The influence of vertebral geometrical parameters on lumbar spine loading

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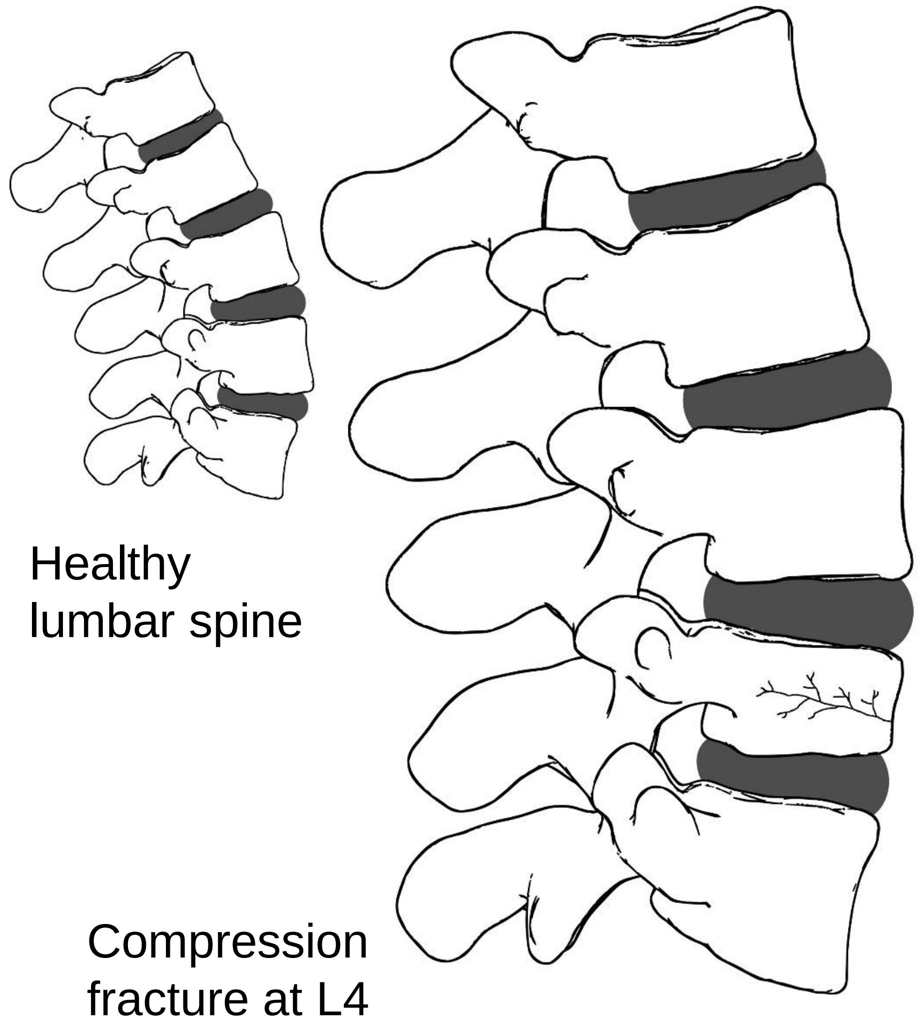
OTH Regensburg

- ~10.000 students in 8 departments

- Mechanical Engineering
  - 1400 students
  - Programs in Mechanical Engineering, Industrial Engineering and Biomedical Engineering (started in 2011)

Introduction

- Back pain is very common in modern civilization
- Number of spine surgeries doubled from 2005 to 2011 (Klauber et al. 2012)
- Possible causes for back pain:
  - muscle tension
  - degenerative disc disease
  - compression fractures
  - facet joint degeneration
  - etc.



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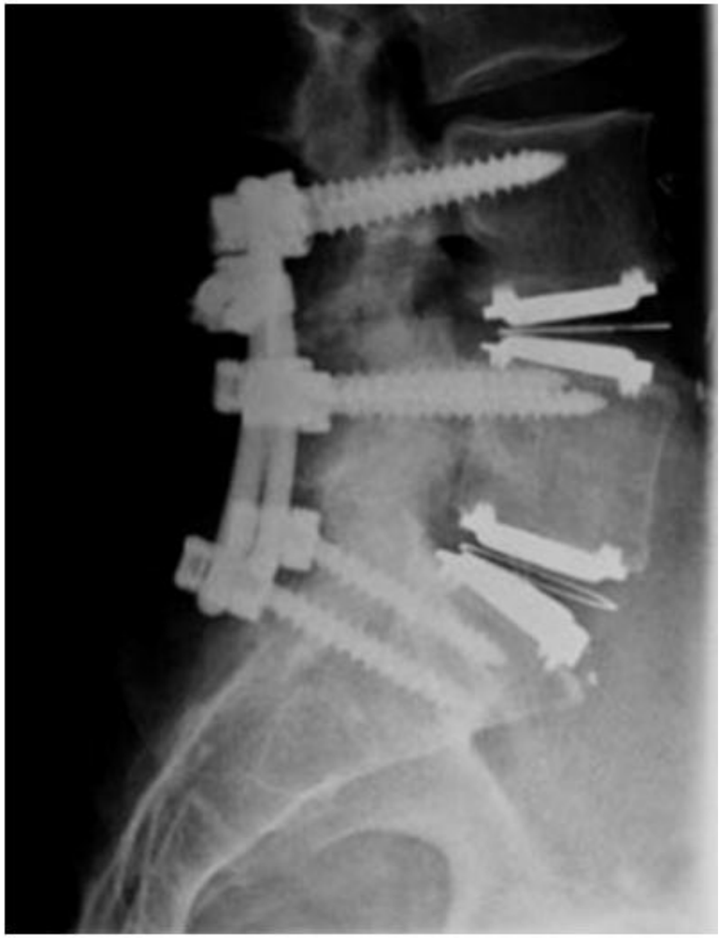

Rosen et al., 2007

Introduction

- Different causes of back pain which are sometimes not easy to diagnose
- Success of surgery depends on surgeon‘s training level (Wang et al., 2013)
- A revision rate of 10.3% for lumbar interbody fusion for spinal stenosis is reported (Nemani et al., 2014)

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- Better understanding of lumbar spine loading is essential
- Only limited experimental data available

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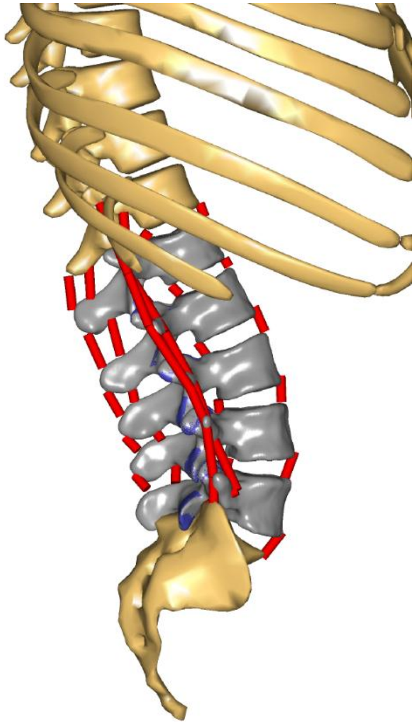
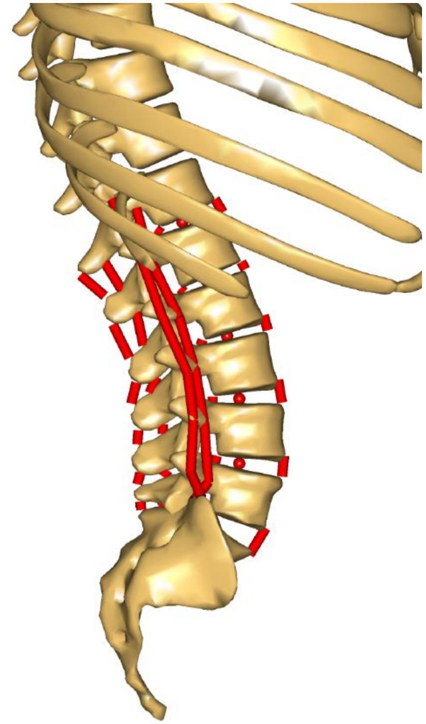
Subject-specific simulations

What is needed for subject-specific simulations?

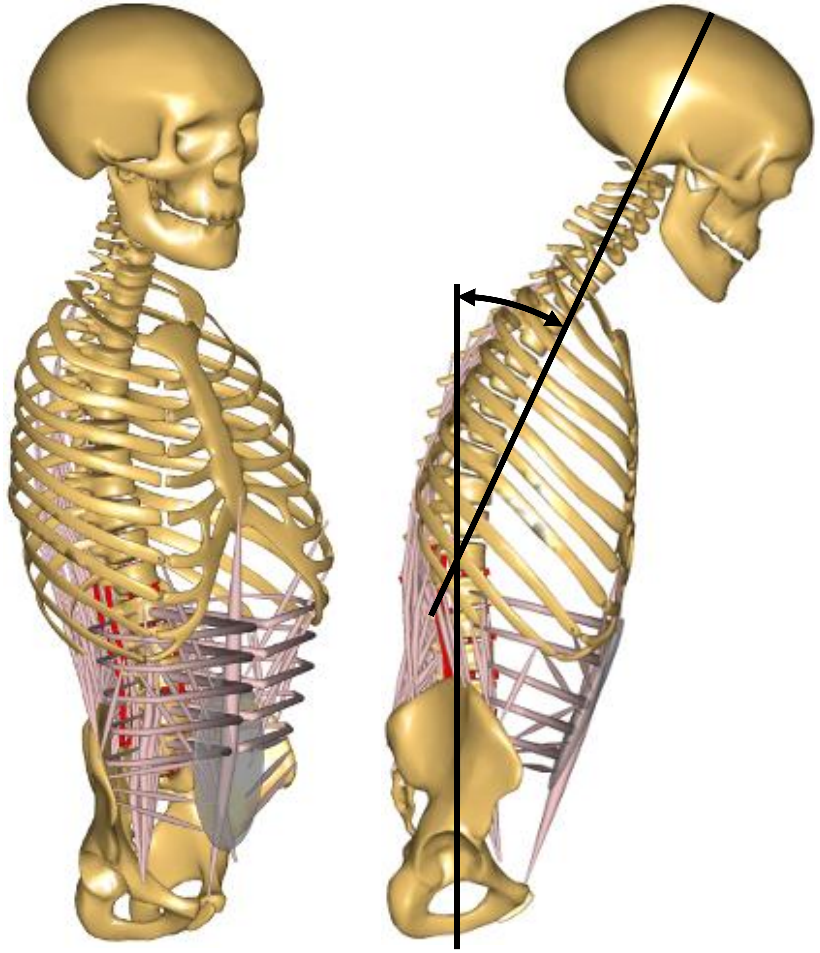




- Which geometrical parameters are critical for a subject-specific model?
- How do ligament properties influence the results?

Musculoskeletal Model

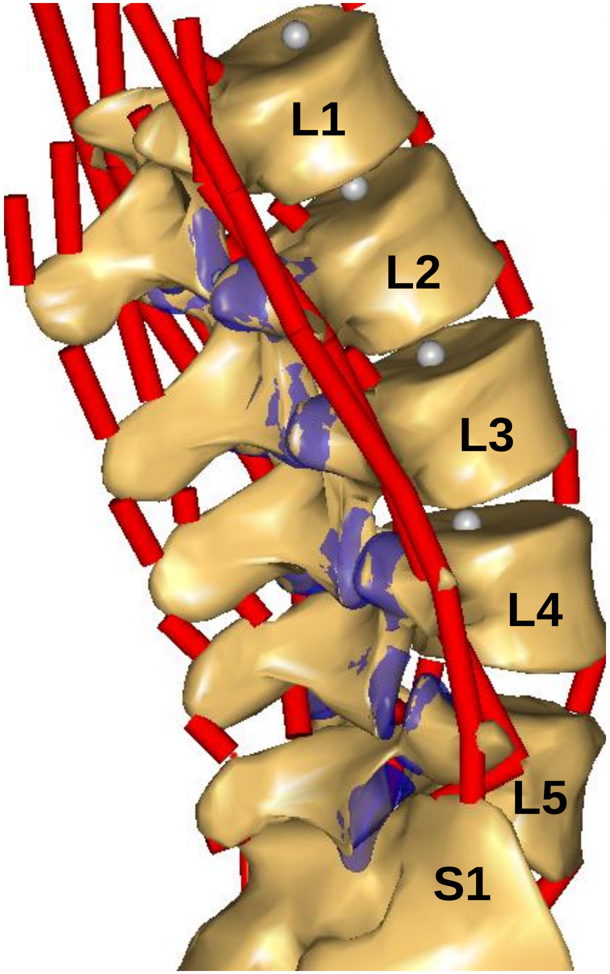
- Spine fixation with force dependent kinematics model (AMMR v1.4.1)
- Detailed modeling of the lumbar spine
- Postures are measured between pelvis and thorax
- FDK is used in the lumbar joints

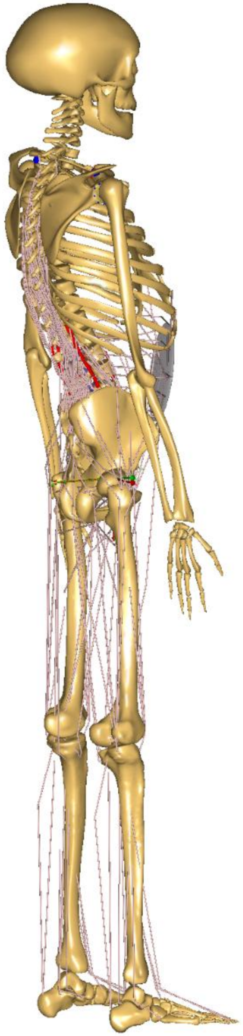


Musculoskeletal Model

Modifications:

- Subject-specific vertebral geometry
- Attachment points for muscles and ligaments altered
- Axes of rotation aligned with data from fluoroscopic radiographs of a flexion motion (Ortho Kinematics, Inc.)





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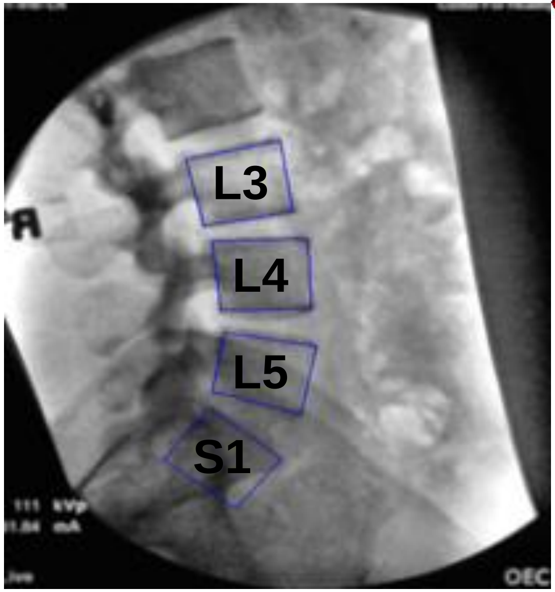
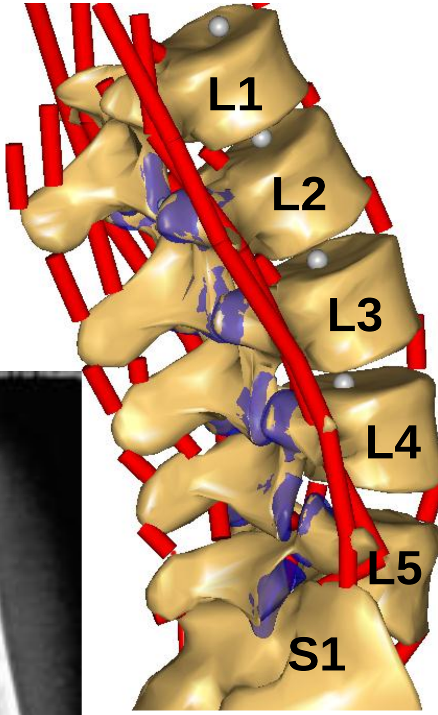
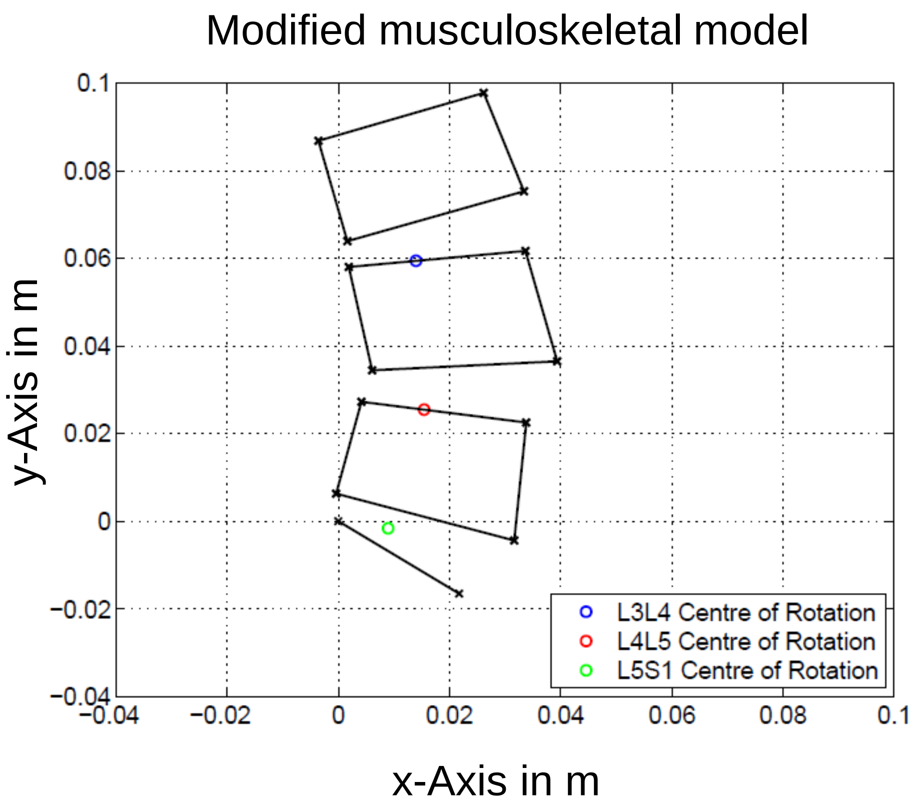
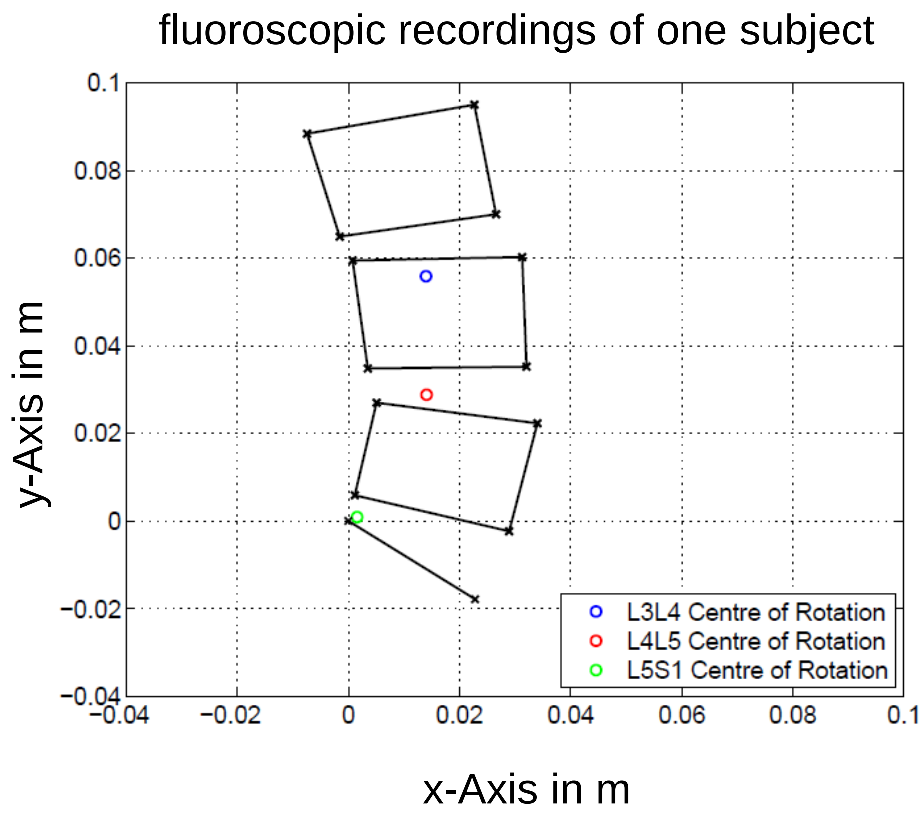


Source: Ortho Kinematics, Inc.

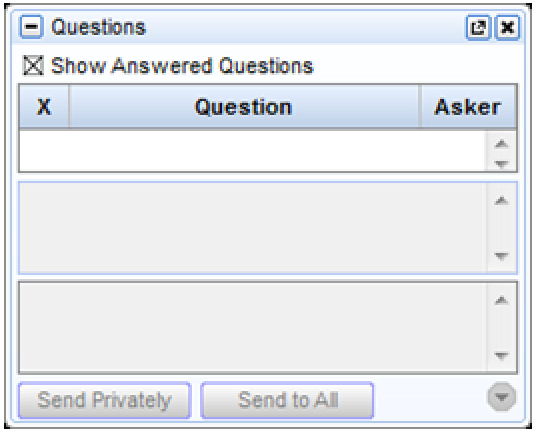


Axes of rotation

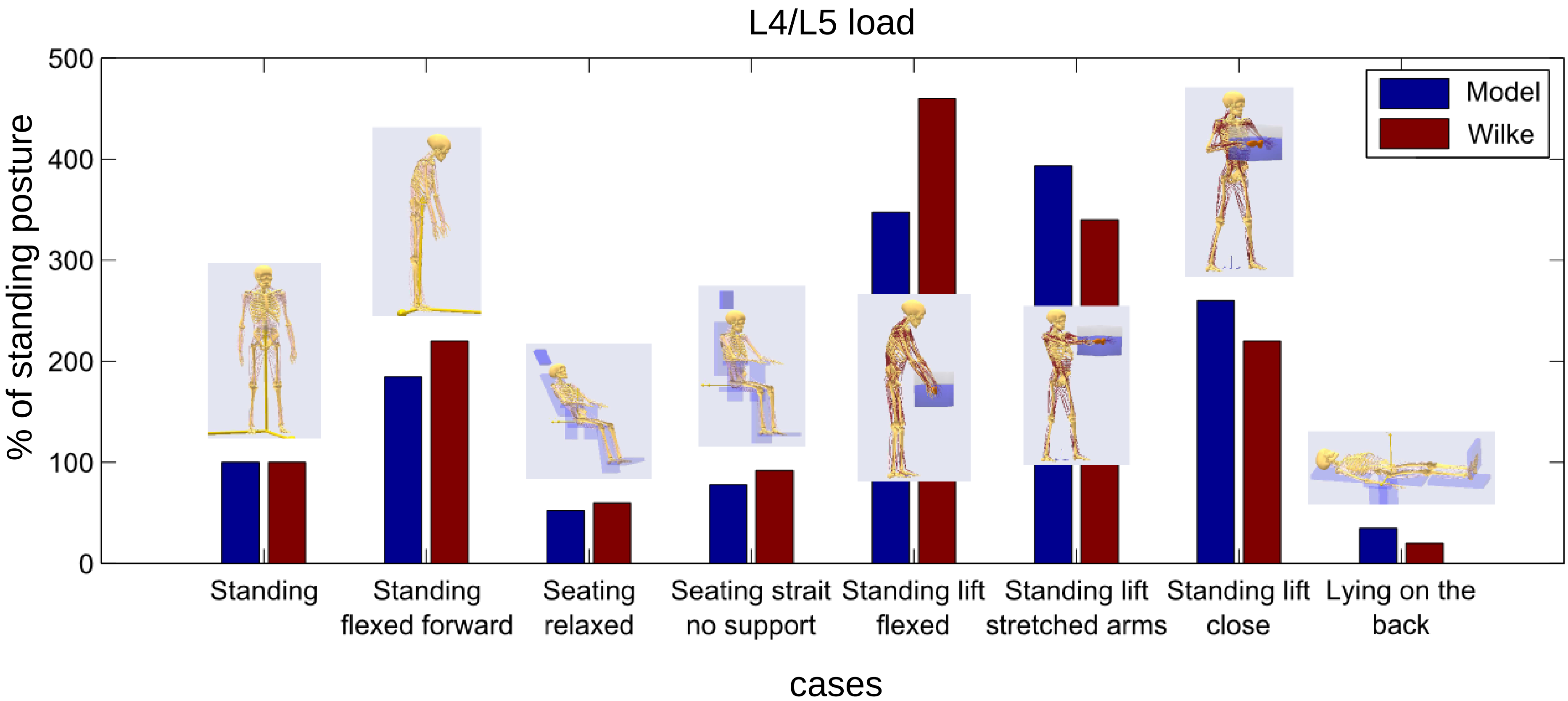




Reminder for questions

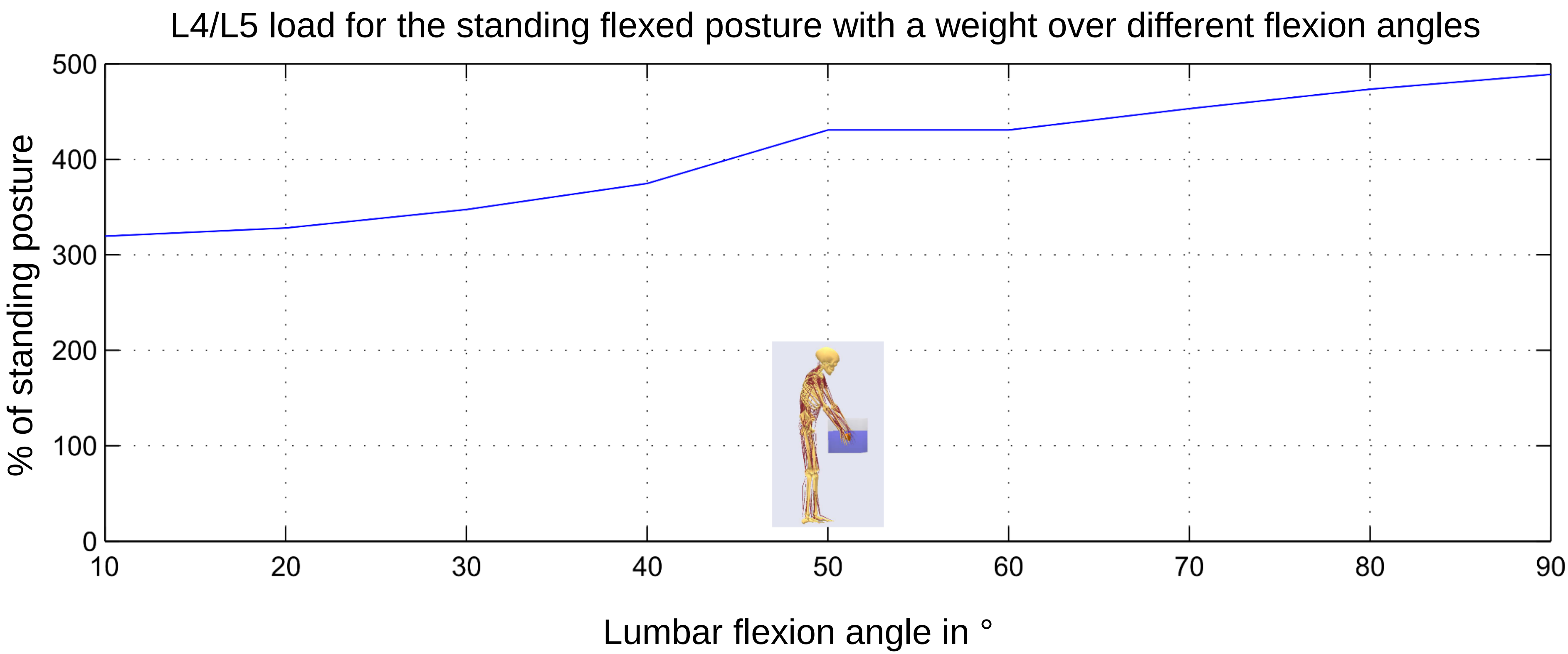


Validation

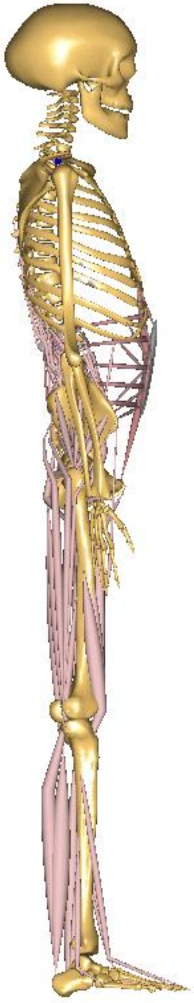


Wilke et al., 2001

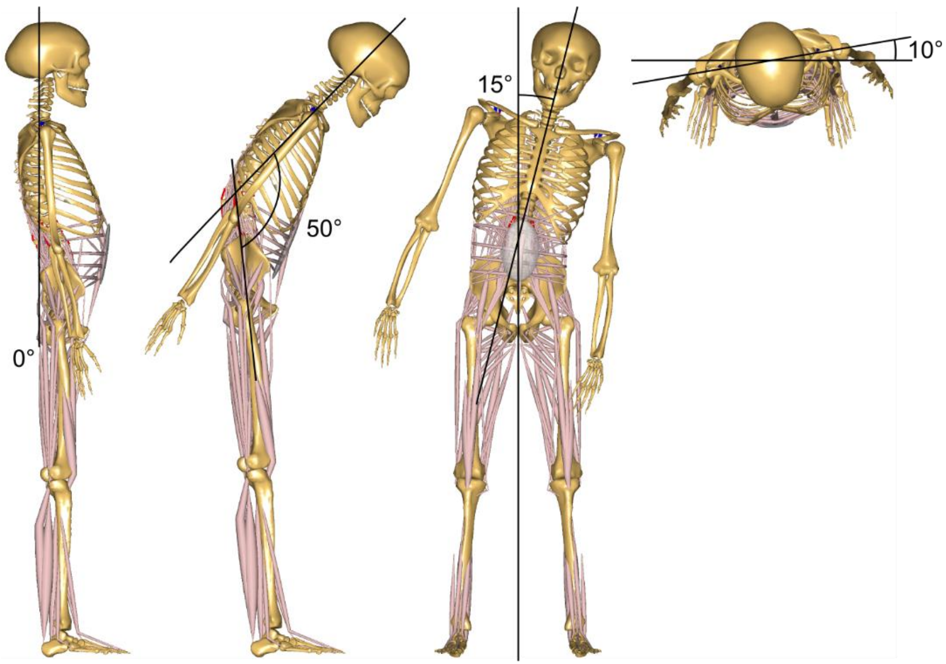
Validation

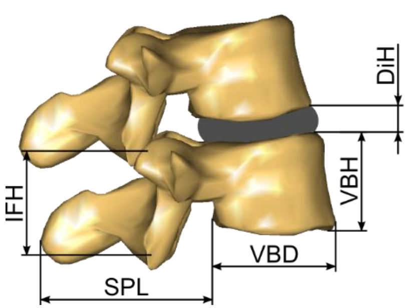

L4/L5 load for the standing flexed posture with a weight over different flexion angles
% of standing posture
0
100
200
300
400
500
10
20
30
40
50
60
70
80
90
Lumbar flexion angle in °

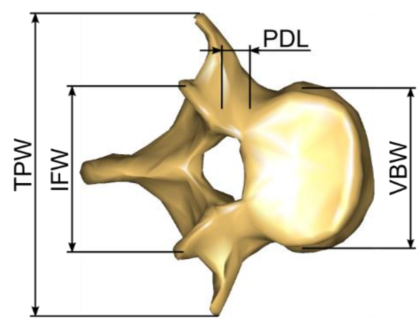
Body movements



Study – Vertebral dimensions



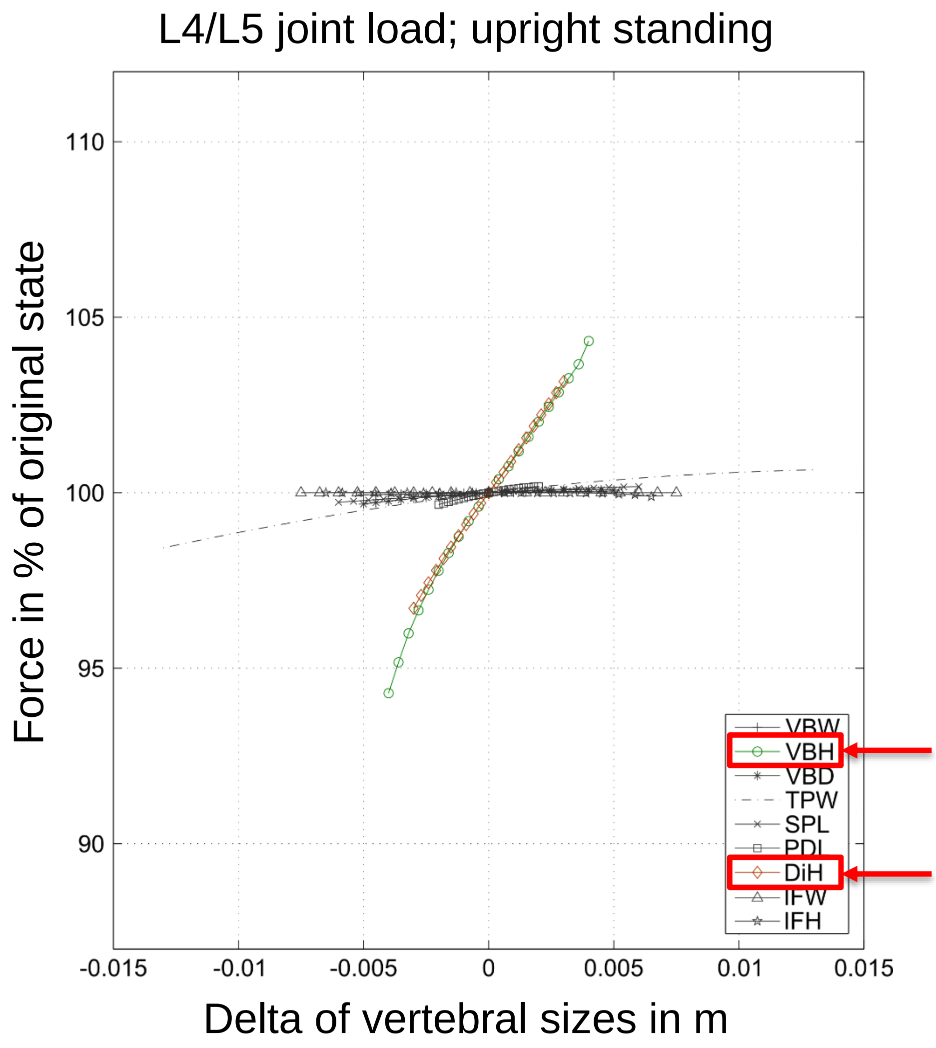


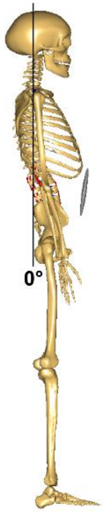


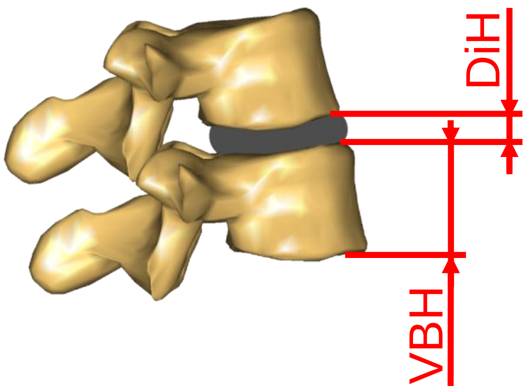
Parameter	Abbreviation	Interval in mm
Vertebral body width	VBW	+/- 5
Vertebral body height	VBH	+/- 4
Vertebral body depth	VBD	+/- 5
Transverse process width	TPW	+/- 13
Spinous process length	SPL	+/- 6
Pedicle length	PDL	+/- 2
Disc height	DiH	+/- 3
Interfacet width	IFW	+/- 7.5
Interfacet height	IFH	+/- 6.5
		Interval in °
Curvature of the lumbar spine (Lordosis angle)	LOR	+/- 5

(Berry et al., 1987; Panjabi et al., 1992; Panjabi et al., 1993; Scoles et al., 1988)

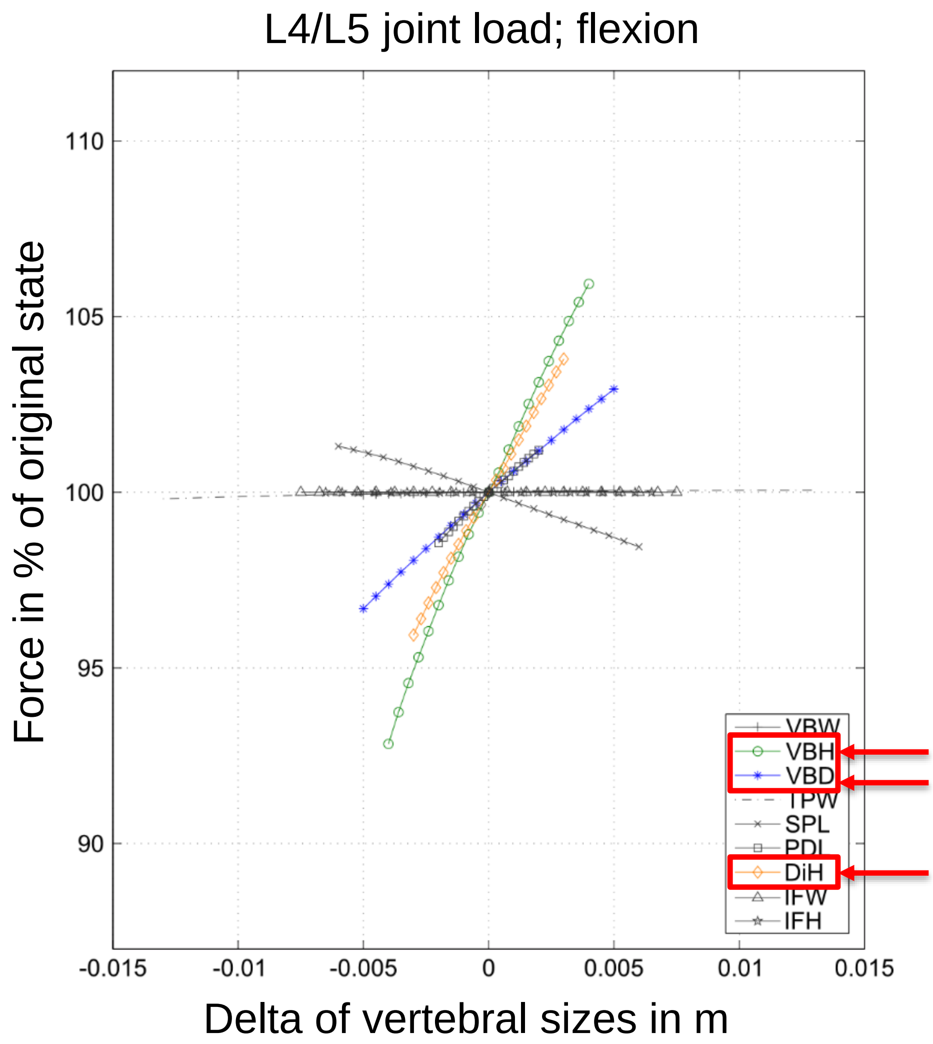
Results – Single Parameter (upright standing)

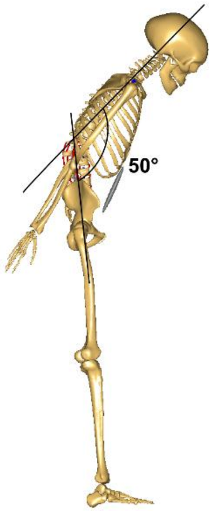


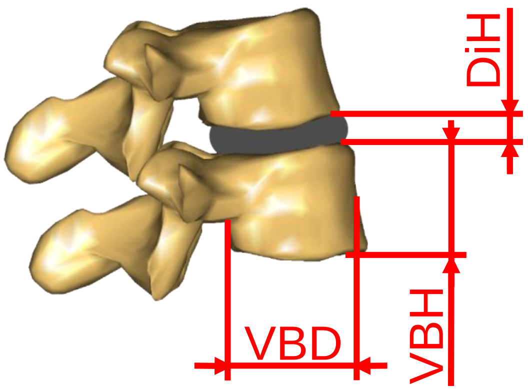




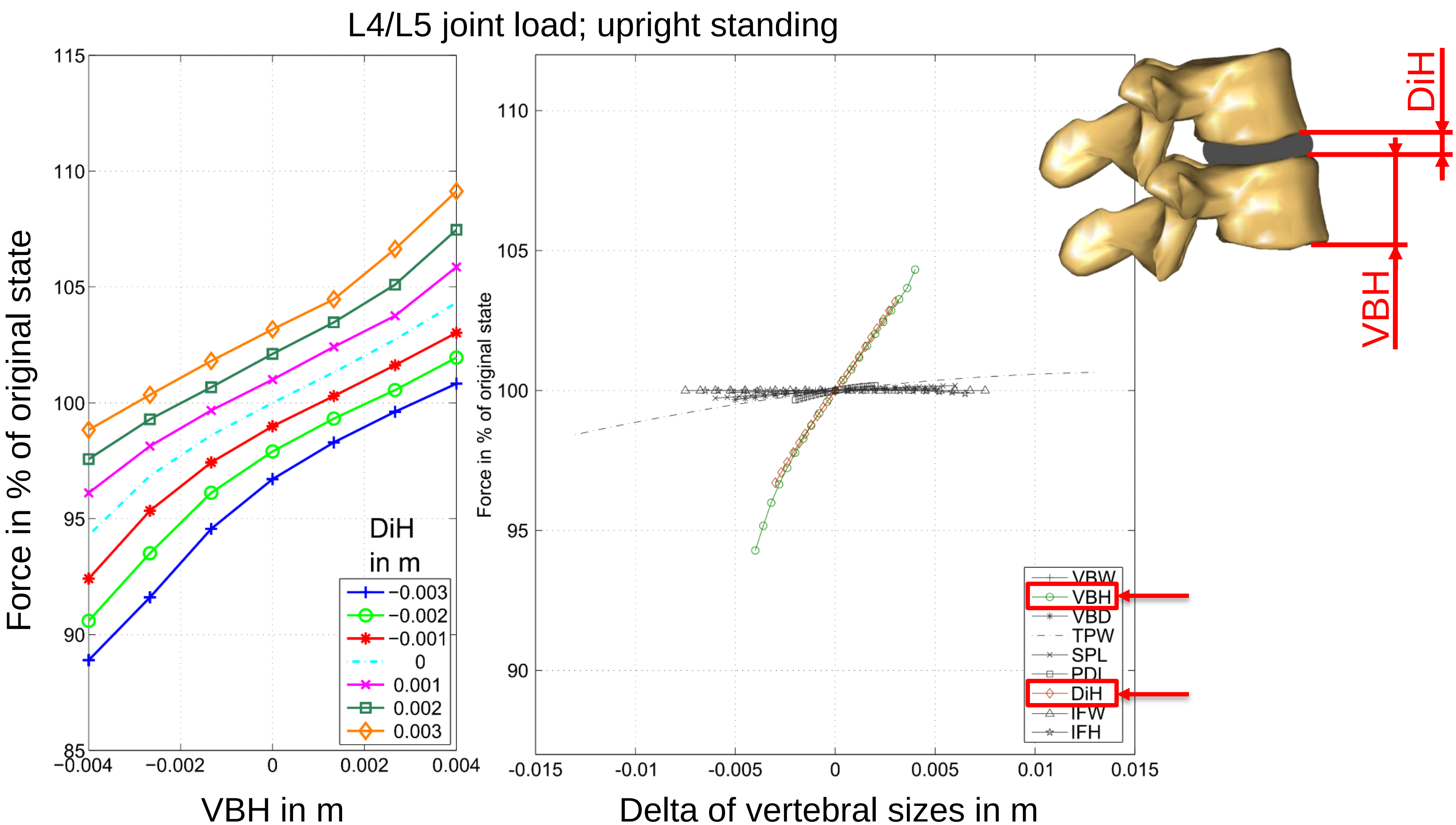
Results – Single Parameter (flexion)



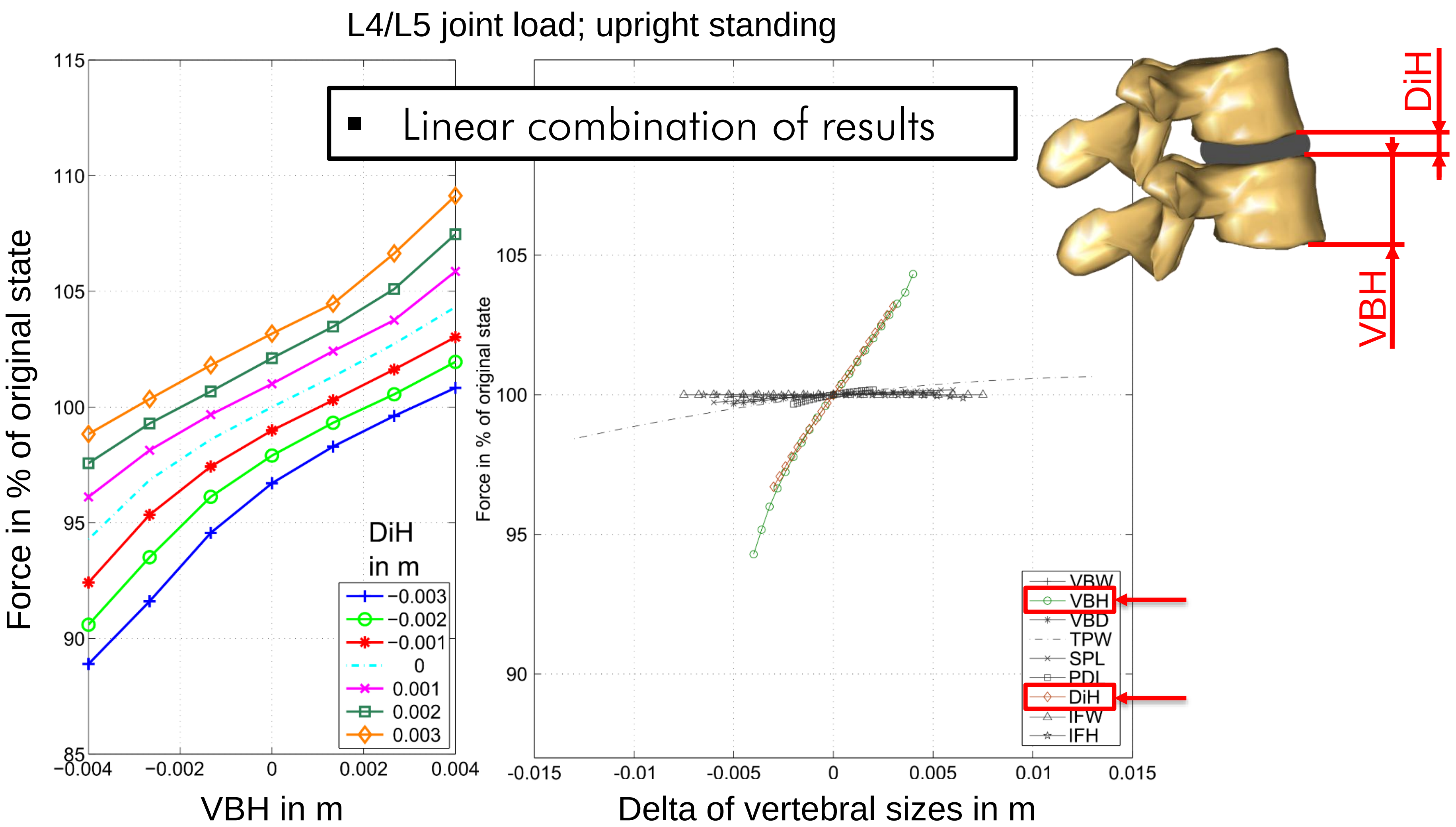




Results – Combinations (upright standing)



Results – Combinations (upright standing)

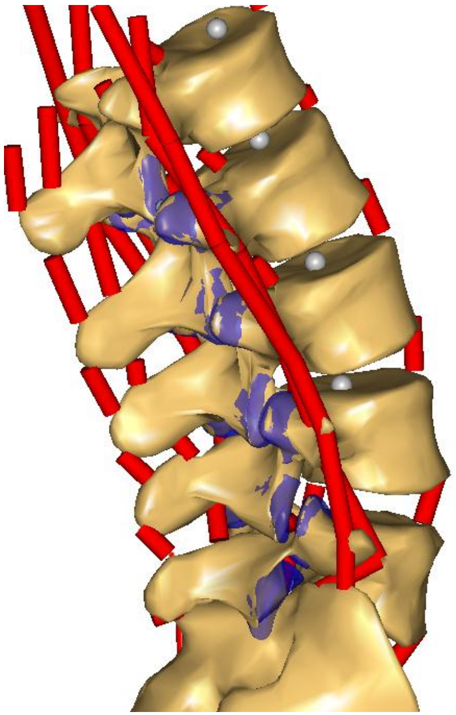


- Linear combination of results

Study – Ligament stiffness

- Constitutive model for ligament force:

$$\boxed{F1 = k \cdot eps1 \cdot L0}$$



- Variation of ligament stiffness (k) (Pintar et al., 1992)
- 3 different subjects (adjusted kinematics)
- Flexion movement

Influence on lumbar disc loading?

Results – Ligament stiffness

Relative changes in disc loading	Subject 1	Subject 2	Subject 3
L3/L4	9%	14%	7%
L4/L5	17%	23%	18%

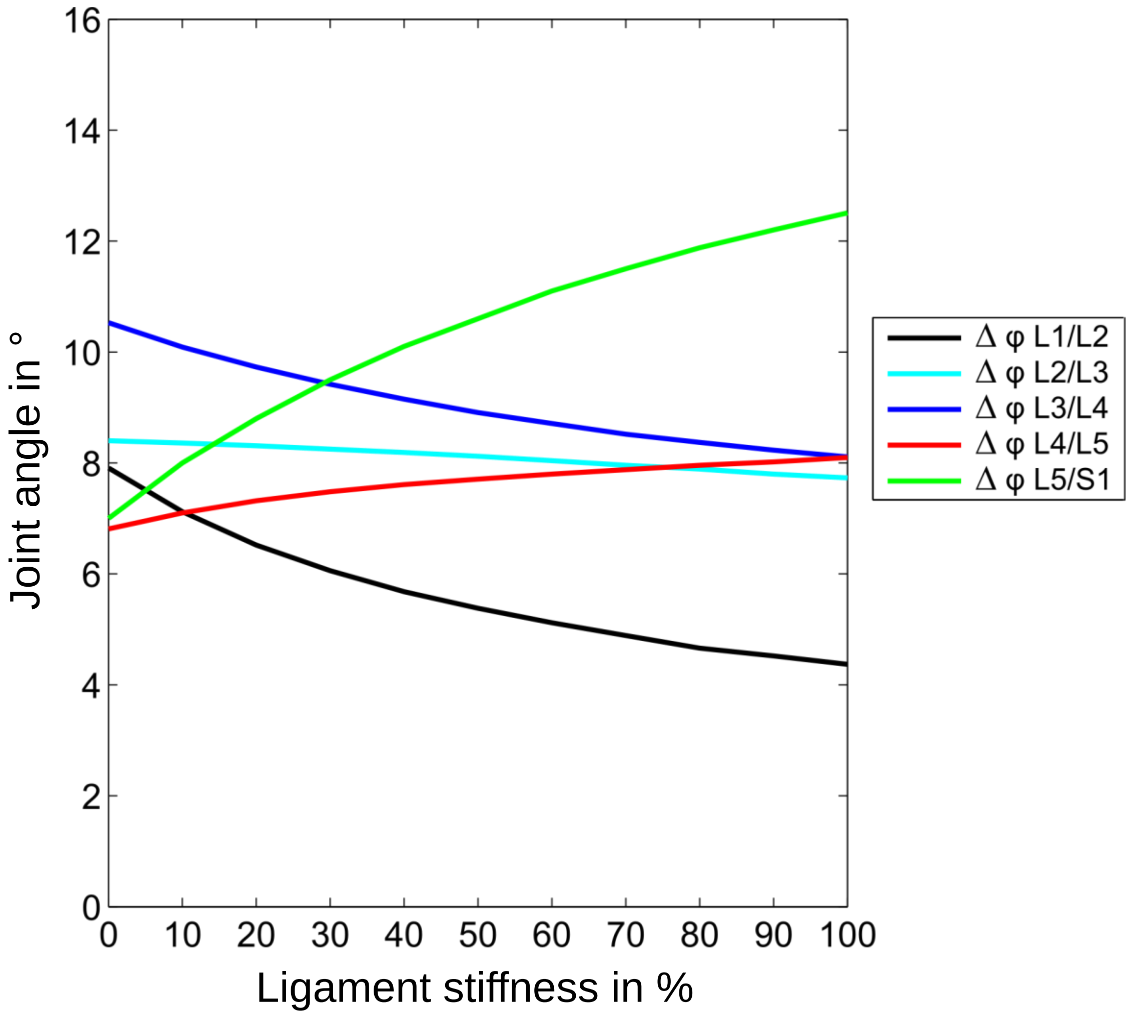
Increased ligament stiffness lead to:

- Increase of loading in ligaments and discs
- Lower disc gets more relative loading

Results – Ligament stiffness

Increasing ligament stiffness:

→ Motion shifts to the lower segments



Conclusion I

- The results indicate that measurements of vertebral body height and depth as well as disc height and curvature of the spine could be sufficient to build a subject-specific model of the lumbar spine.
- Those dimension can be taken from radiographs.
- Lower radiation exposure.
- Fast access to a subject-specific model in pre-operative planning.

Conclusion II

- Increasing ligament stiffness
  - increases disc loading 23%
  - Shifts motion to lower lumbar parts

- Possible clinical implications:
  - Degeneration affects spine kinematics and kinetics in different parts of the spine