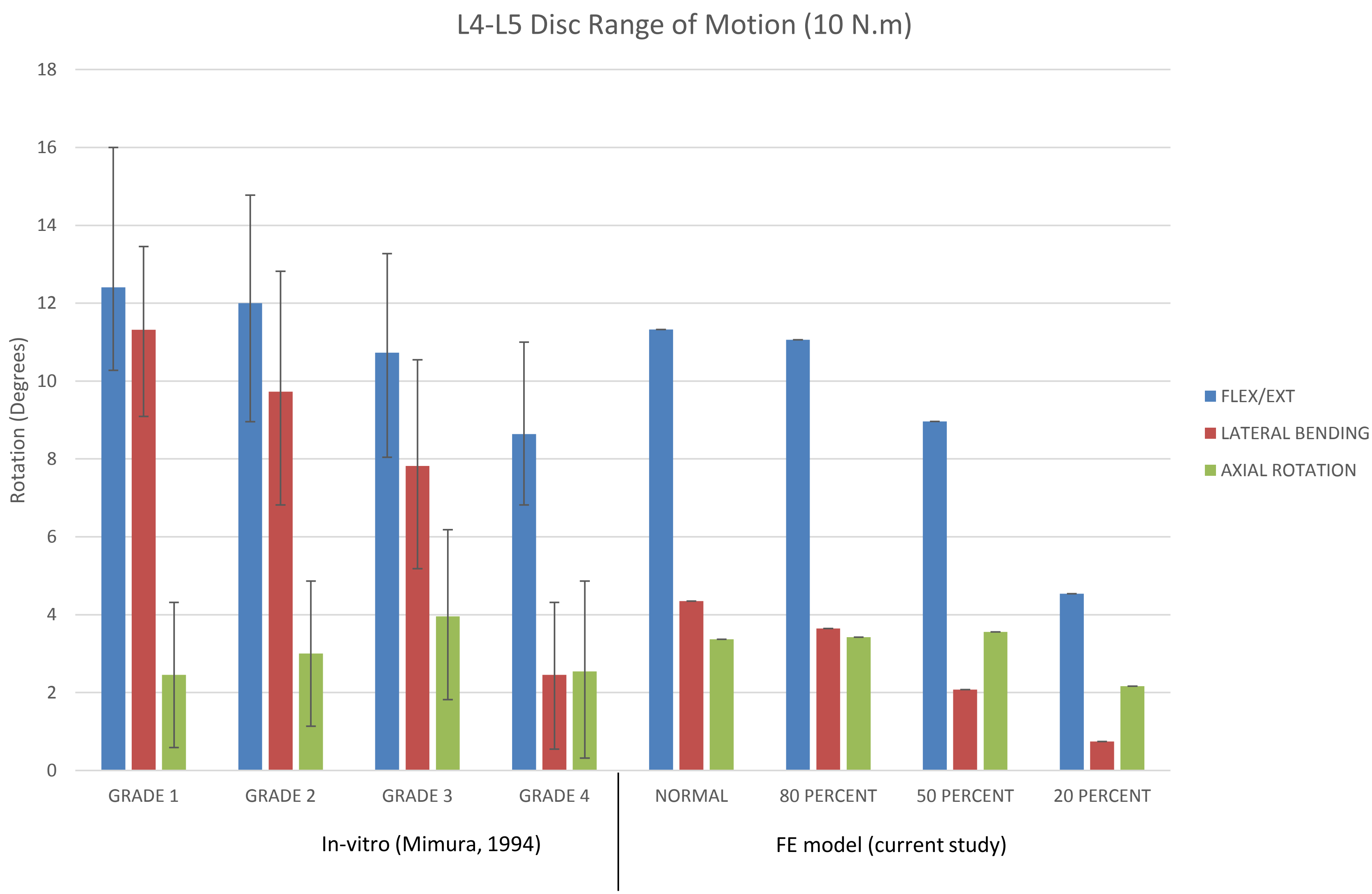


Results: Disc Degeneration Validation



Results: Disc Degeneration Validation

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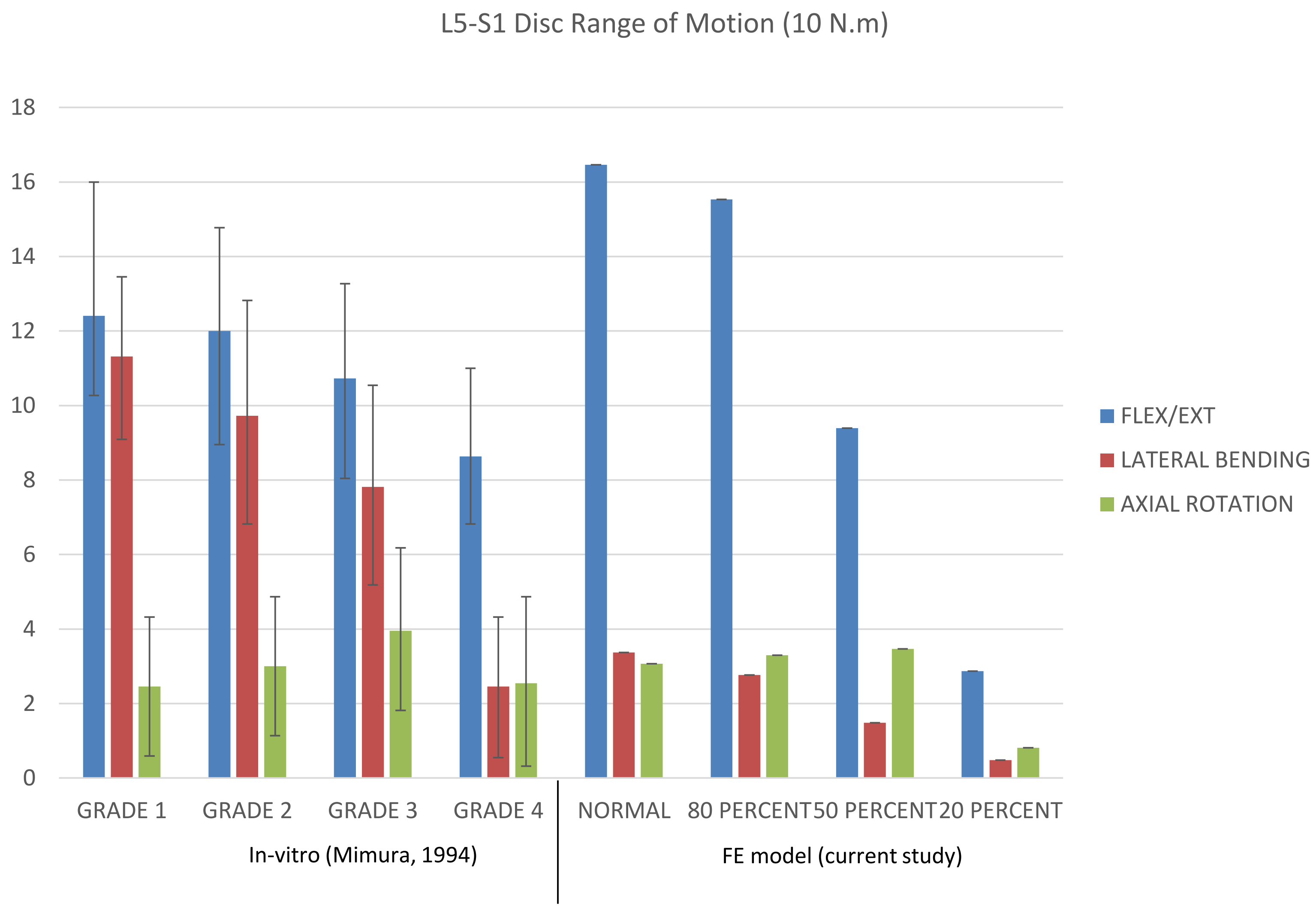

Results: Instrumented PSO Validation

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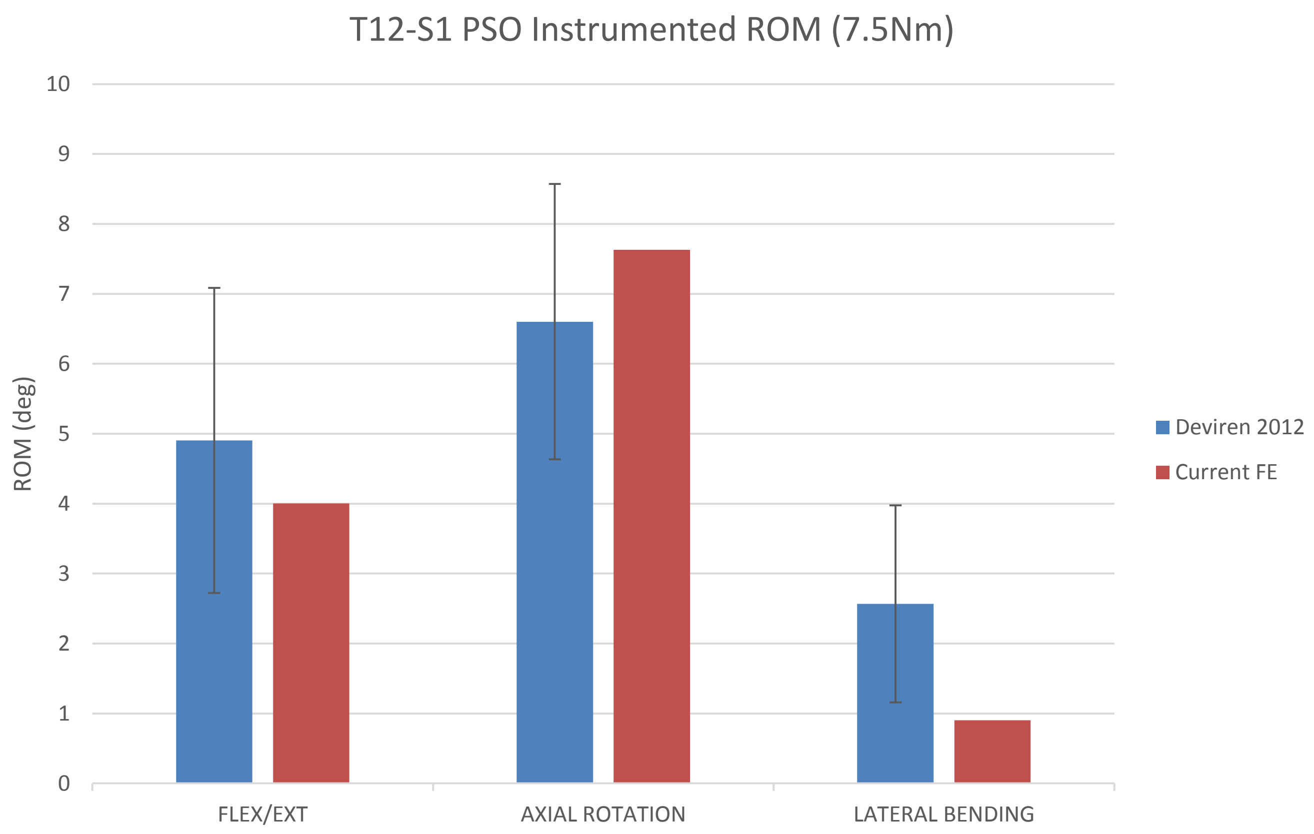
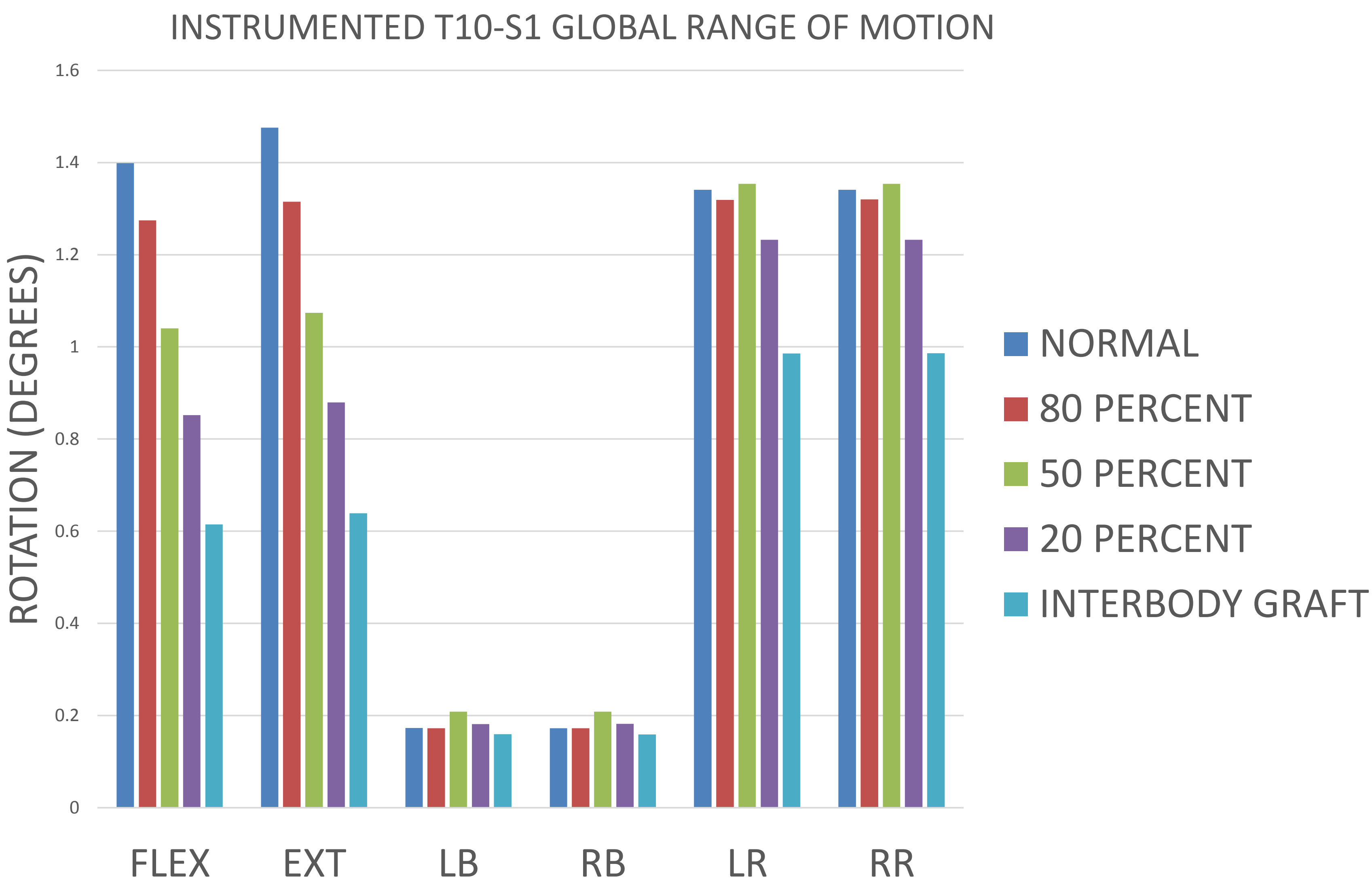
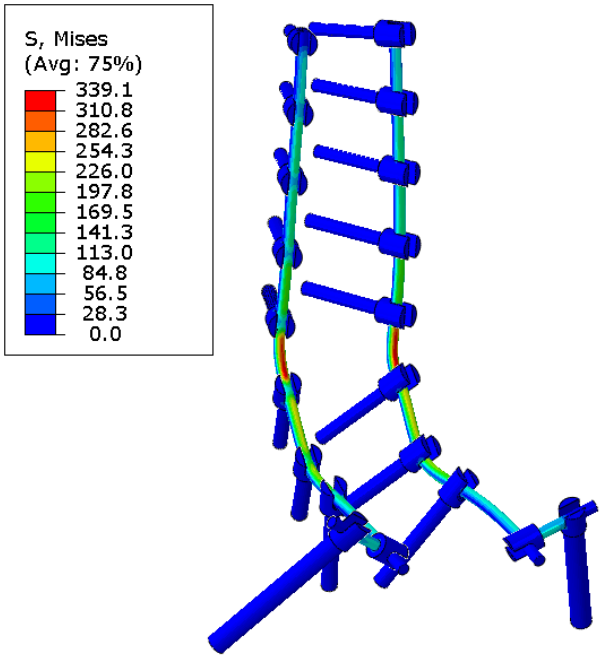


Results: Instrumented Models T10-S1 ROM



Results: Maximum von Mises Stress-Location

	Flexion	Extension	Lateral Bending	Axial Rotation
NORMAL	339/PSO	107/L4-L5	221/PSO	256/PSO
80 PERCENT	319/PSO	90/L4-L5	212/PSO	238/PSO
50 PERCENT	266/PSO	81/Adjacent to Iliac Connector	185/PSO	196/PSO
20 PERCENT	221/PSO	84/Adjacent to Iliac Connector	155/PSO	172/PSO
INTERBODY GRAFT	133/T11-T12	83/Iliac Connector	125/T10-T11	180/T11-T12



Results: Summary

In PSO:

- The maximum von Mises stress on the rods is happening at the PSO level.
- The flexion motion causes the highest von Mises stress on the rods.
- As the discs degenerate the flexion-extension motions in the instrumented models decrease significantly.
- As the discs degenerate the maximum von Mises stress on the rods decrease.
- Adding Interbody grafts is decreasing the range of motion in all rotations.

Conclusions

- Rod failure may be higher during the flexion motion and as the discs height decrease due to degeneration rod failure rate may decrease.
- Using interbody grafts decrease the von Mises stress on the rods at the PSO region.

Milestones & Timeline

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Milestones	
Data analysis, publications and report	August 31, 2017

Acknowledgement

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- Dr. Agarwal, MD
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- Industrial Advisory Board