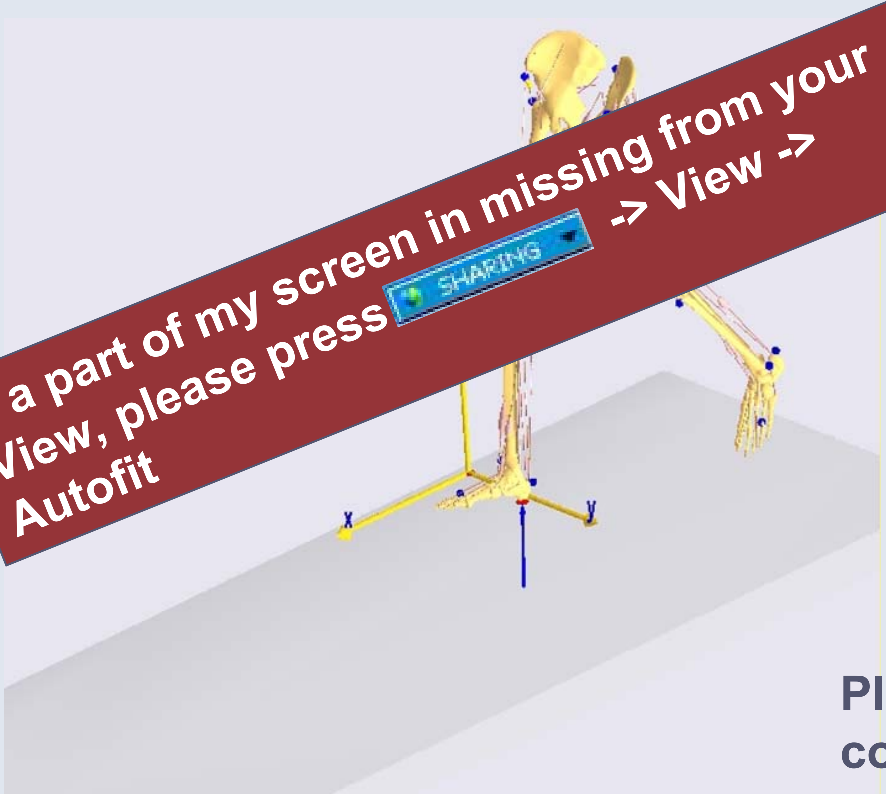
The AnyBody model library: Content, model design strategy, and applications



If a part of my screen in missing from your View, please press SHARING -> View -> Autofit

The web cast will begin in a few minutes….

- Introduction (~5 min)
- Body Parts (~ 25 min)
- Applications (~15 min)
- Q&A session (~10 min)

Please check that your audio settings correspond to the instructions in the email you have received from us.

ANYBODY
RESEARCH PROJECT

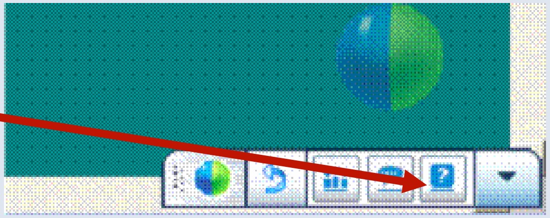
Presenters

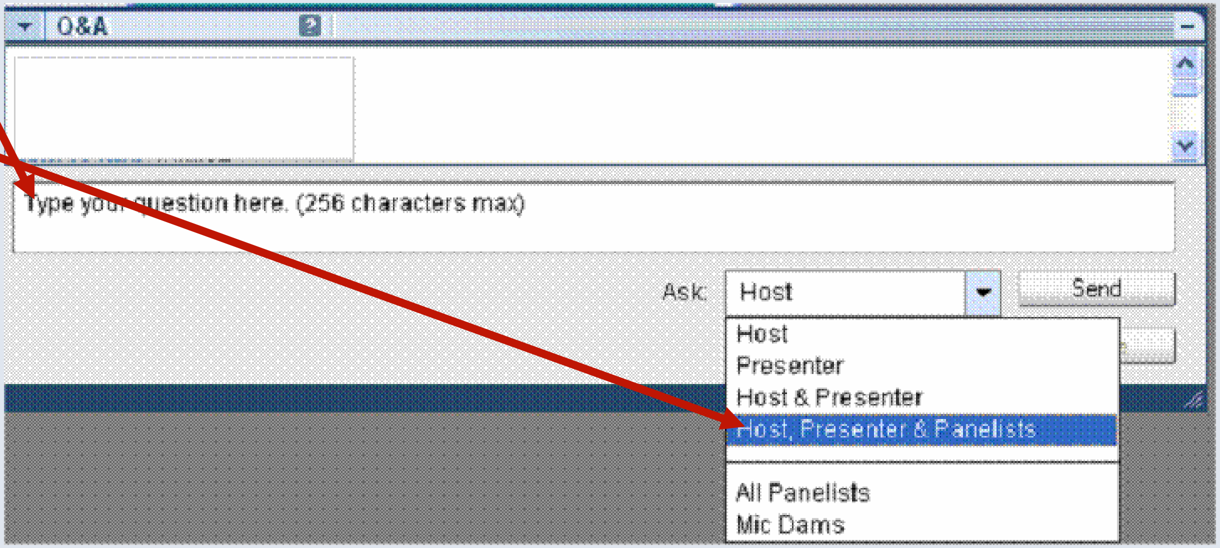
Søren Tørholm Christensen
(Presenter)

Arne Kiis
(Host)

Q&A Panel

- John Rasmussen
- 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.





Repository structure

- Repository 6
  - BRep
    - Aalborg
      - Arm3D
      - Spine
      - Leg2D
      - Leg3D
      - BodyModels
      - Scaling
      - Toolbox
    - Pisa
      - Upper limb
    - Aarhus
      - SymmetricMandible1
  - ARep
    - Aalborg
    - Ulm
    - Pisa
    - Aarhus

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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 **general models**, which can give information about a number of yet unknown problems

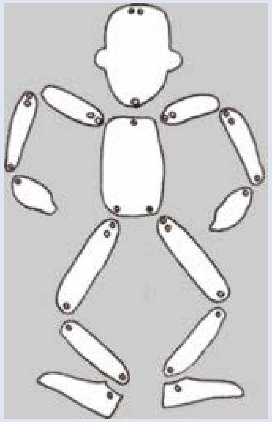
Our goal

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

Repository structure BRep

A modular block building technique, which makes it easy to change and connect different body parts, has been developed. The philosophy is that when building for example a leg model, the model should be self-contained.

The BRep does not contain any motion drivers for the body parts. These are added in the application



Body parts in Brep have no drivers applied

BodyModel collections

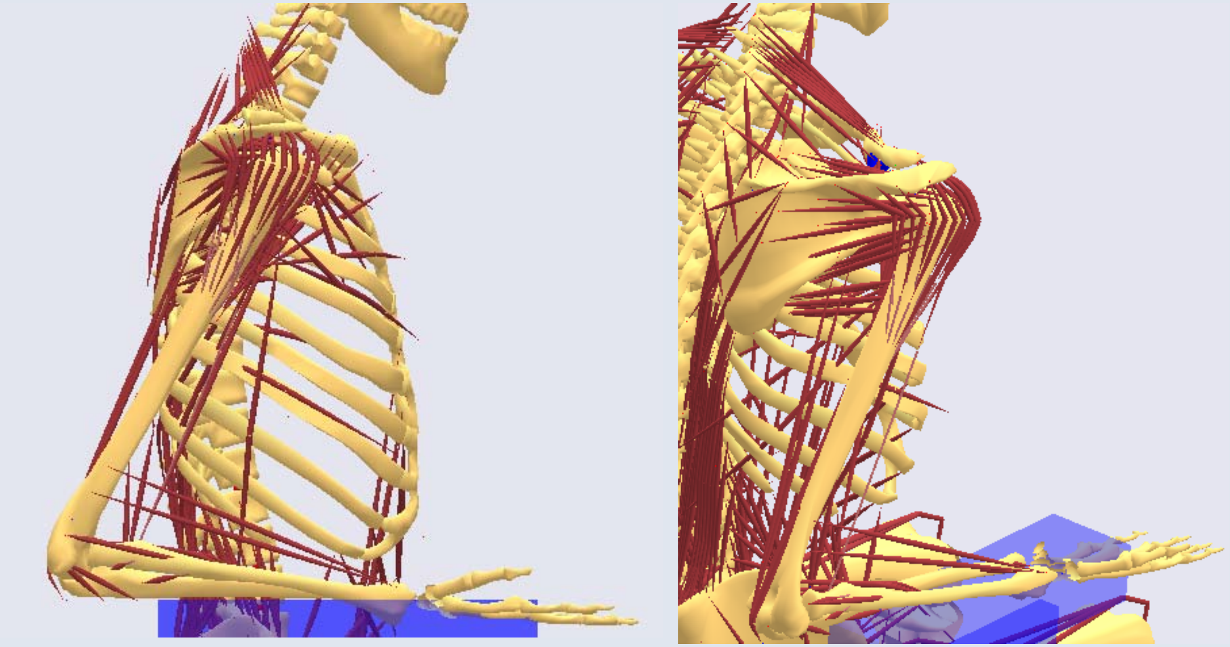
In addition to the individual body parts, the BRep now contains a BodyModel directory with popular collections of body parts:

- FullBodyModel
- SpineTwoArms
- SpineTwoLegs
- SpineRightArm
- TwoLegs

These even come in various combinations with and without muscles and with different muscle models.

BRep: Shoulder arm model

The arm block includes the shoulder region and comprises the following bones: clavicle, scapula, humerus, ulna, radius and a hand segment.



The model is mainly based on data collected by the Dutch Shoulder Group and made available on the World-Wide Web.

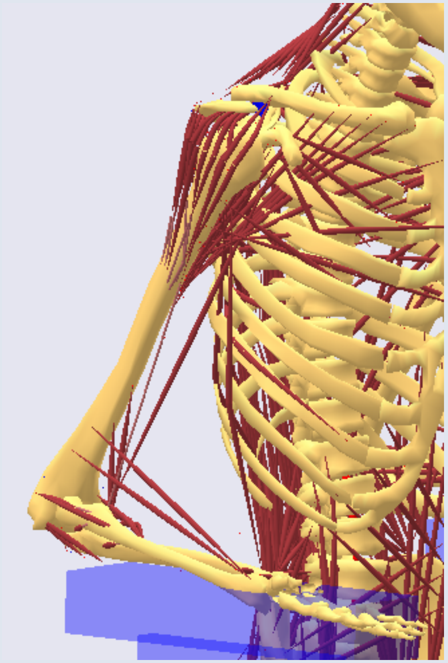
Example file: Brep/Aalborg/Arm3D/ShoulderArm.root.any

BRep: Shoulder arm model

The anthropometrical data originates from two different studies:

- VU study: data was collected for the shoulder region extending to the elbow.
- MAYO study: Data of the lower arm extending to the wrist was collected.

The model of the arm and shoulder has 118 muscle elements on each side.



Example file:
Brep/Aalborg/Arm3D/ShoulderArm.root.any

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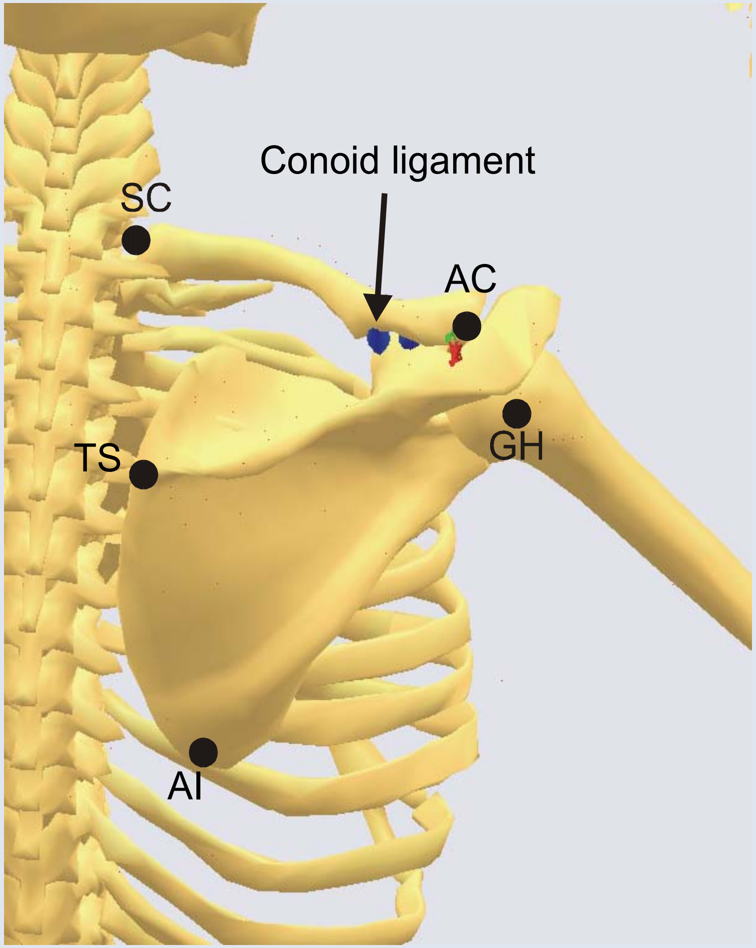
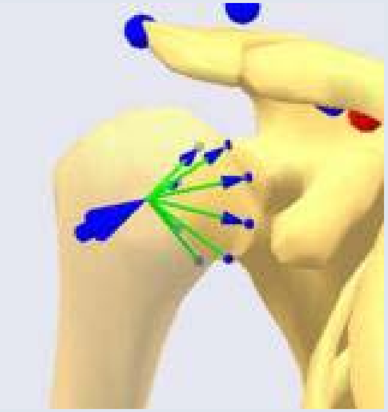
BRep : Shoulder arm model Kinematics



AC	Spherical joint
GH	Spherical joint (kinematically only)
SC	Spherical joint
TS	Scapula thoracic gliding plane, ellipsoid
AI	Scapula thoracic gliding plane, ellipsoid

This gives totally 7 dof. in the shoulder girdle

Eight very strong muscles which points from eight points uniformly distributed points around the cavitas edge on Scapula towards the GH rotation point, ensures that the resultant force in the joint falls inside the Cavitas glenoidalis



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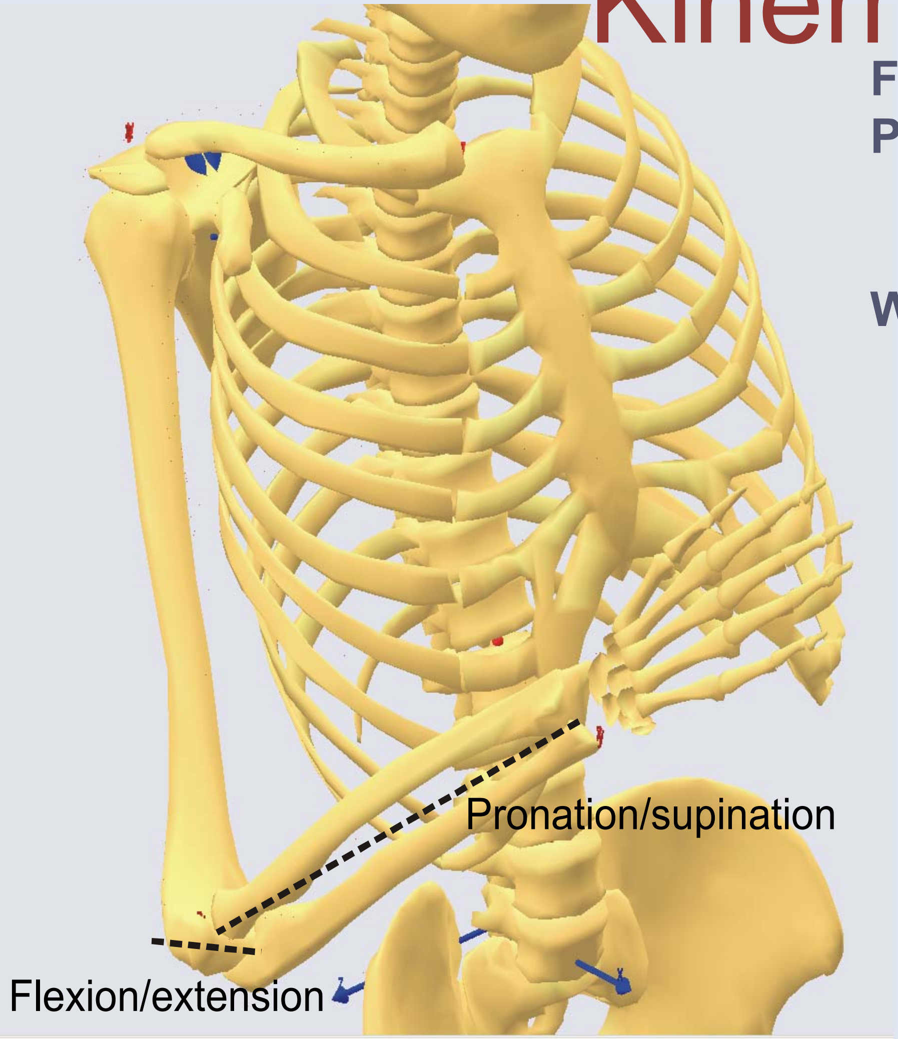
BRep : Shoulder arm model Kinematics

FE	Flexion/estension, revolute joint
PS	Pronation/supination, combination of joints with one DOF
Wrist	Universal joint



Example file: Brep/Aalborg/Arm3D/Joint.any

Shoulder References

R. Happee and F.C.T. Van der Helm, The control of shoulder muscles during goal directed movements, an inverse dynamic analysis, J. Biomechanics, vol. 28, no. 10, pp. 1179-1191, 1995

F.C.T. van der Helm and R. Veenbaas, Modeling the mechanical effect of muscles with large attachment sites: application to the shoulder mechanism,Journal of Biomechanics, vol. 24, no. 12, pp. 1151-1163, 1991

F.C.T. van der Helm, A finite element musculoskeletal model of the shoulder mechanism, Journal of Biomechanics, vol. 27, no. 5, pp. 551-569, 1994

F.C.T. van der Helm,Geometry parameters for musculoskeletal modeling of the shoulder system, Journal of biomechanics Vol. 25 no. 2, pp. 129-144, 1992

Kräfteatlas, Teil1, Datenauswertung statischer aktionskräfte, Schriftenreihe der Bundesanstalt für Arbeitsmedizin, Forschung Fb 09.004, Berlin 1994, ISBN 3-89429-524-4

Bjarne Laursen, Bente Rona Jensen, Gunnar Németh, Gisela Sjøgaard: A model predicting individual shoulder muscle forces based on relationship between electromyographic and 3D external forces in static position. Journal of Biomechanics 31 (1998) 731–739

DirkJan (H.E.J.) Veeger, Bing Yu, Kai Nan An, Orientation of axes in the elbow and forearm for biomechanical modeling, Proceedings of the first conference of the ISG, 1997

H.E.J Veeger, Bing Yu, Kai Nan An, Orientation of axes in the elbow and forearm for biomechanical modeling. Proceedings of the First Conference of the ISG

H.E.J. Veeger, Bing Yu, Kai-Nan An and R.H. Rozendal, Parameters for modeling the upper extremity, Journal of Biomechanics, Vol. 30, No. 6, pp. 647-652, 1997

H.E.J. Veeger, F.C.T. van der Helm, L.H.V. van der Woude, G.M. Pronk and R.H. Rozendal,Inertia and muscle contraction parameters for musculoskeletal modelling of the shoulder mechanism. Journal of Biomechanics, vol. 24, no. 7, pp. 615-629, 1991

Spine model

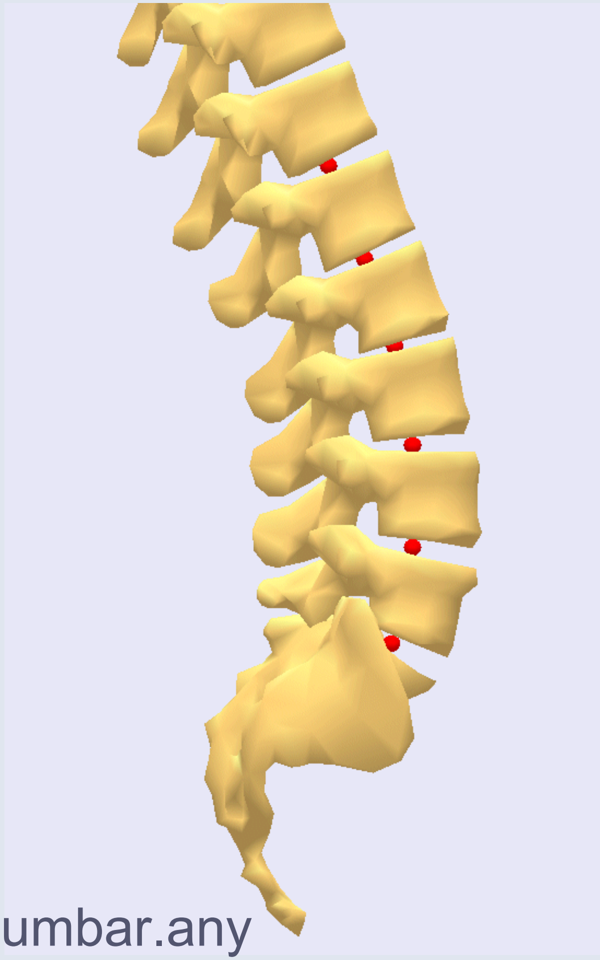
The spine model comprises sacrum, all lumbar vertebrae, a rigid thoracic section, and a total of 158 muscles

Model developed by M. de Zee and L. Hansen

Example file: Brep/Aalborg/Spine/Spine.root.any

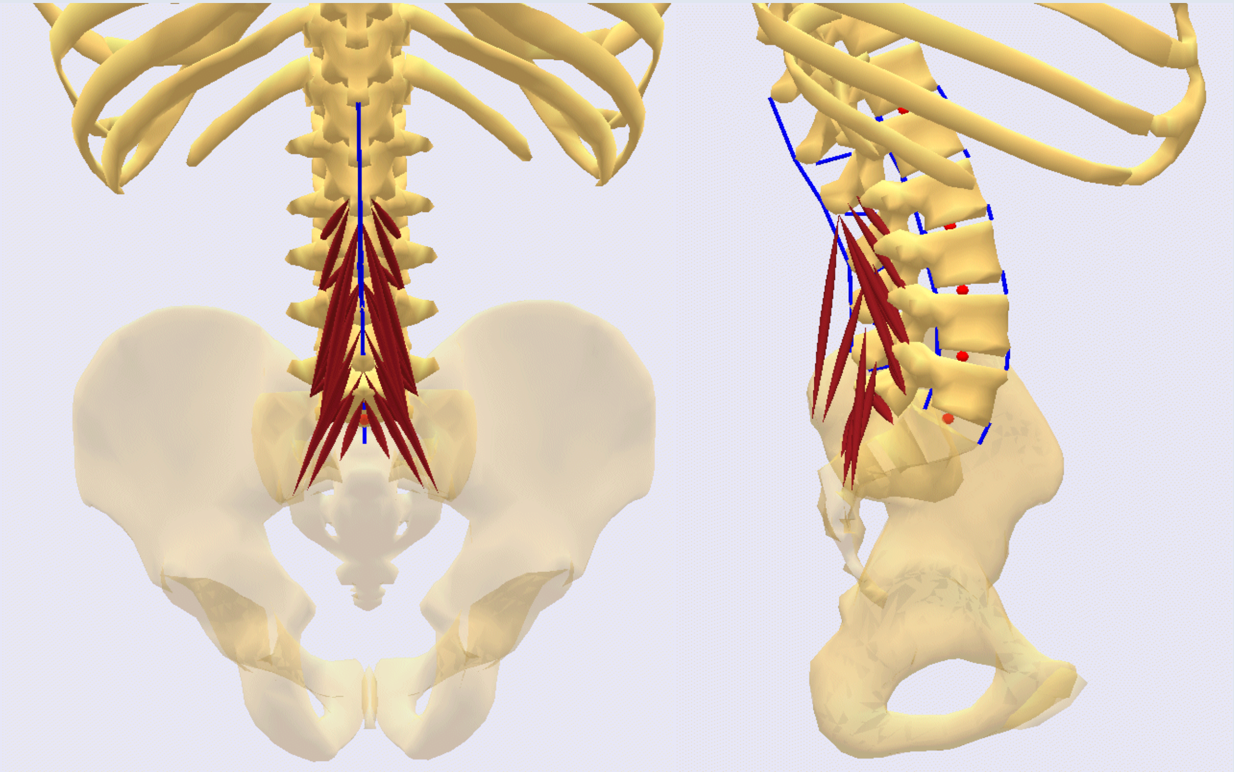
Segments and joints

- 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)



Example file: Brep/Aalborg/Spine/JointsLumbar.any

Muscles: multifidi

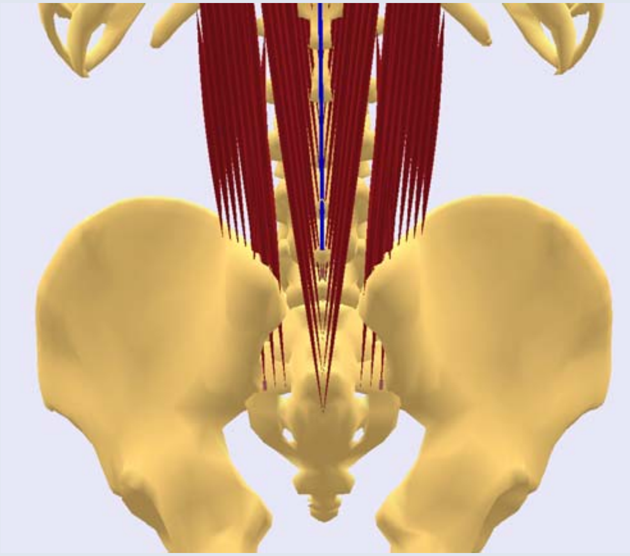


- 19 fascicles on each side
- Based on information by the group of Bogduk

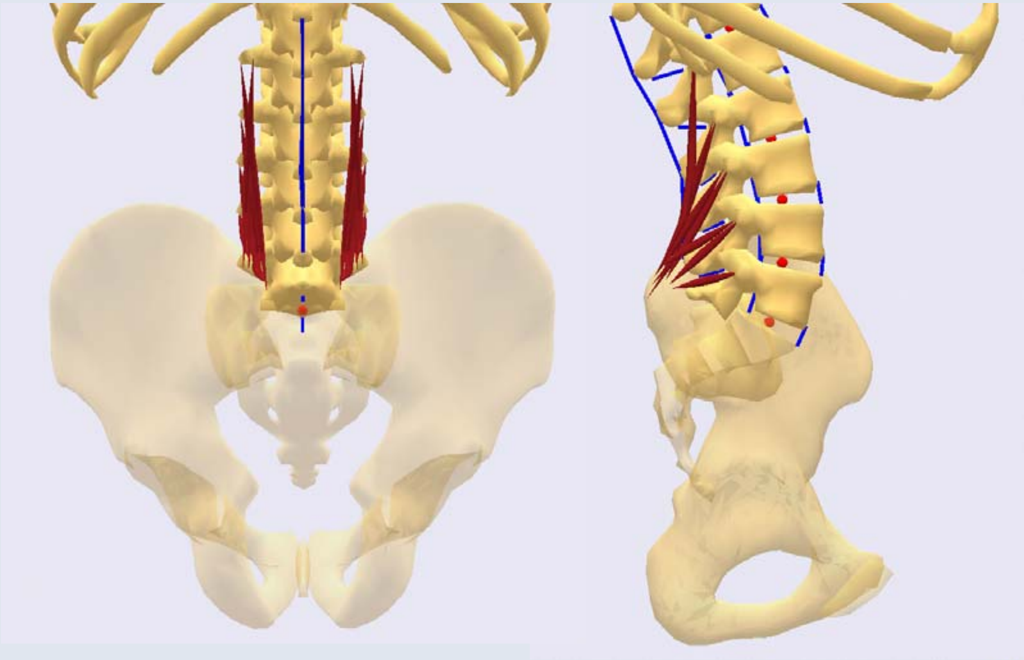
Example file: Brep/Aalborg/Spine/MultifidiRight.any

Muscles: erector spinae

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



pars thoracis divisions

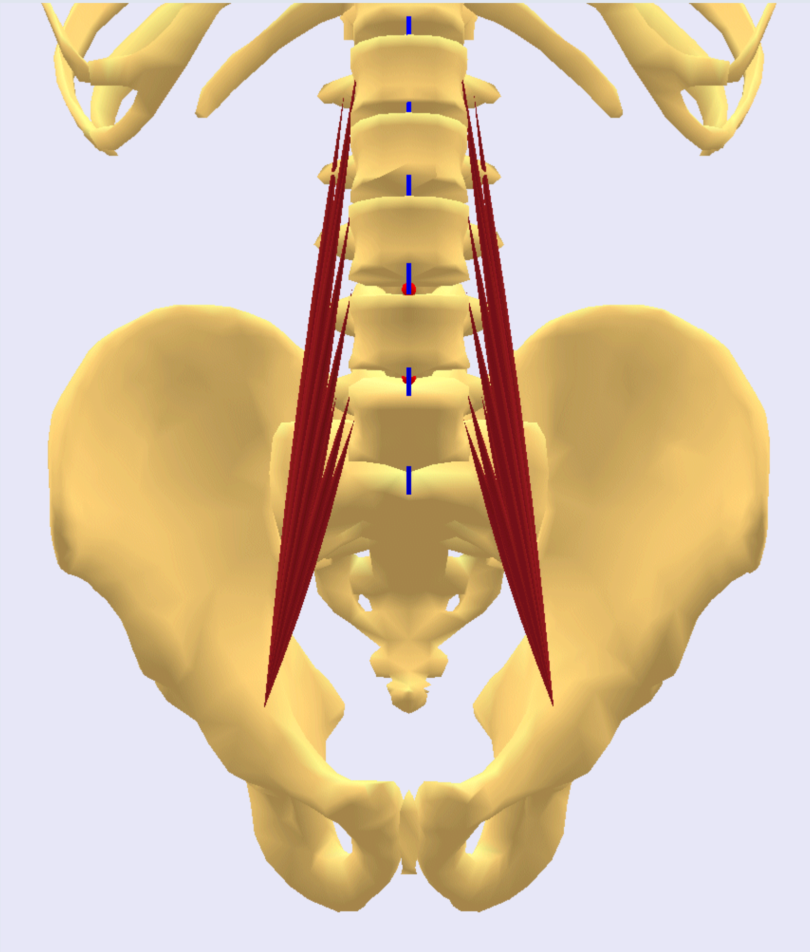


pars lumborum divisions

Example file: Brep/Aalborg/Spine/ErectorSpinae.any

Muscles: psoas major

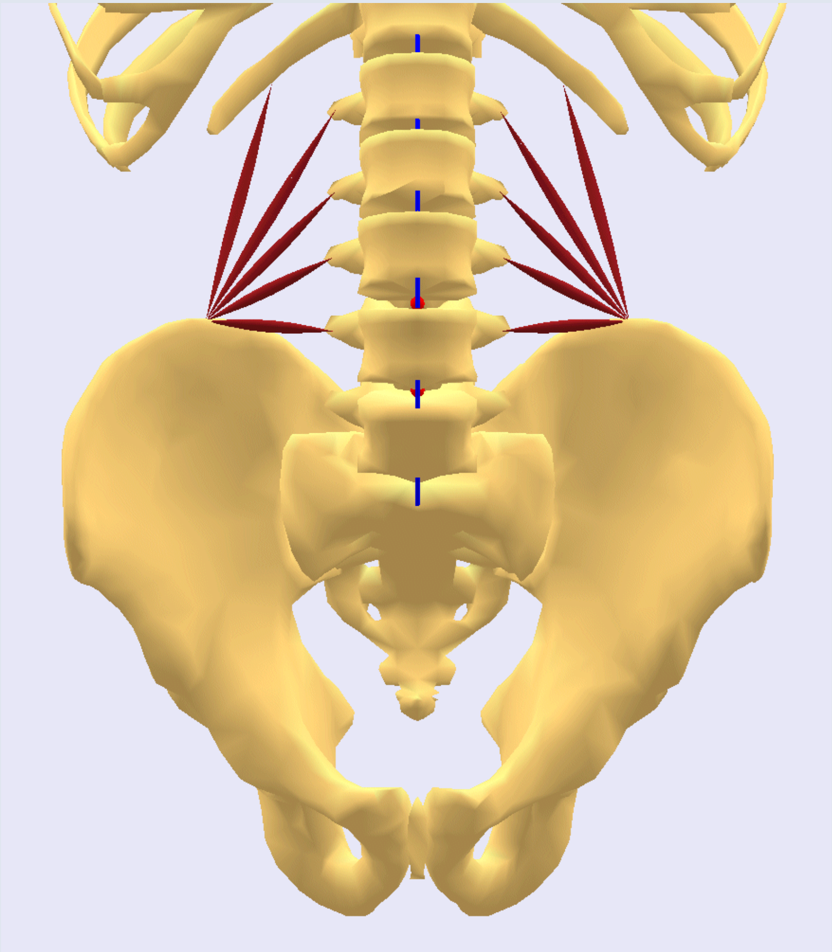
- 11 fascicles on each side
- Insertion on the femur
- Via point on the pelvis (iliopubic eminence)



Example file: Brep/Aalborg/Spine/PsoasMajorRight.any

Muscles: quadratus lumborum

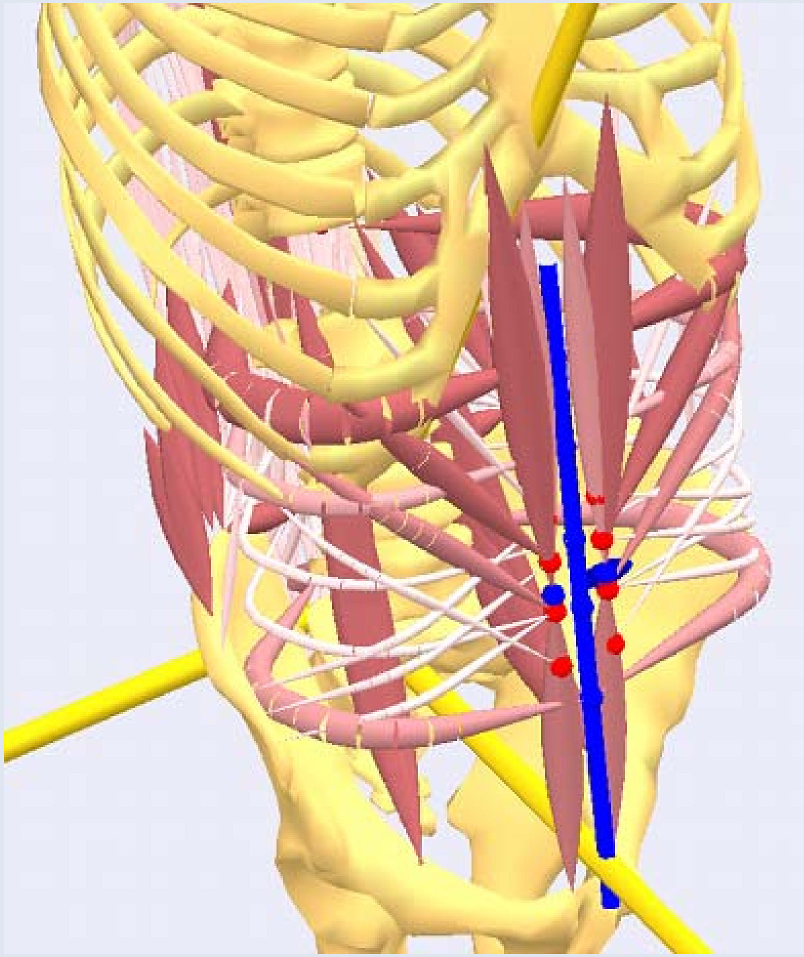
- 5 fascicles on each side
- Based on information by Stokes et al. (1999)



Example file: Brep/Aalborg/Spine/QuadatusLumborumRight.any

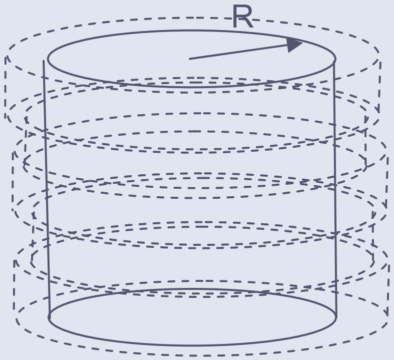
Muscles: abdominal

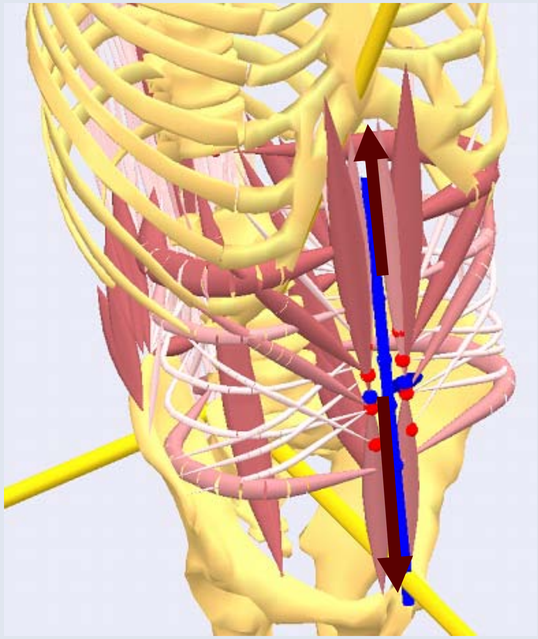
- Rectus abdominis
- Obliquus externus
- Obliquus internus
- Transversus



Example file: Brep/Aalborg/Spine/RectusAbodomisRight.any

Abdominal pressure implementation





The abdominal volume is idealized as a stack of five cylinders

An artificial muscle is acting on the volume and generating forces on the vertebraes, throax and pelvis. This muscle is part of the normal recruitment problem, it will only be active if it is of benefit for the model.

Spine rhythm

A Spine rhythm has been implemented. The rhythm caculates the joint rotations bewteen the vertebrae as a function of the 3D angle between Pelvis and Thorax.

The rhythm removes the necessity for imposing the movement on each individual vertebra.

Only the rotations between Thorax and Pelvis have to be driven.

Example file: ARep/Aalborg/BikeModelFullbody/JointsAndDrivers.any

Showcase

This video shows a standing model doing three different tasks:

1. Flexion/extension
2. Lateral bend
3. Axial twist

Please notice the motion of the five individual disks and the changes of the muscle tone.

Spine References

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Bogduk,N., Clinical anatomy of the lumbar spine and sacrum, Churchill Livingstone, Edinburgh, 1997.

Bogduk,N., Macintosh,J.E., Pearcy,M.J., A universal model of the lumbar back muscles in the upright position, Spine, 17 (1992) 897-913.

Bogduk,N., Pearcy,M.J., Hadfield,G., Anatomy and biomechanics of psoas major, Clin. Biomech., 7 (1992) 109-119.

Daggfeldt,K., Thorstensson,A., The role of intraabdominal pressure in spinal unloading, J. Biomech., 30 (1997) 1149-1155.

Daggfeldt,K., Thorstensson,A., The mechanics of back-extensor torque production about the lumbar spine, J. Biomech., 36 (2003) 815-825.

Heylings,D.J.A., Supraspinous and interspinous ligaments of the human lumbar spine, J. Anat., 125 (1978) 127-131.

Hodges,P.W., Cresswell,A.G., Daggfeldt,K., Thorstensson,A., In vivo measurement of the effect of intra-abdominal pressure on the human spine, J. Biomech., 34 (2001) 347-353.

Macintosh,J.E., Bogduk,N., The biomechanics of the lumbar multifidus, Clin. Biomech., 1 (1986) 205-213.

Macintosh,J.E., Bogduk,N., 1987 Volvo award in basic science. The morphology of the lumbar erector spinae, Spine, 12 (1987) 658-668.

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Macintosh,J.E., Bogduk,N., The attachments of the lumbar erector spinae, Spine, 16 (1991) 783-792.

Macintosh,J.E., Bogduk,N., Munro,R.R., The morphology of the human lumbar multifidus, Clin. Biomech., 1 (1986) 196-204.

McGill,S.M., Norman,R.W., Effects of an anatomically detailed erector spinae model on L4/L5 disc compression and shear, J. Biomech., 20 (1987) 591-600.

Pearcy,M.J., Bogduk,N., Instantaneous axes of rotation of the lumbar intervertebral joints, Spine, 13 (1988) 1033-1041.

Penning,L., Psoas muscle and lumbar spine stability: a concept uniting existing controversies. Critical review and hypothesis, Eur. Spine J., 9 (2000) 577-585.

Prestar,F.J., Putz,R., Das Ligamentum longitudinale posterius - morphologie und Funktion, Morphol. Med., 2 (1982) 181-189.

Prilutsky,B.I., Zatsiorsky,V.M., Optimizationbased models of muscle coordination, Exerc. Sport Sci. Rev., 30 (2002) 32-38.

Rasmussen,J., Damsgaard,M., Voigt,M., Muscle recruitment by the min/max criterion – a comparative numerical study, J. Biomech., 34 (2001) 409-415.

Stokes,I.A., Gardner-Morse,M., Lumbar spine maximum efforts and muscle recruitment patterns predicted by a model with multijoint muscles and joints with stiffness, J. Biomech., 28 (1995) 173-186.

Stokes,I.A., Gardner-Morse,M., Quantitative anatomy of the lumbar musculature, J. Biomech., 32 (1999) 311-316.

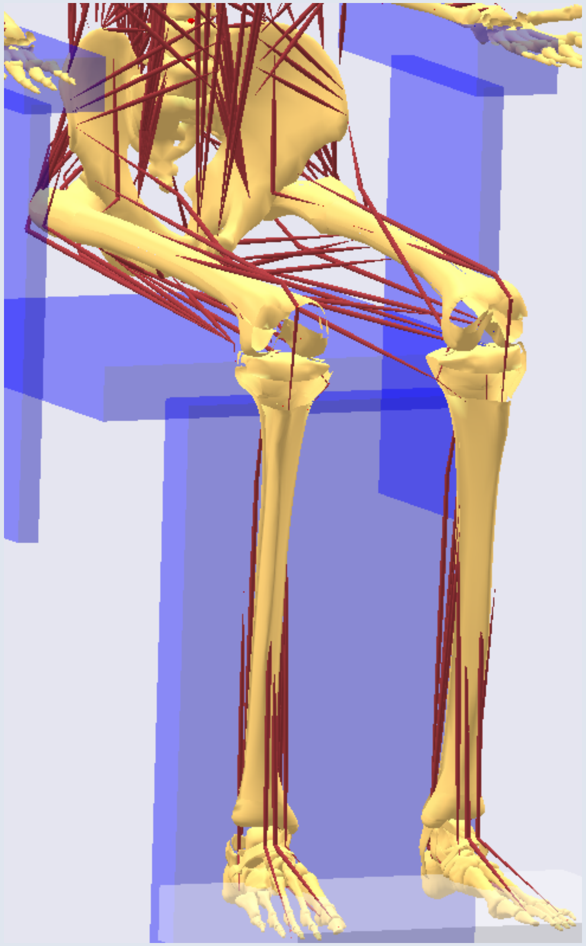
Leg model

The leg model comprises the following bones: pelvis, thigh, shank and foot

The hip joint is modeled as a spherical joint, while the knee and ankle are modeled as hinge joints.

The leg model is equipped with 35 muscles elements.

Thanks to Mark Thompson, Lund University Hospital, for his help on developing the lower extremity model.



Leg model

A couple of muscles with broad insertions (like the m. gluteus maximus) are divided into multiple individual muscle units to represent the real geometry and the mechanical actions of the muscle.

The parameters of these muscles are mainly based on the data published by Delp and Maganaris

Leg References

S. Delp, Parameters for the lower limb, http://isb.ri.ccf.org/data/delp

Maganaris, C. N. In vivo measurement-based estimations of the moment arm in the human tibialis anterior muscle-tendon unit. Journal of Biomechanics, Vol. 33, pp. 375-379, 2000

Dostal, W. F. and J. G. Andrews. A three-dimensional biomechanical model of hip musculature. Journal of Biomechanics, Vol. 14, pp. 803-812, 1981.

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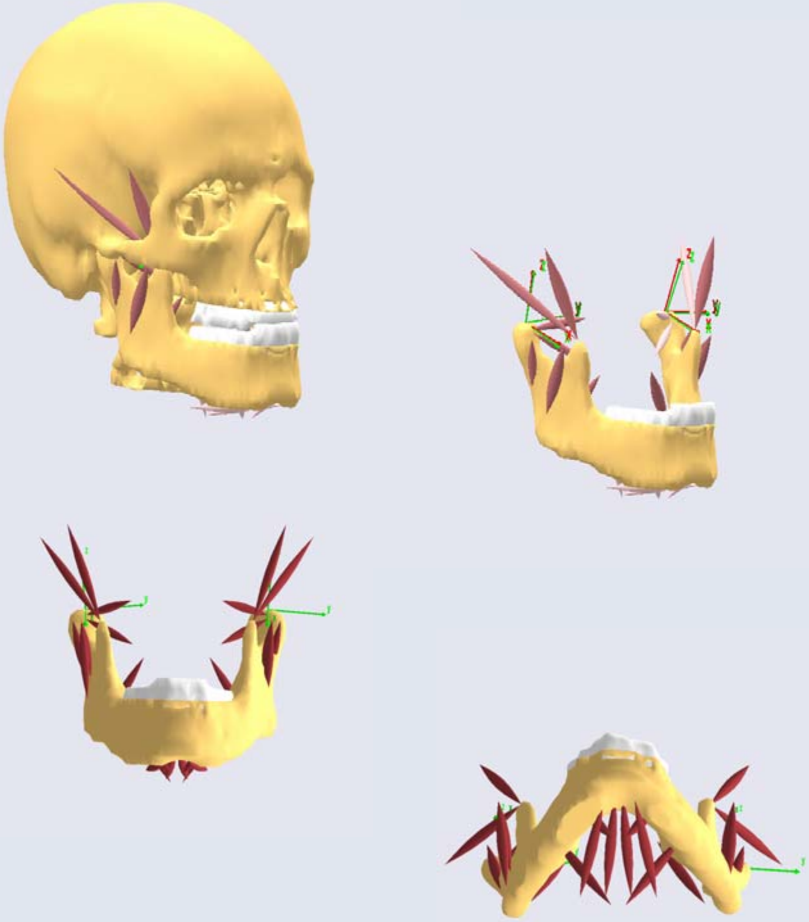
Hintermann, B., B. M. Nigg, and C. Sommer. Foot movement and tendon excursion: an in vitro study. Foot & Ankle International, Vol. 15, pp. 386-395, 1994

Mandible model



The model is developed by
Mark de Zee
Department of Orthodontics
School of Dentistry
Faculty of Health Sciences
University of Aarhus
Denmark

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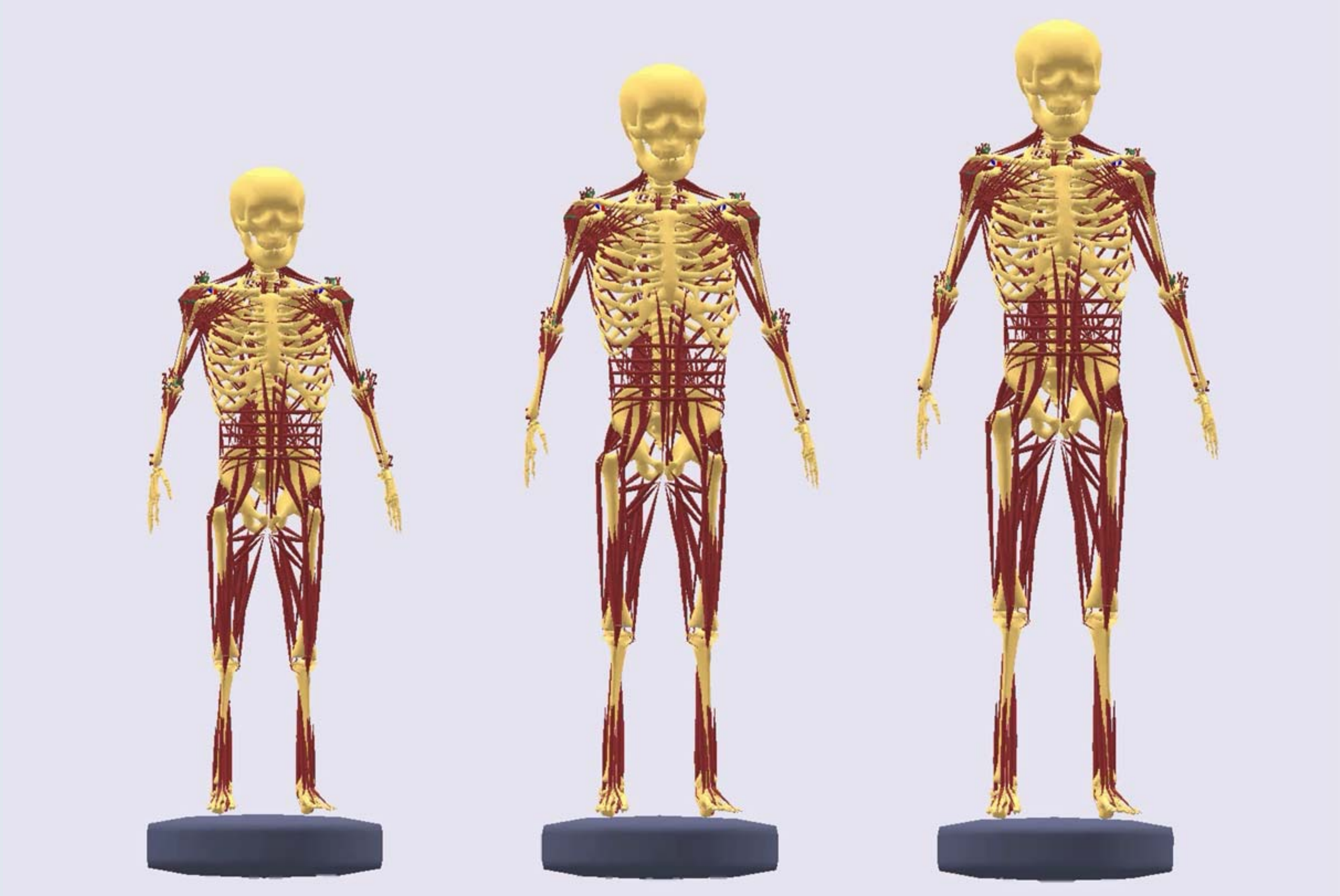
Scaling



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Introduction

The musculoskeletal models have been made scalable in size. This is no simple task since it involves changing literally thousand of parameters, properties like:

- mass and inertia
- geometry: muscle insertion points, joint centers etc.
- muscle parameters
- wrapping surfaces.

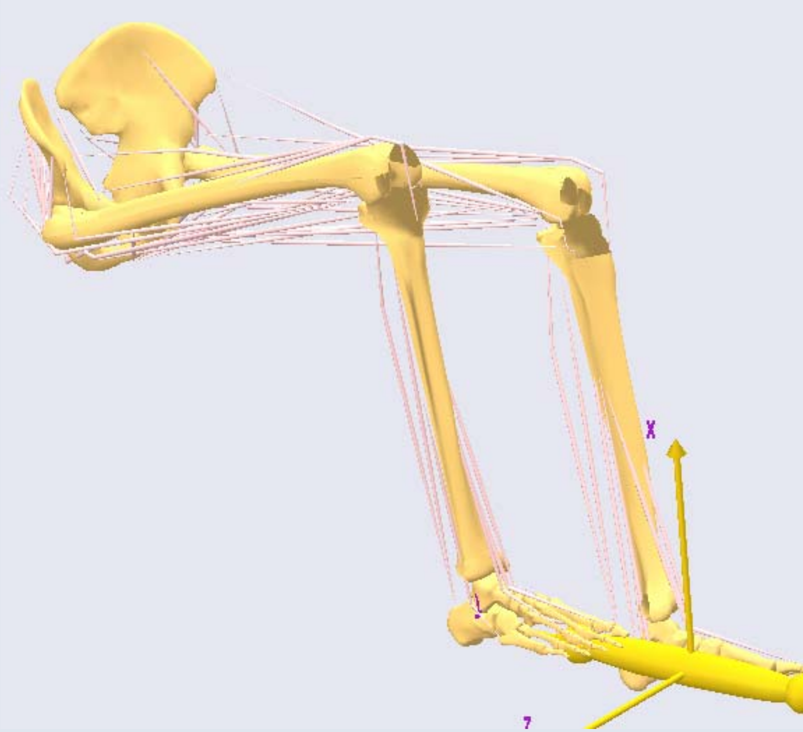
The scaling procedure is implemented in a generic manner and allows for user-defined scaling laws.

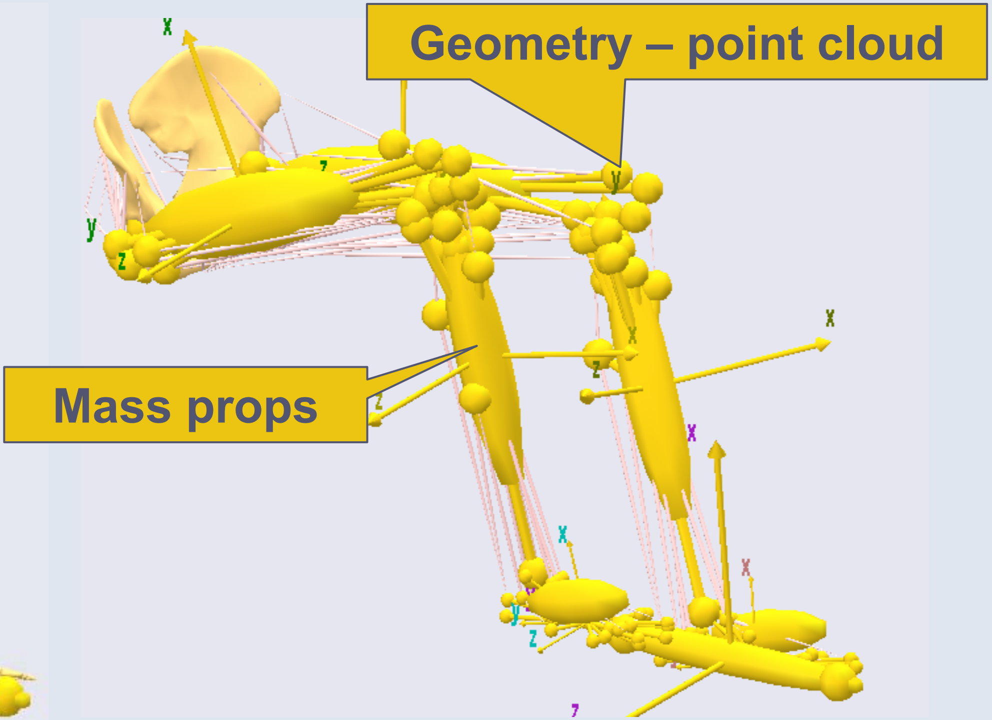
Scaling Scenarios

- Overall population level
  - Investigate ergonomic compatibility for a broad range of the population
  - Based on anthropometric databases
- Individual level
  - Sports biomechanics for a particular athlete
  - Gait analysis of a particular individual
- Detailed level
  - Purpose-specific modeling based on scans, ultrasound data, and similar.
  - Detailed data for each mode

This has always been possible because AnyBody models are fully accessible.

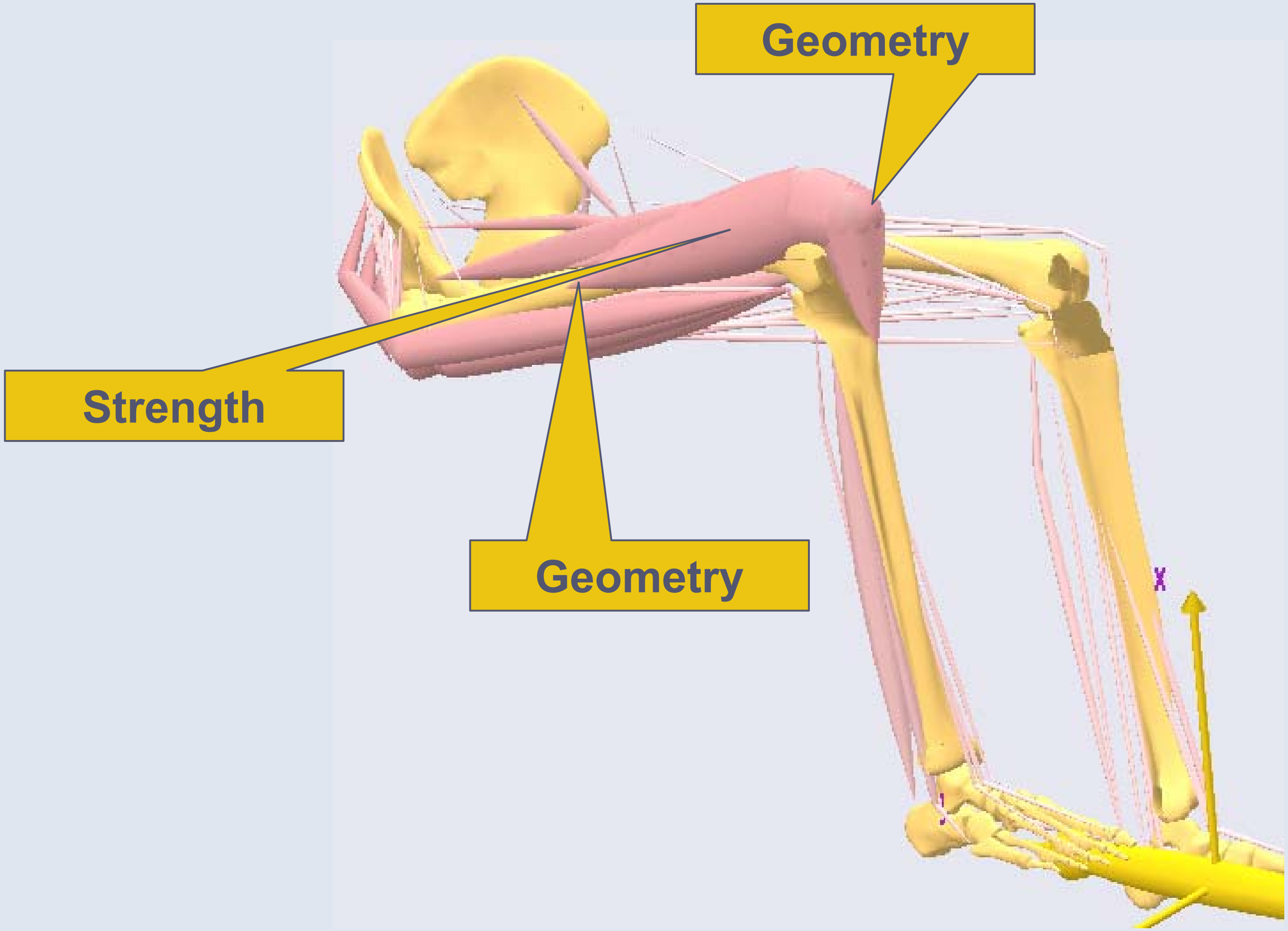
How a segment is defined



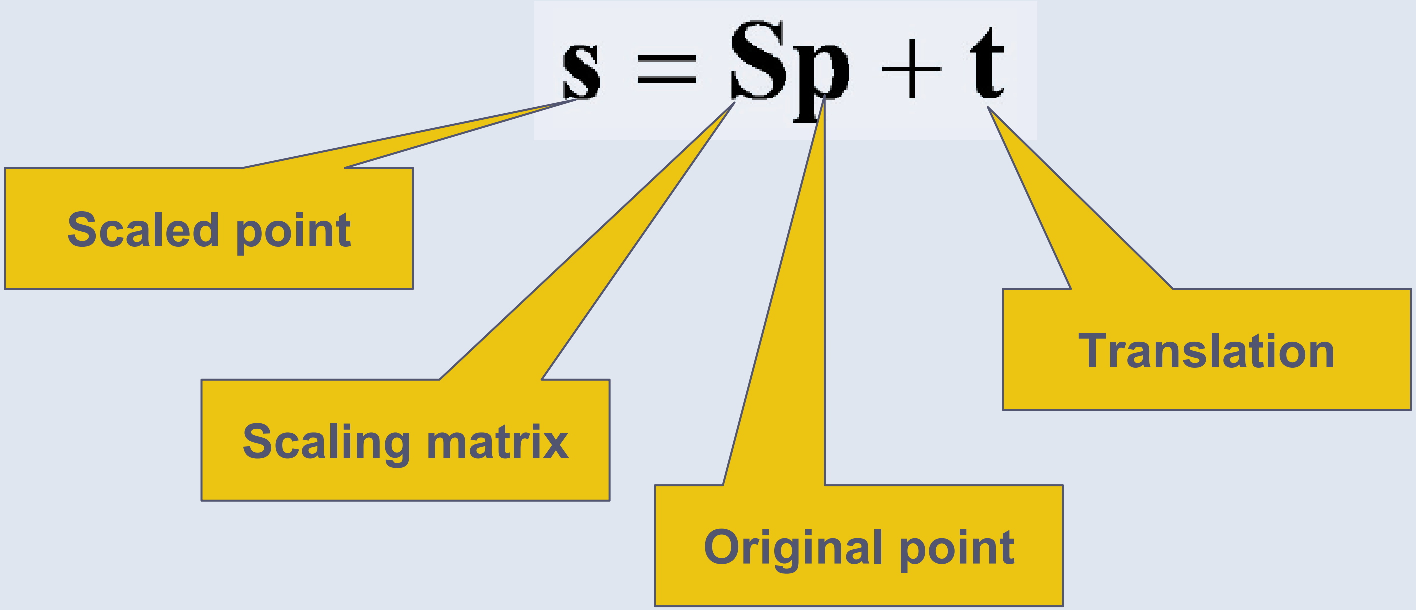

Geometry – point cloud

Mass props

How a muscle is defined



Linear geometry scaling



$$\mathbf{s} = \mathbf{S}\mathbf{p} + \mathbf{t}$$

Scaled point

Scaling matrix

Original point

Translation

Different choices of $\mathbf{S}$ ant $\mathbf{t}$ lead to different scaling laws

Scaling laws

Uniform scaling

- Same scaling factor in all directions.
- Does not seem to fit well with imperical data.

$$\mathbf{S} = \begin{bmatrix} k_L & & \\ & k_L & \\ & & k_L \end{bmatrix}$$

Length-mass scalin

- Scale the length to dimension and sca obtain the specifie

Length-mass-fat sca

- Idea: Take the fat account.
- The fat percentage can be estimated from the BMI
- - or it can be measured directly.

This means that the scaling is implemented into the models and not into the system:

•Accessible to all users

•Can be modified by the user

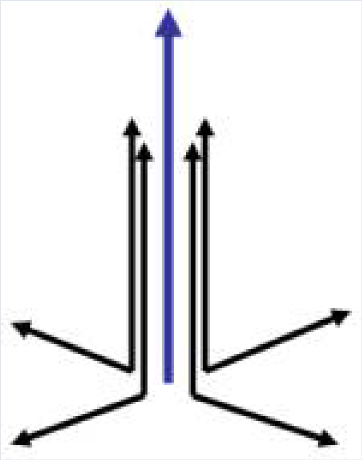
•New scaling methods can be defined by users

BRep/Aalborg/Toolbox:Friction

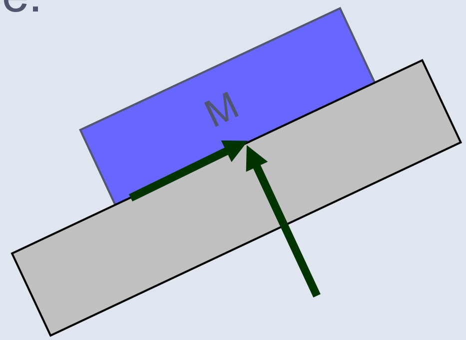
Friction is very important in order to obtain the correct boundary conditions between human models and environment elements such as seats, floors and handles.

A true Coulomb friction element have been added to the models. It is a combination of general muscles and linear combination measures.

The arrangement exploits the muscle recruitment to link normal and friction forces in such a way that friction is limited by the normal force but friction can be smaller than the maximally available value.



Schematic friction modeled by artificial muscles. Blue signifies the normal force; black the combined normal and friction forces.



The friction element can be used very easily by using an include file, which are a part of the Repository.

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BRep/Aalborg/Toolbox: Conditional contact

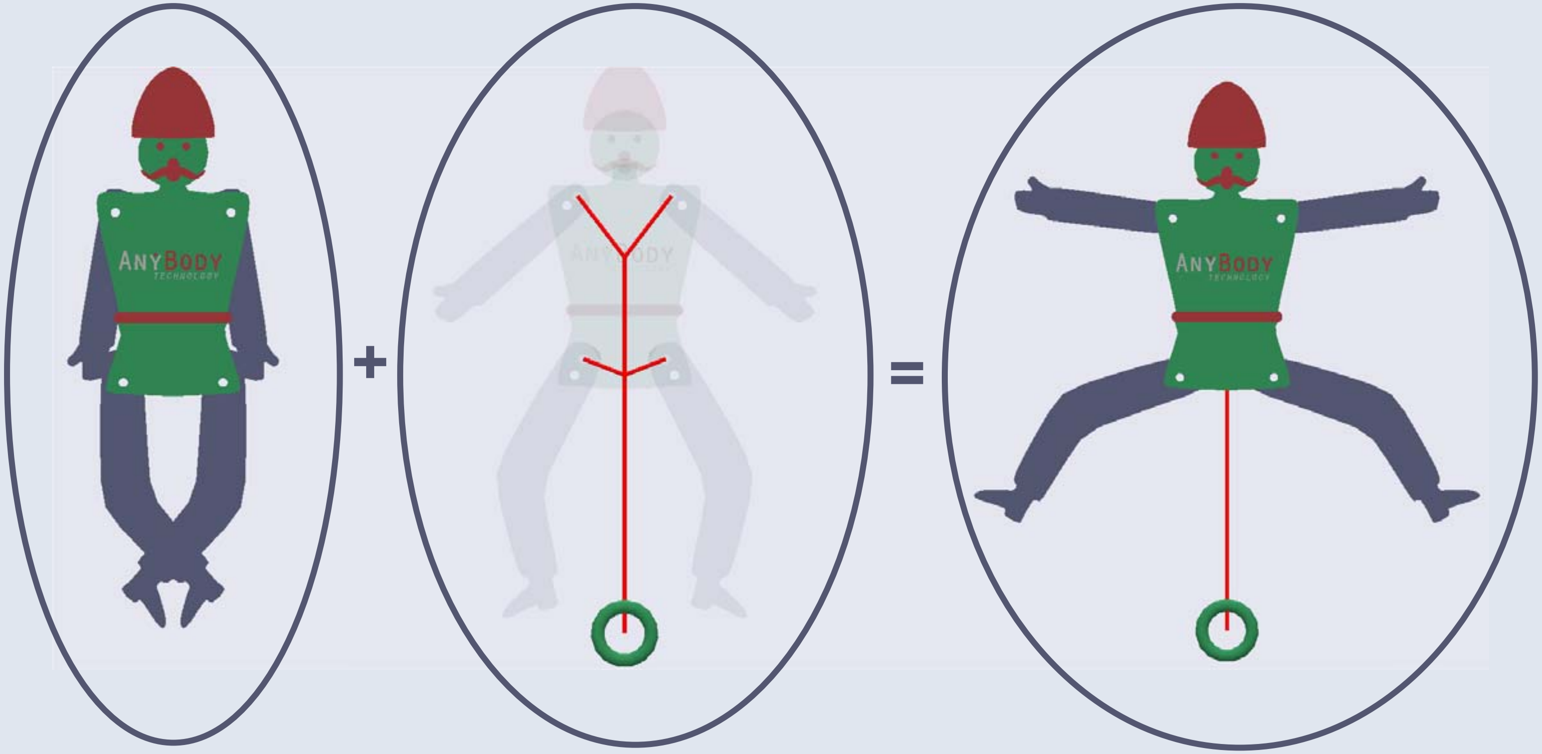
The new version 2.0 of AnyBody allows for user defined muscle strength definitions and it is possible to have dependency on kinematic measures such as distances.

This makes it easy to define contact which are conditional and dependent on distances.

Conditional muscle creates the contact force betwen foot and pedal

Structure of an ARep Model

ARep stands for "Application Repository", and it contains a collection of applications which are all based on BRep body parts.
This slide shows a typical structure of an application model.



Body parts in (BRep) + Drivers and environment = Working situation (ARep)

Application repository ARep/Aalborg

This slides gives an overview of the applications in the ARep Aalborg directory branch.

- **ARep**
  - **Aalborg**
    - ArmCurl
    - BikeModelFullBody
    - BikeSpring
    - BikeModel2D
    - BikeModel3D
    - Egress
    - FreePosture
    - FreePostureMove
    - Gait3D
    - Gearstick
    - JumpingJack
    - KneeLoad
    - LawnMover
    - PedalDemo
    - Pushup
    - SeatedHuman
    - StandingModel
    - StandingModelLift
    - StandingModelCircumduction
    - StandingModelMove
    - WheelChair
    - WheelTurn

New applications are constantly being added.

The repository contains a wide variety of models, if you are trying to model a specific case, it is normally a good idea to start with one of the applications as a basis for your model.

Application Categories

This table tries to categorize some of the features of the models

Model	FullBody -Model	Friction	Conditional contact	Marker driven	Center of mass drivers	Mannequin driven	Driven by environment and mannequin	Initial pos. from mannequin
GearStick							X	X
Gait3D				X				X
WheelChair-Rancho				X				X
FreePosture	X					X		X
FreePostureMove	X					X		X
BikeModel-FullBody	X						X	X
ConditionalPedal		X	X				X	X
Egress	X						X	X
StandingModel					X	X	X	X
SeatedHuman	X	X					X	X

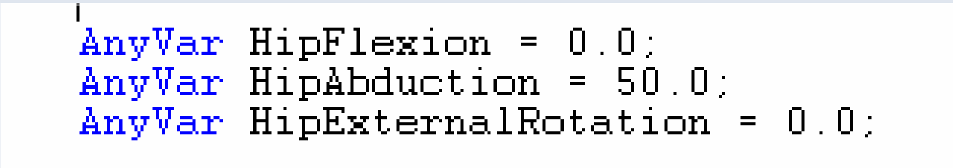
FreePosture

This is a full body model, the pelvis is locked to the environment.

The main file of the model is :
Arep/Aalborg/FreePosture/FreePosture.main.any

This model can be used for driving a fullbody model into any static posture, simply by setting the joints angles on the human model. These are all controlled from a the file ”Mannequin.any”

Example from the file ”Mannequin.any



```
AnyVar HipFlexion = 0.0;
AnyVar HipAbduction = 50.0;
AnyVar HipExternalRotation = 0.0;
```

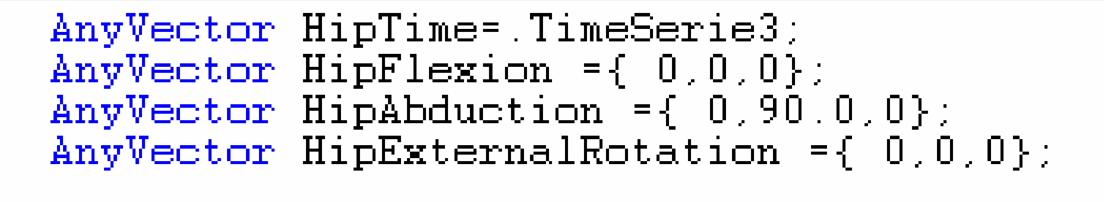
FreePostureMove

This is a full body, the pelvis is locked to the environment.

The main file of the model is :
Arep/Aalborg/FreePostureMove/FreePostureMove.main.any

This example can be used for driving the ***motion*** of a fullbody model. All joints are equipped with interpolation drivers. In the mannequin file it is possible to give vectors for each joint that will be used for interpolation it’s motion. These are all controlled from a the file ”Mannequin.any”

Example from the file ”Mannequin.any



```
AnyVector HipTime=.TimeSerie3;
AnyVector HipFlexion ={ 0,0,0};
AnyVector HipAbduction ={ 0,90.0,0};
AnyVector HipExternalRotation ={ 0,0,0};
```

Standing model

The human model is made using the body collection directory

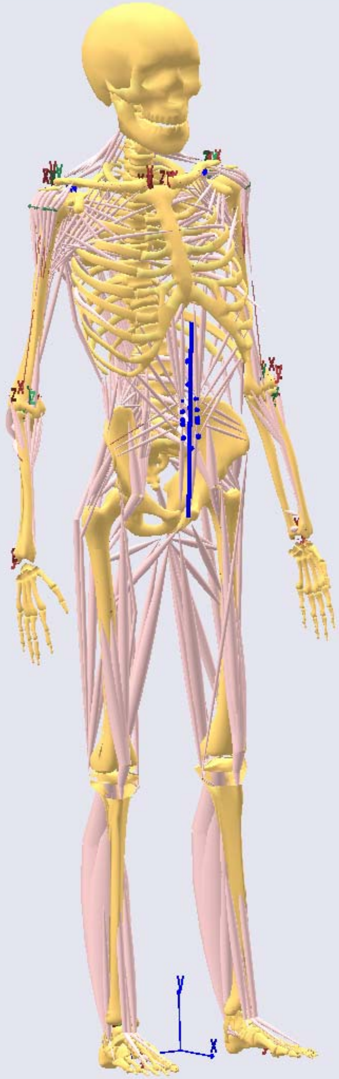
”BRep/BodyModels/FullBodyModel”

The main file of the model is :

ARep/Aalborg/StandingModel/StandingModel.main.any

What can the model be used for?

- This is a good starting point for applications using full body models, since the posture of the model is controlled through a mannequin file.



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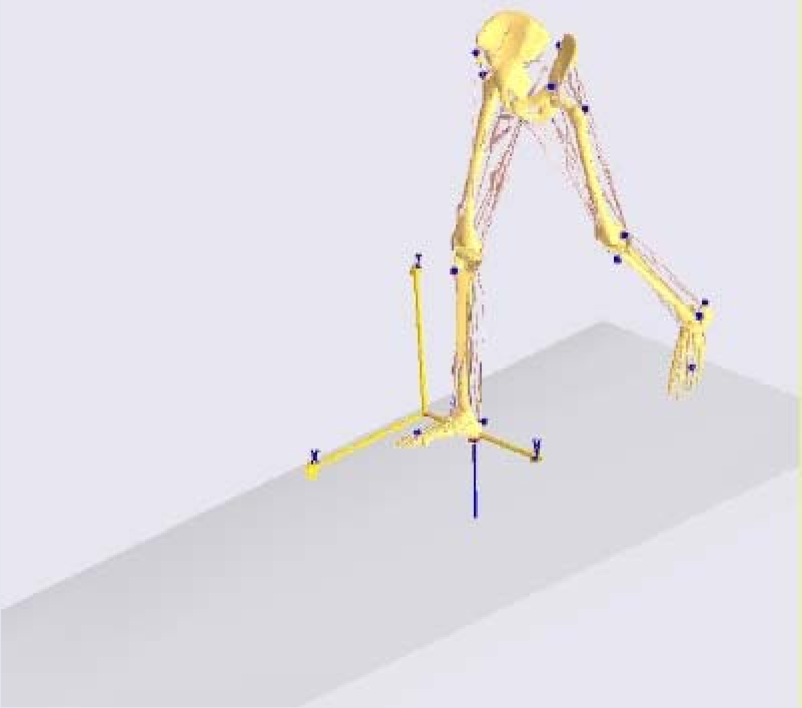
ARep : StandingModel

Gait modeling

The human model is made using the body collection directory Brep/BodyModels/TwoLegs

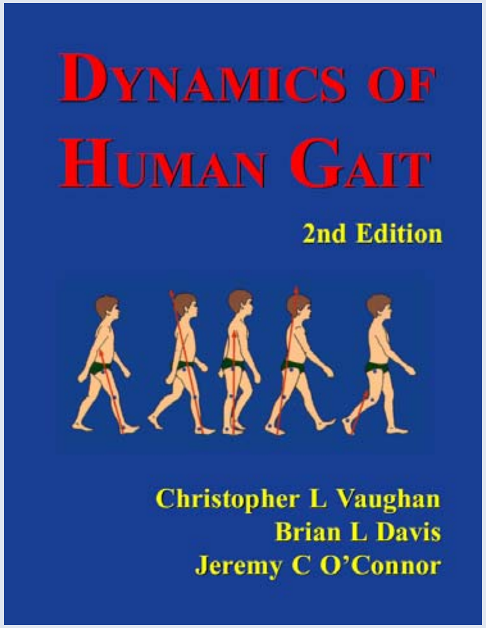
The main file of the model is : Arep/Aalborg/Gait3D/AnyGait.main.any



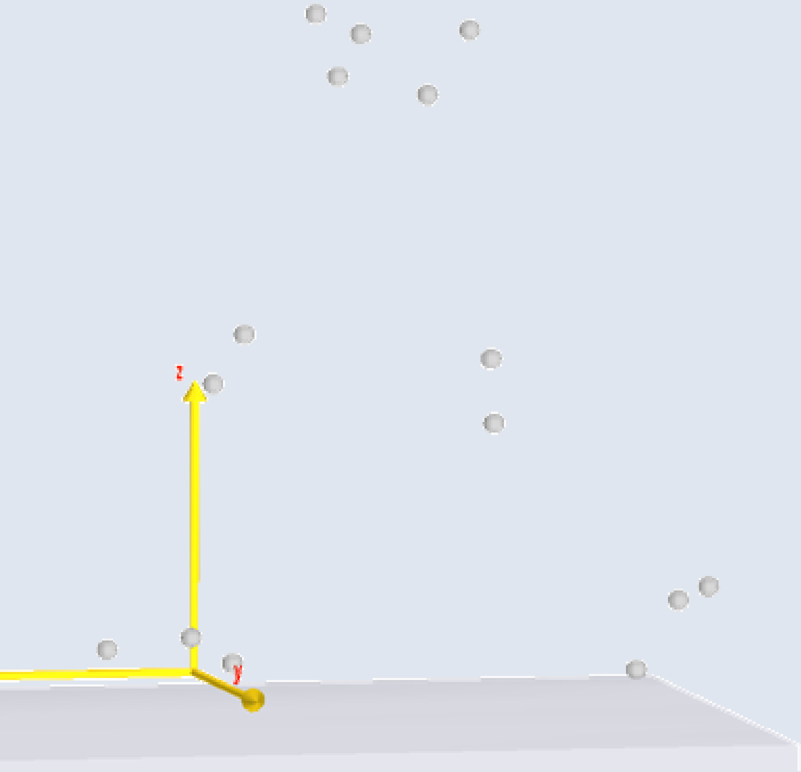
Gait data set

To have something fairly standardized and accessible, we grabbed the motion data and ground reaction force measurements from the book by Vaughan et al: Dynamics of Human Gait.

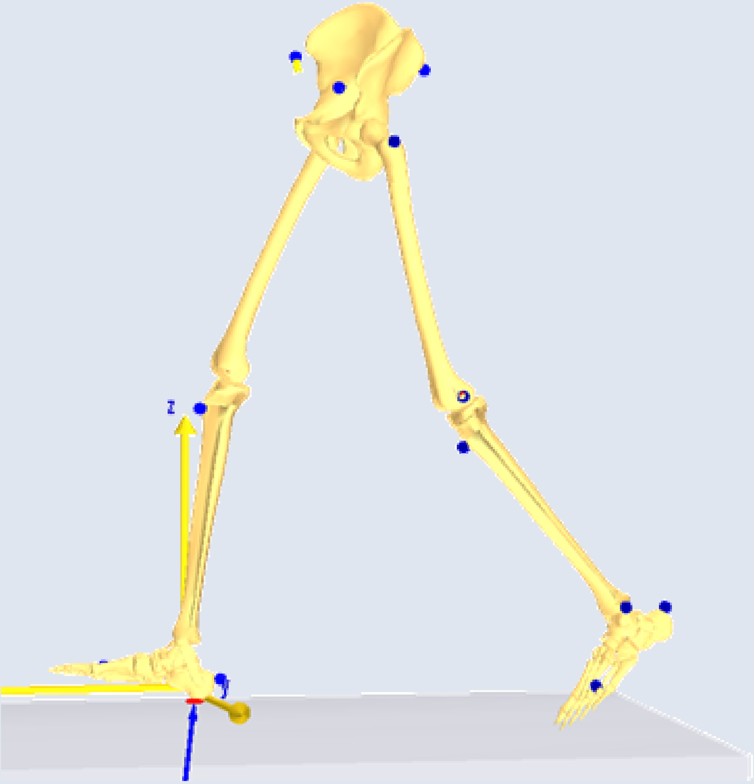
These data sets are available to the public domain from http://isbweb.org/o/content/view/66/73/.
We used the "Man" dataset.


DYNAMICS OF HUMAN GAIT
2nd Edition
Christopher L Vaughan
Brian L Davis
Jeremy C O'Connor

Driving the model with markers



All markers from the dataset are present in the model. They can be seen as the grey spheres. The position of these markers are controlled from the dataset.



Corresponding markers are defined on the bones. They can be seen as the blue spheres

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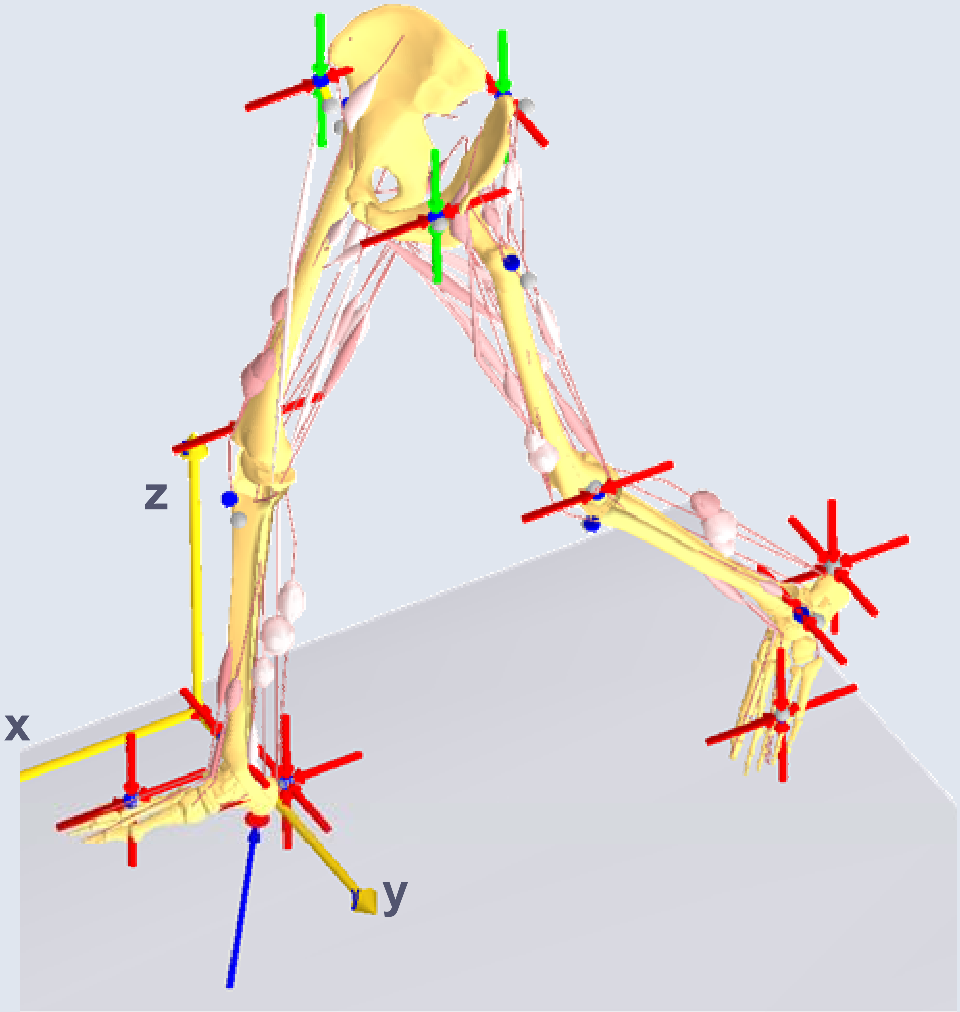
18 Drivers

The model is driven by requiring coincidence between the free floating markers (grey) and the markers on the bones (blue) for selected DOFs.



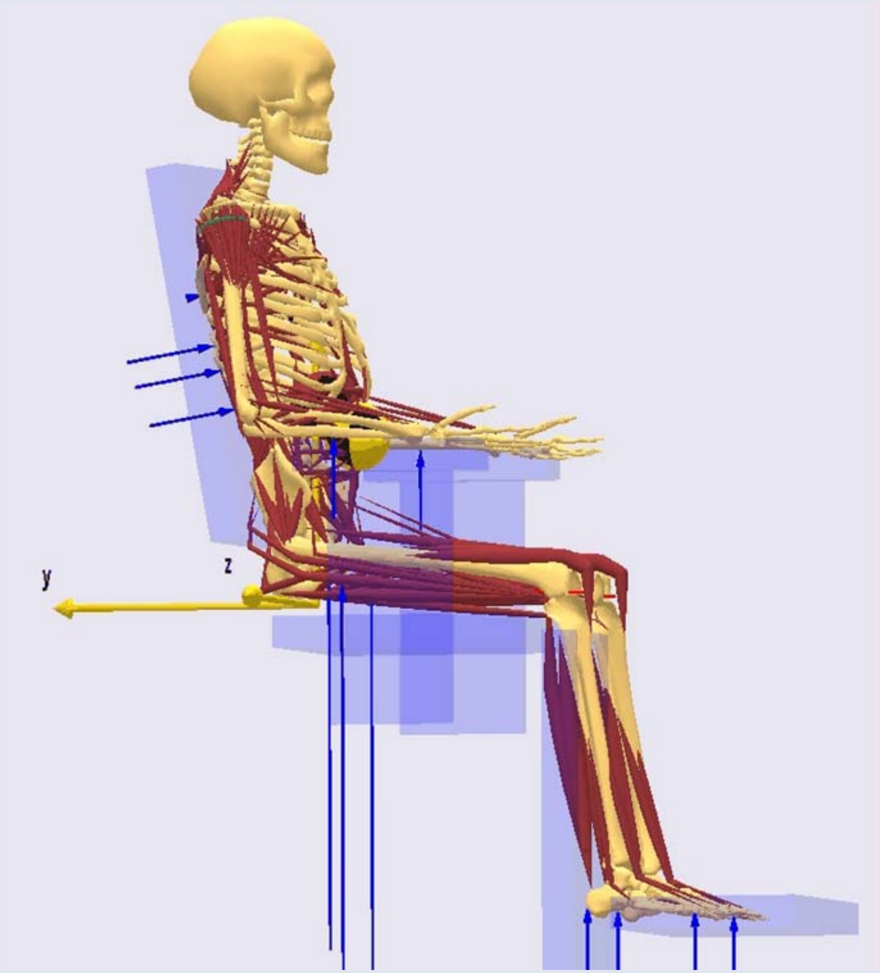
Seated human model

The human model is made using the body collection directory ”BRep/BodyModels/FullBodyModel”

The main file of the model is :

ARep/Aalborg/SeatedHuman/SeatedHuman.main.any

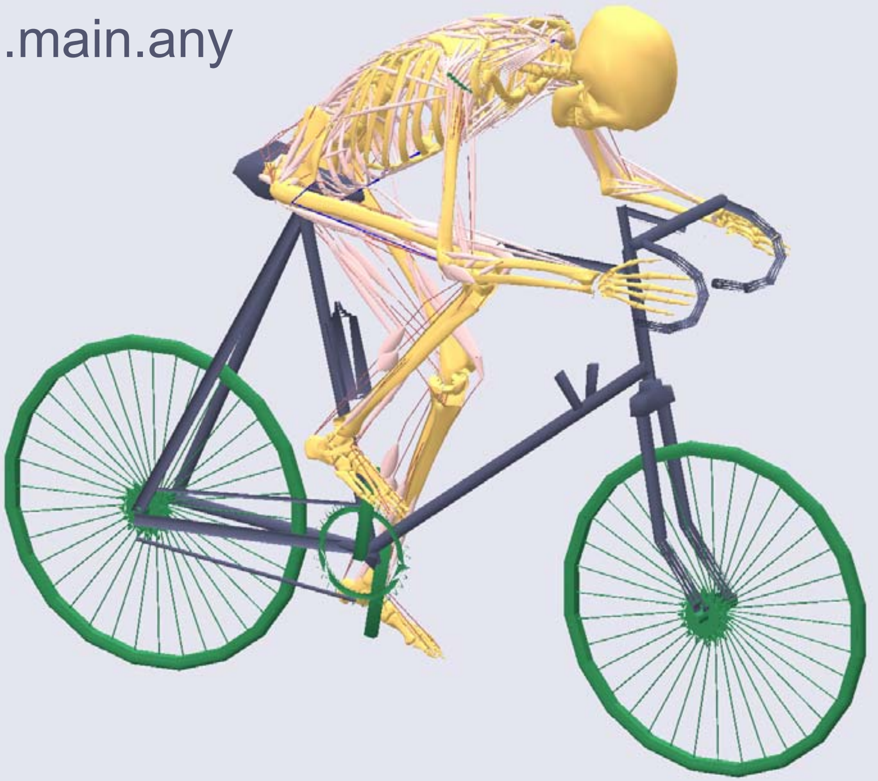
This is a model comprising the full body model, a chair and an interface between them. The interface is made such that the posture of the body is dependent of the settings if the chair.



BikeFullBody

This is a full body model of a bicycle rider

The main file of the model is :
Arep/Aalborg/BikeFullBody/BikeModel.main.any



Various parameters such as saddle position, cadence etc can be controlled from this file.

Since the model has 501 muscles it runs fairly slowly!

Bike3D

This is a bike model which utilizes the Leg3D model and the spine model with no muscles on.

The human model is made using the body collection directory

”Brep/BodyModels/SpineNoMusclesTwoLegs”

The main file of the model is :

Arep/Aalborg/Bike3D/BikeModel.main.any

Various parameters such as saddle position, cadence etc. can be controlled from this file.

Egress

The human model is made using the body collection driectory

”Brep/BodyModels/FullBodyModel

The main file of the model is :

Arep/Aalborg/Egress/Egress.main.any

What can the model be used for?

This egress model demonstrates how the position of an assistive handle on the window frame influences the knee joint forces as well as the muscular effort of egress.

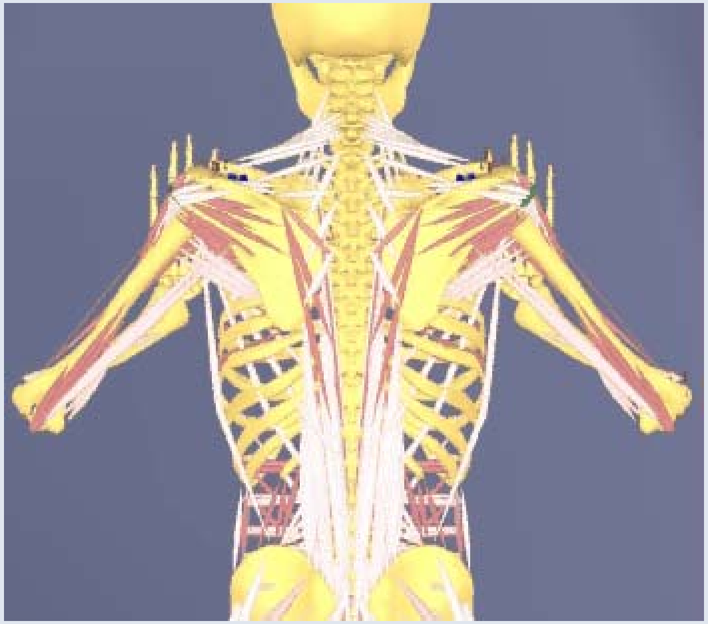
Pushup

The human model imported from the body collection directory

”BRep/BodyModels/FullBodyModel”

The main file of the model is :

ARep/Aalborg/StandingModel/Pushup.main.any



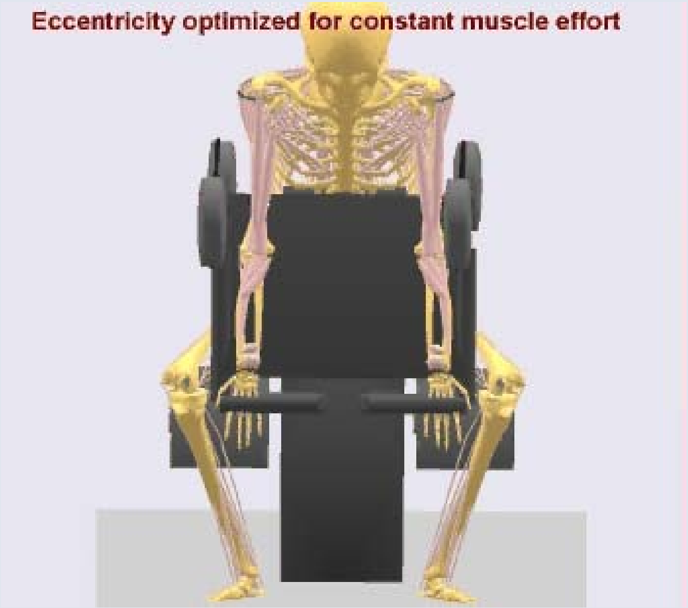
What can the model be used for?

- This is a good starting point for applications using full body models.
- The model has been used for adjusting the strenght betwen the different muscle groups

ArmCurl

This is a full body model of a person doing an armcurl

The main file of the model is :
Arep/Aalborg/ArmCurl/ArmCurl.main.any



In this example we have optimized the eccentricity of the wheel that the cable winds about to obtain an almost constant muscle effort throughout the arm curl.

Since the model has 501 muscles it runs fairly slowly!

WheelChair

The human model is made using the body collection directory

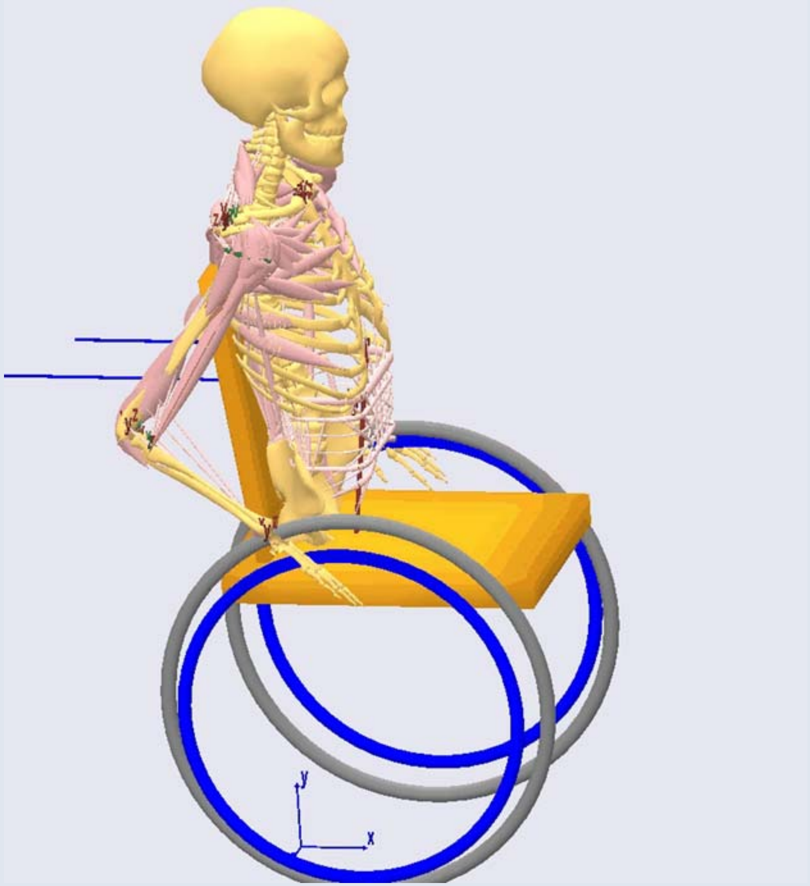
”BRep/BodyModels/SpineTwoArms”

The main file of the model is :

ARep/Aalborg/WheelChair/WheelChair.main.any

This is a model of a person sitting in a wheelchair. The model only comprises the upper body including the pelvis.

Purpose: Investigation of wheelchair ergonomics.



We hope that the models will be

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

The models require the AnyBody Modeling System v.2.0

Online resources

- The AnyBody Modeling System
  - Free demo license www.anybodytech.com
  - Email: anybody@anybodytech.com
- The AnyBody Research Project anybody.auc.dk
  - Public domain library of body models and applications

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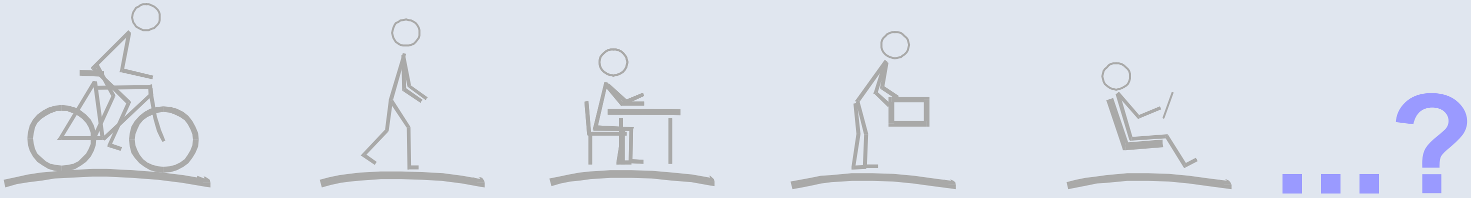
Thank you!



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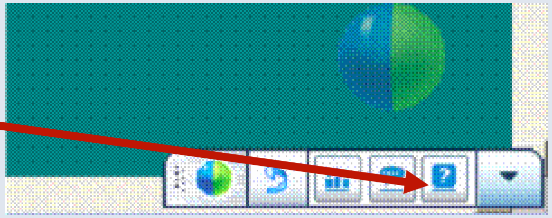
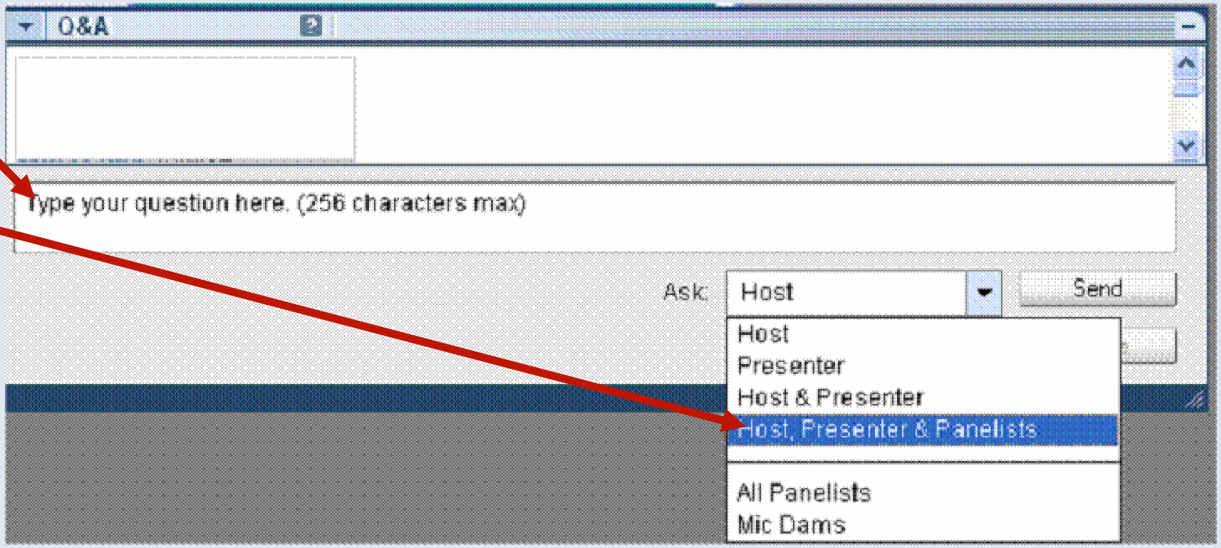
Q&A Panel

- John Rasmussen
- 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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