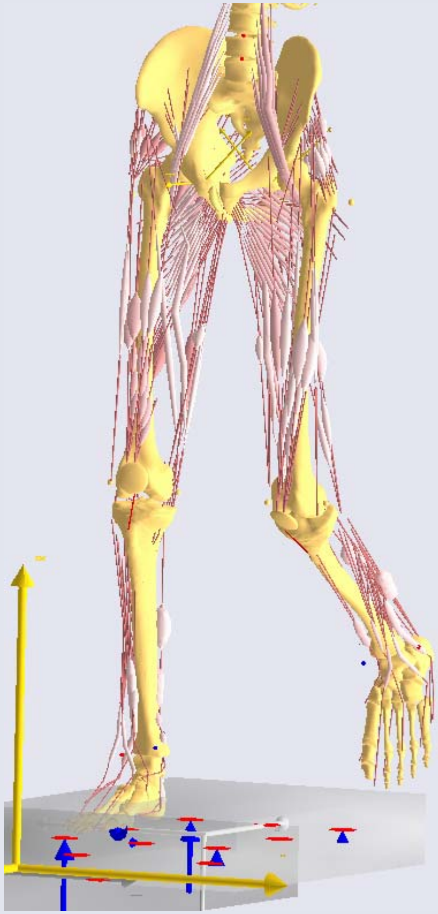
# A new detailed lower extremity model



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*This project was funded by the European Space Agency (ESA/ESTEC)*

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# Presenters

Sebastian Dendorfer
(Presenter)

Arne Kiis
(Host/Panelist)

Bart Koopman
University of Twente
(Panelist)

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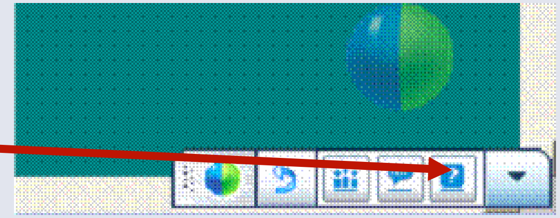

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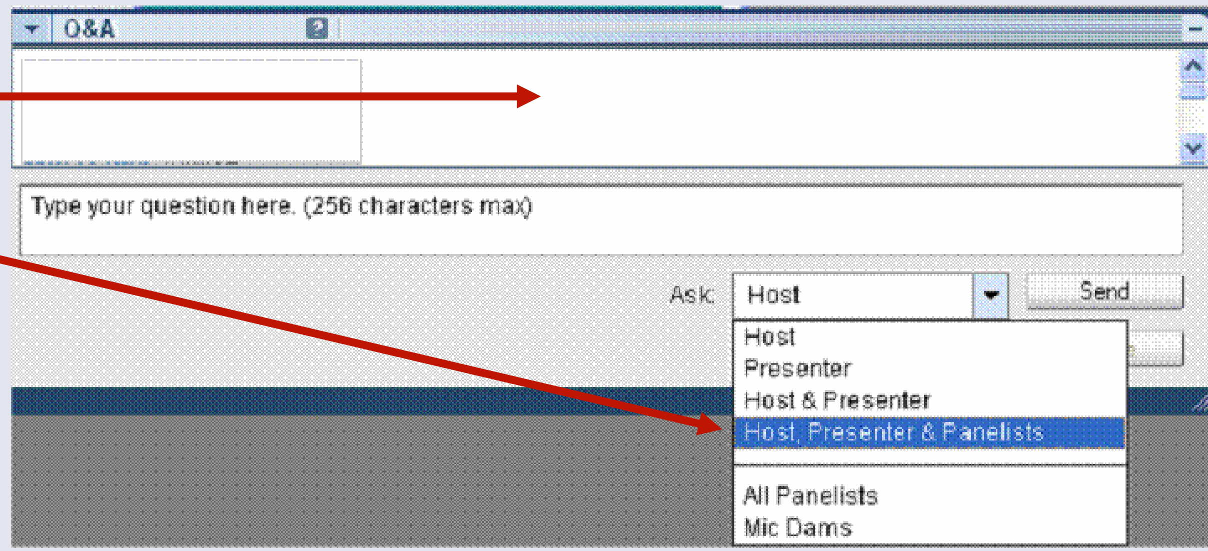


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# Outline

- Data for the new leg model
- Model details
- Leg validation
- Application:
  - Evaluation of tibia strains during walking in 1g and microgravity (study for the European Space Agency, ESA)

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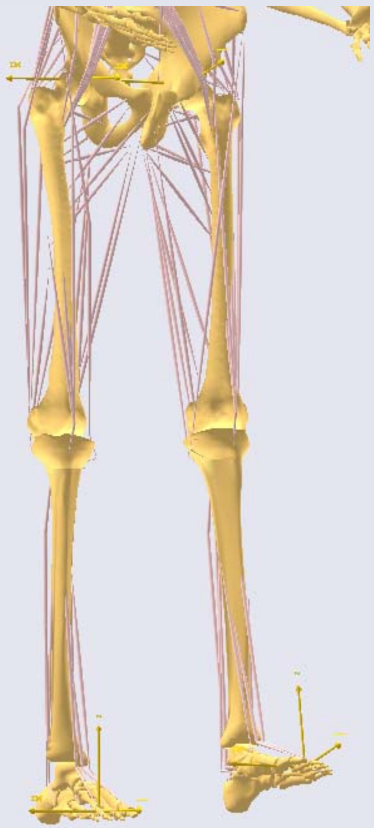
# Aim



- Increase the level of detail in the lower extremity
- Template for more advanced joint kinematics (knee, ankle)

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# The Twente Lower Extremity Model

Comprehensive and consistent dataset from one donor (77 y, 1.74 m, 105 kg)

- Joint parameters
- Muscle parameters (optimum length, cross sectional area)
- Geometrical parameters (attachment sites, via-points)
- Inertia properties

[1]Klein-Horsman, M. D. (2007), 'The Twente lower extremity model - consistent dynamic simulation of the human locomotor apparatus', PhD thesis, Universiteit Twente.

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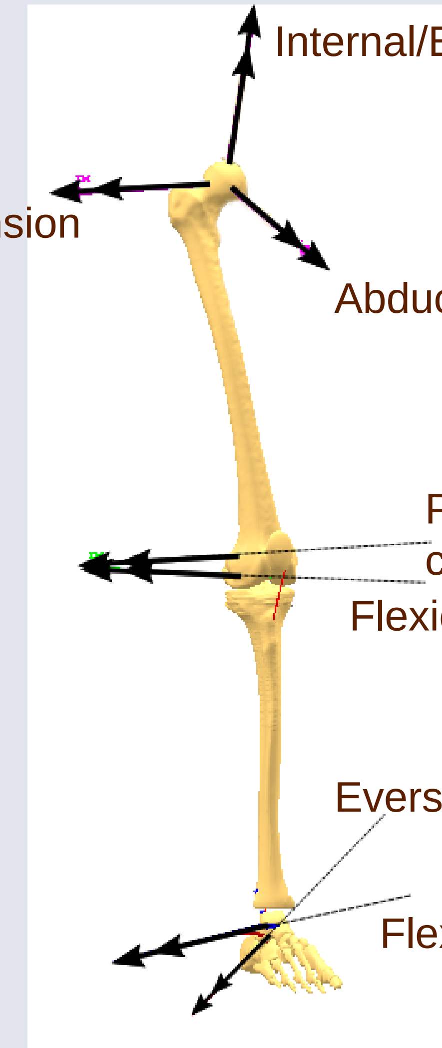
# Data for the new leg

Most muscle and joint data is taken from the Twente study.

Modified are:

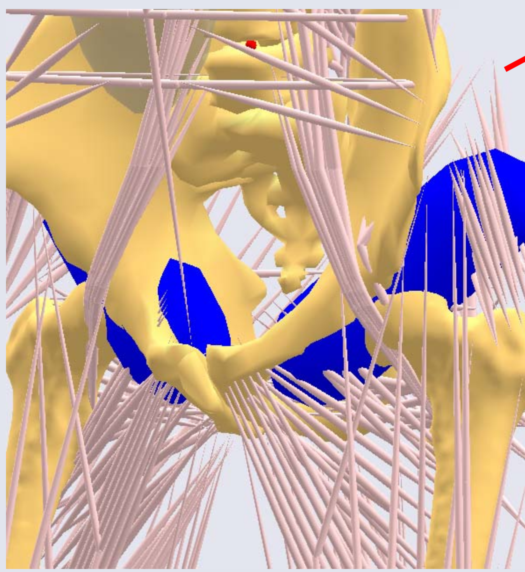
- Joint axes and centers of ankle and subtalar joint
- Wrapping surface for Iliacus muscles adjusted to pelvis
- Muscle insertion points
  - Foot-muscles, insertion on the foot, via-points also on the shank
  - Gluteus Maximus Superior
  - Psoas
  - Iliopsoas muscles are taken from the old leg (connection to spine)

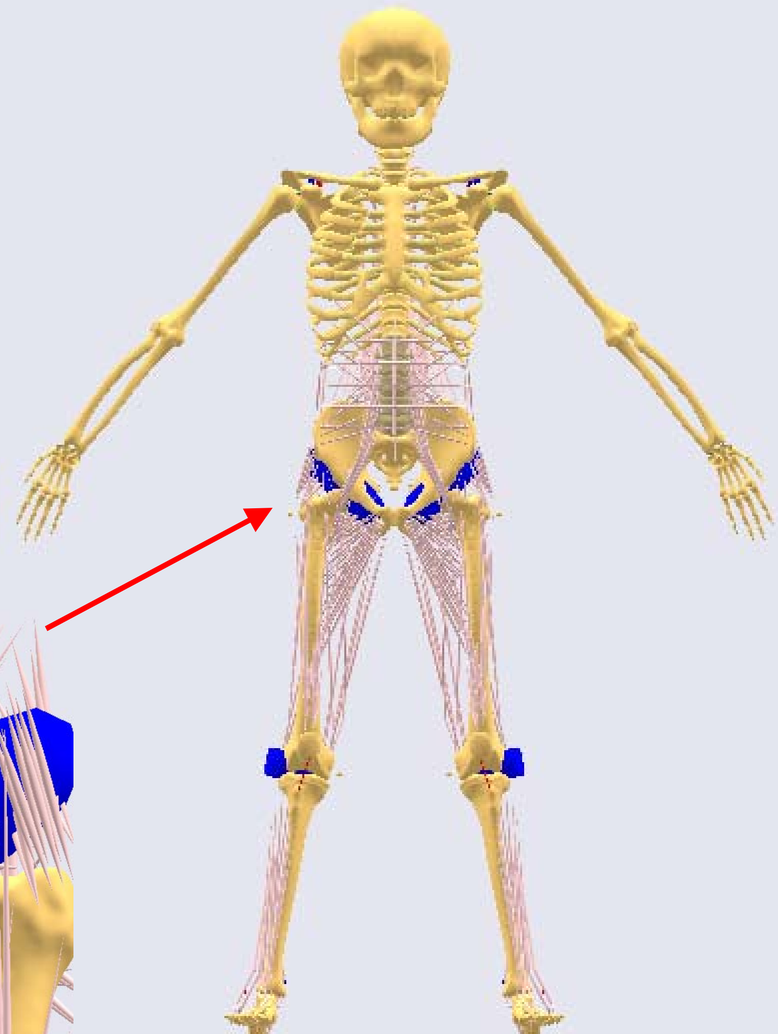
# Degrees of freedom



# Muscles

- 55 Muscles divided in 159 branches per leg
- 11 wrapping muscles (Gastrocnemius, Illiacus)





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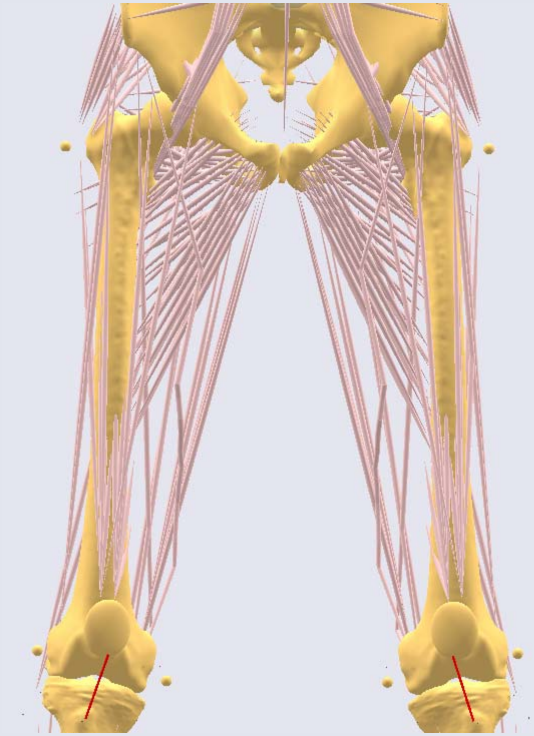
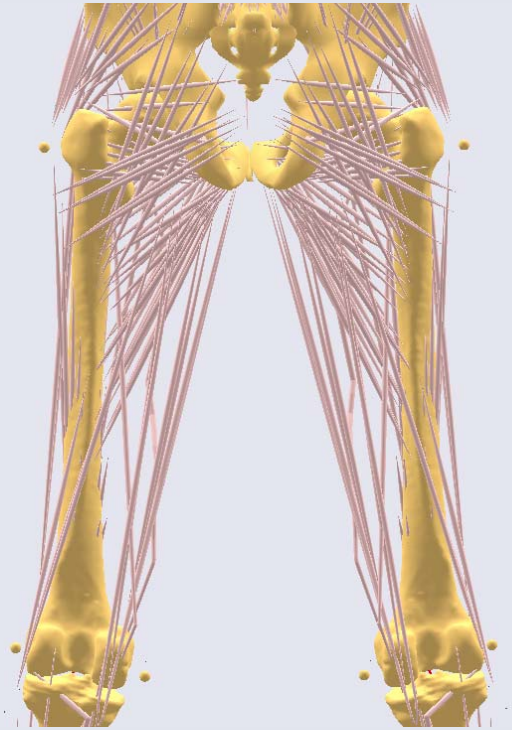
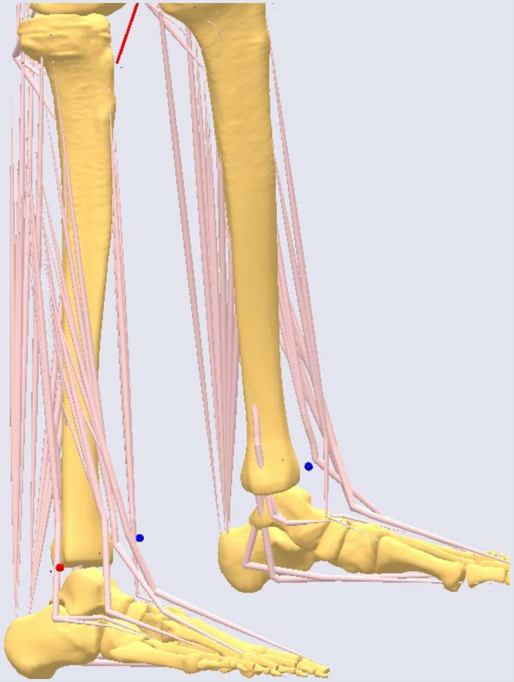
# Muscles



anterior



posterior



lateral

New femur and tibia geometries were kindly supplied by P. Worsley, University of Southampton

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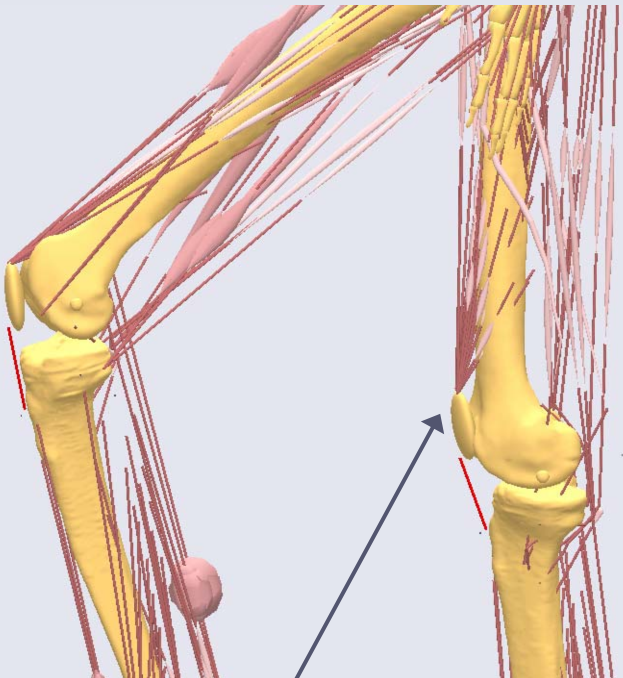
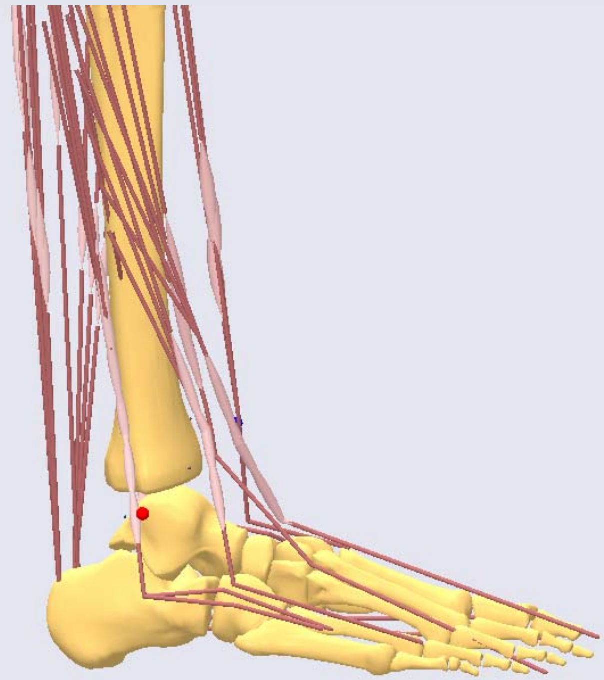
# Muscles – knee, ankle

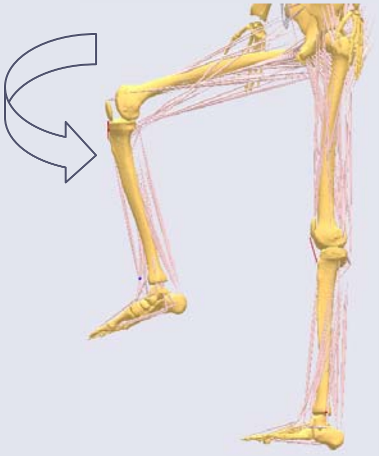




Quadriceps Femoris *(Vastus lat. (8), Vastus med. (10), Vastus int. (6), Rectus Femoris (2))* connected to the Patella

# Validation

- Muscle moment arms
  - Derivative of the elongation of the muscle element with respect to the corresponding DOF (tendon excursion method)
- Maximal isometric joint moment
  - Ratio between applied moment at a certain DOF and the maximum muscle activity
- Gait analysis
  - Joint forces
  - Muscle activation patterns



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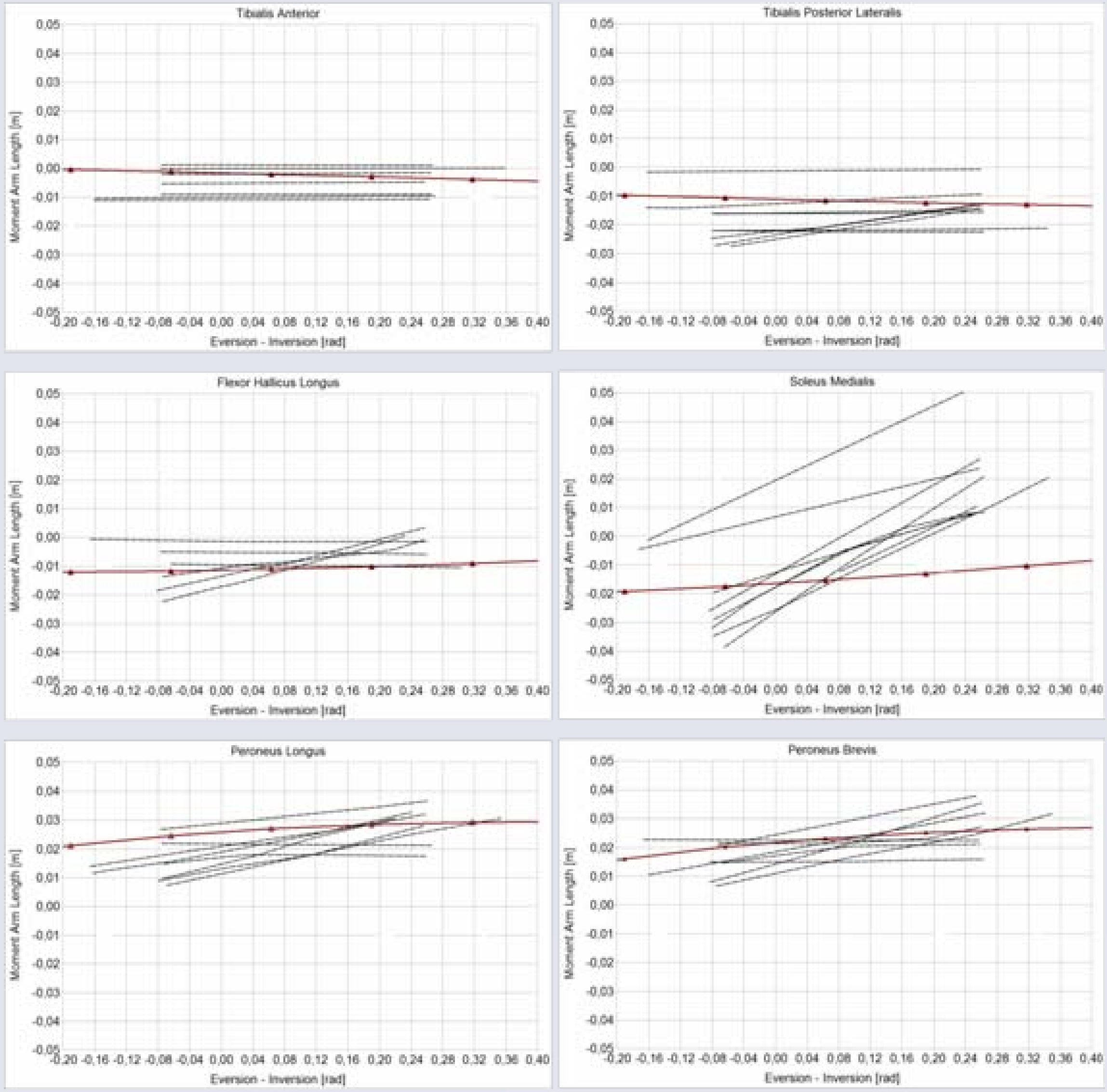
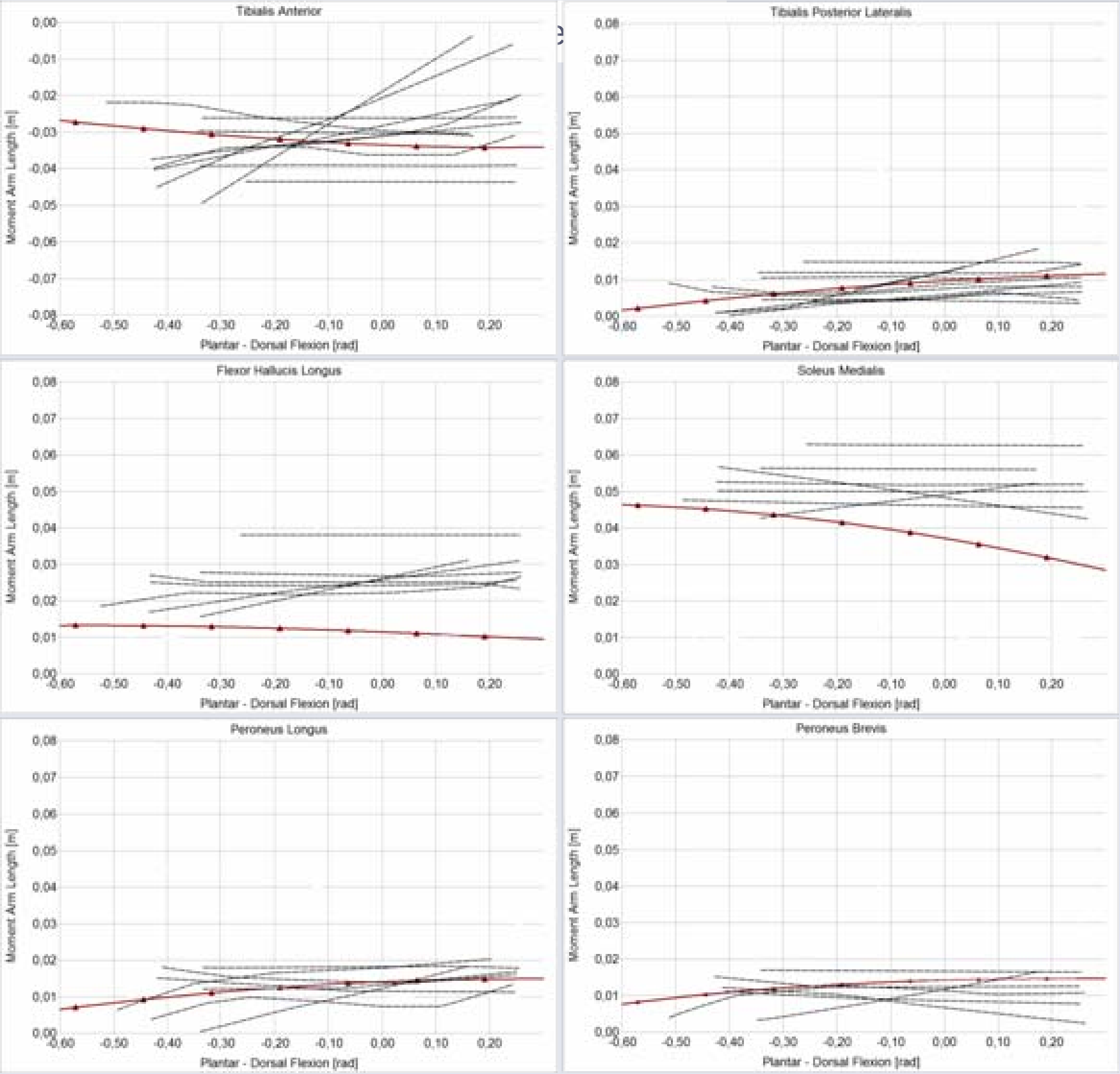
# Moment arms – subtalar joint

- Good correlation for most muscles with average literature values



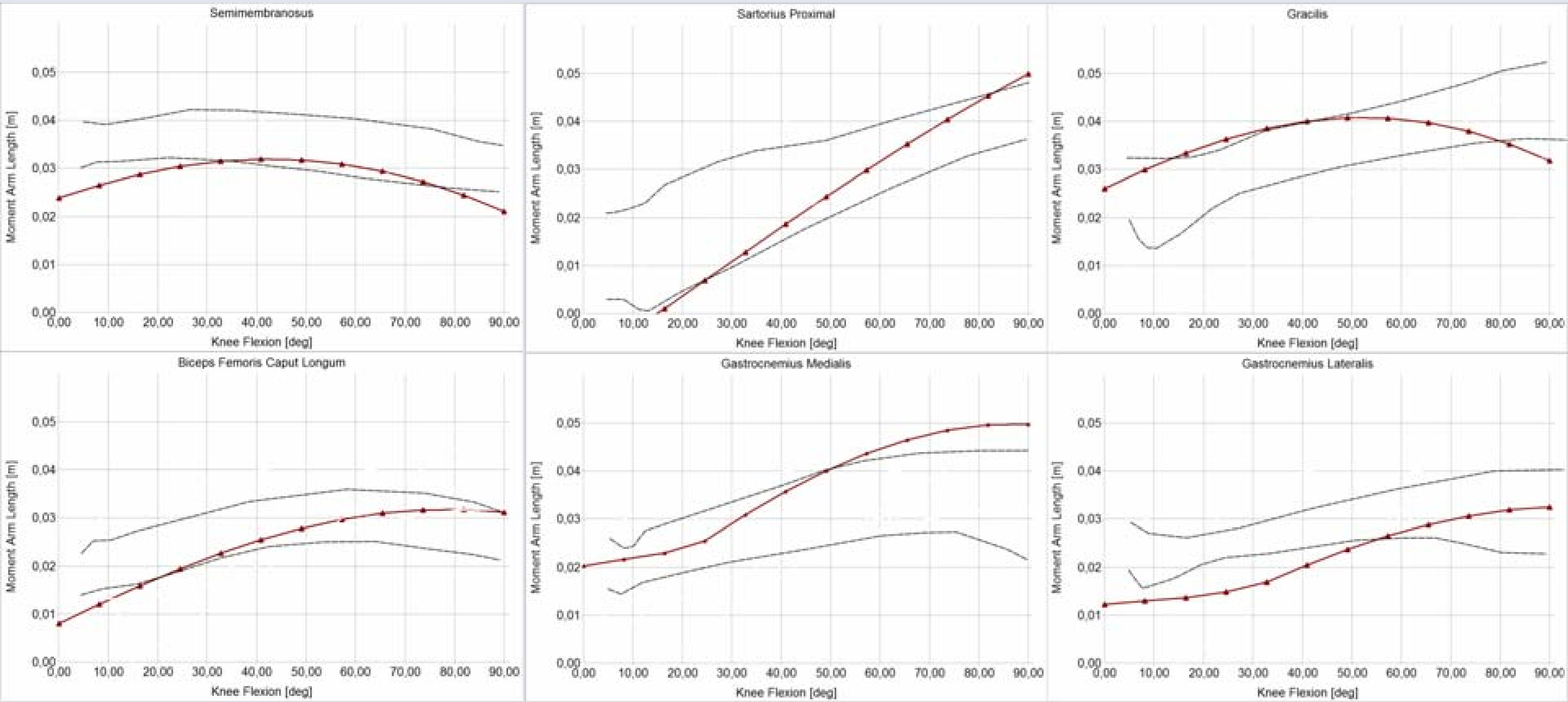

*Data reproduced from Klein et al., J Biomech*, vol. 29, no. 1, pp. 21–30, Jan 1996.

# Moment arms – ankle joint



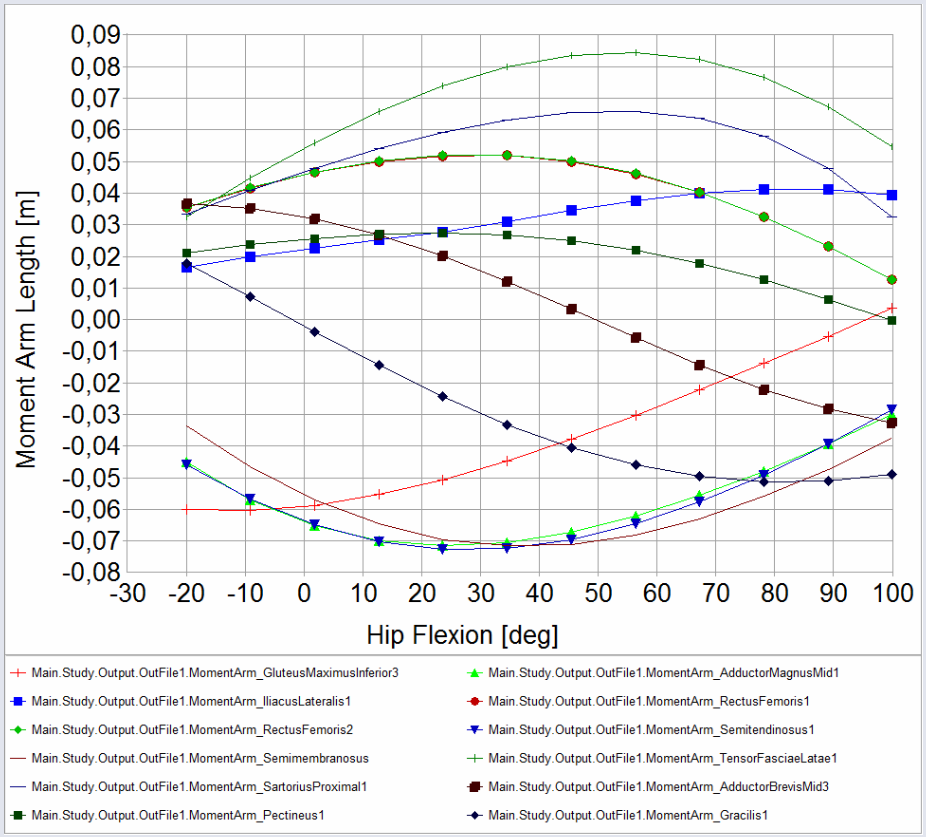

*Data reproduced from Klein et al., J Biomech*, vol. 29, no. 1, pp. 21–30, Jan 1996.

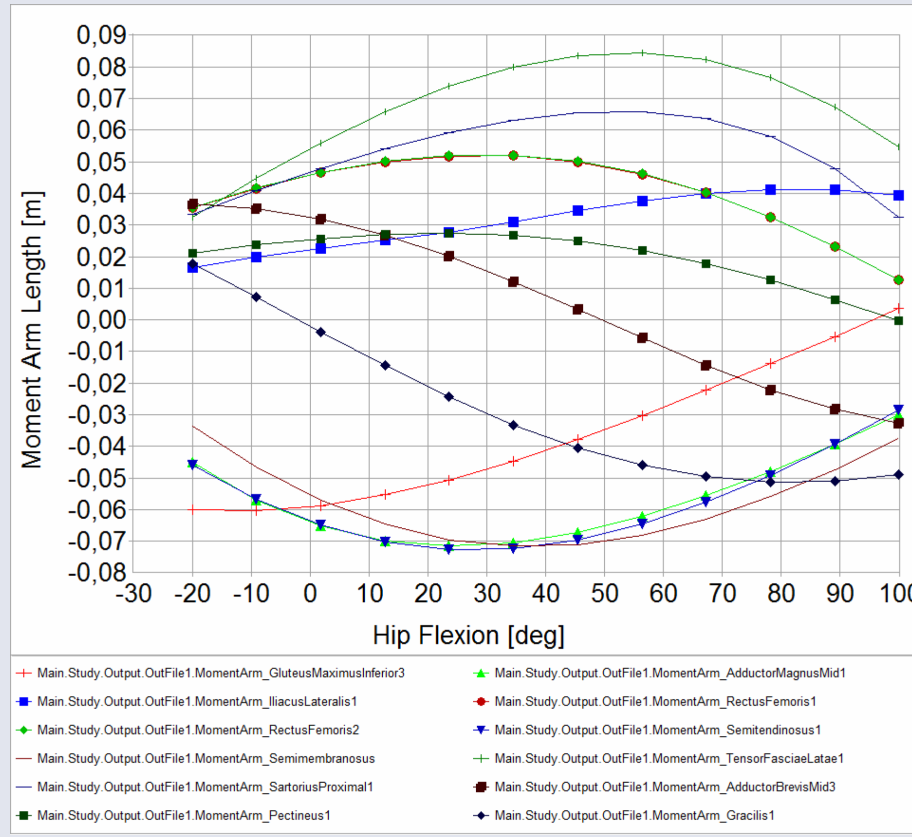
# Moment arms – knee joint




*Data reproduced from* Buford, W. L.. et al. (1997), *IEEE Trans Rehabil Eng* **5**(4), 367—379, red line: Anybody

# Moment arms – hip joint

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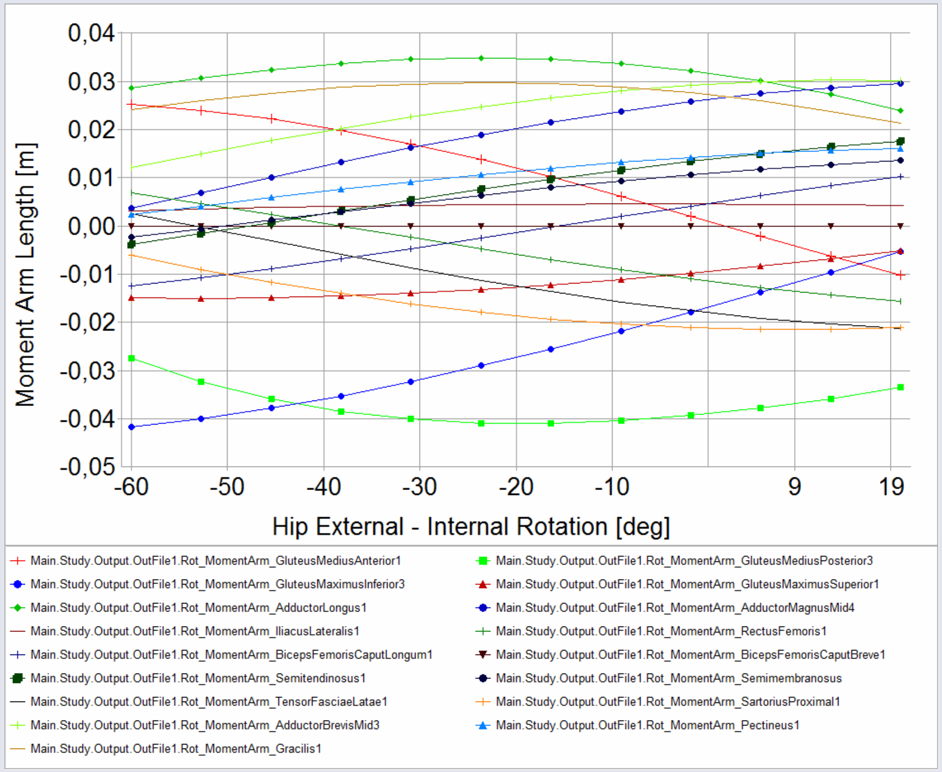
# Moment arms – hip joint II

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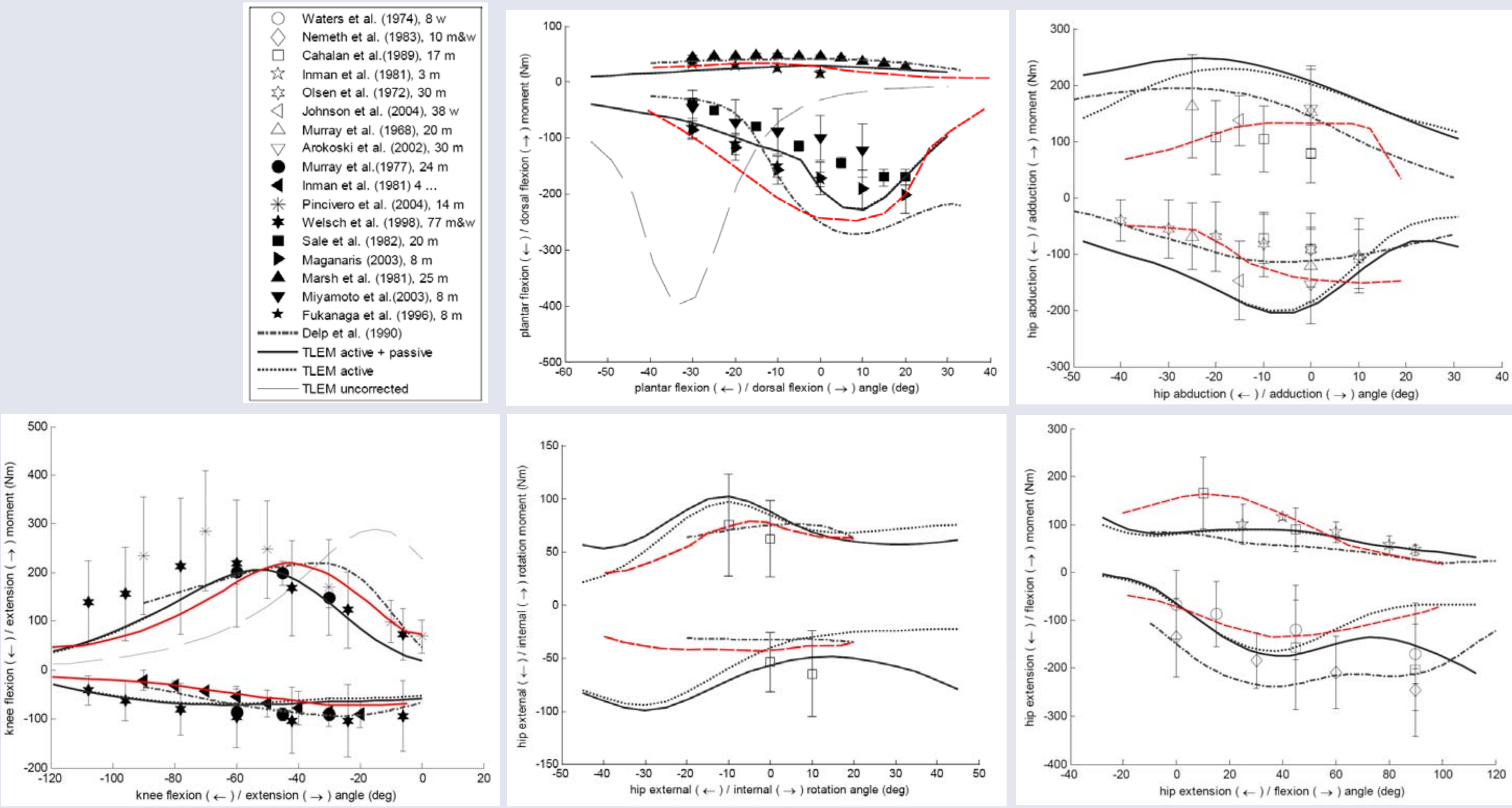
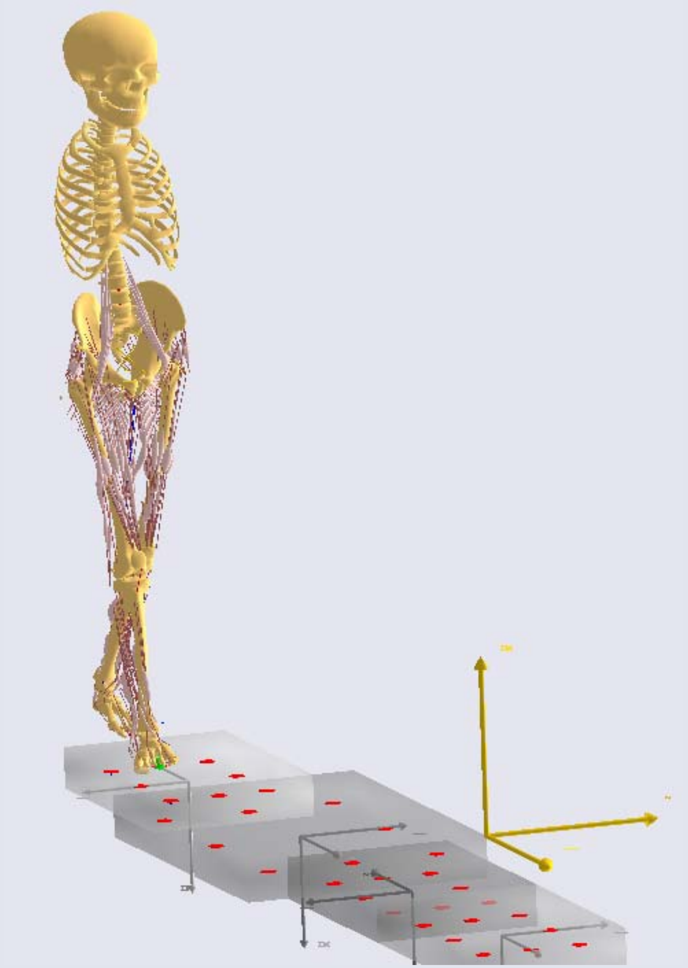
# Validation – joint strength




*Klein-Horsman, M. D. (2007), 'The Twente lower extremity model - consistent dynamic simulation of the human locomotor apparatus', PhD thesis, Universiteit Twente. red line: AnyBody*

# Normal walking

- Bodymodel includes new leg
- Hill-type 3 element muscle model
- Motion and force plate data given
- Load balanced by body forces and support for residuals



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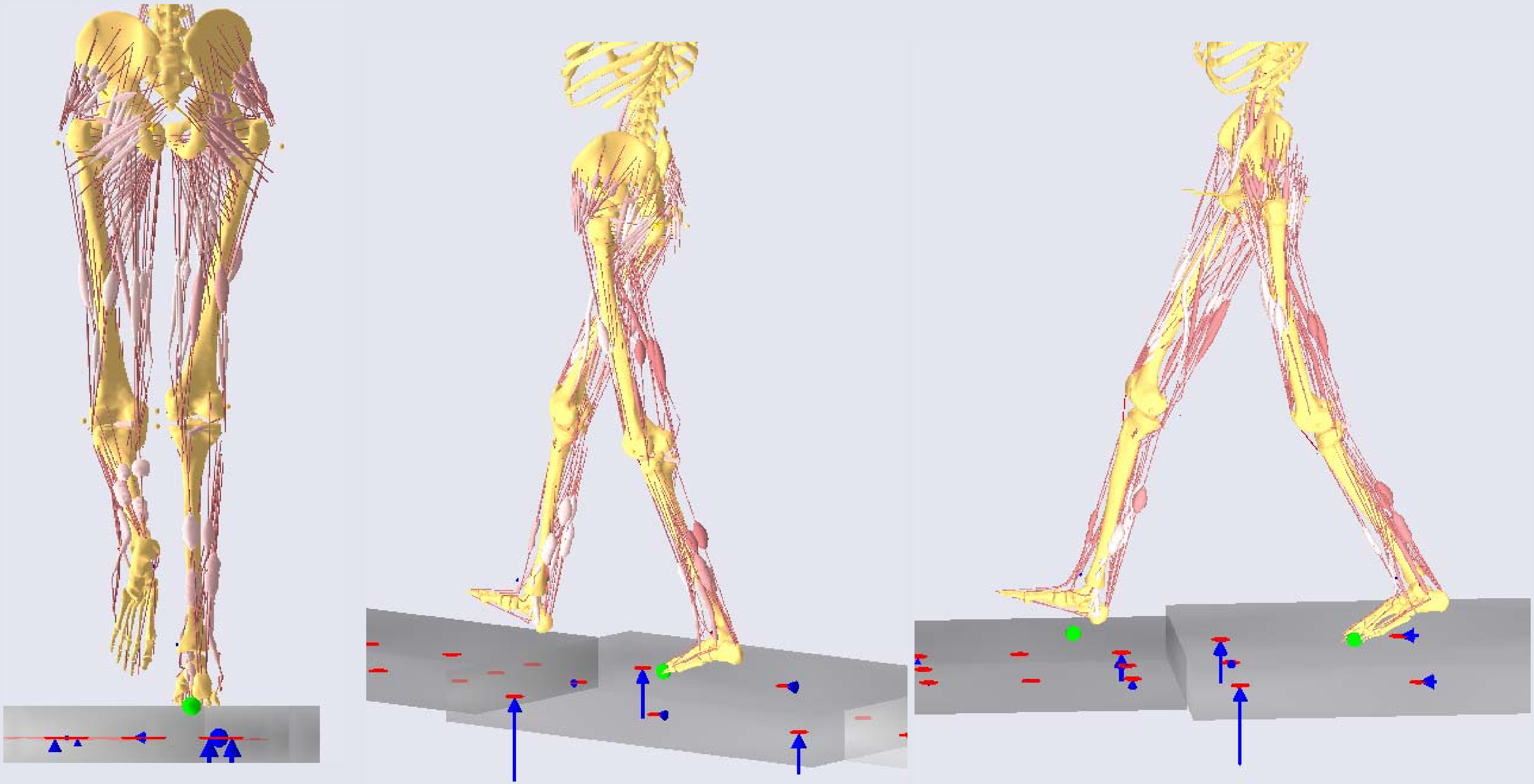
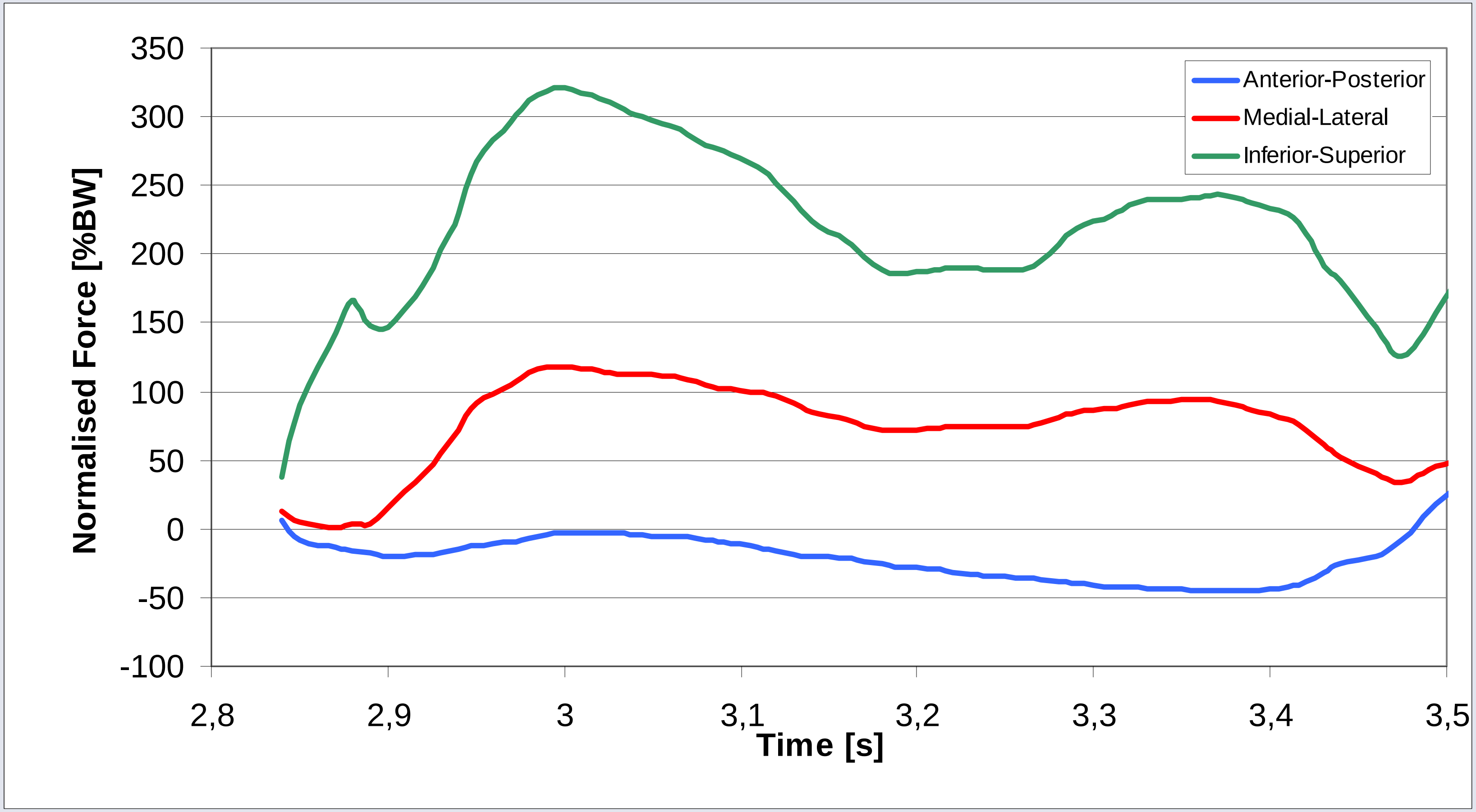
# Normal walking



# Normal walking

# Hip reaction forces – normal walking




Dataset: GaitUniMiami, Solver: MinMaxOOSolQP; e2 = 1000;

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# Application: Analysis of tibia strains in normal walking and walking in microgravity

This project was funded by the European Space Agency (ESA)

# Countermeasure exercise

- Tissue degeneration in space
- Treadmill walking
- Microgravity conditions
- Harness provides gravity replacement load (GRL)
- Questions:
  - Design
  - Level of GRL
  - Exercise
  - Efficiency of the exercise

http://www.spaceflight.esa.int/

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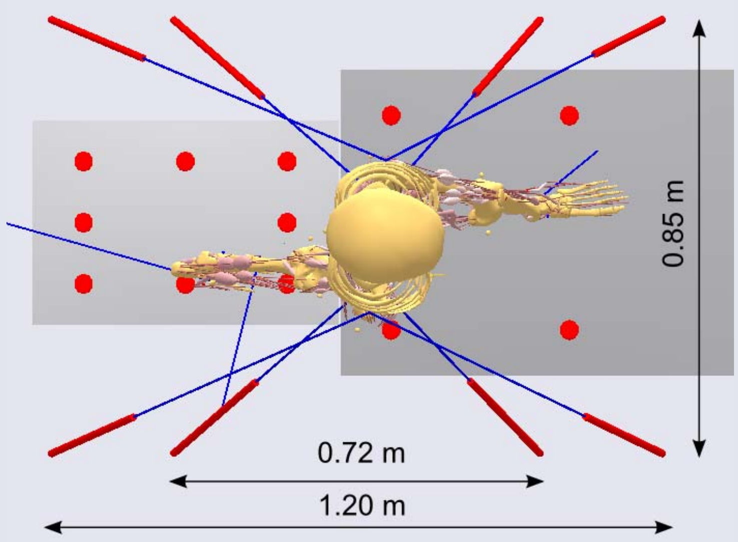
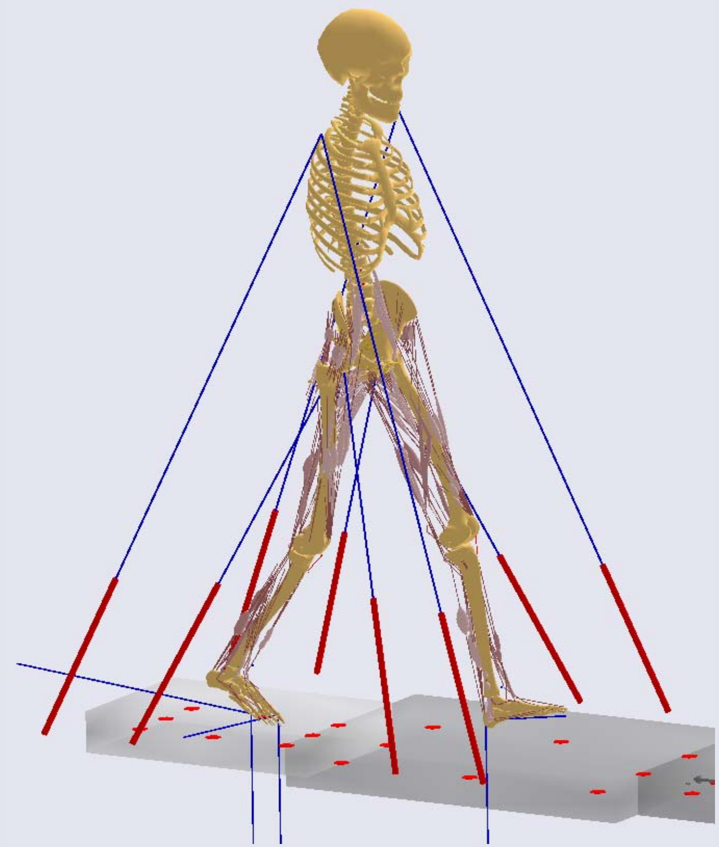
# Walking with harness – 0g

- Includes shoulder and waist harness[1]
- Motion data given, ground reaction forces computed with simple contact
- Gravity replacement load:
  - 80% bodyweight
  - 100% bodyweight



[1] McCrory et al., *Aviat Space Environ Med*, vol. 73, no. 7, pp. 625–631, Jul 2002

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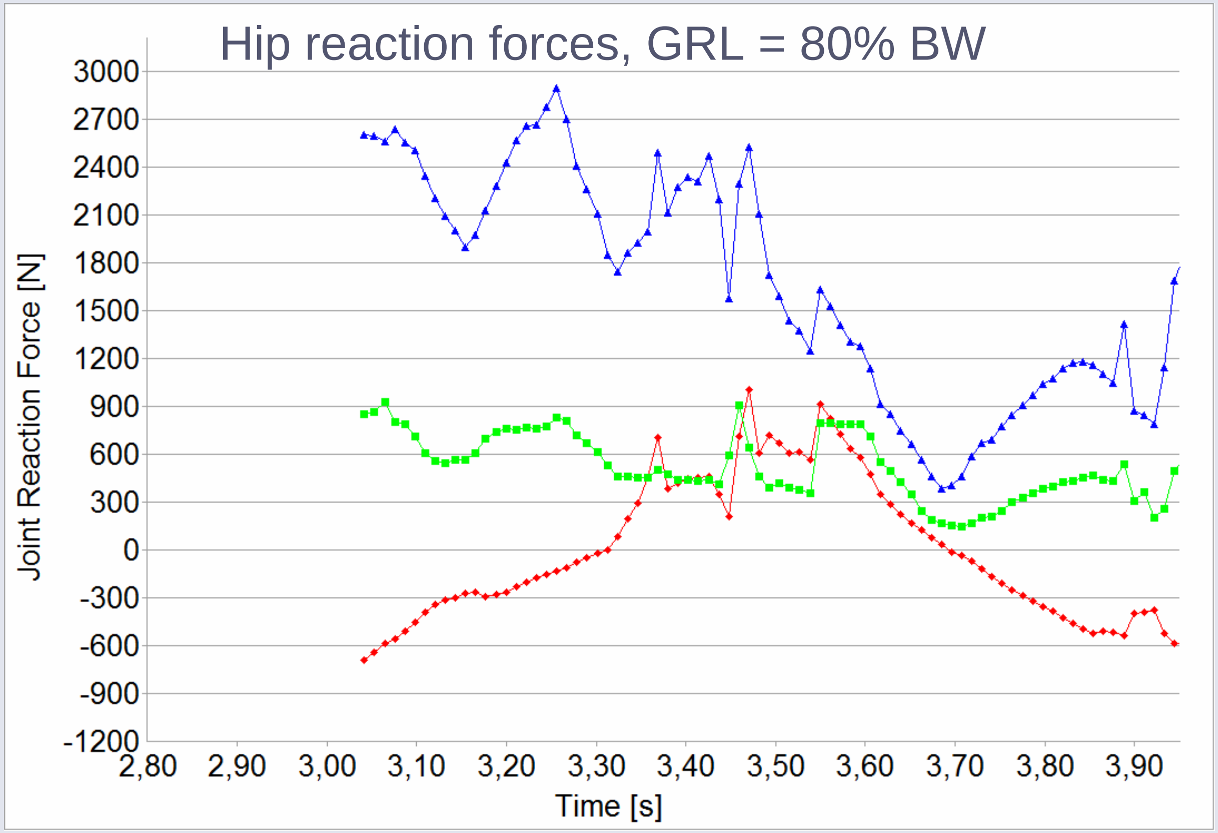
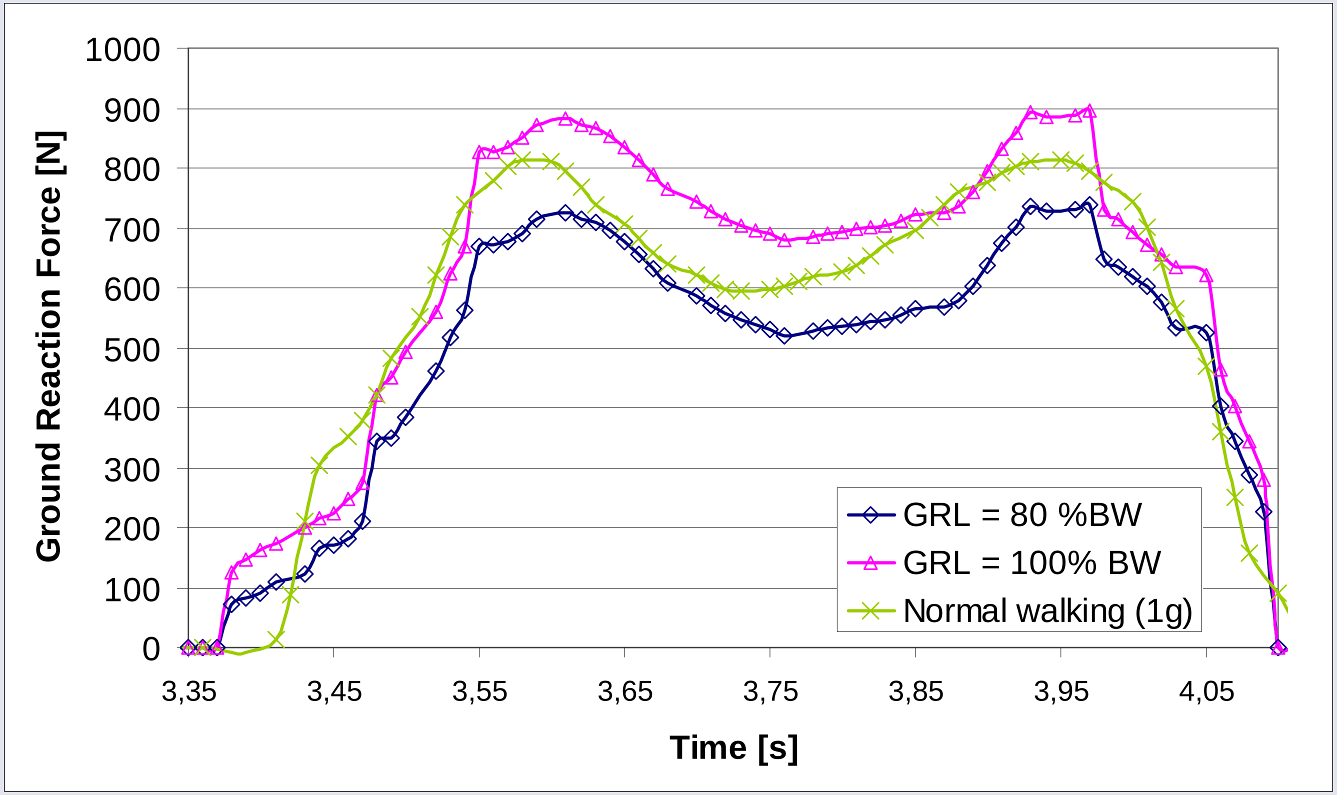
# Results – harness walking

- Joint reaction forces and EMG patterns differ from normal walking



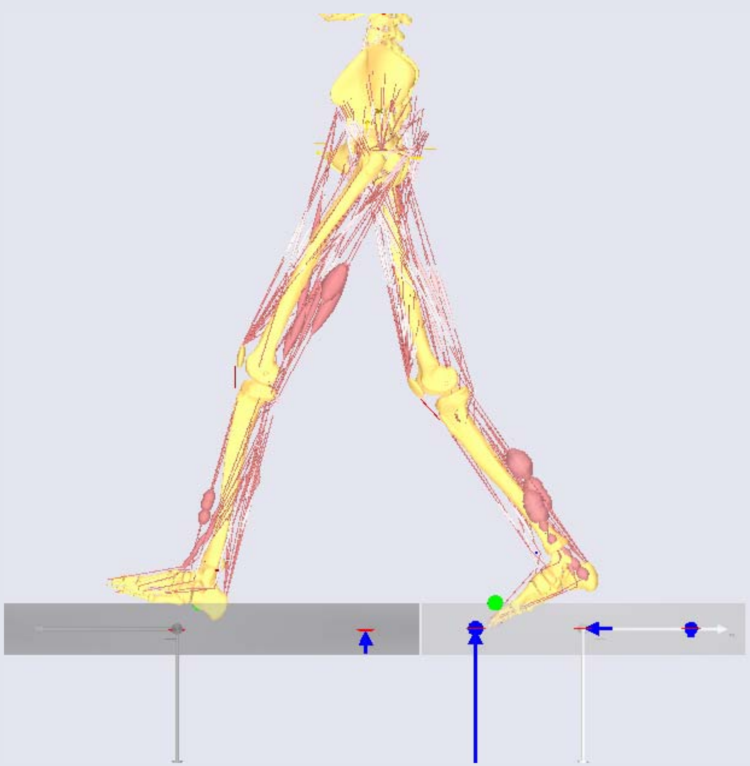
# Results – harness walking

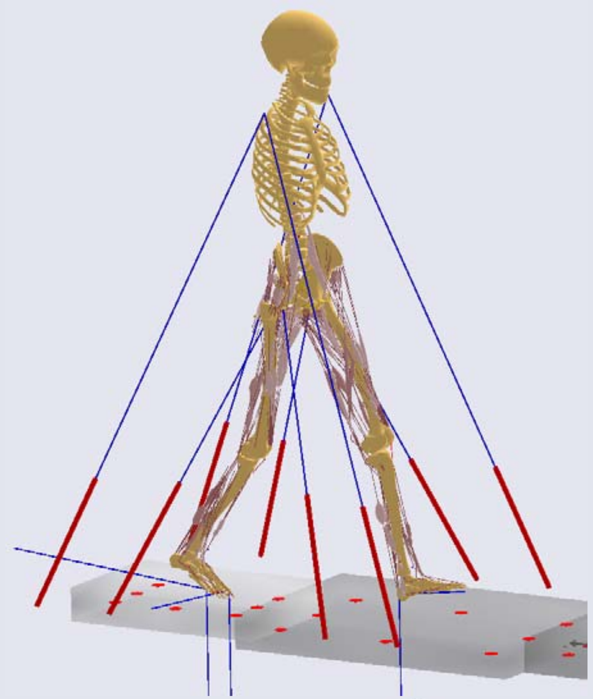
- GRF of normal walking and harness walking are similar in shape



# Stress state in the tibia

- Point of evaluation: Preswing (stance phase)
  - High knee reaction forces
  - High muscle activity
- Including all forces and moments acting on the tibia (> 180)





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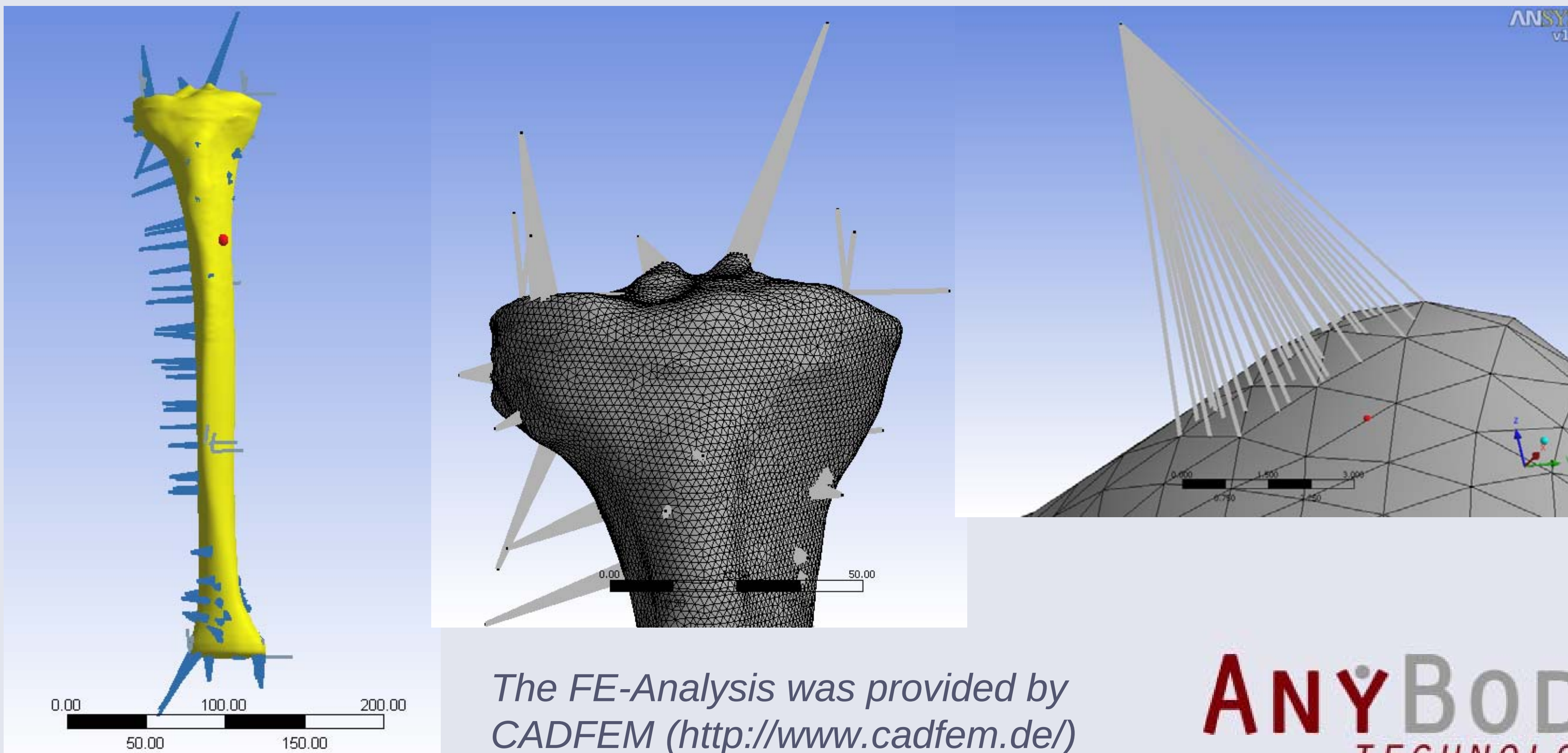
# Finite Element Model

- Linear, isotropic material model (E = 15000 MPa)
- Medullary canal is modelled, Epiphysis filled with cortical bone
- Rigid beams connecting muscle insertion points and tibia
- Ansys V11




*The FE-Analysis was provided by CADFEM (http://www.cadfem.de/)*

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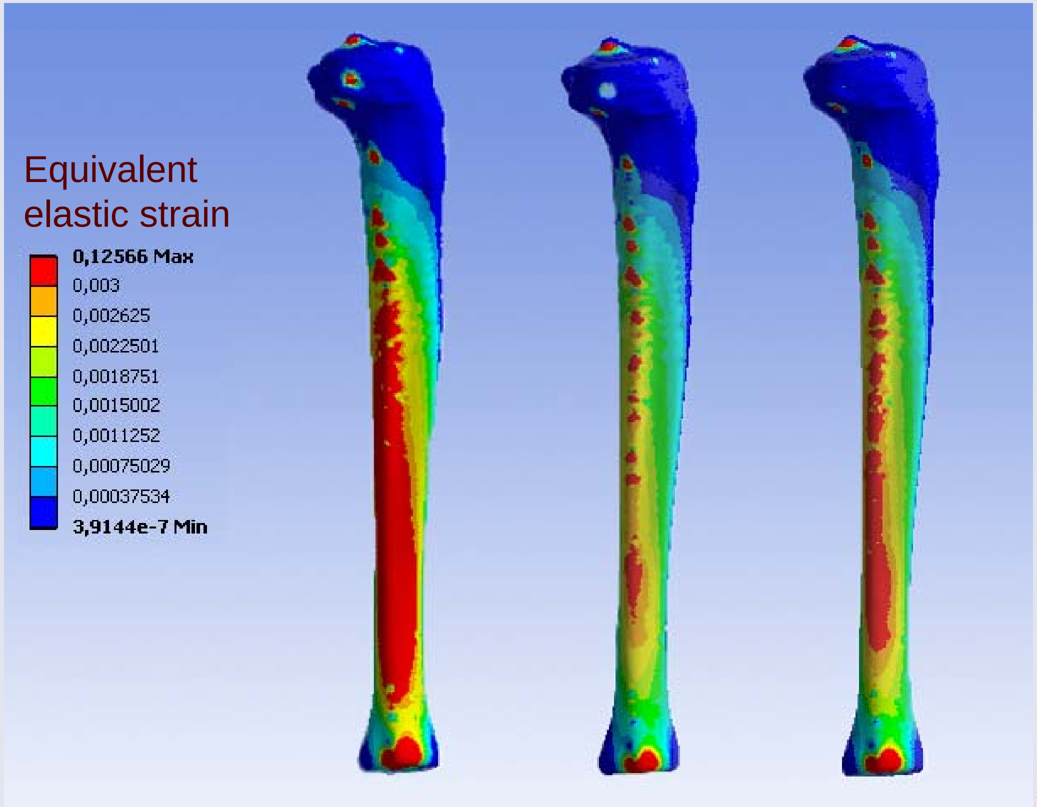
# Results - FEM

- Stresses are lower for both harness models
- Regions of highest stresses are similar

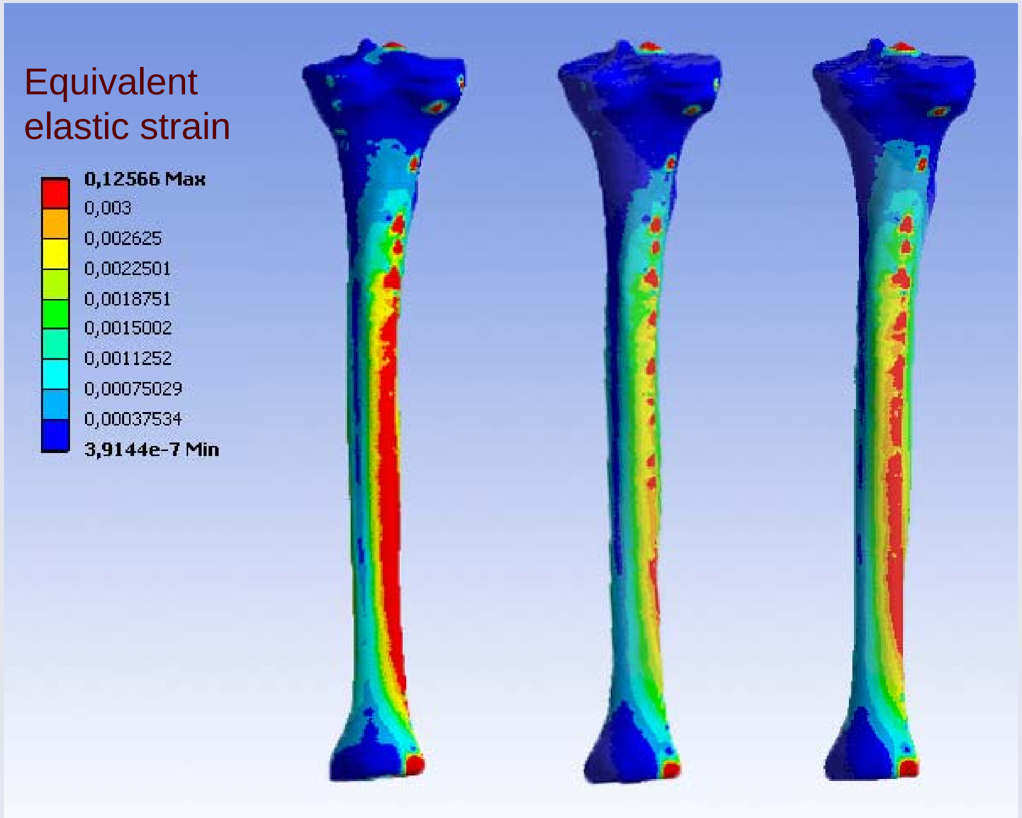
Lateral view




NW 80% BW 100% BW

# Results - FEM

Posterior view




NW 80% BW 100% BW

# Summary

- A very detailed leg model is proposed
- High level of detail in muscle definitions
- Validation results show a reasonable performance

Future:

- A more detailed validation for various applications
- A combined dataset for EMG and motion to analyze the activation patterns
- Advanced joint definitions in knee, ankle and foot

# Acknowledgement


- Martijn Klein-Horsman, University Twente
- Karin Gorter, University Twente
- P. Worsley, University of Southampton

- Eurpean Space Agency ESA/ESTEC for financial support

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**Validation:**

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- *A. L. Hof, H. Elzinga, W. Grimmius, and J. P. K. Halbertsma, "Speed dependence of averaged emg profiles in walking." Gait Posture, vol. 16, no. 1, pp. 78–86, Aug 2002.*

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# We hope, that the model will be

- Downloaded
- Improved
- Validated for particular purposes
- Used for solving development and research questions

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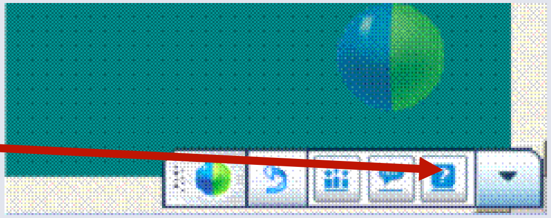
# Q&A Panel



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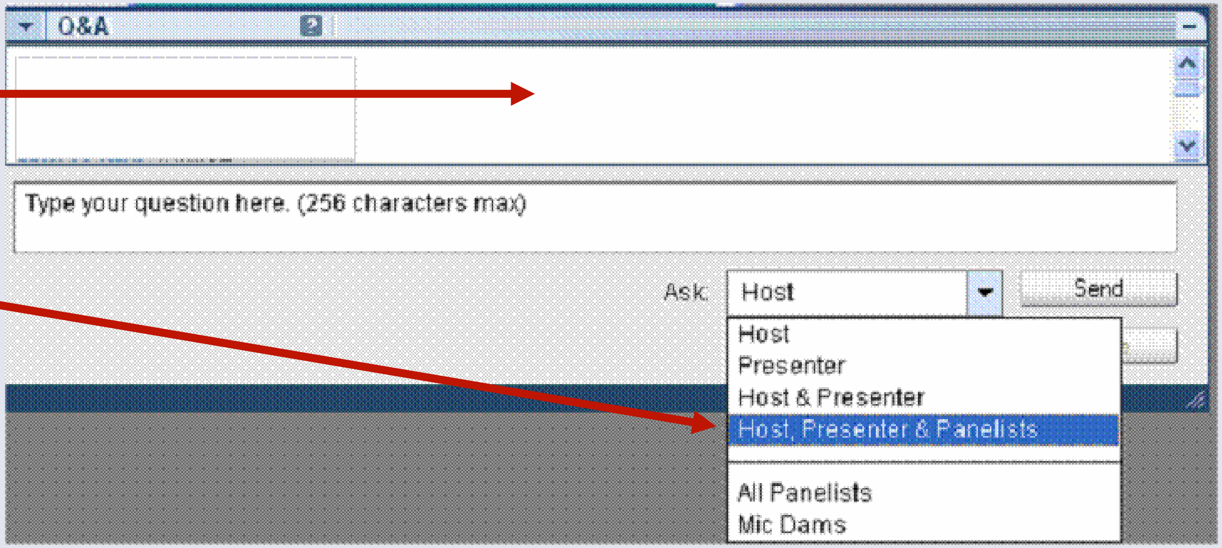


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