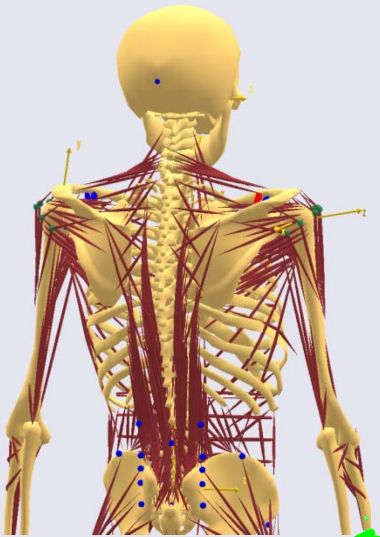
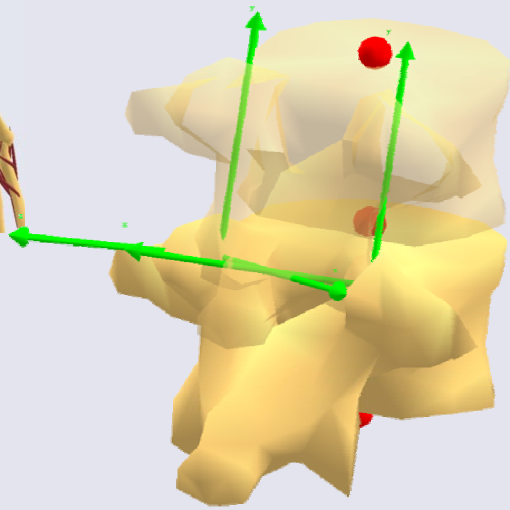
Implementation of facet joints in a detailed musculoskeletal lumbar spine model based on inverse dynamics





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Mark de Zee

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Presenters

Mark de Zee

(Presenter)

Casper Gerner Mikkelsen

(Host)

Sebastian Dendorfer

(Panelists)

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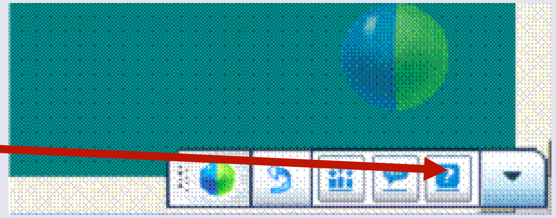

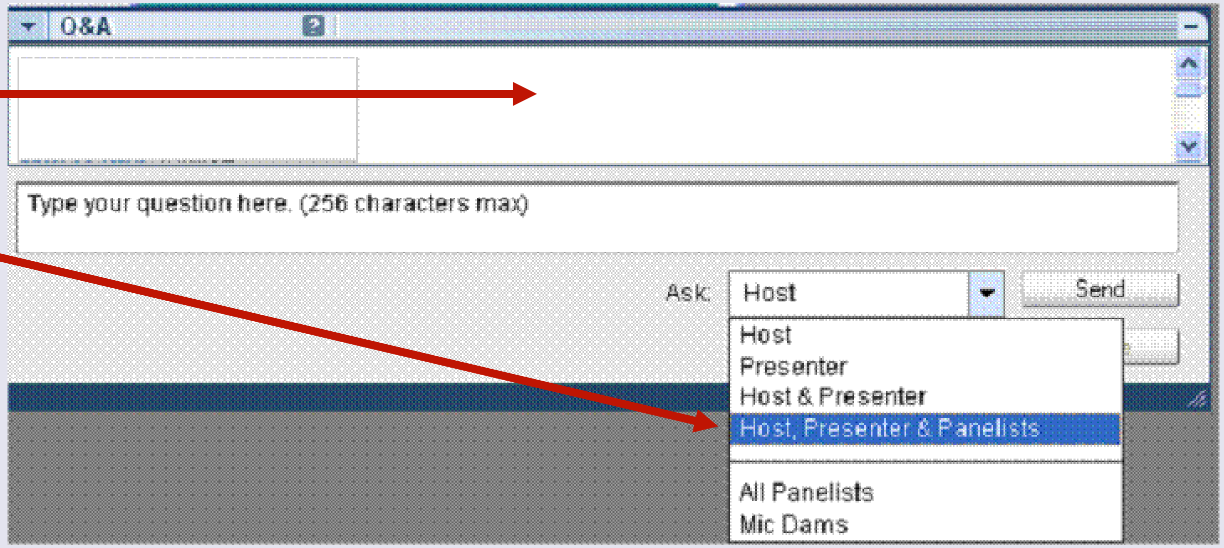

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Co-workers

- Peter Mikkelsen
- Christian Wong
- Erik B. Simonsen
- Michael Voigt
- John Rasmussen

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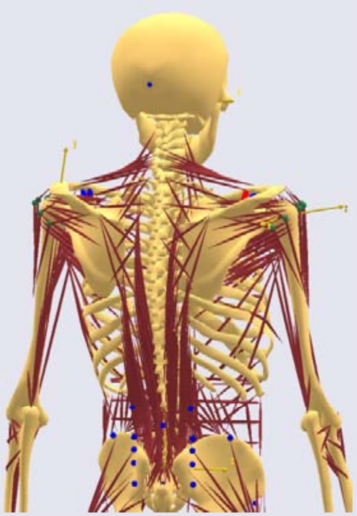
Background

- de Zee M, Hansen L, Wong C, Rasmussen J, Simonsen EB. A generic detailed rigid-body lumbar spine model. *Journal of Biomechanics* 2007; 40(6):1219-1227.
  - Built in the AnyBody Modeling System
  - Rigid-body model based on inverse dynamics and optimization principles
  - 154 muscles



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Articles

Lone Hansen, Mark de Zee, John Rasmussen, Thomas B. Andersen, Christian Wong, Erik B. Simonsen

Anatomy and biomechanics of the lumbar spine with special reference to biomechanical modelling.

Spine 2006; 31: 1888-1899

Mark de Zee, Lone Hansen, Christian Wong, John Rasmussen, Erik B. Simonsen

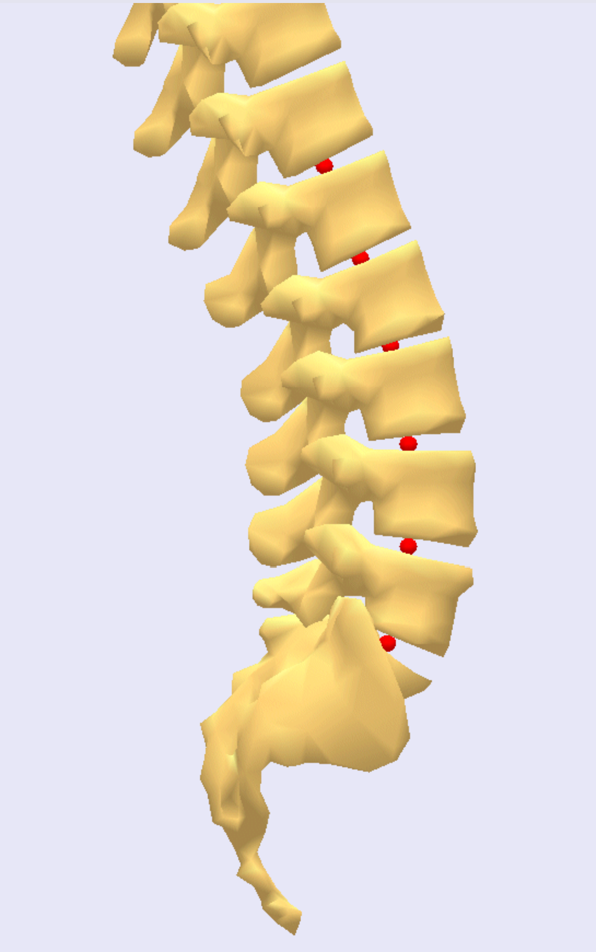
A generic detailed rigid-body lumbar spine model.

Journal of Biomechanics 2007; 40(6):1219-1227.

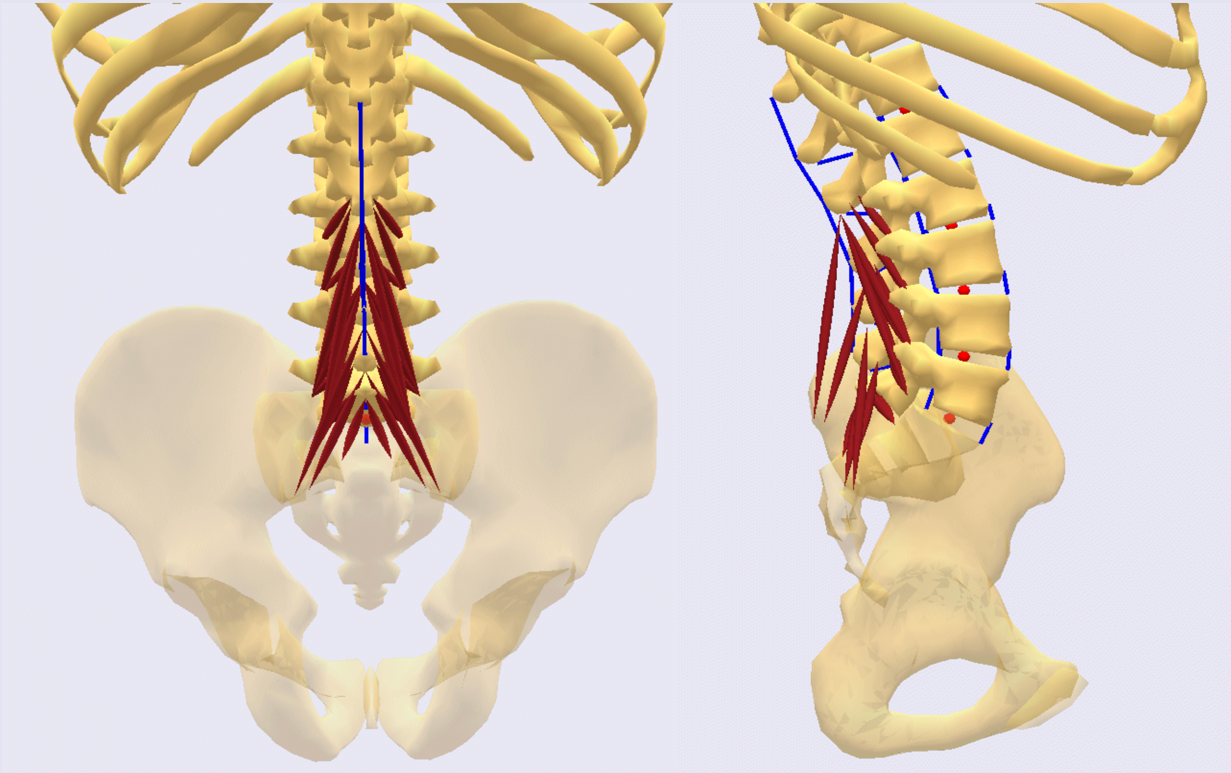
URL: http://dx.doi.org/10.1016/j.jbiomech.2006.05.030

Segments and joints

- 7 rigid segments
  - Pelvis
  - 5 lumbar vertebrae
  - Thoracic part
- Joints between vertebrae
  - 3 dof spherical joint
  - Centre of rotation based on Pearcy and Bogduk (1988)



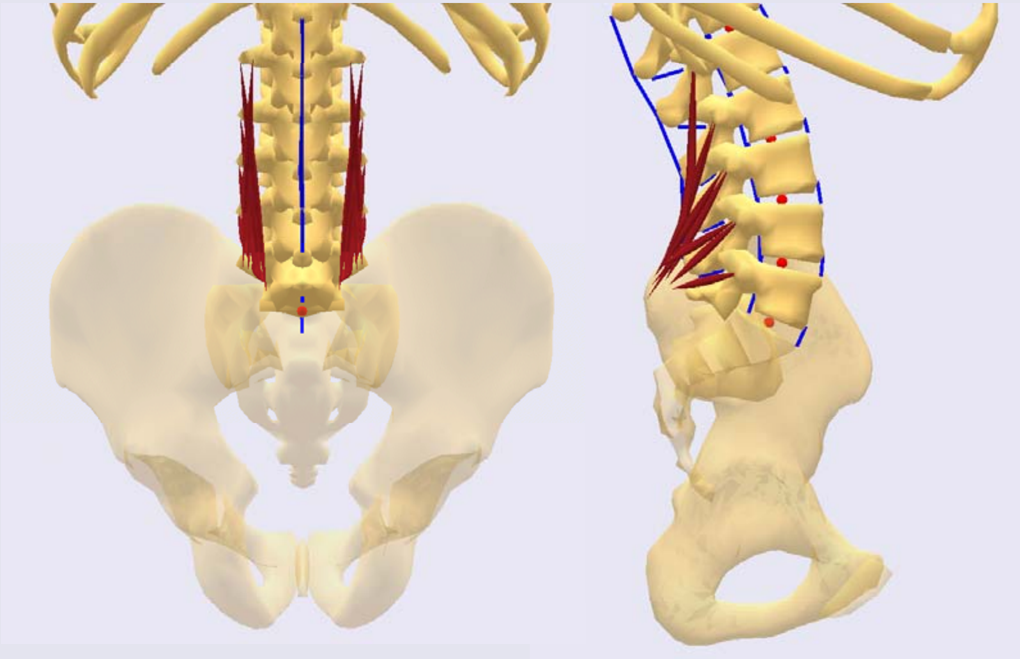
Muscles: multifidi



- 19 fascicles on each side
- Based on information by the group of Bogduk

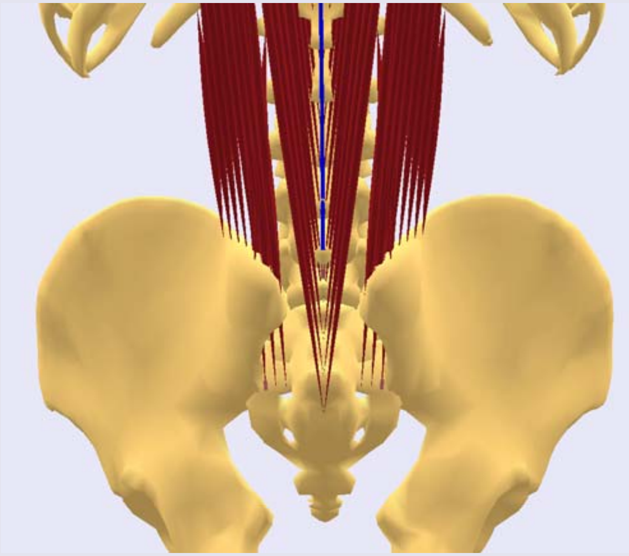
Muscles: erector spinae

- 29 fascicles on each side
- Divided into 4 divisions:
  - Longissimus thoracis pars lumborum
  - Iliocostalis lumborum pars lumborum
  - Longissimus thoracis pars thoracis
  - Iliocostalis lumborum pars thoracis
- Based on information by the group of Bogduk

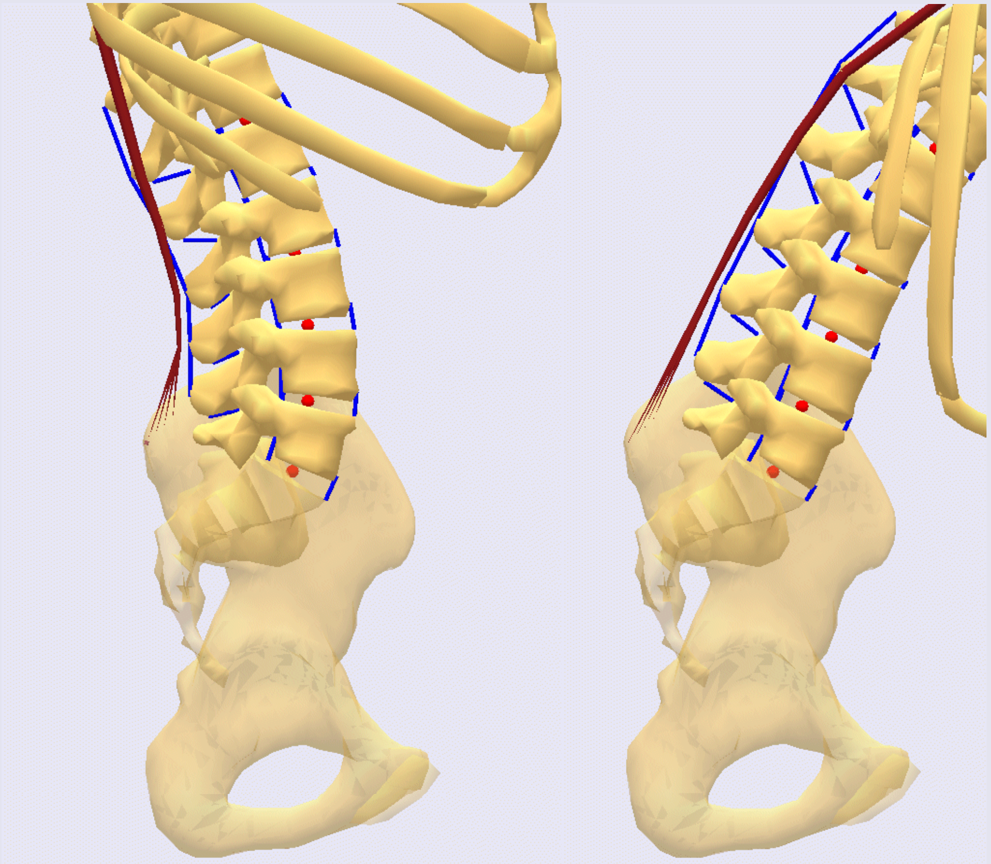


pars lumborum divisions

Muscles: erector spinae



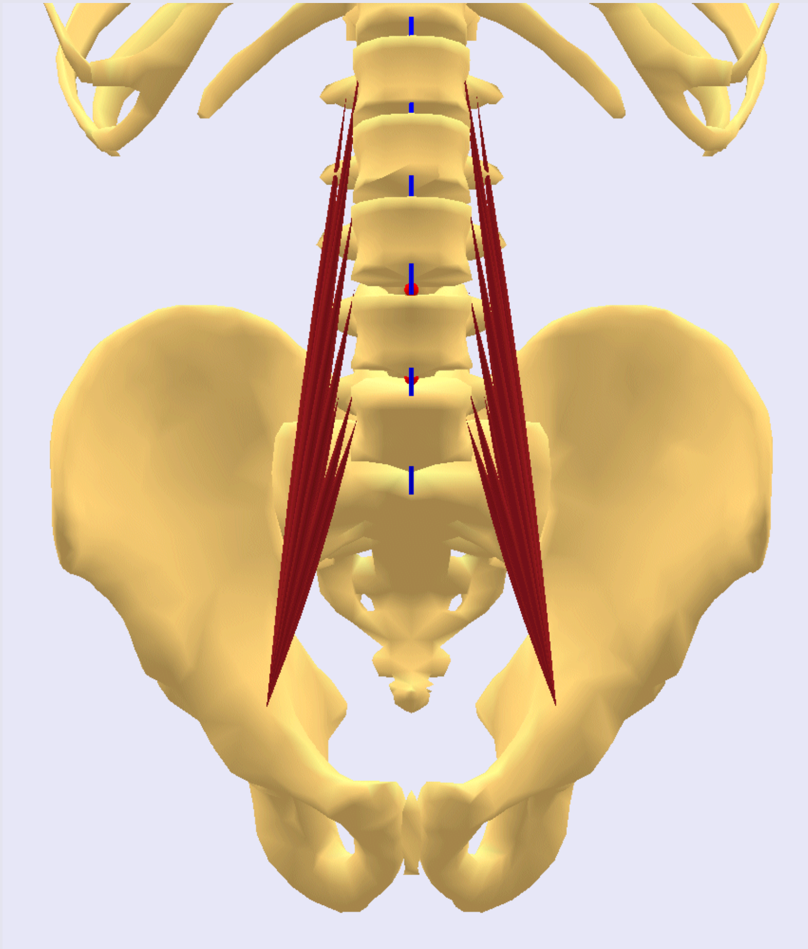
pars thoracis divisions



Effect of fascia thoracolumbale

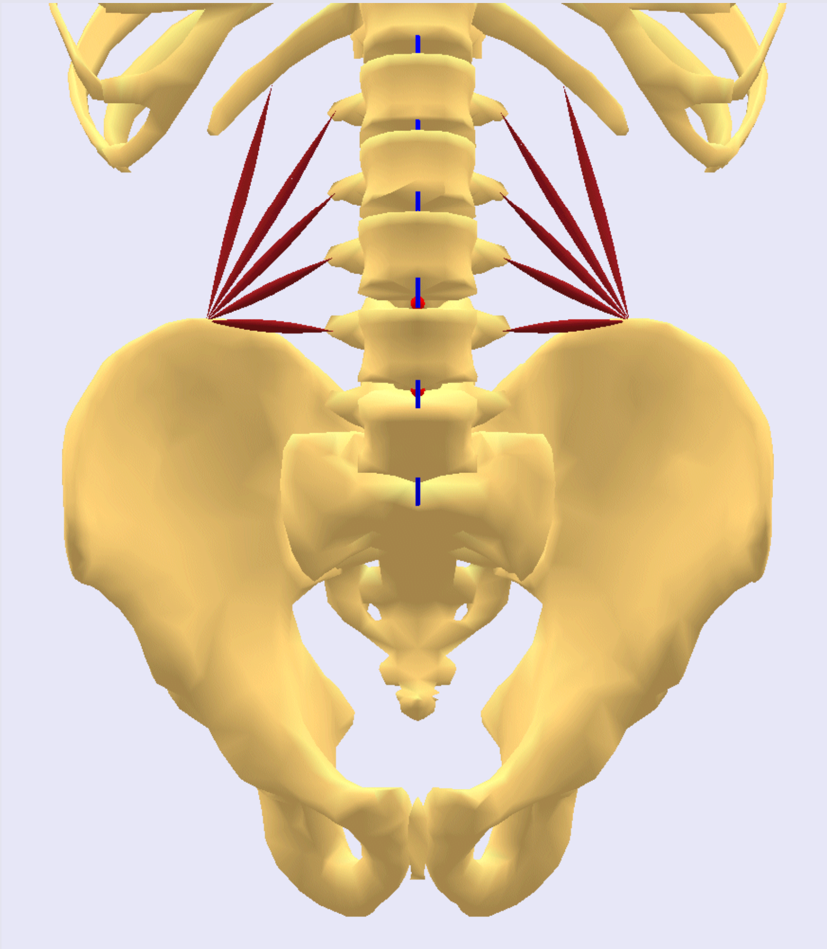
Muscles: psoas major

- 11 fascicles on each side
- Insertion on the femur
- Via point on the pelvis (iliopubic eminence)



Muscles: quadratus lumborum

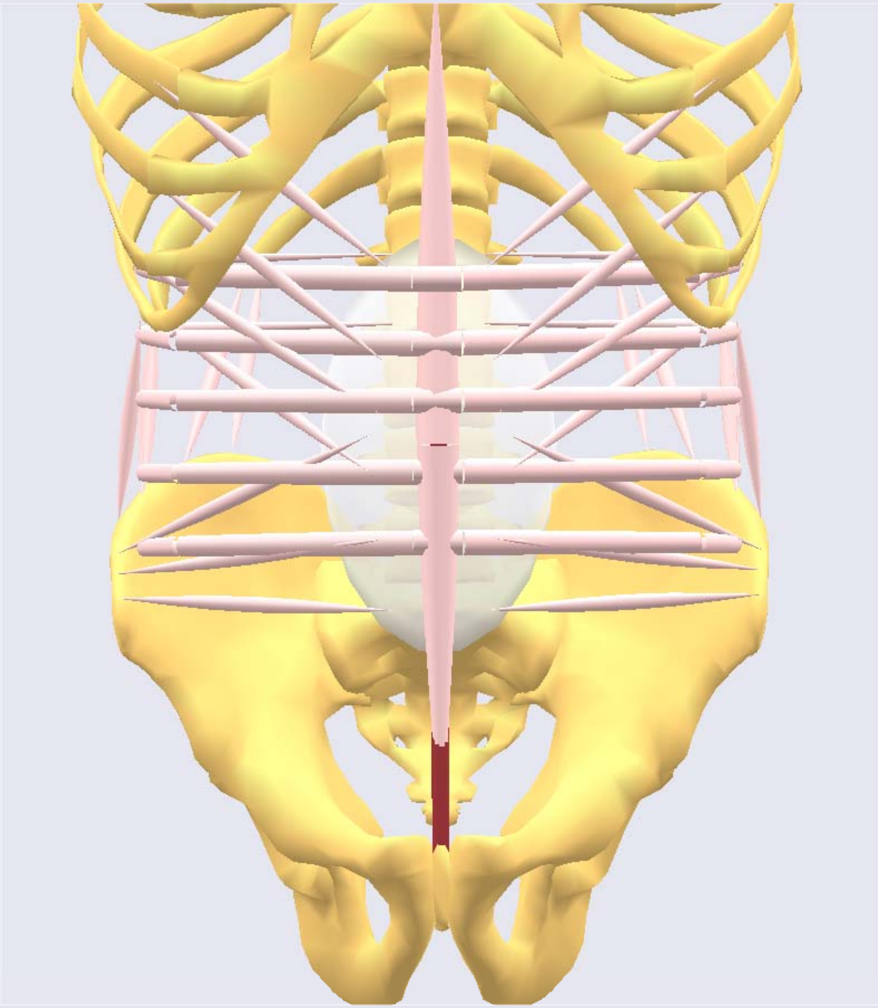
- 5 fascicles on each side
- Based on information by Stokes et al. (1999)



Muscles: abdominal

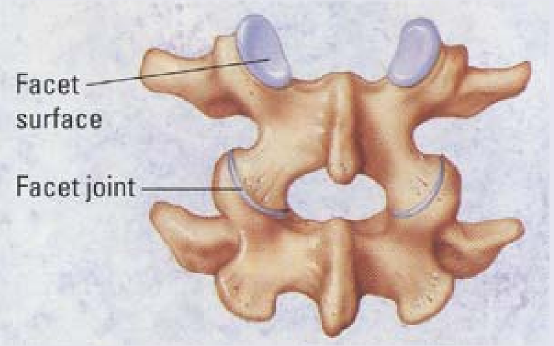
- Rectus abdominis
- Obliquus externus
- Obliquus internus
- Transversus

- The mechanical effect of intra-abdominal pressure



However

- The lumbar model is not equipped with facet joints, which will limit the use of the model
  - Experiments show that facet joints can carry a significant amount of load (Schendel *et al.*, 1993; Sawa and Crawford, 2008)
  - Facet loading will therefore have an effect on the muscle recruitment in an inverse dynamics model and on the estimated reaction forces in the disc



Challenge

- Implementation of facet joints is not straightforward in an inverse dynamics rigid-body model

- The reaction forces in the facet joints depends on both:
  1. The kinematics
  2. Contact conditions
  3. And the muscle forces around the lumbar spine

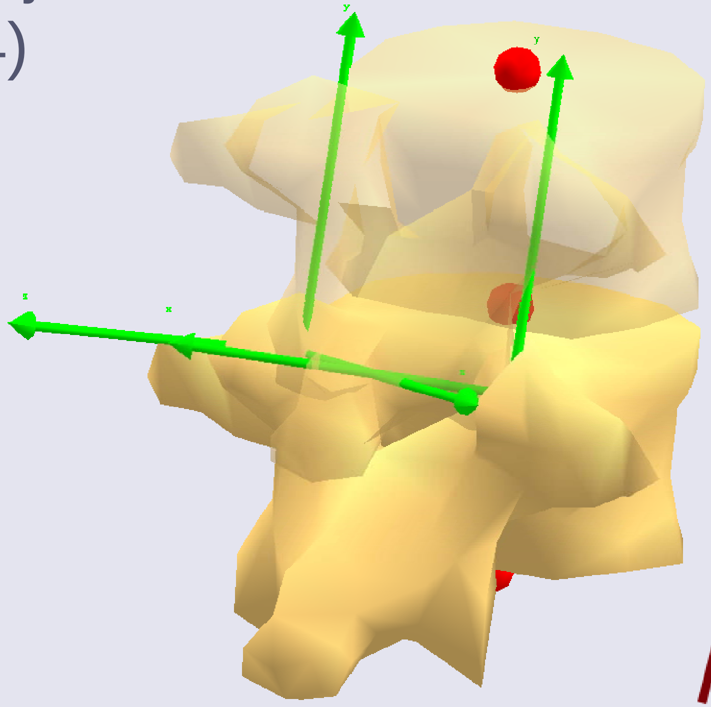
Aim

- To present a new methodology for implementation of facet joints in the lumbar spine musculo-skeletal model based on inverse dynamics

Location and orientation

- Location of each facet joint was defined as a node in the center of the facet contact site on each vertebra.

- Orientation of the facet joints was based on work by Masharawi *et al.* (2004)



Facet reaction forces

- Contact points between the superior and inferior facet joint surfaces can transfer compression forces, only when the distance is zero

- The facet reaction forces are subject to a redundancy problem that is equivalent to the redundant muscle recruitment problem.

The classical redundant muscle recruitment problem

Minimize

$$\max\left(\frac{f_i^{(M)}}{N_i}\right), \qquad i \in \{1,..,n^{(M)}\}$$

"Max muscle activity"

Muscle force

Muscle strength.

Subject to

$$\mathbf{Cf} = \mathbf{d}$$

$$f_i^{(M)} \geq 0, \qquad i \in \{1,..,n^{(M)}\}$$

The redundant recruitment problem incl. facet forces

Minimize

$$\max\left(\frac{f_i^{(M)}}{N_i}\right), \qquad i \in \{1,..,n^{(M)}\}$$

"Max activity"

Unknown unilateral forces

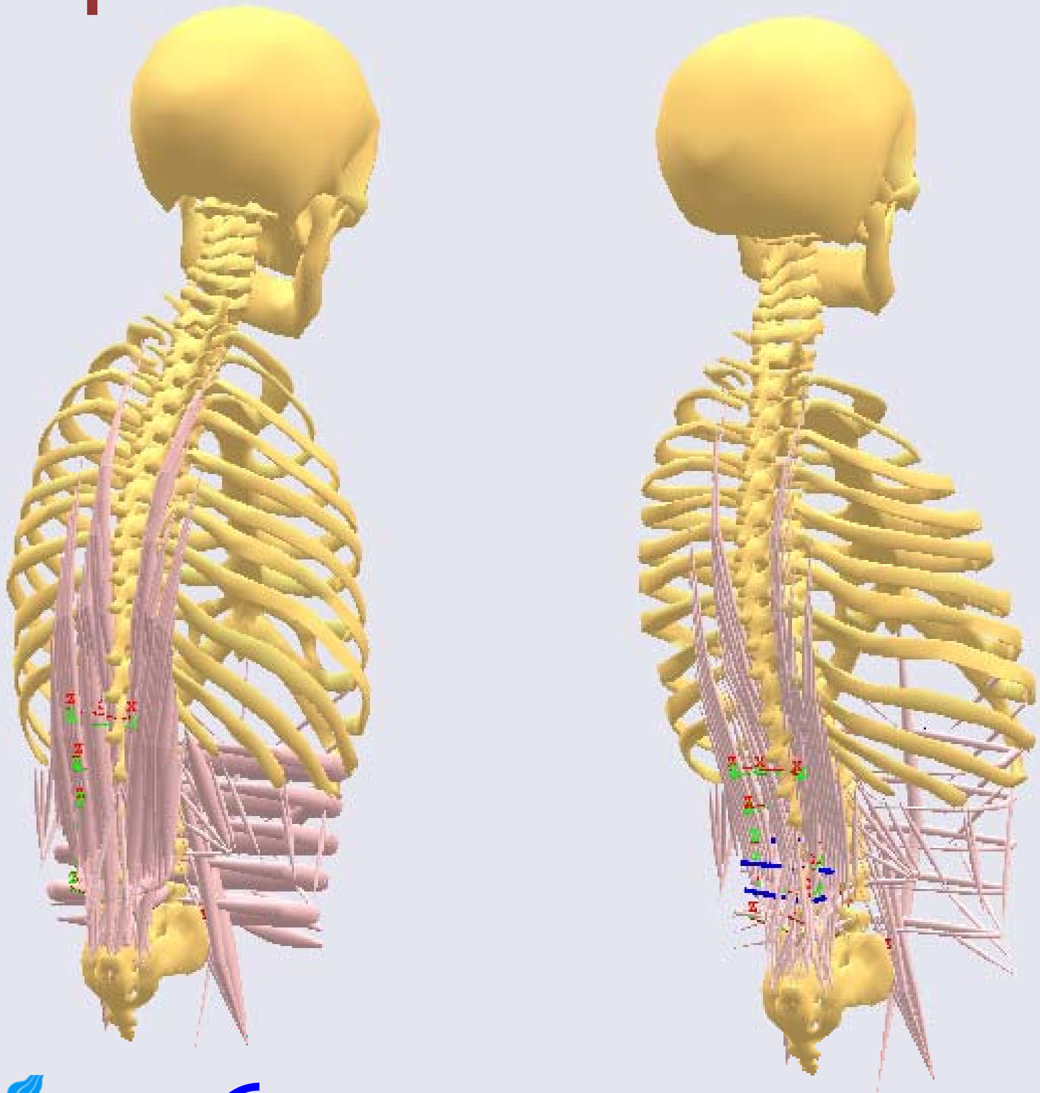
Normalization factor

Subject to

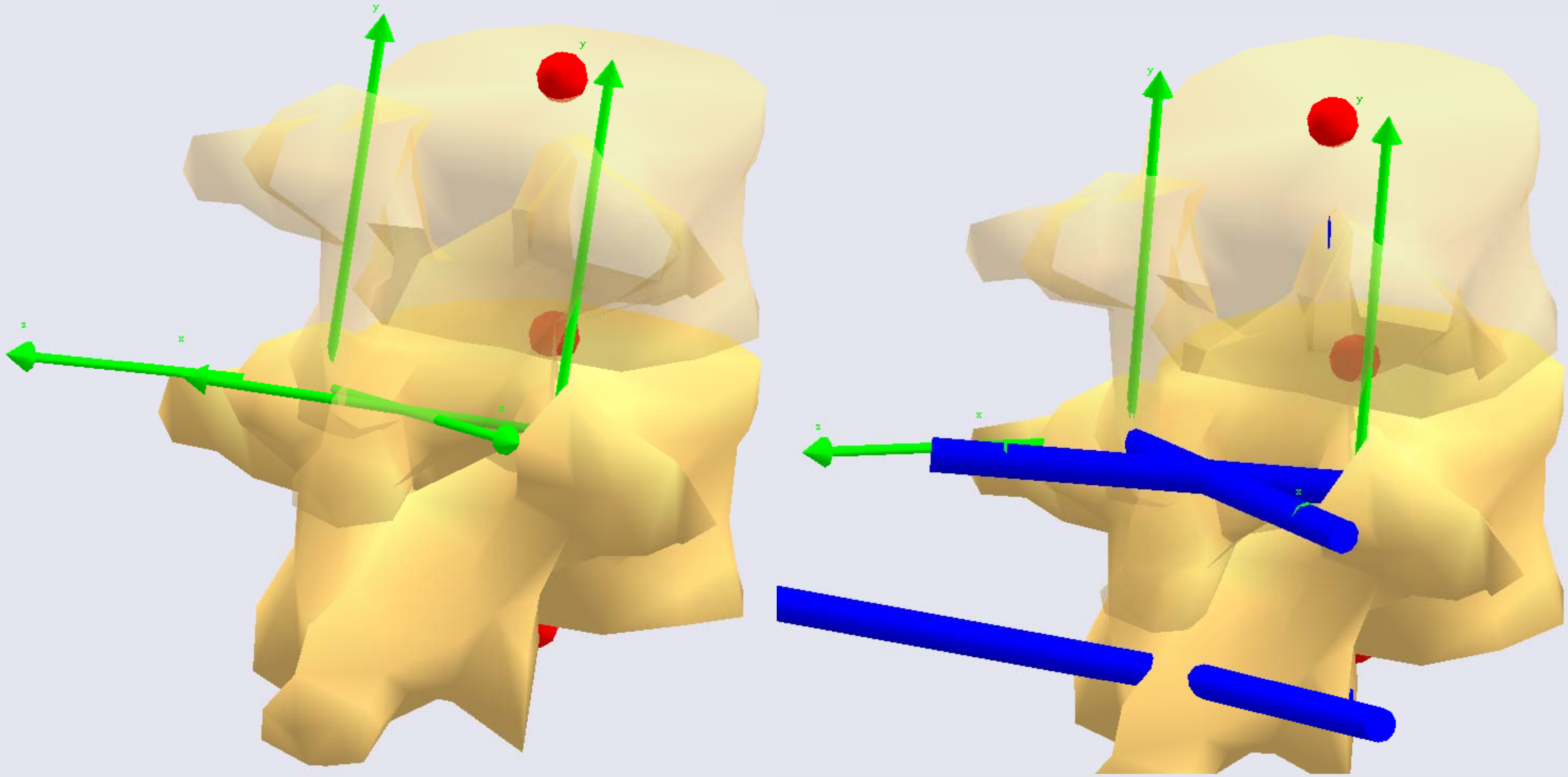
$$\mathbf{Cf} = \mathbf{d}$$

$$f_i^{(M)} \geq 0, \qquad i \in \{1,..,n^{(M)}\}$$

Example: flexion to extension



Example: flexion to extension



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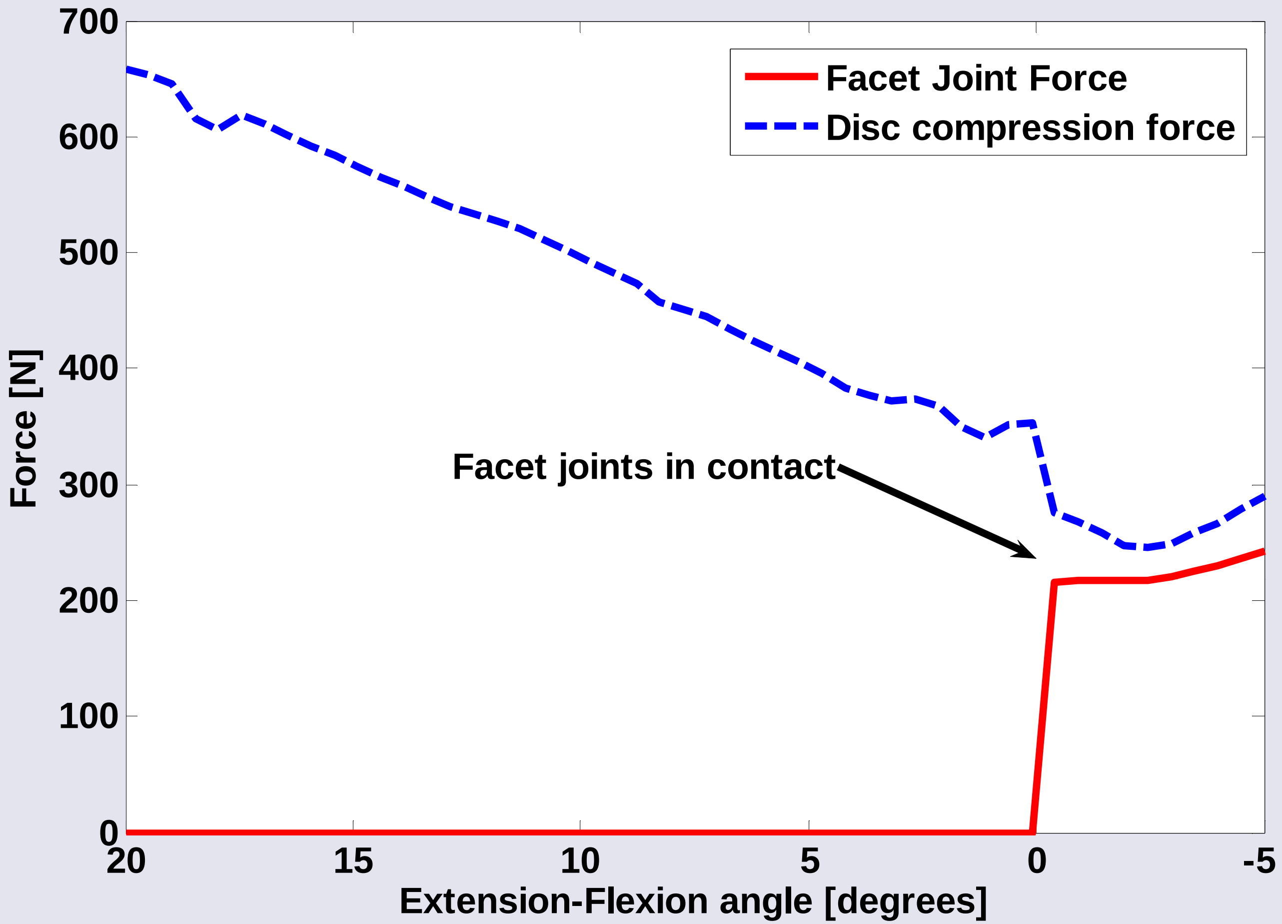
Results example: L2-L3



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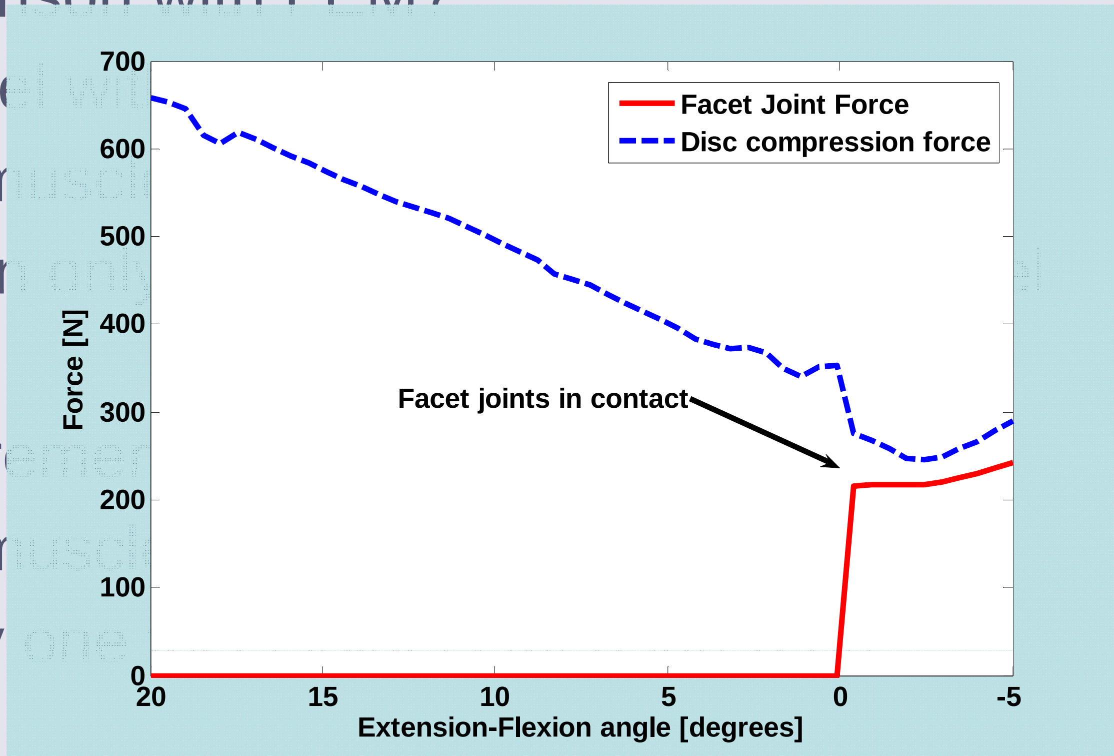
Validation?

- Comparison with FEM?
  - Mode
  - No m
  - Ofte
- Measur
  - No m
  - Only
- In vivo measurements of disc pressure?
  - Indirect



Interesting applications

- One can monitor the development of all facet forces, disc forces and muscle forces in the lumbar spine during dynamic movements
- One could monitor the effect of motor control on loading if one tries to minimize the load on one the facet joints for example in the case of pain

Simulation of pain in facet joints

Minimize

$$\max\left(\frac{f_i^{(M)}}{N_i}\right), \qquad i \in \{1,..,n^{(M)}\}$$

Unknown unilateral forces

Normalization factor:
Lower in case of pain

Subject to

$$\mathbf{Cf} = \mathbf{d}$$

$$f_i^{(M)} \geq 0, \qquad i \in \{1,..,n^{(M)}\}$$

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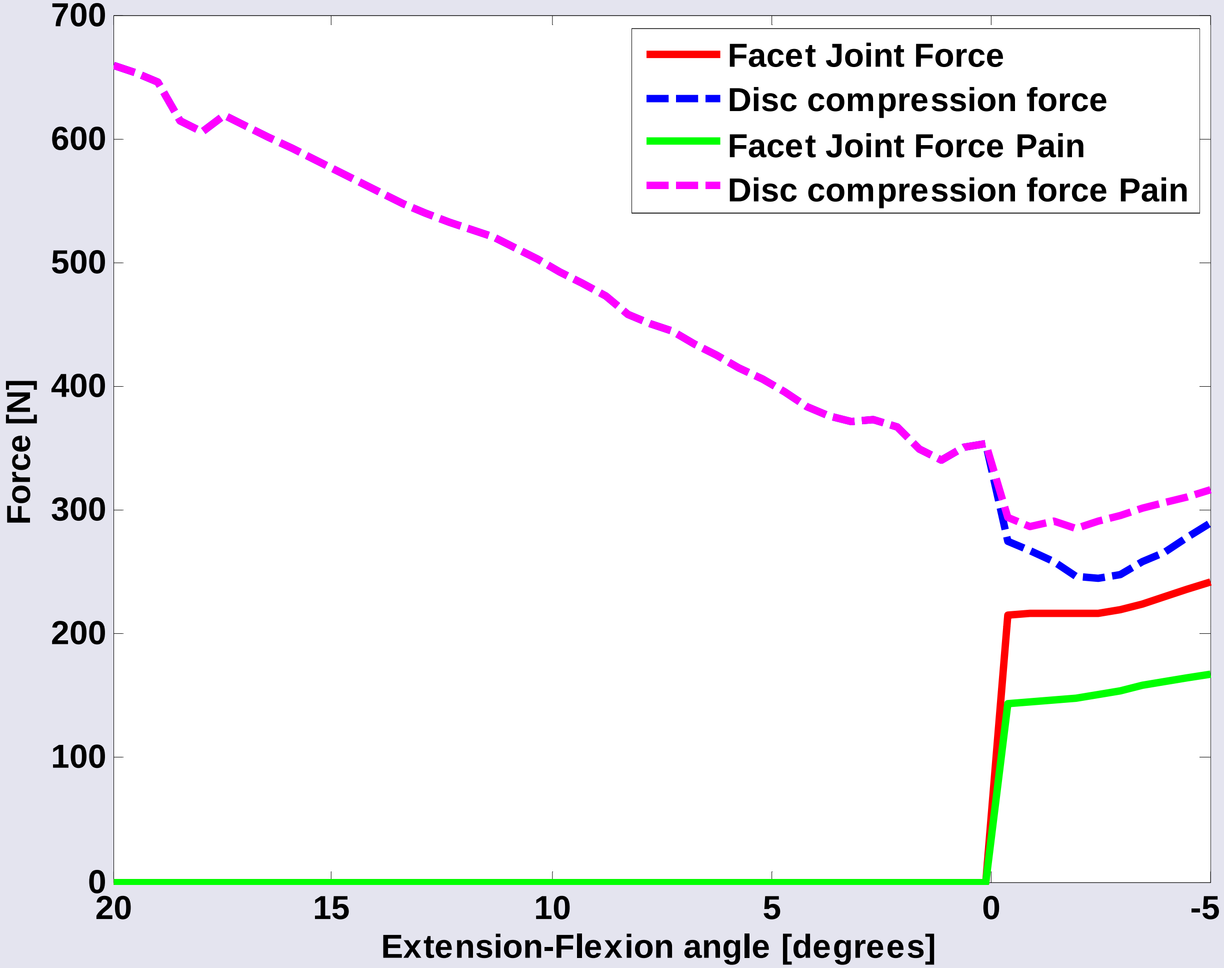
Simulation of pain in facet joints



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Future perspective

Biomechanical Analysis of Prosthetic Discs in the Lumbar Spine

The effect on the surrounding tissue with ideal placement and the tolerance for non-ideal placement dependent on prosthetic design

Background

- Many mechanically related dysfunctions in the lumbar spine are treated by fusing of adjacent vertebrae
- The incidence rate of implanting prosthetic discs in the lumbar spine has been increasing
- However, lacking production quality of the surgical procedure might have a very significant impact on the survival rate of the prosthesis

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Aim

The purpose of this is to investigate the consequence of implantation tolerances and if possible to make recommendations for a minimum production quality of the procedure

Methods

- Musculoskeletal modeling based on inverse dynamics
- With finite element (FE) analysis one can with the use of the estimated muscle and joint forces calculate stresses and strains

Hypothesis

The CoR of the artificial disc is assymmetric

↓

This leads to different moment arms

↓

A change in muscle coordination for a given movement and external load

↓

A change in loading of the surrounding tissues

What needs to be done?

- Validation of the spine model with facet joints
- Parameter study with respect of the CoR

Thanks!

- Center for Sensory-Motor Interaction, Aalborg University
  www.smi.hst.aau.dk
- The AnyBody Modeling System
  www.anybodytech.com
- The AnyBody Research Project, Aalborg University
  www.anybody.aau.dk

Acknowledgements

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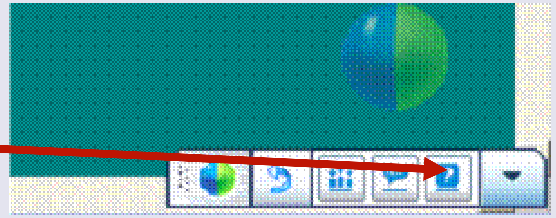

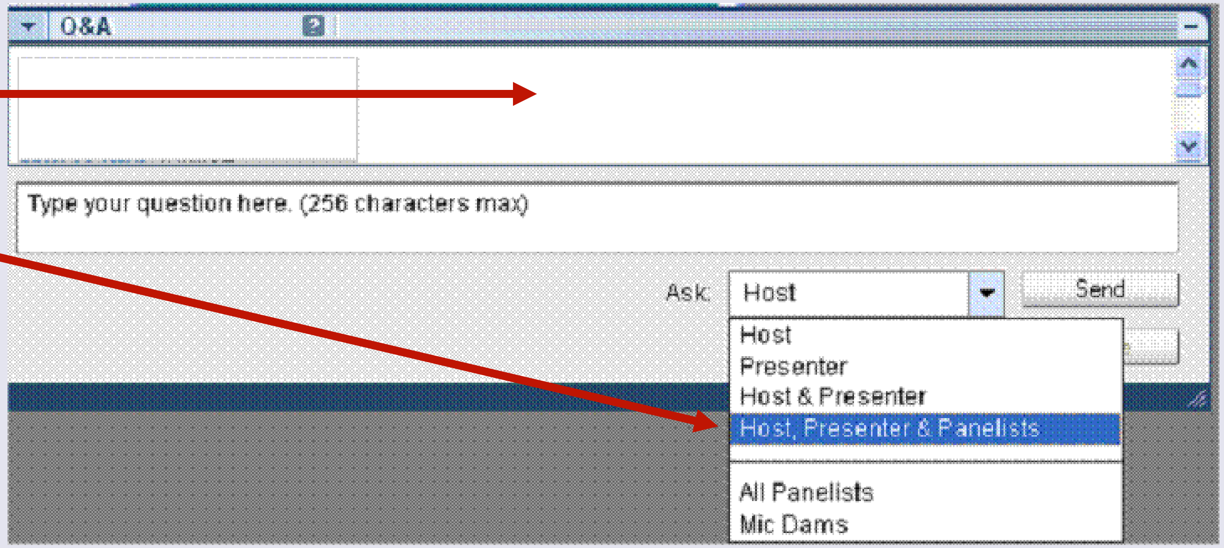

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