A generic detailed rigid-body spine model

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Presenters

Mark de Zee
(Presenter)

Arne Kiis
(Host)

Søren T. Christensen
(Panelist)

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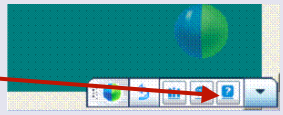
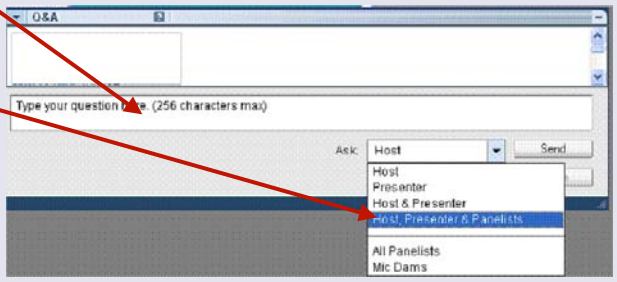
Q&A Panel

- Søren T. Christensen
- Launch the Q&A panel here.
- Type your questions in the Q&A panel.
- Send the question to ”Host, Presenter & Panelists”
- Notice the answer displays next to the question in the Q&A box. You may have to scroll up to see it.





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The presenter: Mark de Zee

Affiliated with:

Institute of Mechanical Engineering
Aalborg University
Denmark

and

Department of Health Science and Technology
Center for Sensory-Motor Interaction (SMI)
Aalborg University
Denmark

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Agenda

- Introduction
- The spine model in detail
  - Joints
  - Muscles
  - Intra abdominal pressure
- Validation
- Future work: Cervical spine
- Q&A session

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The spine project

- Start: 2002
- End: 2004

Funded by the Danish Technical Research Council

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Partners in project

- Inst. of Mechanical Engineering, Aalborg University
  - Mark de Zee, John Rasmussen, Søren T. Christensen
- Inst. of Medical Anatomy, University of Copenhagen
  - Lone Hansen, Erik B. Simonsen
- Danish Institute of Occupational Health
  - Morten Essendrup
- Dept. of Sport Sciences, University of Århus
  - Thomas Bull Andersen
- Dept. of Orthopaedics, University Hospital Malmö
  - Christian Wong

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Introduction

- Several spine models have been introduced:
  - McGill et al., Stokes et al., Daggfeldt and Thorstensson
- Locally developed software
  - Difficult to share
  - Differences in simulation and modelling techniques
  - One has to start all over
    - Define the model – segments, joints, muscles, etc.
    - Develop the equations
    - Implement into software
    - Solve

This can be done automatically by a system.

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Difference with normal approach

- Most research groups start with a problem and build a model to solve that particular problem
- We want to build a general model, which can give information about a number of yet unknown problems

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Our goal

- To develop a general detailed spine model which:
  - can predict muscle and reaction forces in the spine for a given movement.
  - will facilitate sharing of the model.
  - will give the opportunity to scrutinize and improve the model by other groups.

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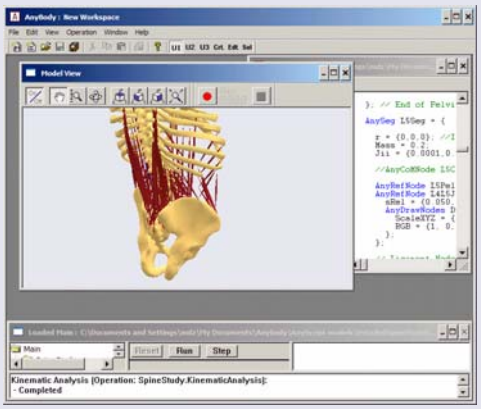
The AnyBody System

(www.anybodytech.com)

- A system for modelling and analysis of the musculo-skeletal system
- Main features
  - Based on inverse dynamics and optimisation principles
  - Built-in model definition language: AnyScript
  - Capable of handling models with hundreds of muscles on personal computers



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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 (in press)

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

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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)

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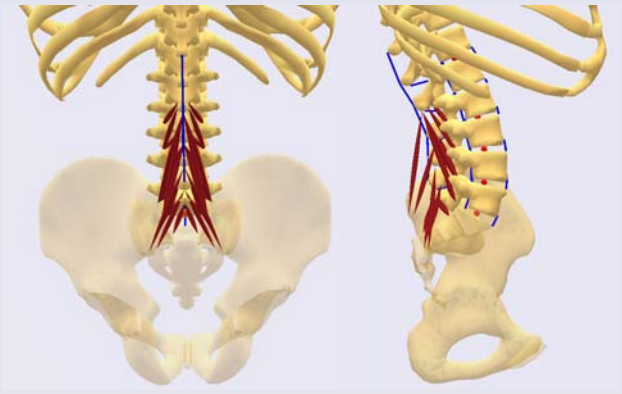
Muscles: multifidi



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

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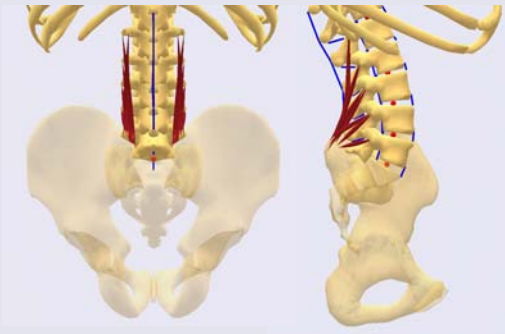
Muscles: erector spinae

- 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

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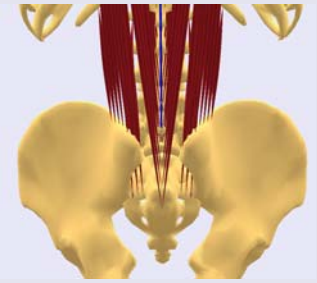
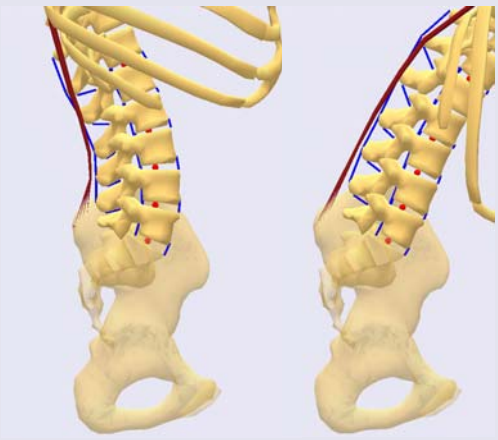
Muscles: erector spinae



pars thoracis divisions



Effect of fascia thoracolumbale

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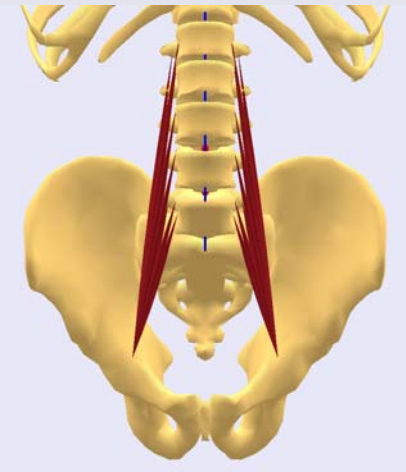
Muscles: psoas major

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



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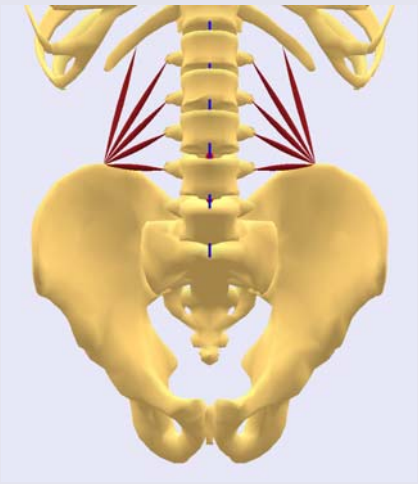
Muscles: quadratus lumborum

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



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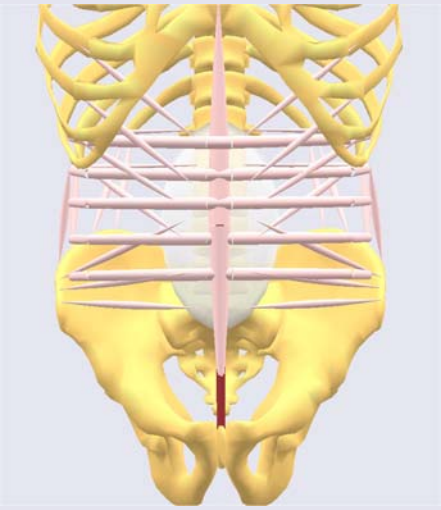
Muscles: abdominal

- Rectus abdominis
- Obliquus externus
- Obliquus internus
- Transversus

- The mechanical effect of intra-abdominal pressure



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Intra abdominal pressure (IAP)

- Daggfeldt and Thorstensson have shown that the IAP can unload the spine.
- The unloading mechanism can be viewed as a pressurised column pushing the rib cage and pelvis apart (quoted from Daggfeldt and Thorstensson, J.Biomech. 30: 1149-1155, 1997).
- Transversus is by far the most important muscle to create this pressure.

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IAP design requirements

- Needs to be an integral part of the whole muscle recruitment.
- It should be possible to turn it off.

Main assumptions

- Only the transversus muscle can generate abdominal pressure.
- The pressurized column is idealized as a cylinder.

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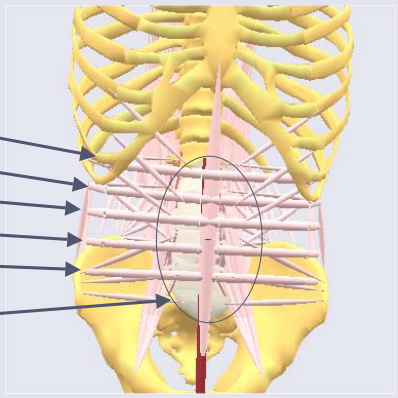
Segments in abdominal model

Five disks each attached to a vertebra using a spherical joint

Disk 1
Disk 2
Disk 3
Disk 4
Disk 5

Buckle segment
(mimics the rectus sheath)



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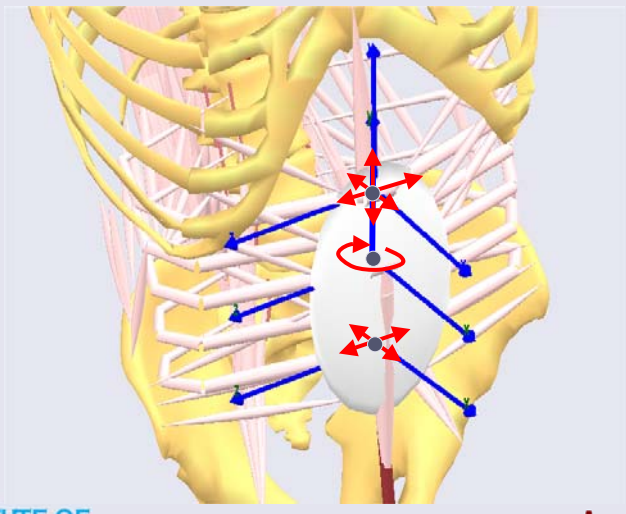
Kinematics of the buckle

The buckle is an assembly point for all the abdominal muscles from different directions



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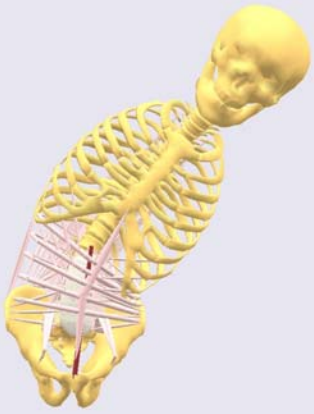
Kinematics



Abduction adduction

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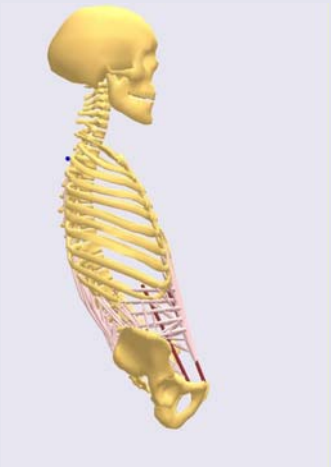
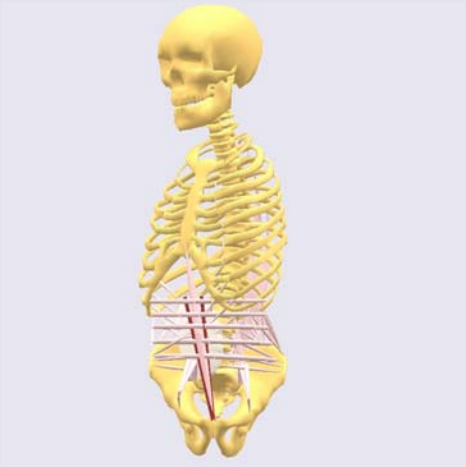
Kinematics



Flexion-Extension



Rotation

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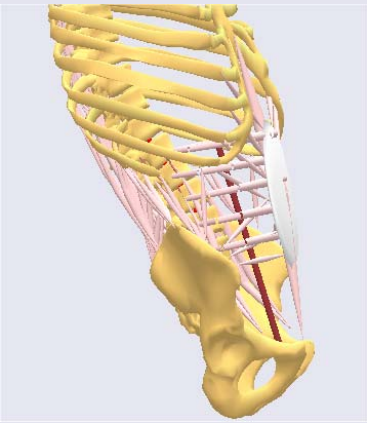
Abdominal pressure

The IAP is modelled as a constant volume.

Pushes on the thorax and the pelvic floor when the transversus muscles squeeze this volume and extends the spine.

The transversus can therefore work as an indirect spine extensor and become part of the whole recruitment problem.



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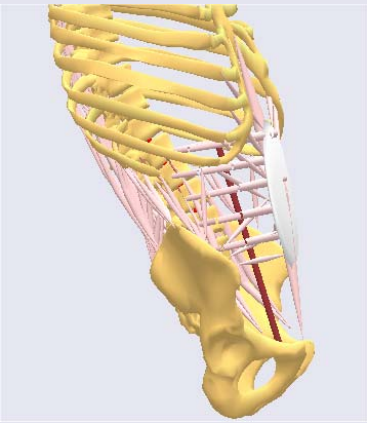
Abdominal pressure

The limit of the IAP was set to 26.6 Kpa based on measurements on well-trained subjects.

Morten Essendrop

Significance of intra-abdominal pressure in work related trunk loading.

2003, Ph.D. Thesis, National Institute of Occupational Health, Denmark



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Validation

- Always a big challenge, especially with so many parameters
- As a first approach we looked at the maximum extension moment
- Second a comparison was made with in vivo intradiscal pressure measurement of the L4-5 disc available from the literature

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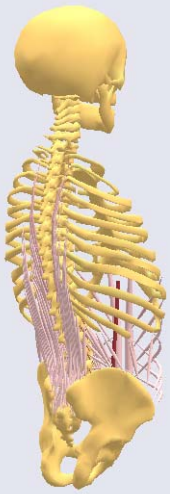
Increasing force on thorax



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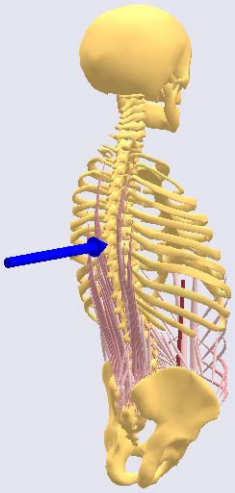
Increasing force on thorax



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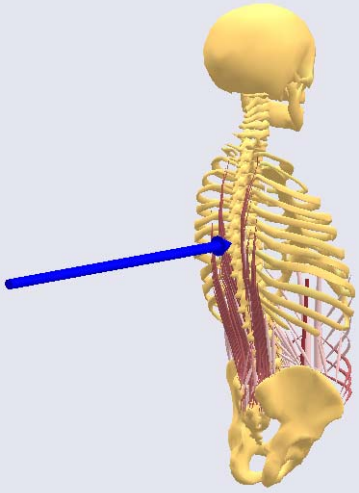
Increasing force on thorax



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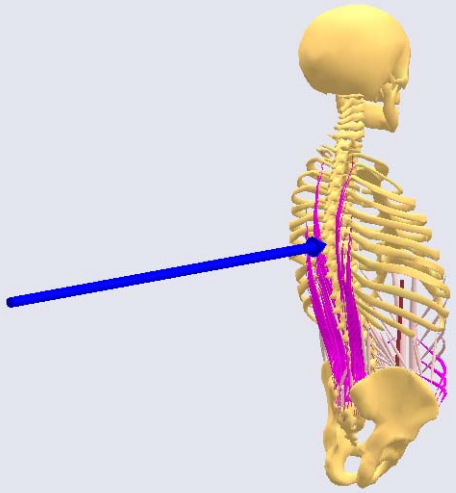
Increasing force on thorax



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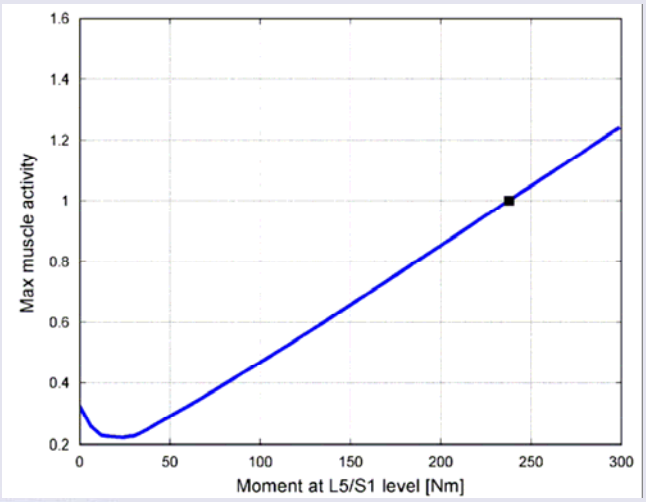
Maximum extension moment



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Results

- Maxium extension moment around L5/S1:
  - 238 Nm
- Axial force in L5/S1 disc:
  - 4520 N
- Shear force in L5/S1 disc:
  - 639 N

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Comparison with intradiscal pressure measurement

Wilke H, Neef P, Hinz B, Seidel H, Claes L

Intradiscal pressure together with anthropometric data – a data set for the validation of models.

Clinical Biomechanics 2001; 16 (Suppl. 1): S111-S126.

URL: http://dx.doi.org/10.1016/S0268-0033(00)00103-0

1.8 MPa in the L4-5 disc when holding a crate of 19.8 kg

Disc area: 18 cm^2

Axial force: 3240 N

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Comparison with intradiscal pressure measurement

Measurement

1.8 MPa in the L4-5 disc when holding a crate of 19.8 kg

Disc area: 18 cm^2

Axial force: 3240 N

Model estimation

Without IAP:

3410 N

With IAP turned on:

2776 N

IAP unloads the spine by roughly 18 %

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Flexibility of the model

- There are still some uncertainties in the IAP model
  - Easy to turn it on and off
- The influence of the ligaments might be limited
  - Easy to include ligaments if you have the right parameters
- Force-length relations of muscles
  - Easy to switch to a complex model with these relations if you have the necessary parameters

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Future/ongoing work

The cervical spine

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Why the neck?

- Lots of people have neck and shoulder problems.
- Working postures

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Why the neck?

- Our heads are comparatively heavy.
- Muscles must stabilize the cervical spine.

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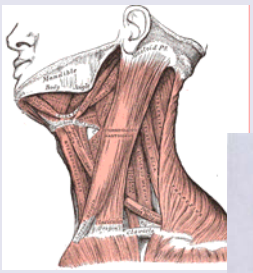
Development of the neck model

- Complex mechanical system.



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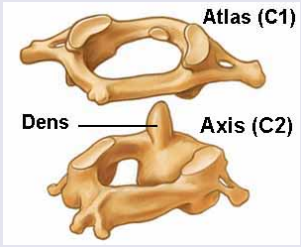
Development of the neck model

- Seven vertebrae



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Development of the neck model

Based on a neck model described in a PhD thesis written by **Marike van der Horst**

Human Head Neck Response in Frontal, Lateral and Rear End Impact Loading – modelling and validation

ISBN: 90-386-2843-9

URL: http://alexandria.tue.nl/extra2/200211336.pdf

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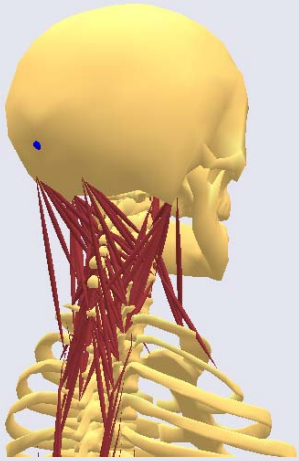
Development of the neck model

- We need approximately 140 muscles.



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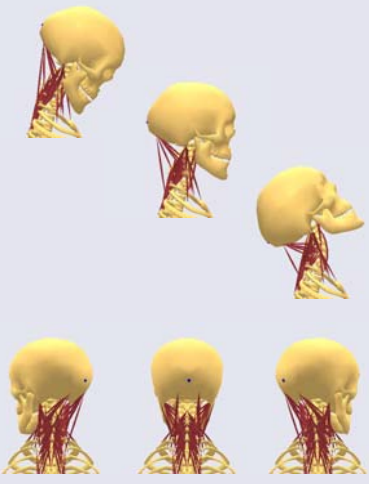
Development of the neck model

- Also this model will become available in the public repository
- Validation experiments in the beginning of next year
- Probably with the use of wire electrodes to measure EMG
- We also plan to include facet joints both in the cervical and lumbar spine



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We hope, that the model will be

- downloaded
- improved
- validated for particular purposes
- used for solving research questions

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Thanks!

- Papers, references and models: www.anybody.aau.dk
- Software downloads and documentation: www.anybodytech.com

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