The webcast will start in a few minutes….

LifeLongJoints

MUSCULOSKELETAL VALIDATION AND WEAR SIMULATION

Grant agreement
no. NMP-310477

Outline

- Brief introduction
- Today's webcast:
  - Musculoskeletal validation and wear simulation
- Models and batch processing
- Questions and answers

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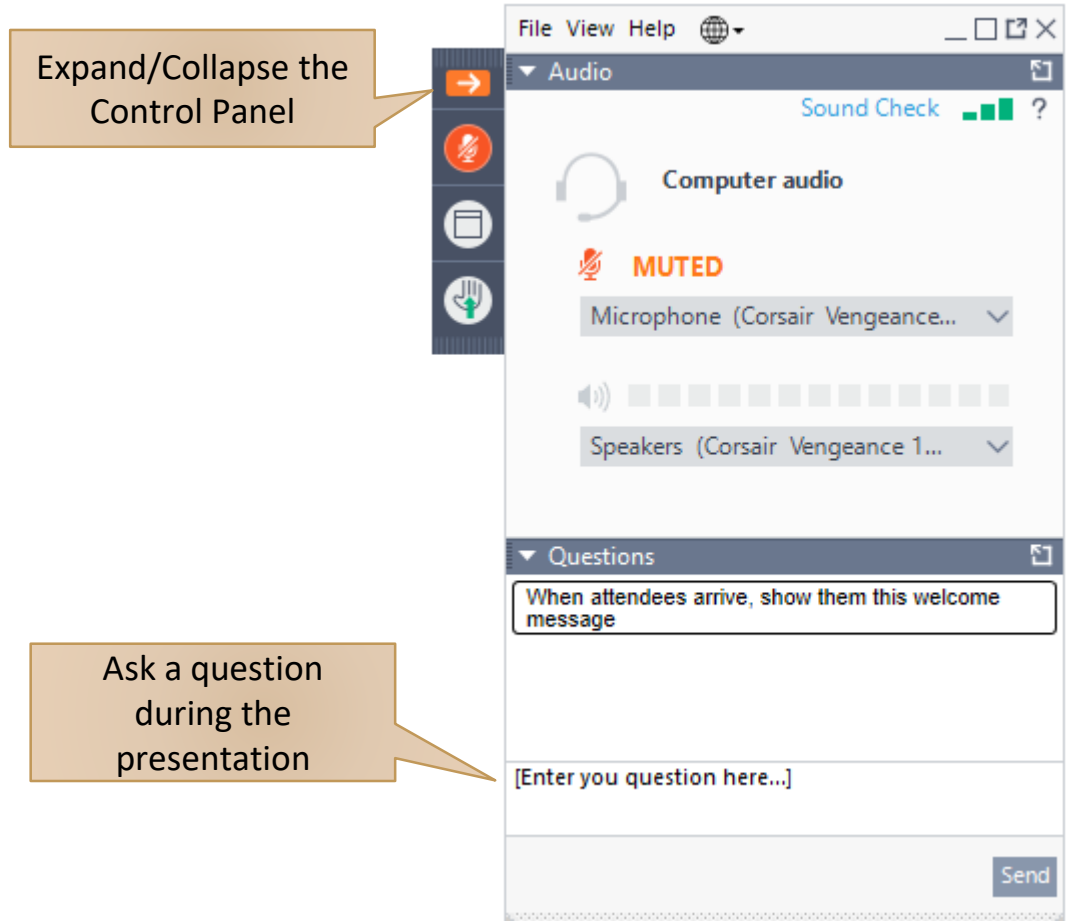
Host:
Morten Enemark Lund
R&D Engineer
AnyBody Technology

Control Panel

The Control Panel appears on the right side of your screen.

Submit questions and comments via the Questions panel.

Questions will be addressed at the end of the presentation. If your question is not addressed we will do so by email.



Musculoskeletal Simulation

Motion data

Kinematics + Forces

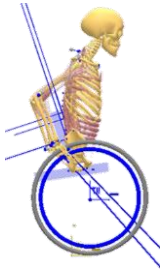
ANYBODY

Modeling System

Body Loads

- Joint moments
- Muscle forces
- Joint reaction forces

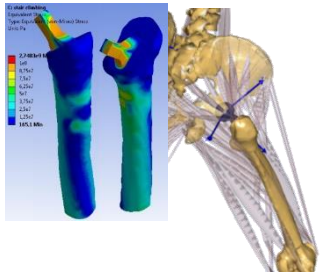
Movement Analysis



Product Design Optimization

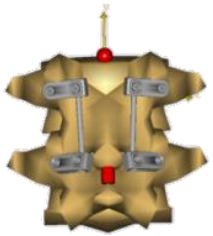
ANYBODY Modeling System

Ergonomic Analysis



Load Cases for Finite Element Analysis

Surgical Planning and Outcome Evaluation



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LifeLongJoints

MUSCULOSKELETAL VALIDATION AND WEAR SIMULATION

ETH zürich

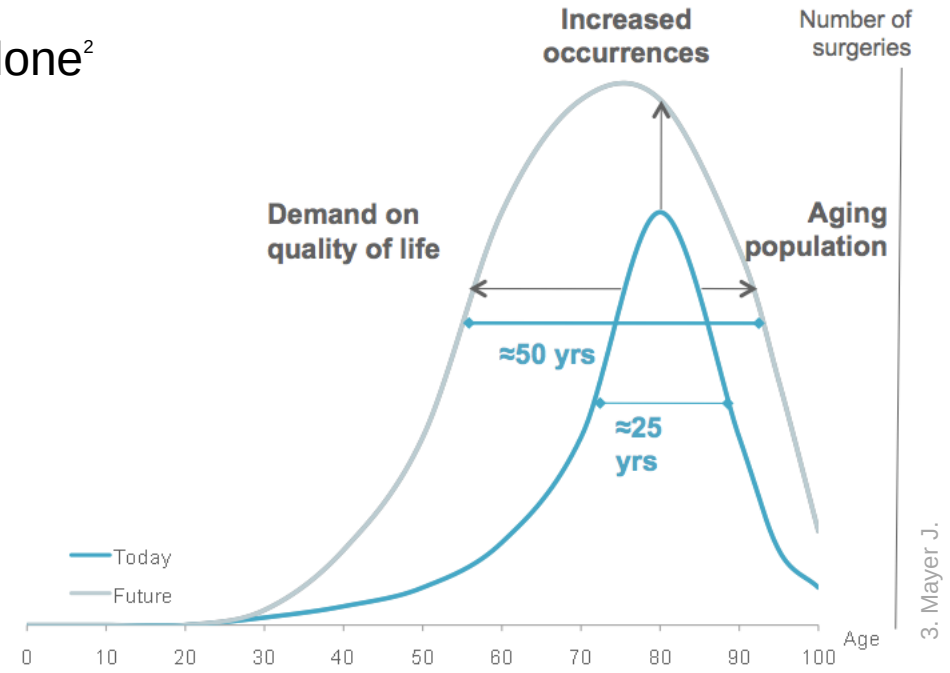
LifeLongJoints: Computational Methods for Implant Design and Treatment Planning "The Virtual Patient"

Enrico De Pieri, Stephen Ferguson

Introduction: Total Hip Replacements

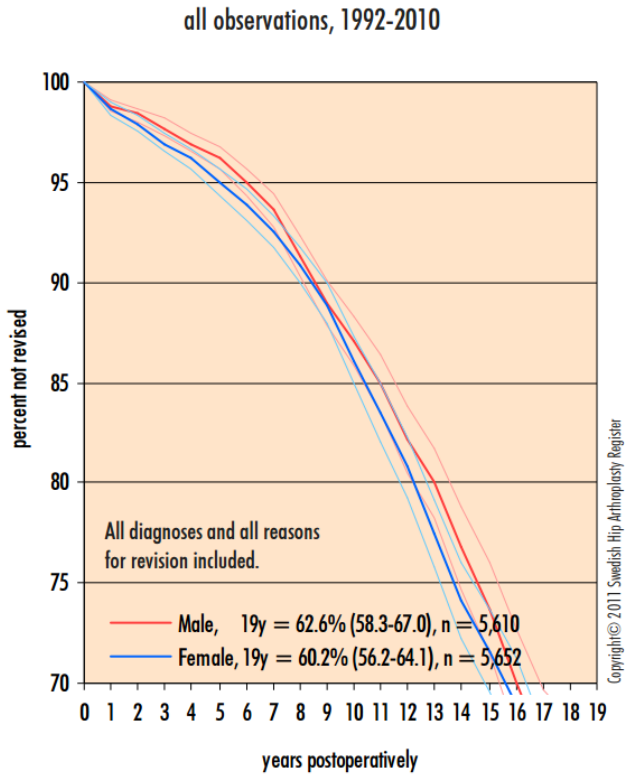
- Solution for arthritis and severe fractures
- Failure rate between 3% and 10% at 10 years[1]
  - → 100.000 failure cases for knee and hip per year in the US alone[2]
  - → Economic burden over 1 billion $ / year
  - → Revision surgery not as successful as primary procedure
- Younger patients needing a THR:
  - → Longer life-span of the implant
  - → More demanding physical activities

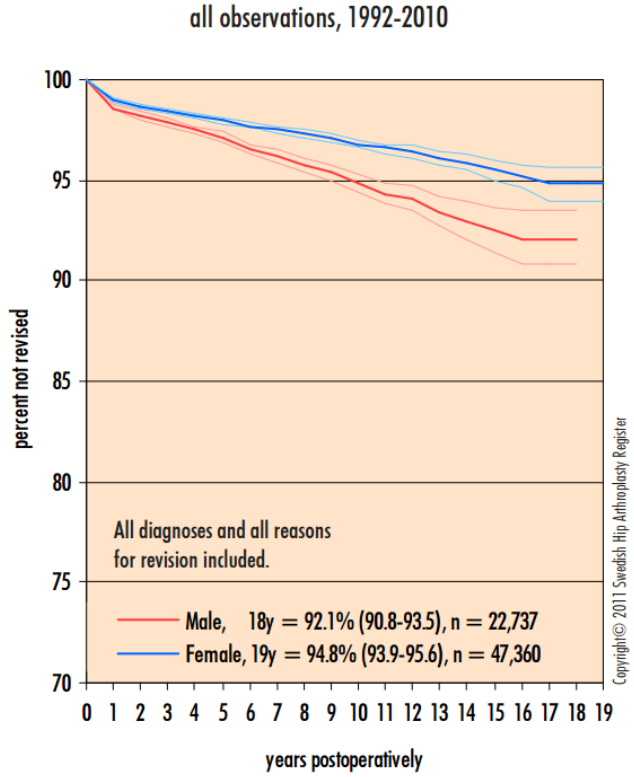
→ Need to improve longevity and robustness



1. Swedish Hip Arthroplasty Register, Annual Report 2010; http://www.shpr.se/Libraries/Documents/AnnualReport-2010-2-eng.sflb.ashx
2. Kurtz S.M. et al., Future Young Patient Demand for Joint Replacement: National Projections from 2010 to 2030. *Clin Orthop Rel Res*, 467: 2606–2612.
3. J.Mayer, S. Hofmann, D. Webster: Biocompatibility of biomedical implants, lecture notes, 2013, ETH Zurich

Implant Performance





Failures beyond 3-5 years are mainly due to wear and related complications

Wroblewski BM, et al. Journal of Bone & Joint Surgery - British Volume. 89(8):1015-8, 2007

Exhaustive Proof Testing

Dauerschwingversuch
ISO 7206-4, 6 und 8

Kugel Torsionstest
ISO 7206-9

Kugel Berstversuch
ISO 7206-10

Kugel Abzugversuch
ASTM F 2009

Luxationsversuch
PI-1/2

Geometriekennwerte
ISO 7206-1/2

Verschleißversuch
ISO 14242-1

Insert Ausdrückversuch
ASTM F1820

Korrosionsversuch
ASTM F1875

Bewegungsumfang
ISO 21535

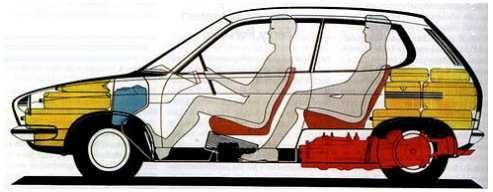
Dauerschwingversuch
Modularverbindung
ASTM F 2580

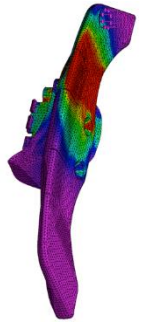
Impingement Test
ASTM F 2582

Dauerschwingversuch
Pfanneninserts
PI-11

http://www.endoloab.org

Design Process Evolution



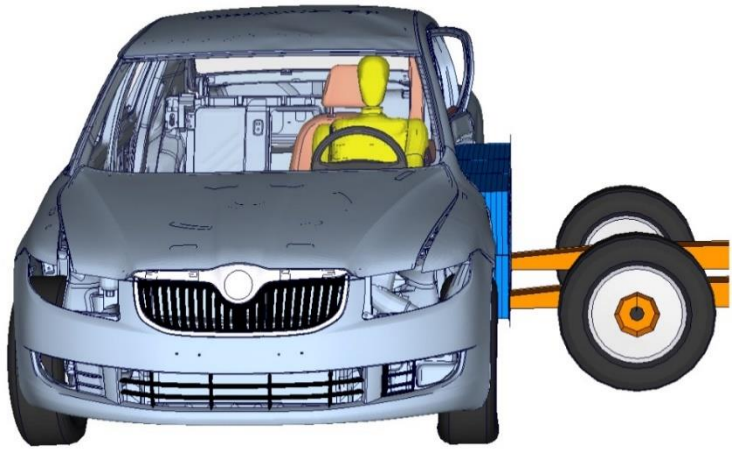


1978 → 2018

How has the design process changed? What can we learn?

The Value of Simulation

- Computer simulations to define better experiments
- Few experiments to validate computer models
- Computer simulations to explore 1000s of situations – reduce time and cost



http://www.esi-group.com

Is Prothesis Wear an "Implant" Problem?

Which Factors Determine the Wear Rate of Large-Diameter Metal-on-Metal Hip Replacements?

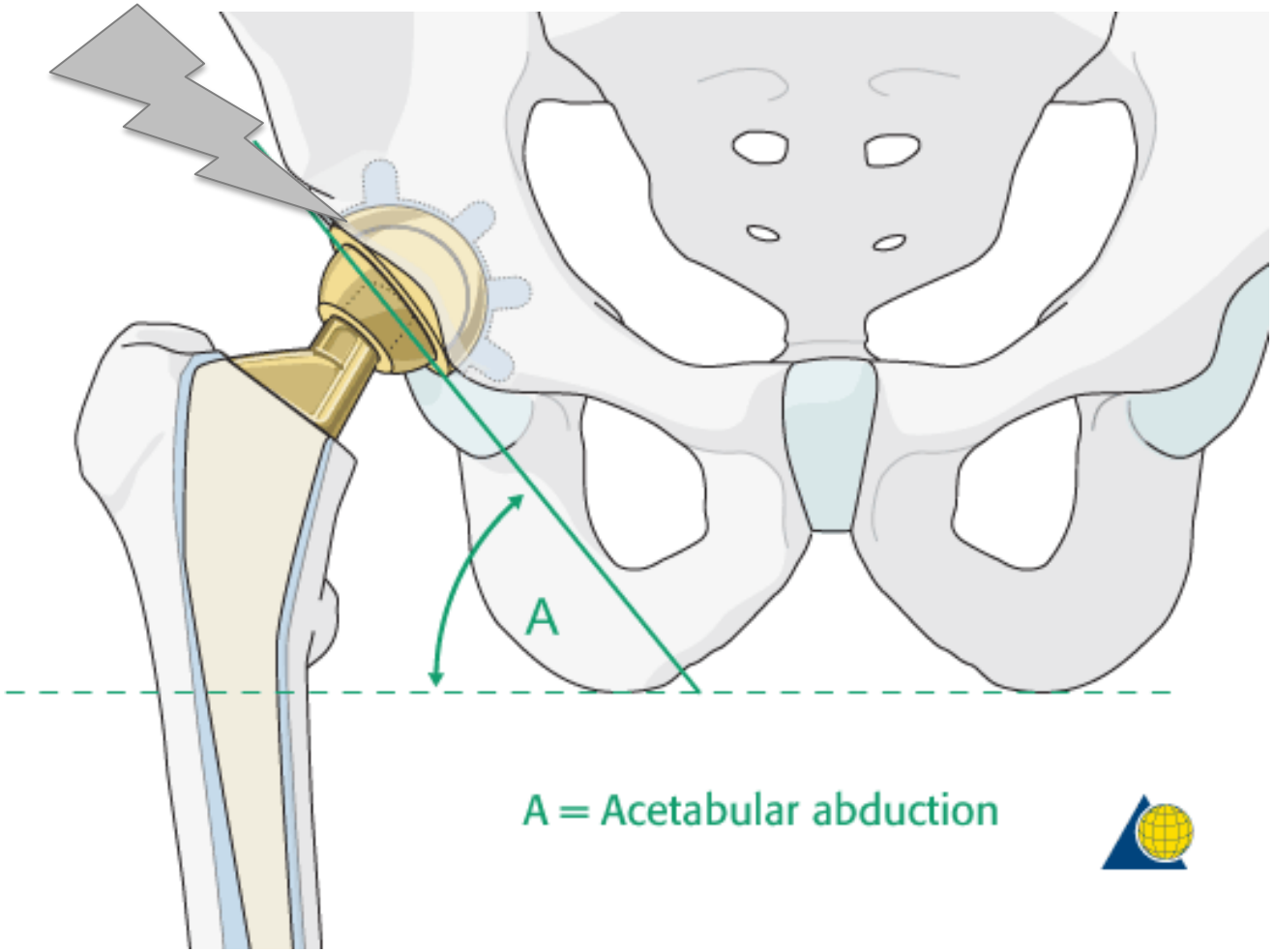
Multivariate Analysis of Two Hundred and Seventy-six Components

A.J. Hart, MA, MD, FRCSG(Orth), S. Muirhead-Allwood, FRCS(Orth), M. Porter, FRCS(Orth), A. Matthies, BSc, MBBS, K. Ilo, BSc, MBBS, P. Maggiore, BSc, MBBS, R. Underwood, PhD, P. Cann, PhD, J. Cobb, FRCS(Orth), and J.A. Skinner, FRCS(Orth)

Investigation performed at the London Implant Retrieval Centre, a Collaboration Between Imperial College London, London, and the Royal National Orthopaedic Hospital NHS Trust, Middlesex, United Kingdom

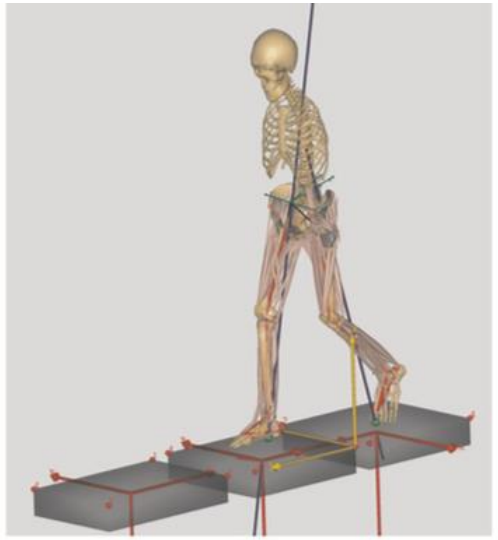
- "…edge-loading was the most important predictor of wear rate"

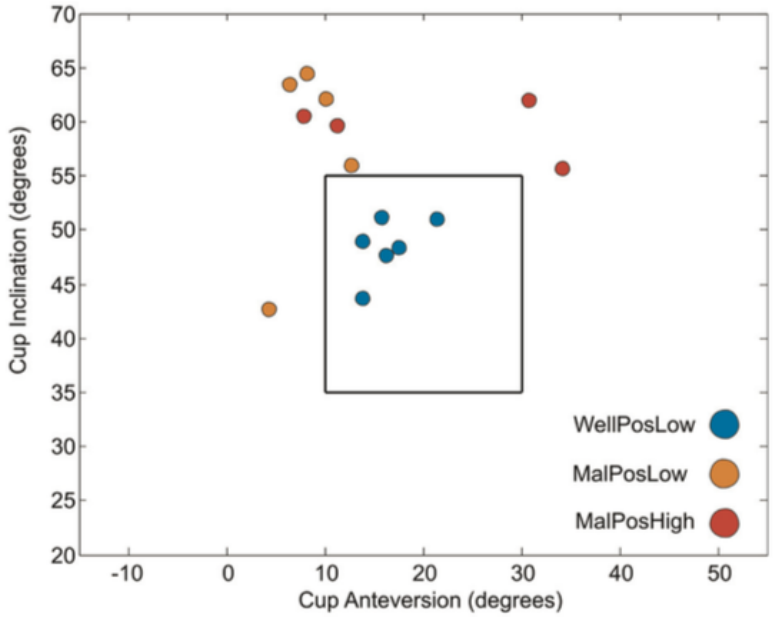
Prosthesis Positioning?



Prosthesis Wear

- Prosthesis wear is a patient-specific, biomechanical problem

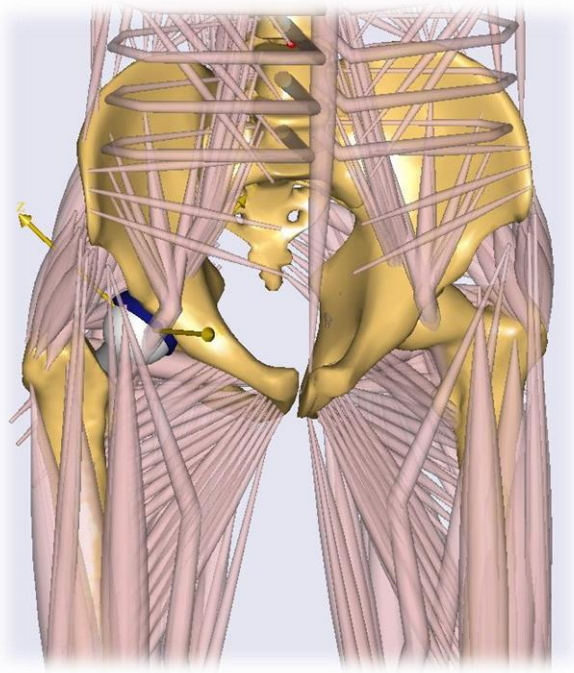




- "wear of metal-on-metal hip resurfacing arthroplasty is … influenced by individual patient activity patterns" *Mellon et al, Proc IMechE Part H: J Engineering in Medicine 2013*

Prosthesis Wear

- Wear is a function of use, not time[4]
  - Knowledge of internal loading needed for:
  - Implant design: wear and fixation
  - Understanding joint biomechanics
  - Surgical planning
  - Rehabilitation intervention
- In vivo measurements[5,6]:
  - Raise ethical considerations
  - Are difficult to perform
  - Represent a small population sample



4. Schmalzried, TP., et al. Clin Orthop Res 381 (2000): 36-46.
5. Bergmann, G., et al. Journal of Biomechanics 34.7 (2001): 859-871.
6. Bergmann, G., et al. PLoS One 11(5) (2016): e0155612.

Exhaustive Proof Testing

Dauerschwingversuch
ISO 7206-4, 6 und 8

Kugel Torsionstest
ISO 7206-9

Geometriekennwerte
ISO 7206-1/2

Verschleißversuch
ISO 14242-1

Simulation results allow the definition of more realistic and demanding physical wear tests

Kugel Abzugversuch
ASTM F 2009

Luxationsversuch
PI-1/2

Korrosionsversuch
ASTM F1875

Bewegungsumfang
ISO 21535

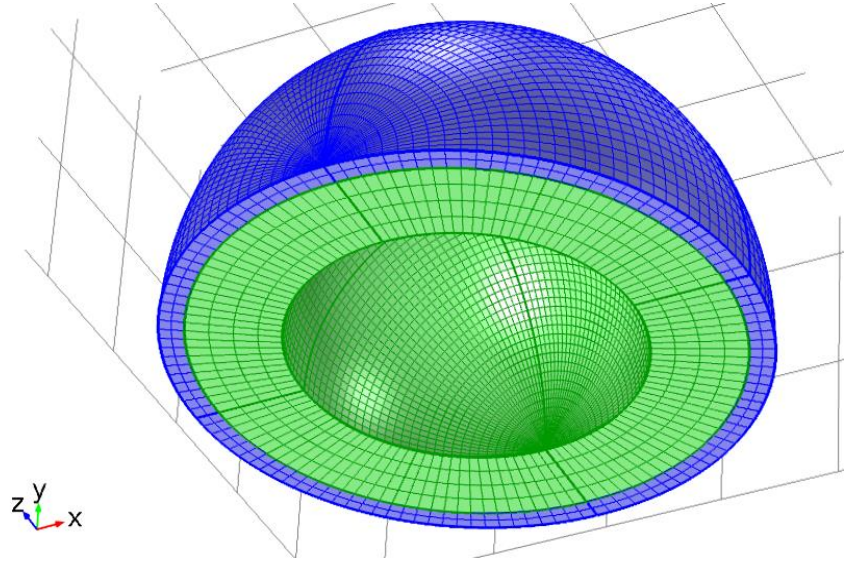
Impingement Test
ASTM F 2582

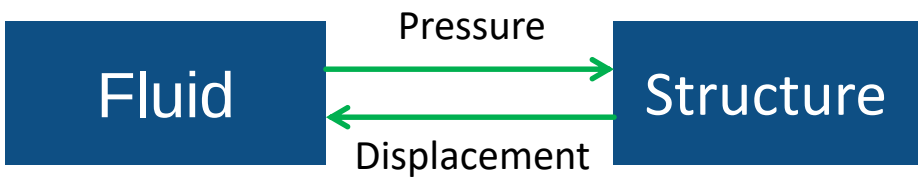
Dauerschwingversuch
Pfanneninserts
PI-11

http://www.endoloab.org

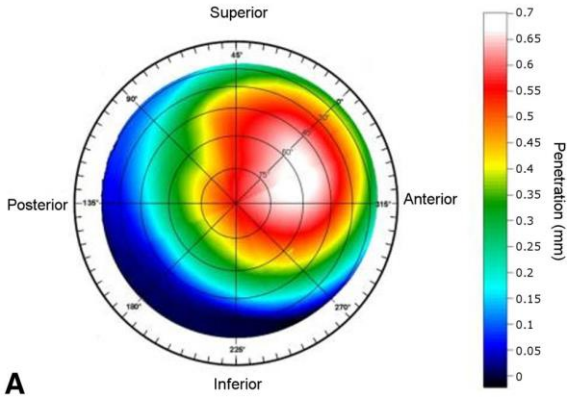
Joint Scale Wear Simulation

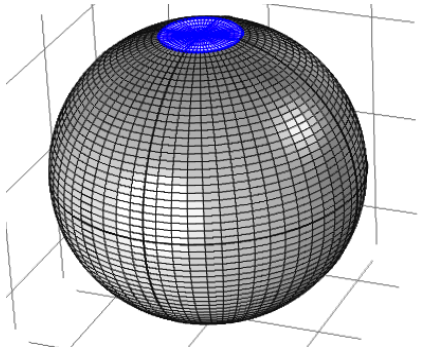
- Elastohydrodynamic (EHL) model developed of hip prosthesis
- Ball in socket geometry allows non-sphericity
- Elastic deformation of both cup and head materials

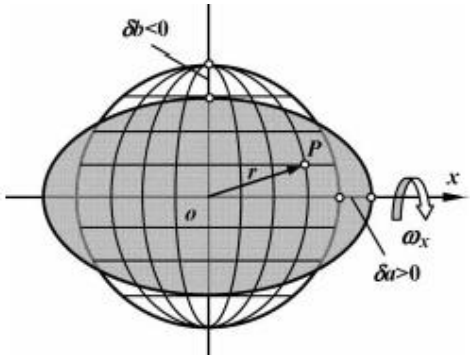


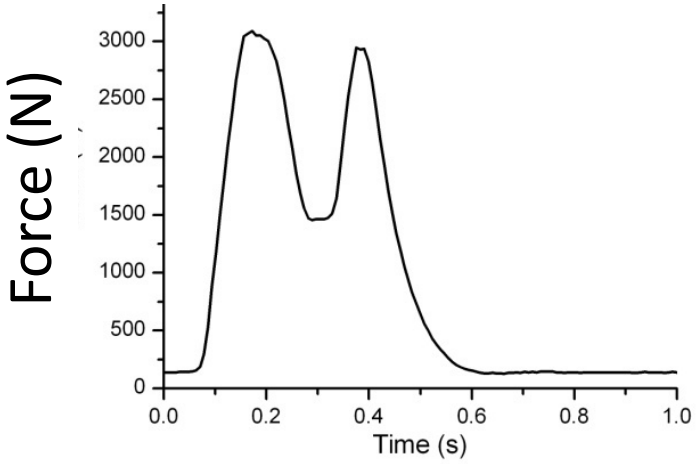


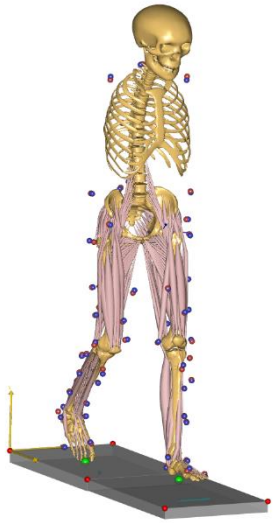
Whole Joint Wear Simulation

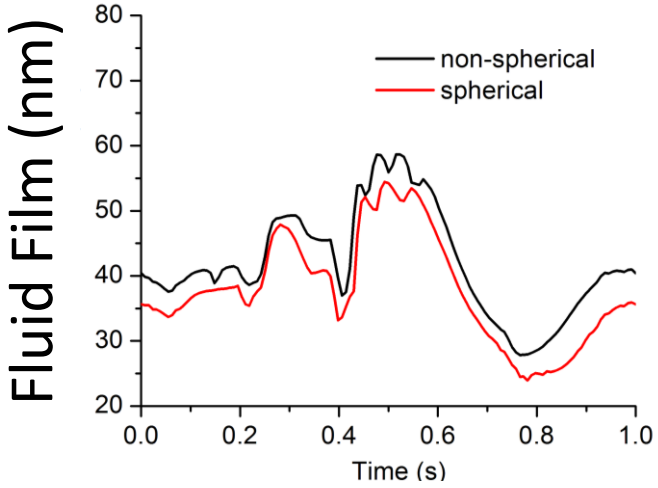












AnyBody Model – Development and Validation

Population Simulations

Model Development

Need for a reliable generic model to predict hip contact forces

Journal of Biomechanics 48 (2015) 734–741

Contents lists available at ScienceDirect

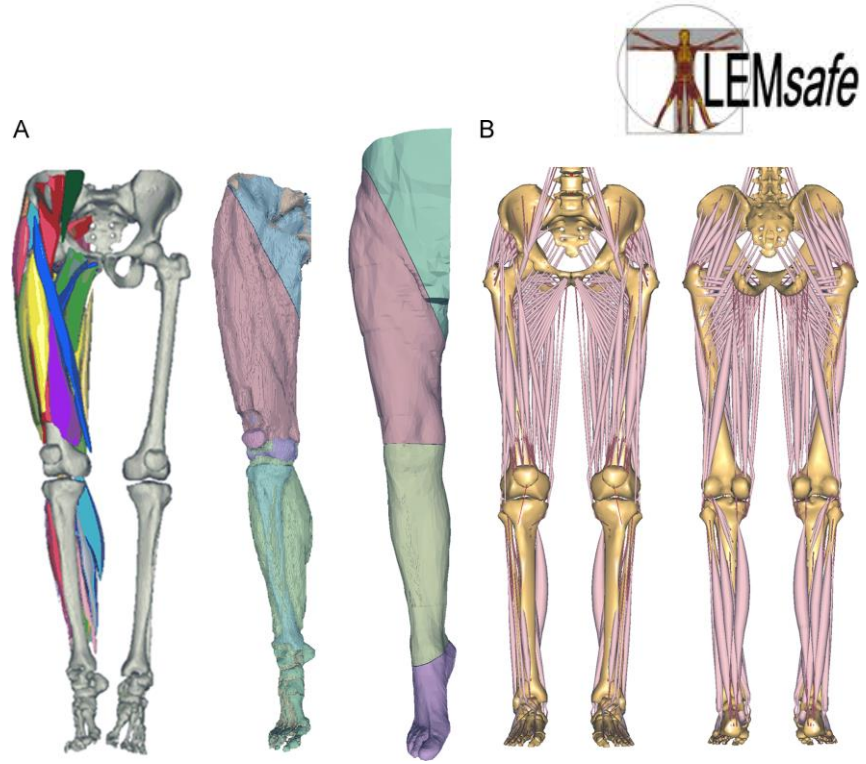
Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

TLEM 2.0 – A comprehensive musculoskeletal geometry dataset for subject-specific modeling of lower extremity

V. Carbone [a,*,1], R. Fluit [a,1], P. Pellikaan [a], M.M. van der Krogt [a,b], D. Janssen [c], M. Damsgaard [d], L. Vigneron [e], T. Feilkas [f], H.F.J.M. Koopman [a], N. Verdonschot [a,c]

[a] Laboratory of Biomechanical Engineering, Faculty of Engineering Technology, MIRA Institute, University of Twente, Enschede, The Netherlands
[b] Department of Rehabilitation Medicine, Research Institute MOVE, VU University Medical Center, Amsterdam, The Netherlands
[c] Orthopaedic Research Laboratory, Radboud University Medical Centre, Nijmegen, The Netherlands
[d] AnyBody Technology A/S, Aalborg, Denmark
[e] Materialise N.V., Leuven, Belgium
[f] Brainlab AG, Munich, Germany

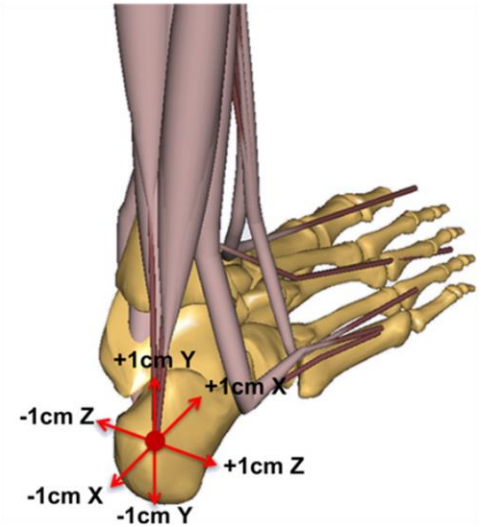


TLEM 2.0:

- Detailed dataset of musculoskeletal geometry
- Model implementation not thoroughly tested
- Particularly for applications focusing on hip

Model Development

- Accuracy in muscle geometry can affect JCF predictions [7,8]
  - Models sensitive to muscle attachment points
  - Particularly muscles spanning the hip joint

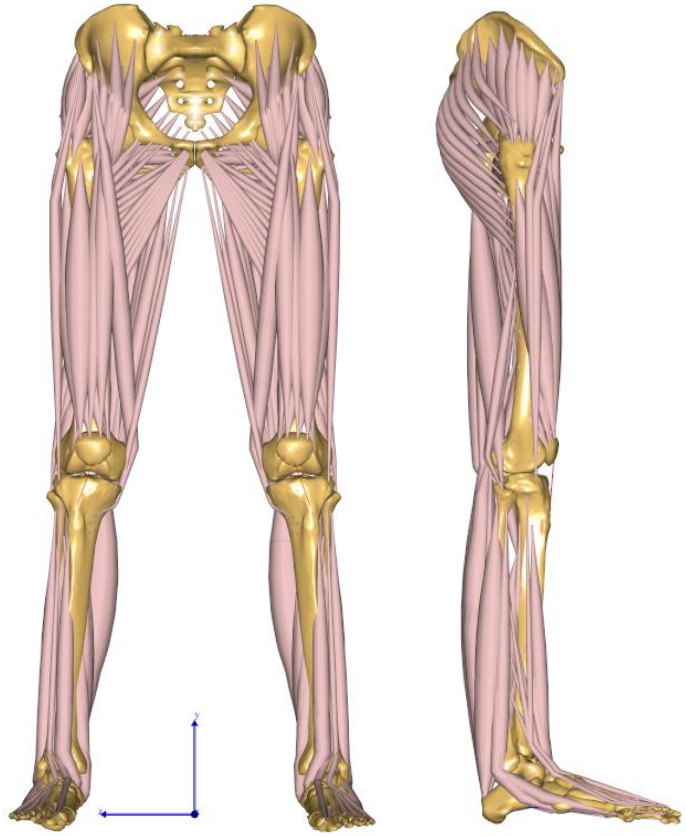


7. Carbone, V. et al

7. Carbone, V., et al. "Sensitivity of subject-specific models to errors in musculo-skeletal geometry." Journal of Biomechanics 45.14 (2012): 2476–80.
8. Bosmans, L., et al. "Sensitivity of predicted muscle forces during gait to anatomical variability in musculotendon geometry." Journal of Biomechanics 48.10 (2015): 2116–23.

Aims

- Document further development of a lower limb model
- Propose a working logic for identifying features in need of refinement
- Initial quantitative validation against measured hip contact forces



Model Validation

- Validation needed for clinical applications
  - Direct comparison with measured Joint Forces
  - Indirect comparison with EMGs

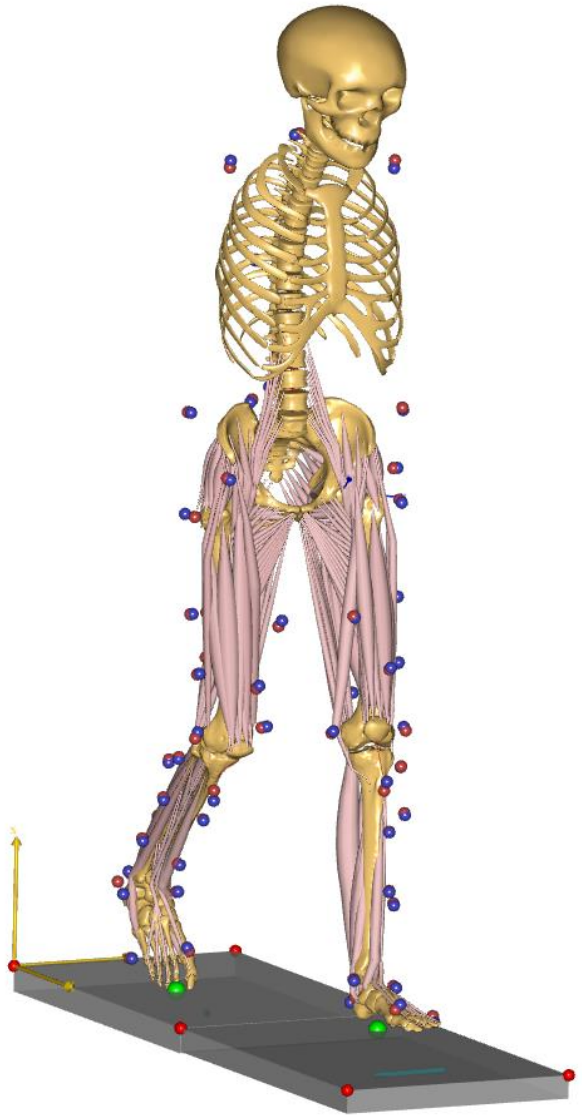
- Release of synchronized MoCap and instrumented HCF data[9] sample

9. OrthoLoad (2016): 'H2R_150811_2_100_labelled.c3d', retrieved from http://orthoload .com, 'Date of access (28/09/2016)'

Model Setup

- Lower limb model based on TLEM 2.0 dataset
- 3-DOFs hip joint
- Simple muscle model

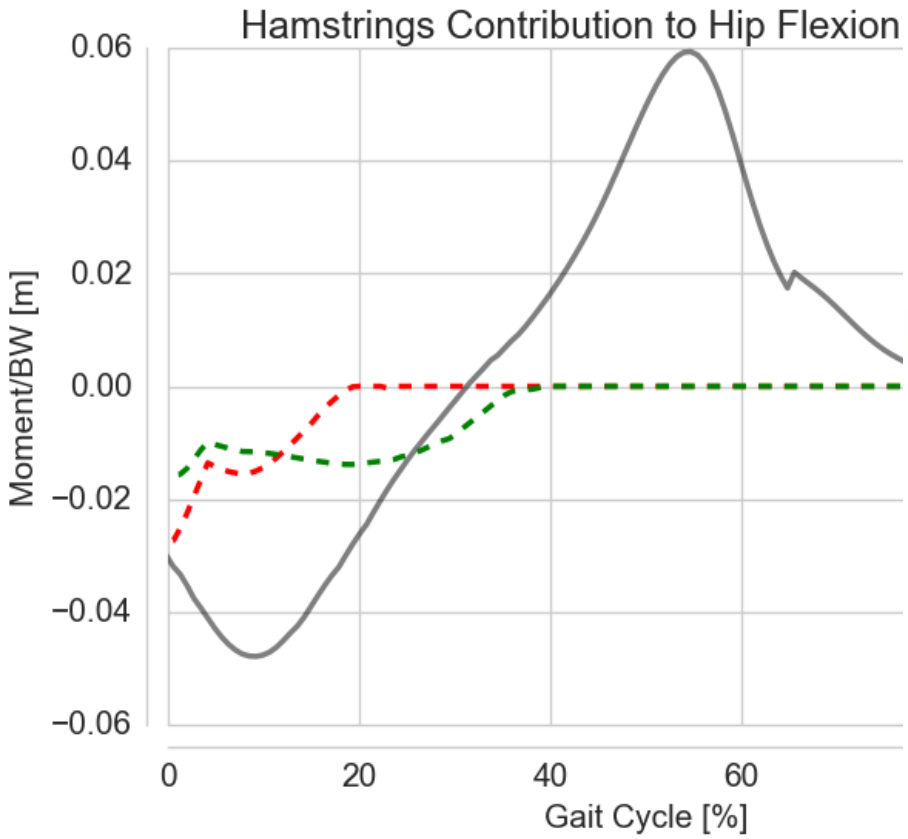
- Marker protocol and laboratory set-up (force plates) from Orthoload dataset
- Model linearly scaled (“Length-Mass-Fat” scaling law) and markers position optimized
- Inverse dynamics analysis

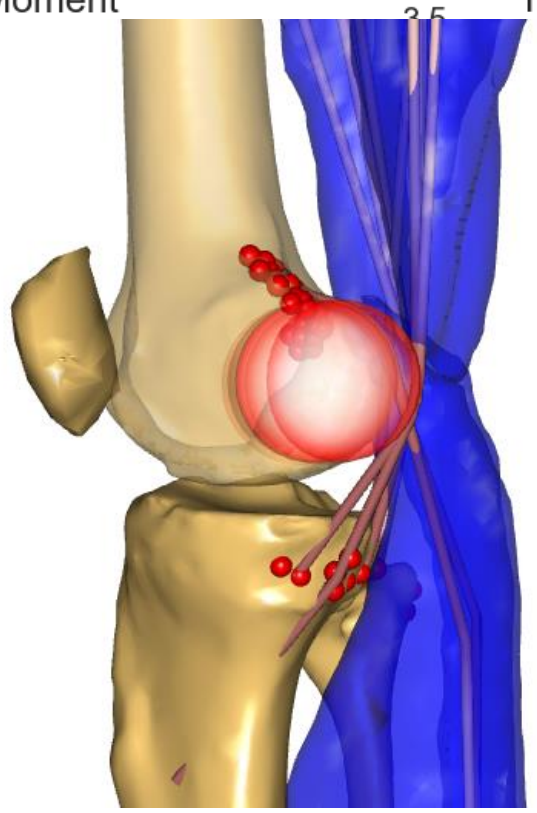


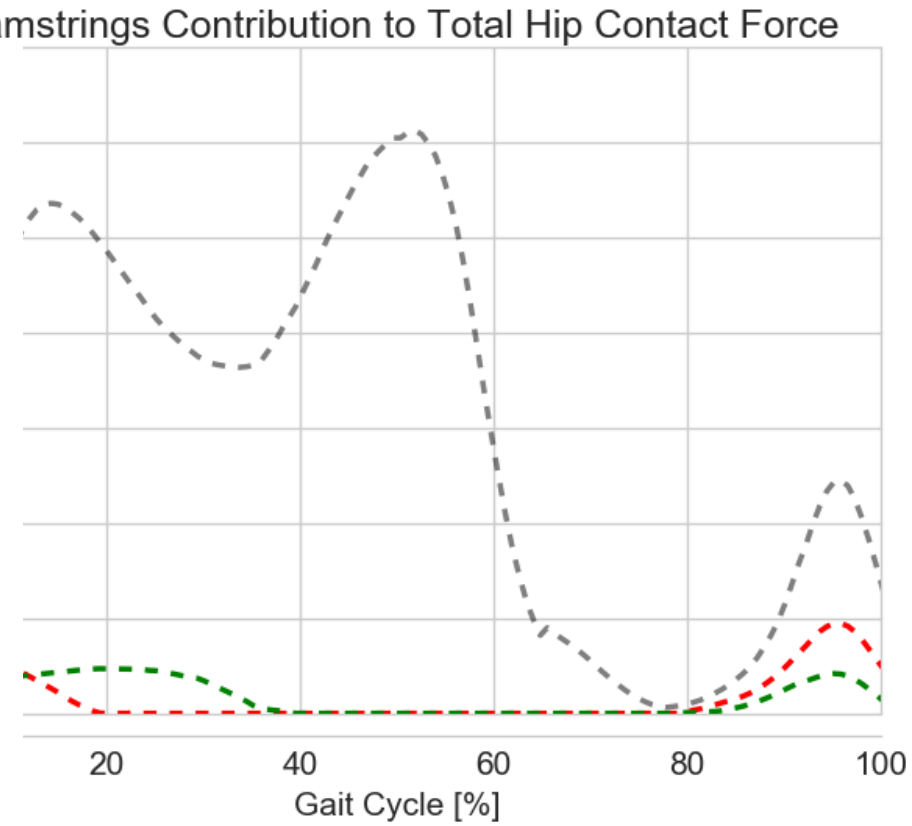
Muscle Contributions

- Evaluate muscle contribution to HCF and hip joints moment
- Identify critical muscle geometries:
  - High HCF contributions but relatively low joint moment contributions
  - Joint moment contributions higher than net moment
- Identified muscles compared to original MRI scans from TLEM 2.0
- Muscle geometry was modified if necessary

Muscle Contributions Example – Hamstrings







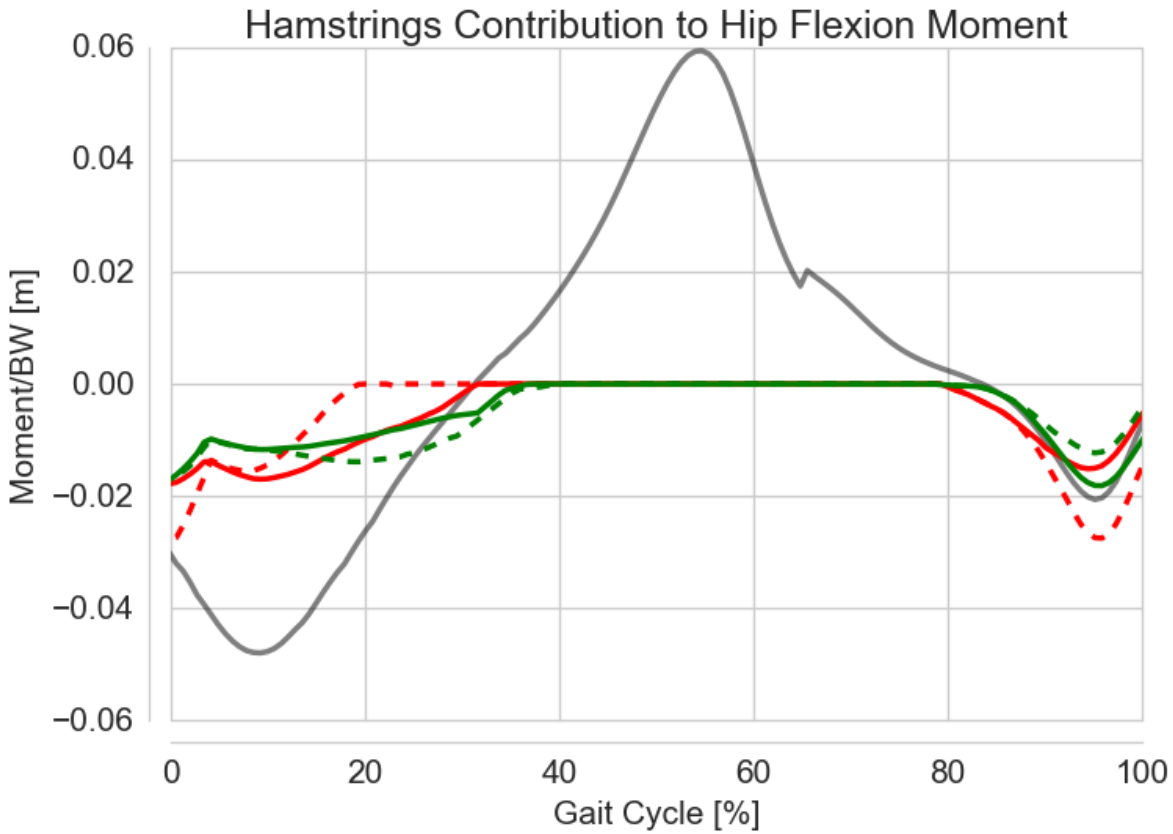
Hip Flexion Moment

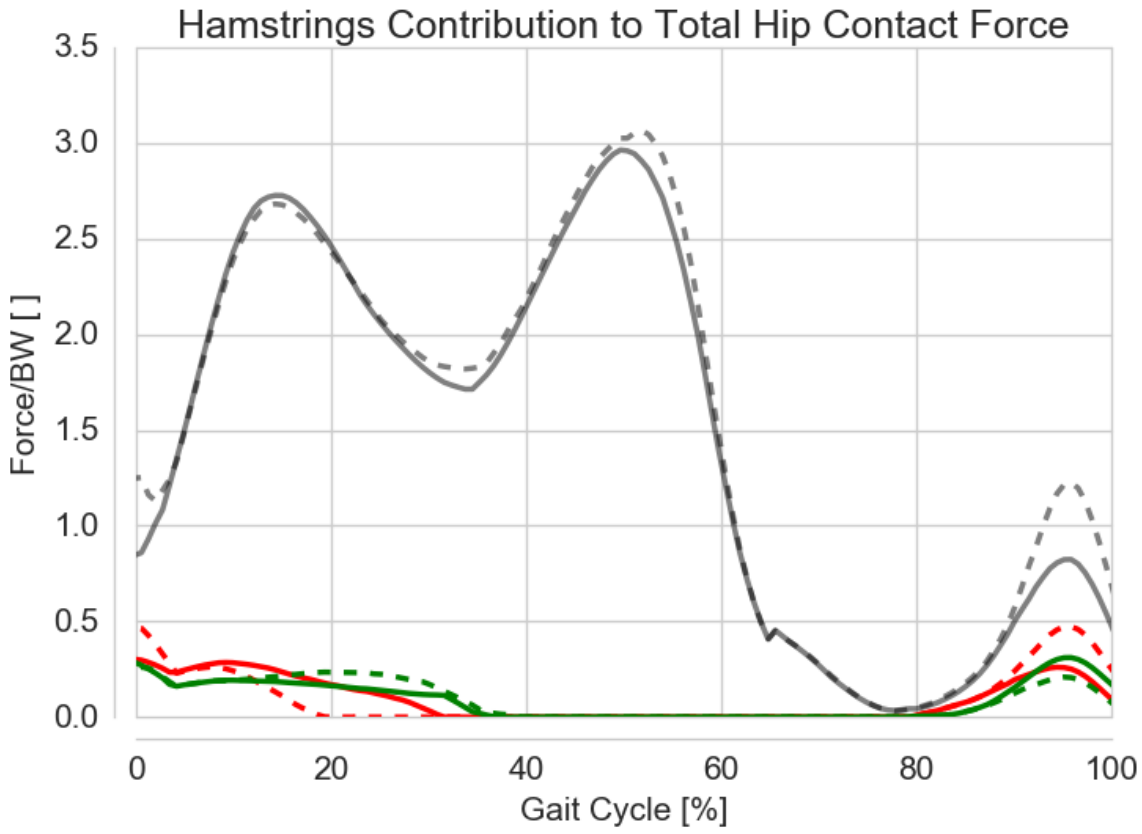
Semitendinosus Semimembranosus contribution before wrapping

Contact force before wrapping

Biceps Femoris Longus contribution before wrapping

Muscle Contributions Example – Hamstrings

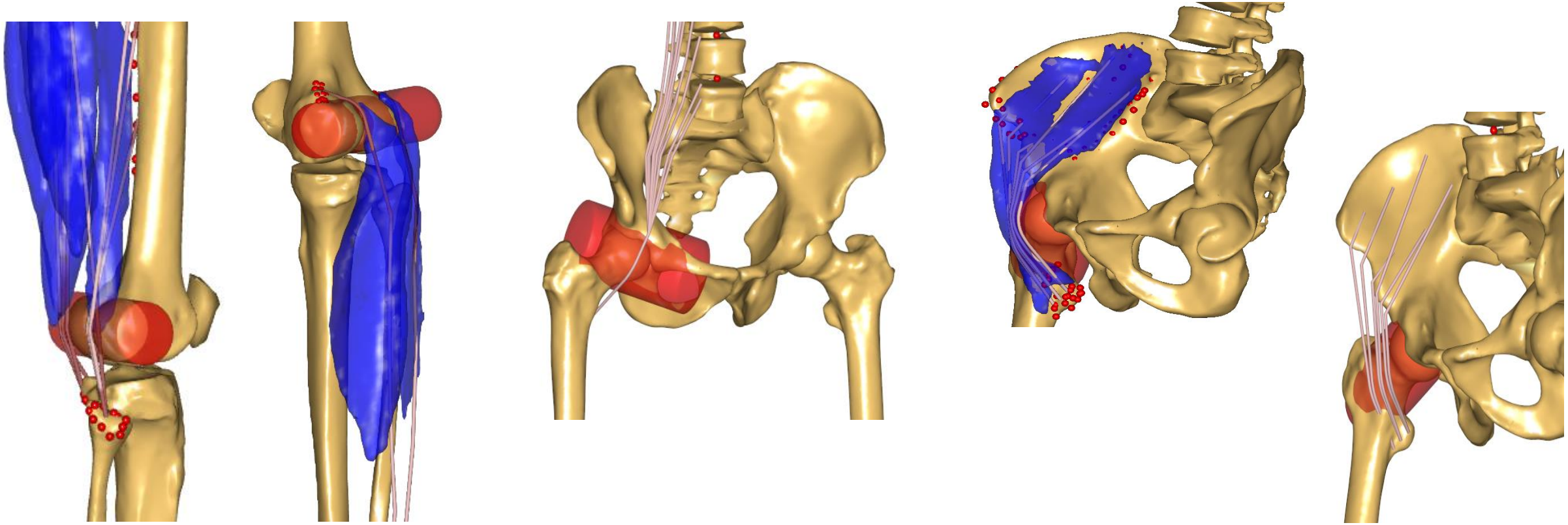




Hip Flexion Moment
Contact force before wrapping
Contact force after wrapping
Biceps Femoris Longus contribution before wrapping
Biceps Femoris Longus contribution after wrapping
Semitendinosus Semimembranosus contribution before wrapping
Semitendinosus Semimembranosus contribution after wrapping

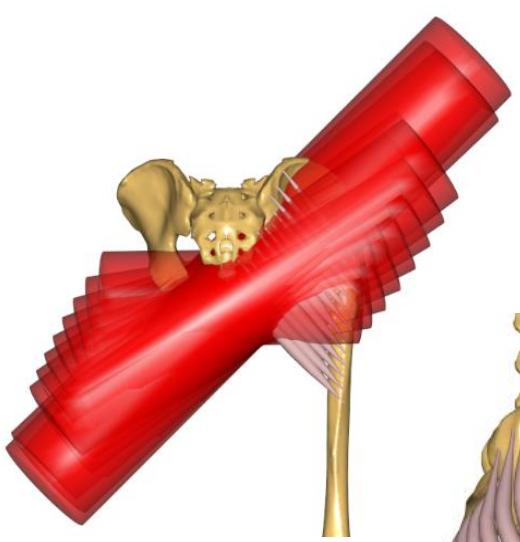
Model Development

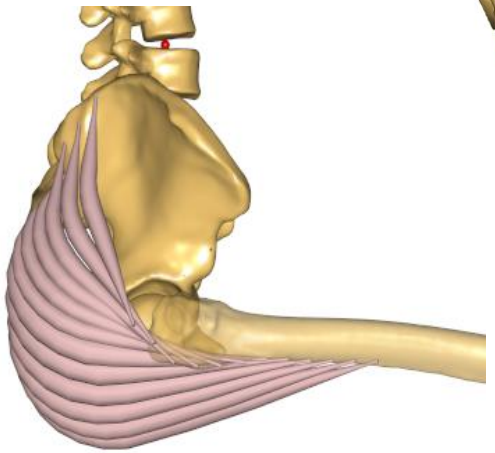
- Accurate wrapping of Semimembranosus, Semitendinosus, Rectus Femoris, Gastrocnemius, Iliacus, and Psoas

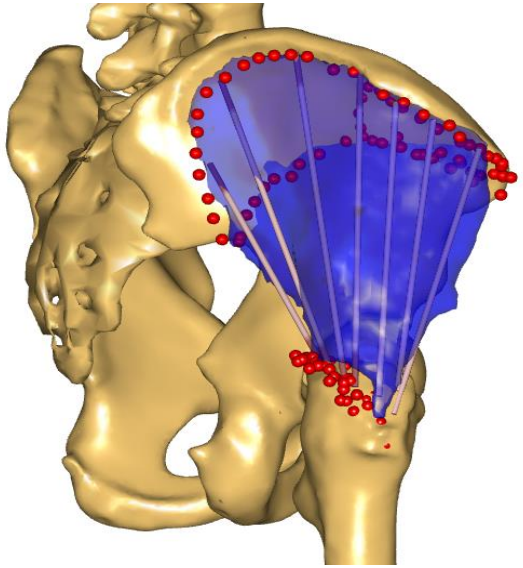


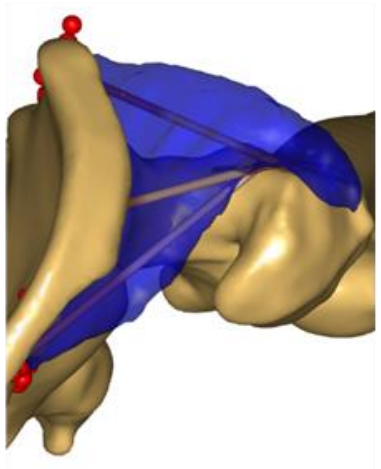
Model Development

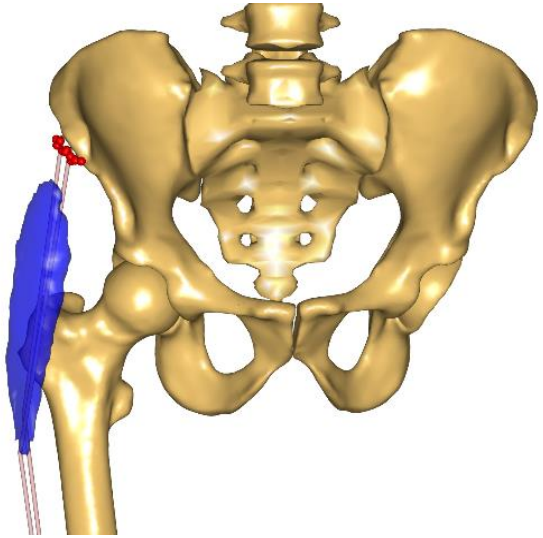
- Accurate wrapping of Gluteus Maximus, Gluteus Medius and Minimus, and Tensor Fasciae Latae





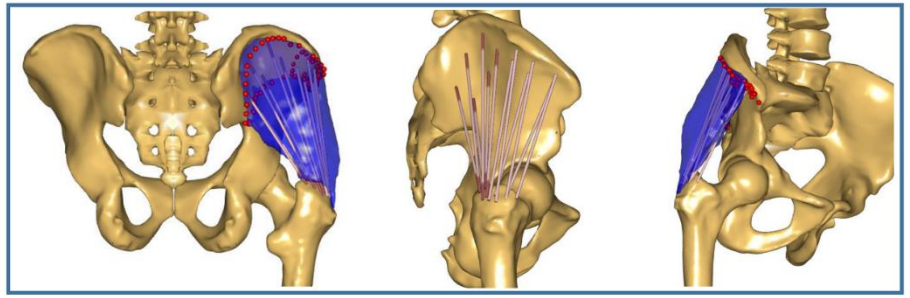




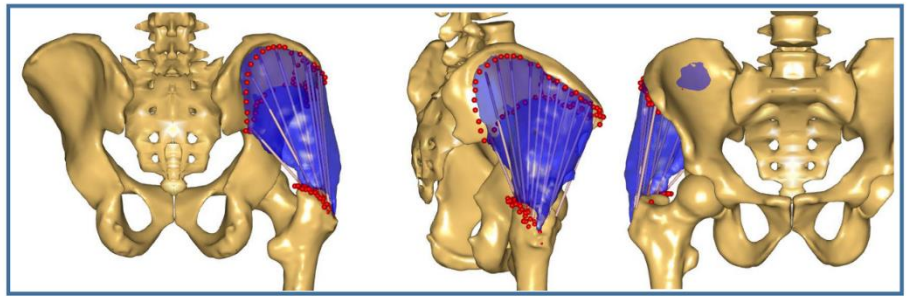


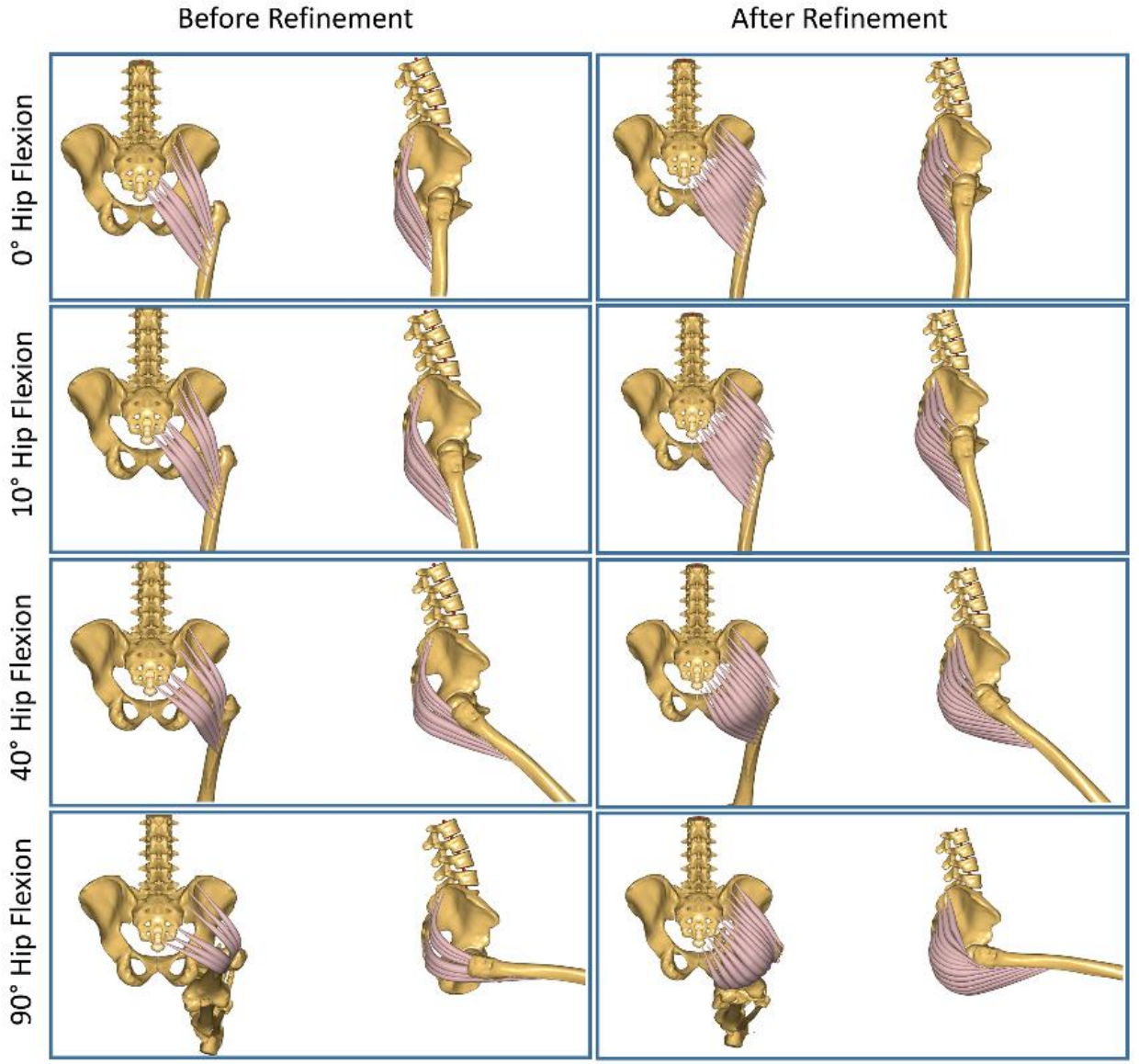
Model Development

Before Refinement

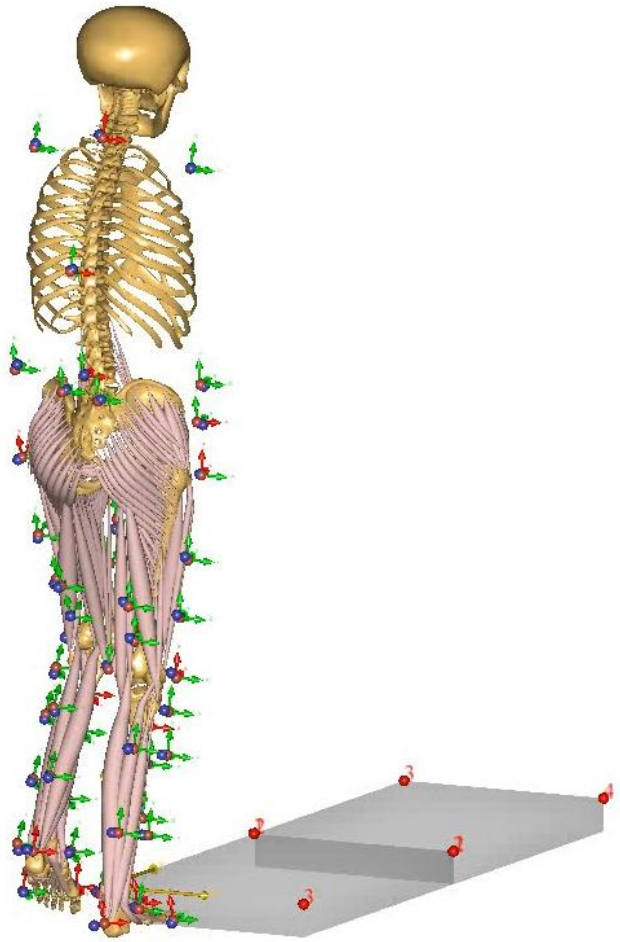


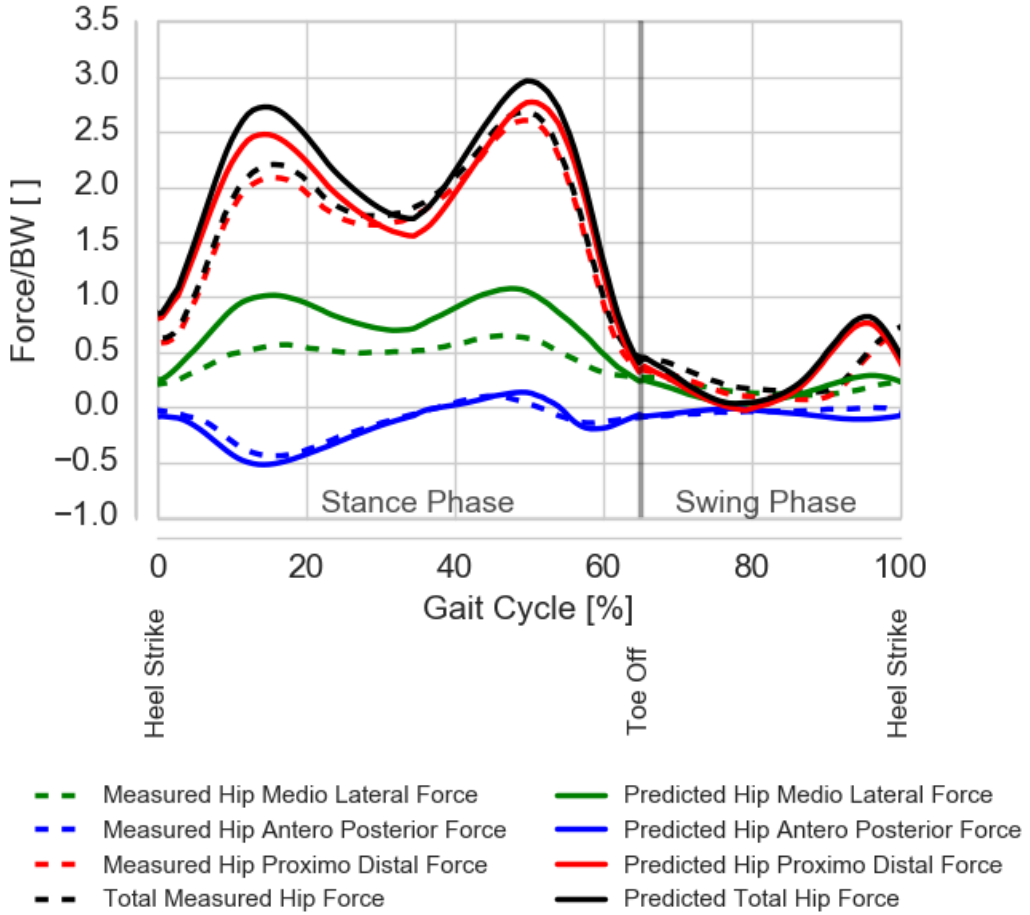
After Refinement





Model Validation

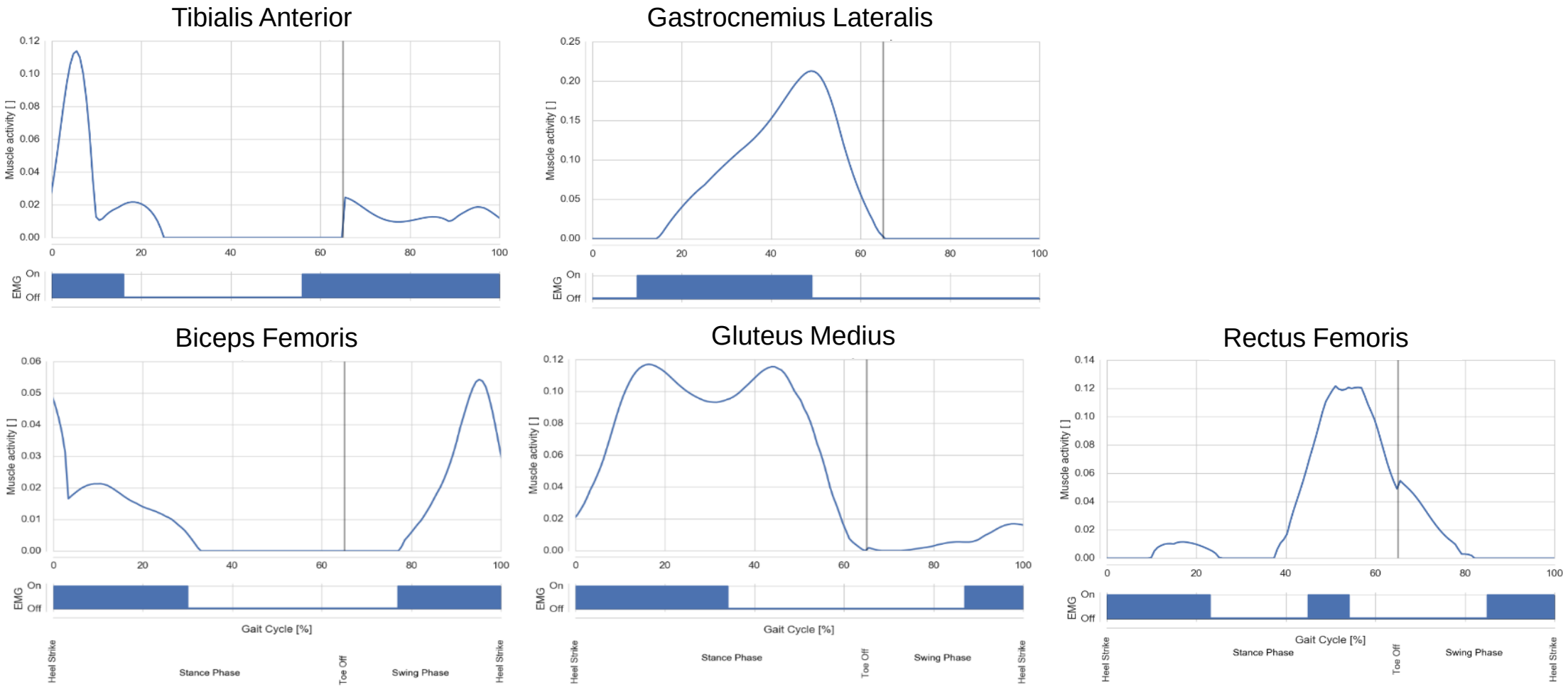




Good agreement with measured HCF

RMSE = 0.298*BW (228 N)

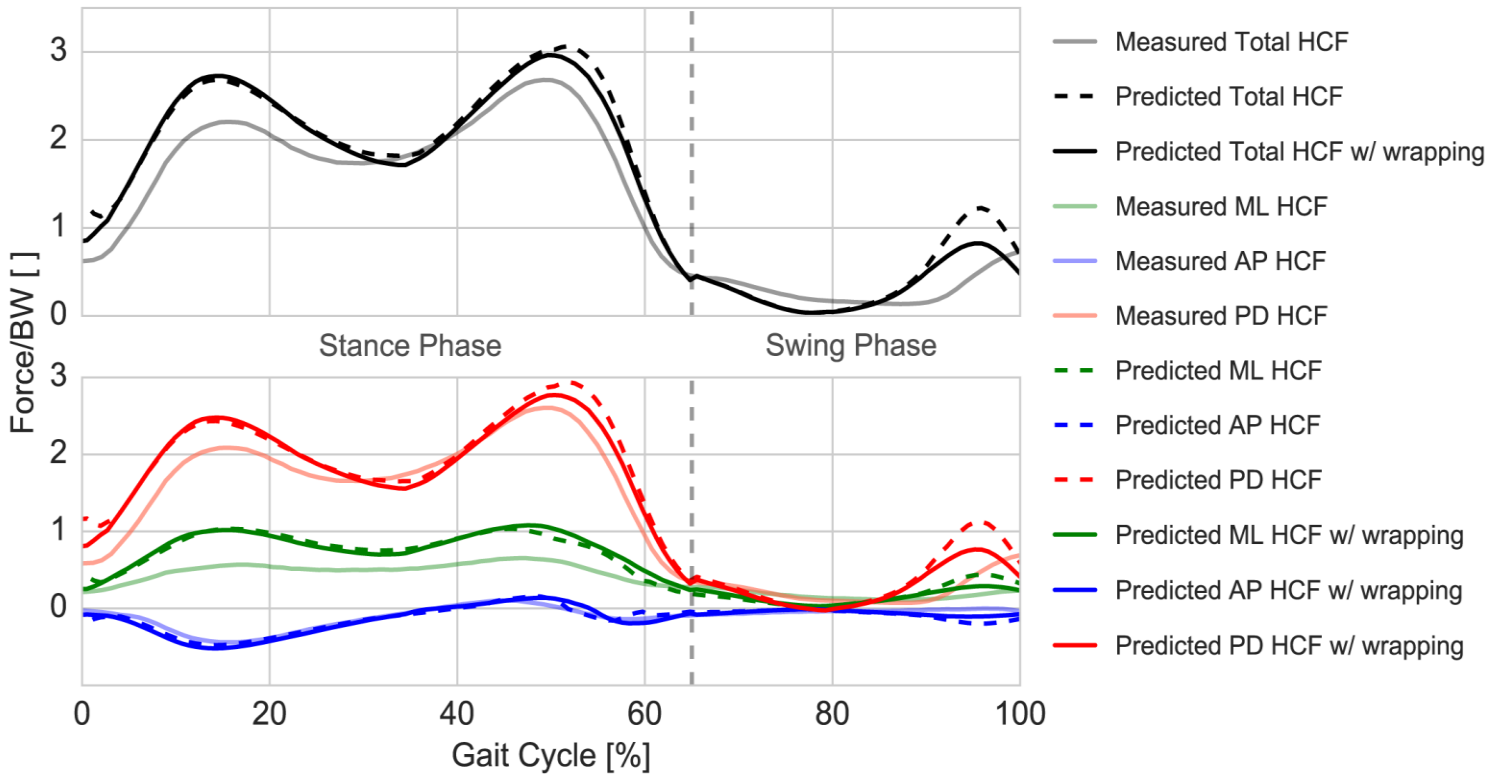
Predicted Muscle Activity vs EMG Timing



10. Agostini, V., et al. "Gait parameters and muscle activation patterns at 3, 6 and 12 months after total hip arthroplasty." Journal of Arthroplasty 28.7 (2014): 762-9.

Discussion

- Muscle Refinement
  - RMSE reduced by 17% (max. error reduction 56%)



- Good agreement with measured HCF
  - Some over-prediction persists
- Good agreement with average EMG timing from literature

Limitations

Model Development

- TLEM 2.0 based on single cadaver
- Simple muscle model and knee kinematics
- No subject specific bone geometry

Quantitative Validation

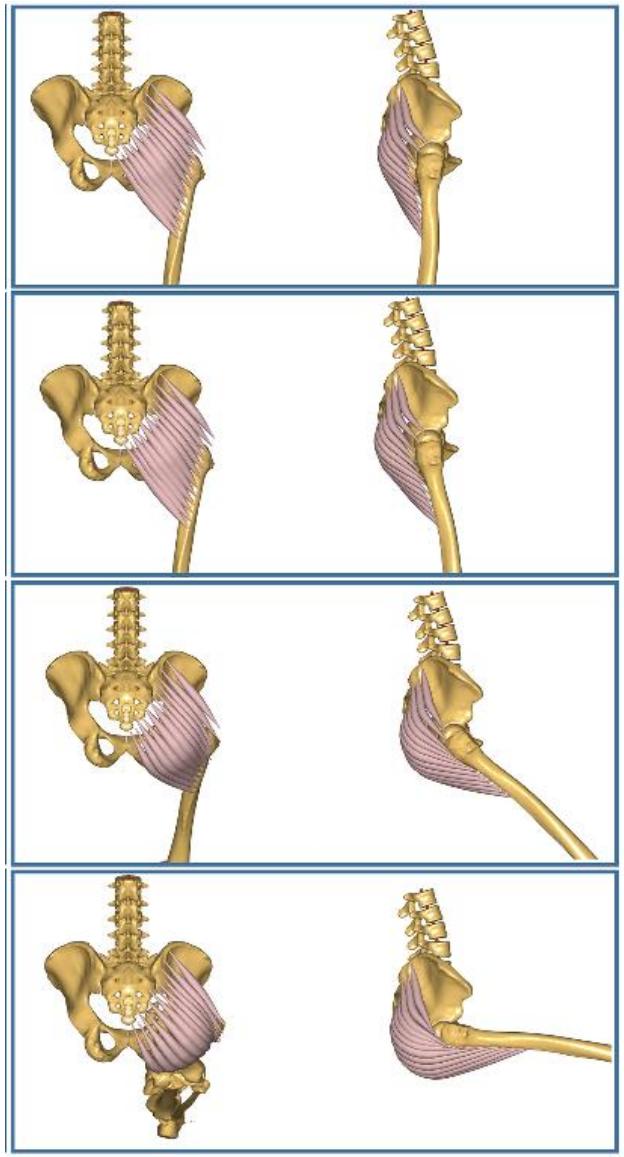
- Performed against a single trial from a single subject
- No variability in anatomy nor kinematic inputs

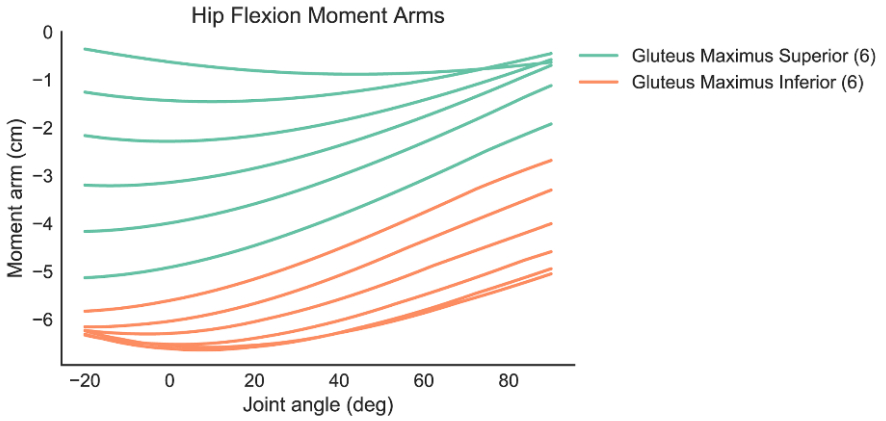
Additional release of sample data would be beneficial

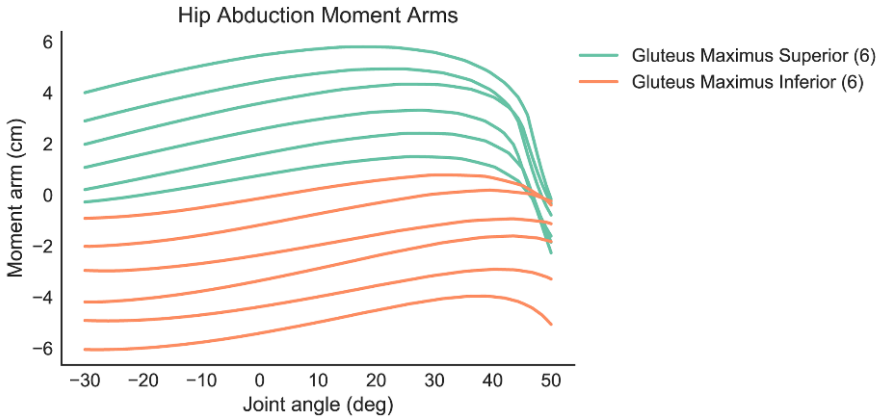
Conclusion

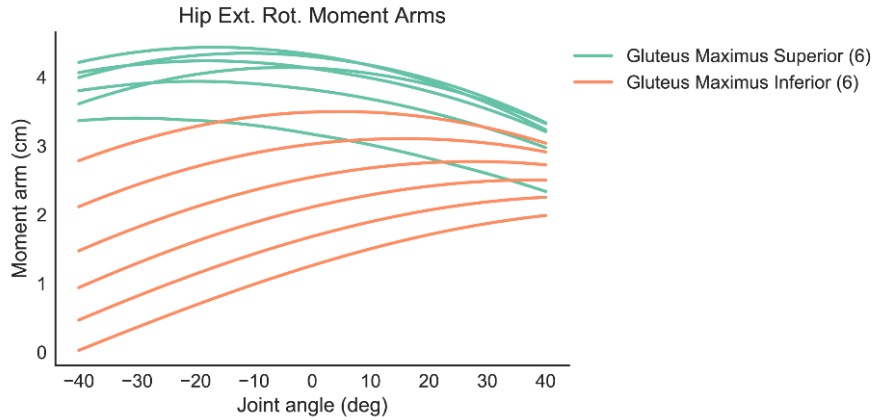
- Satisfactory level of geometrical accuracy achieved
  - Improved HCF predictions
- Initial step in the validation process
- Model has to be continuously validated for new applications
  - Important for activities other than gait
- Muscle moment arms can provide indication for potential limitations

Muscle moment arms ranges

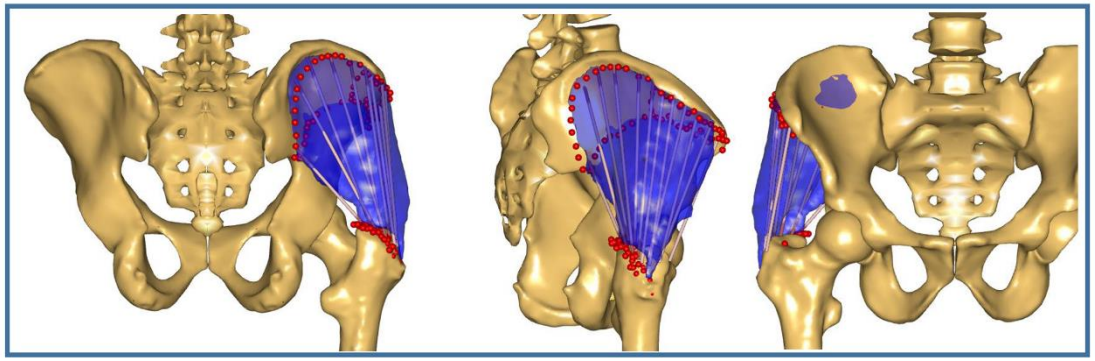


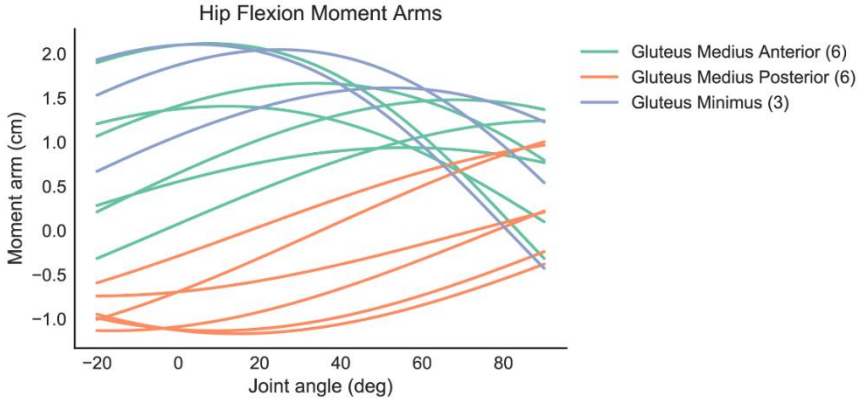


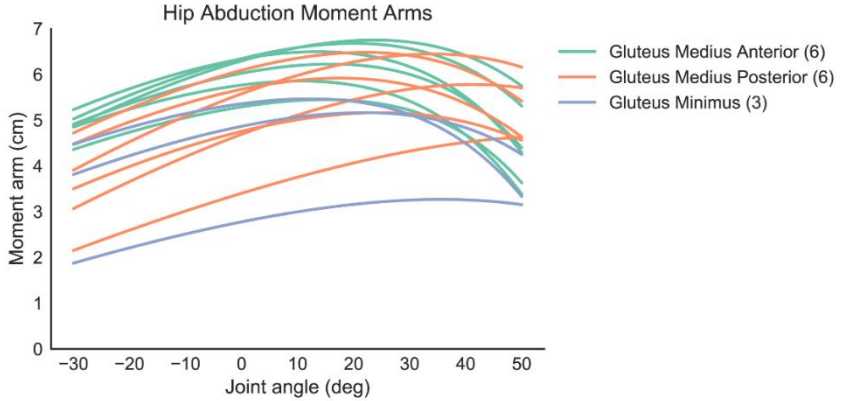


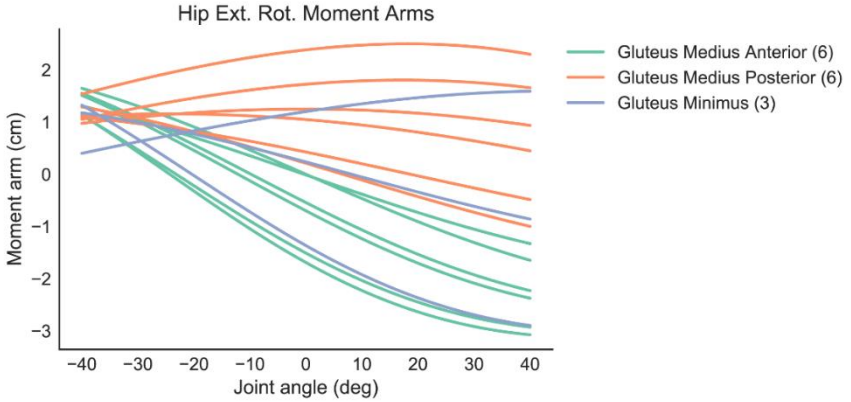


Muscle moment arms ranges



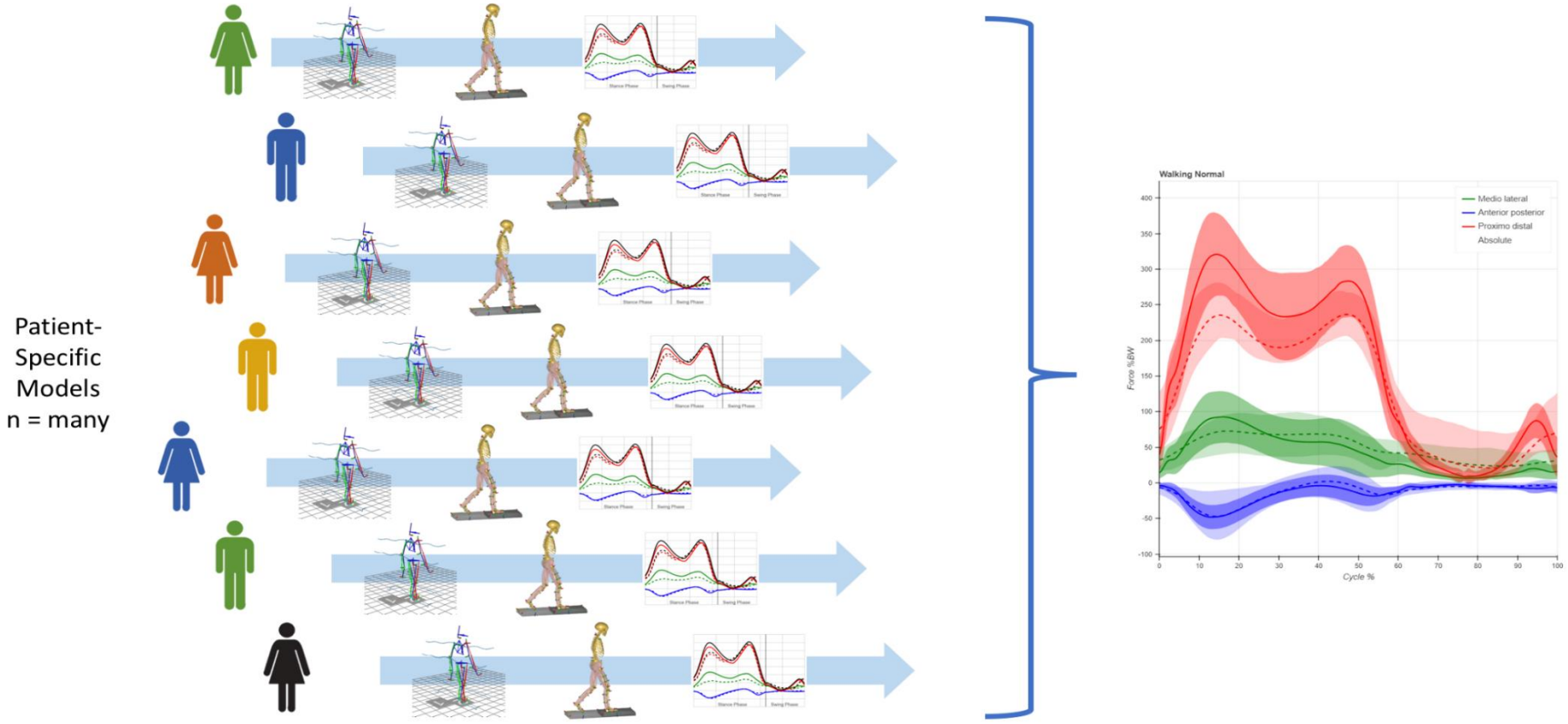






Development of a generic musculoskeletal model ✓ *Submitted to PLOS One*

Virtual Patient Population

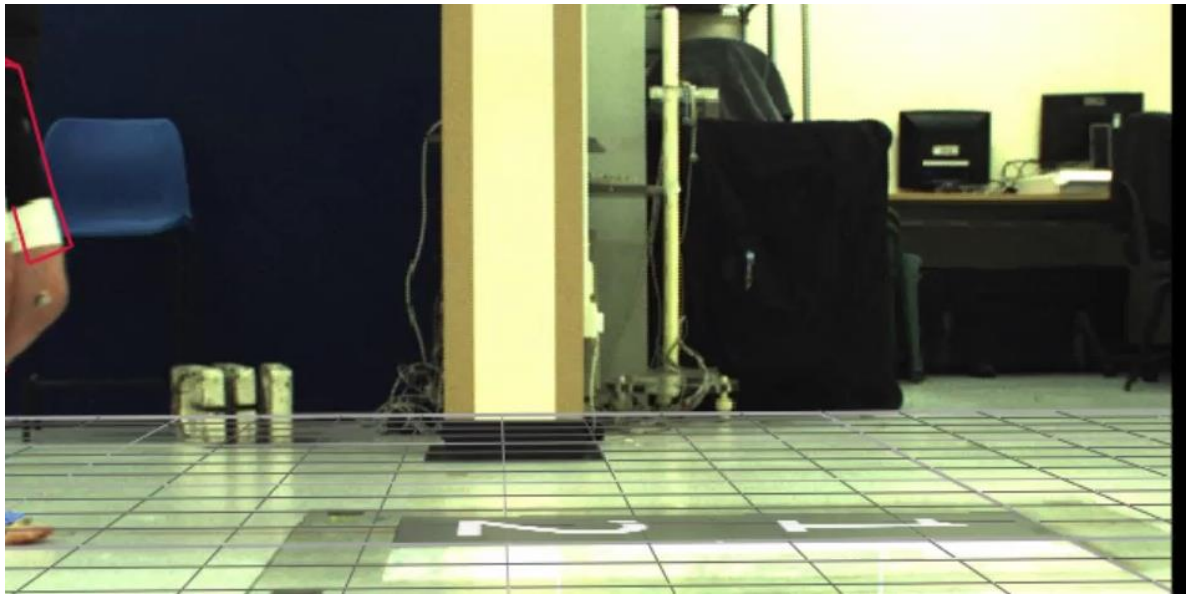


Population Simulations across different Activities of Daily Living

- Important to address variability in overall population

The Leeds Teaching Hospitals NHS
NHS Trust

- **LLJ Patients Dataset**
  - MoCap measurements carried out at Leeds Teaching Hospitals
  - Large patient cohort (137 patients)



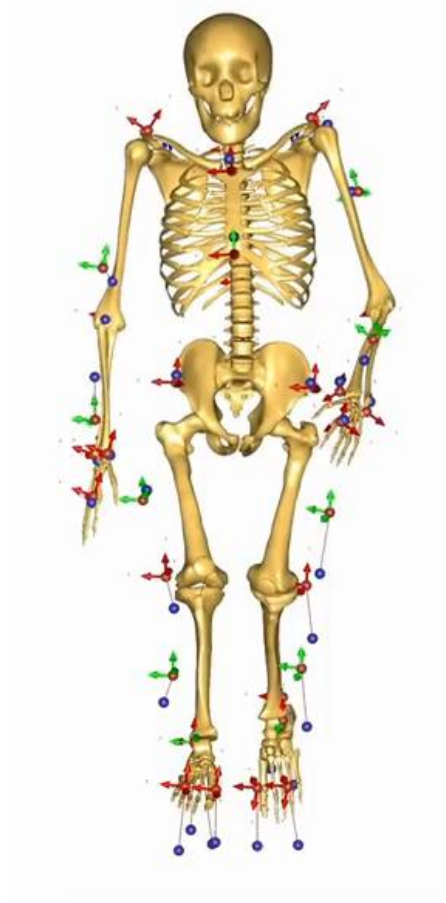
Previous webcast:

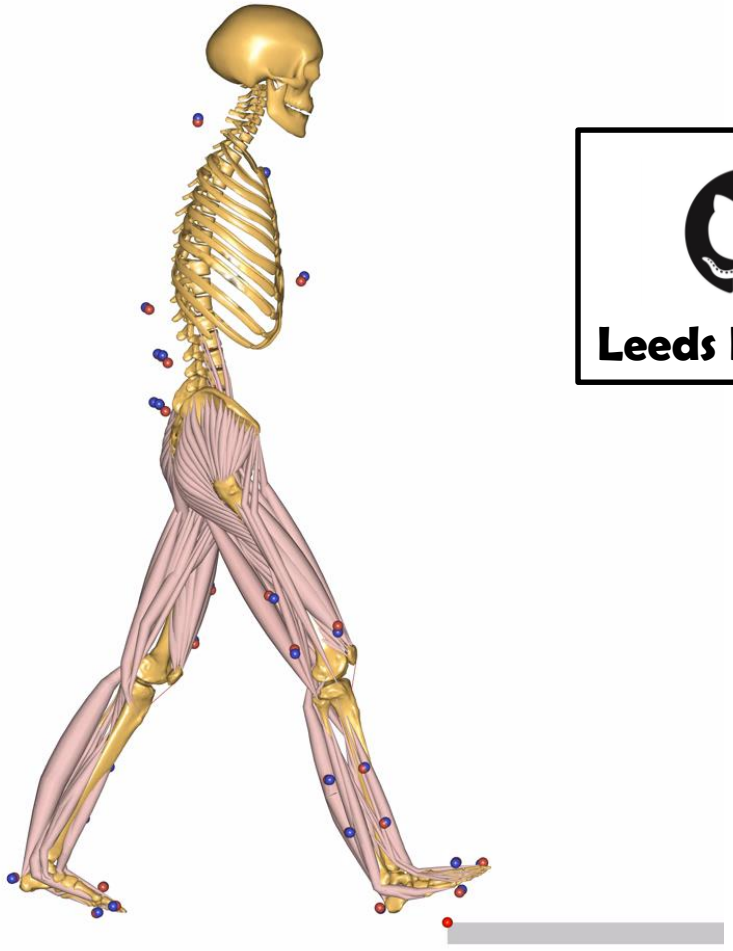
LIFE LONG JOINTS

Large Dataset for assessment of joint replacements

LIFE LONG JOINTS

AnyBody - Batch Processing



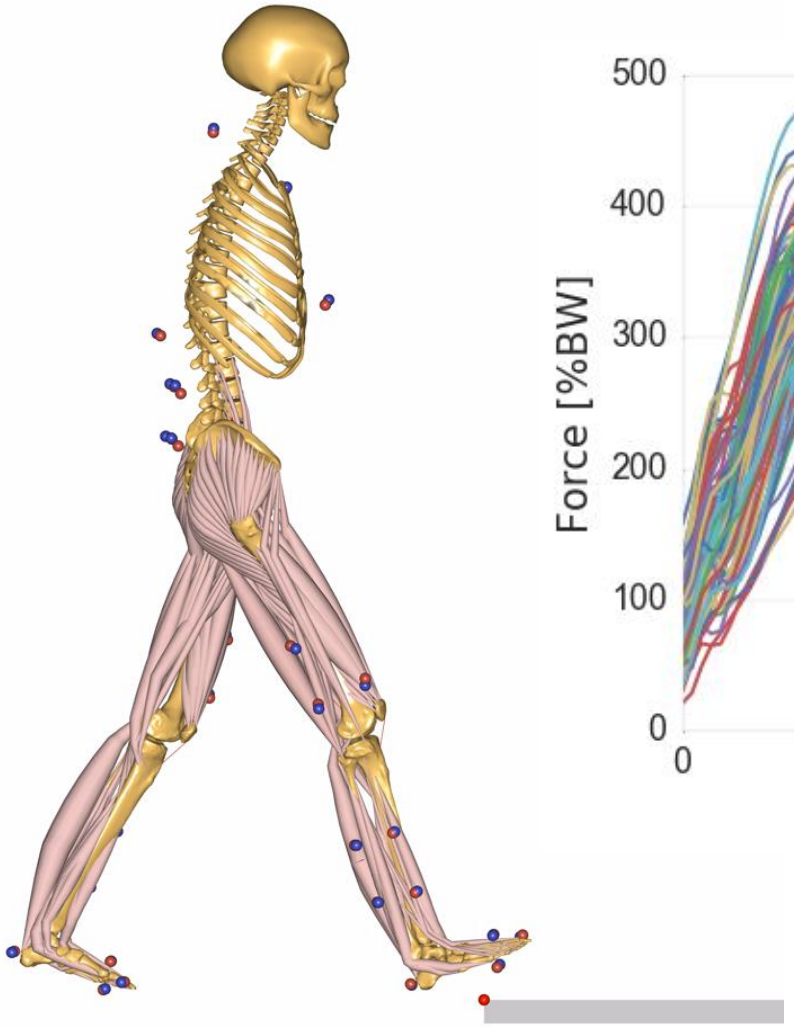


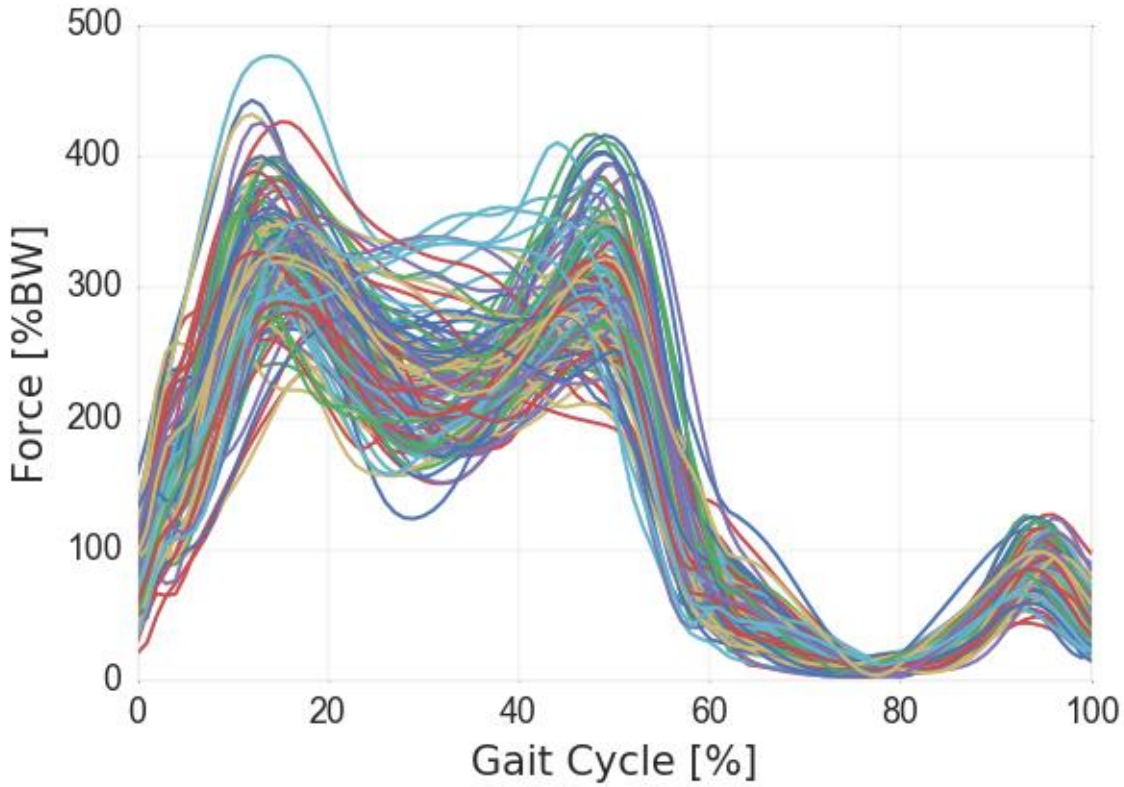
GitHub

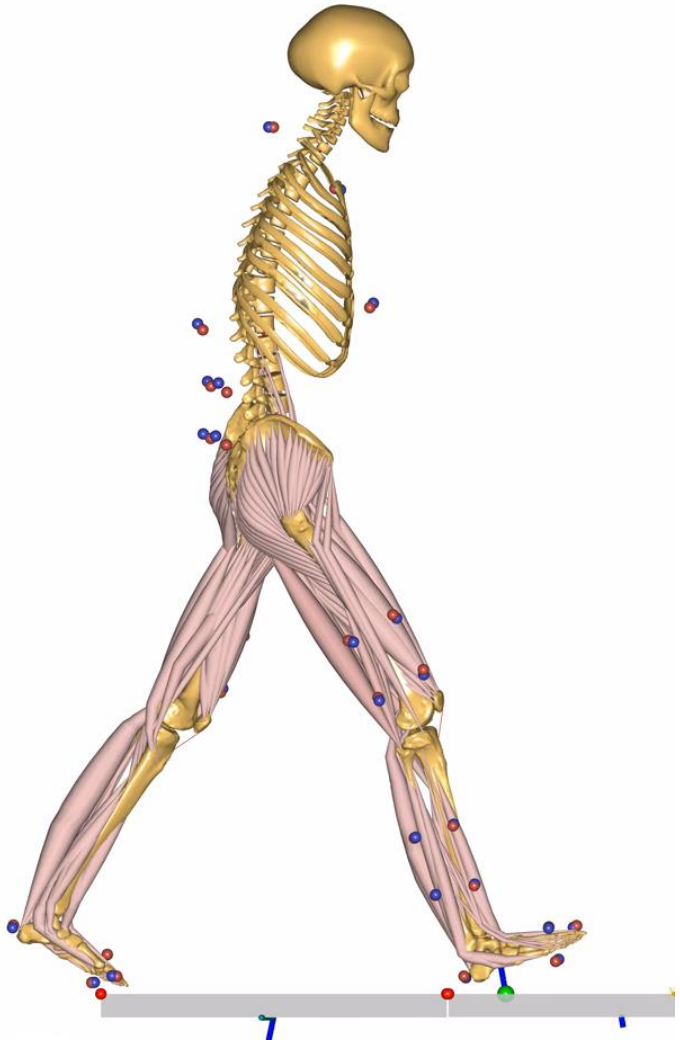
Leeds LifeLongJoints Model

HCF variability during gait

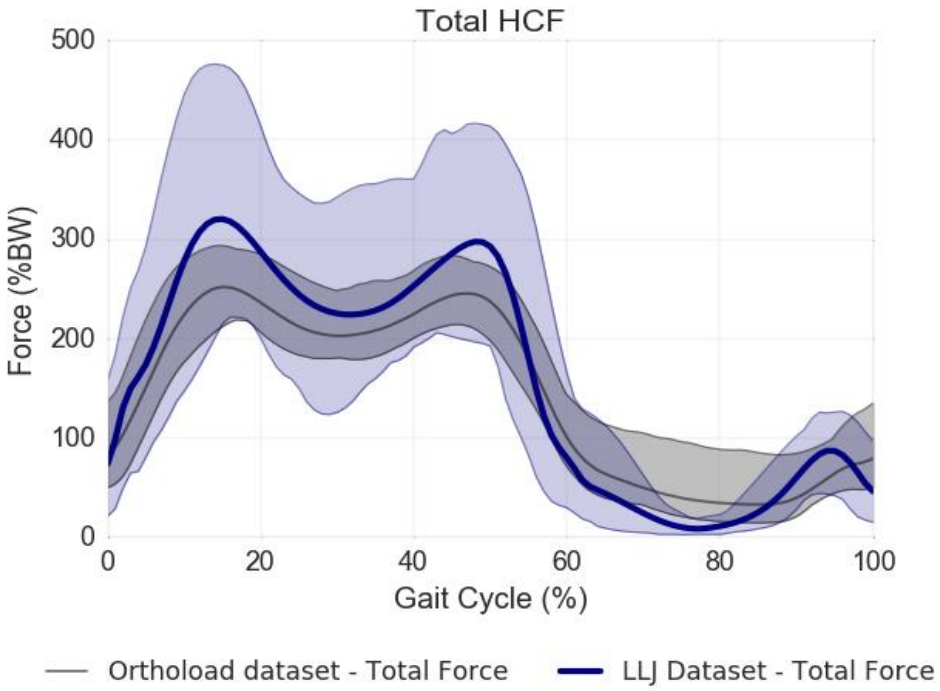
- 132 patients
- 494 gait trials at self-selected speed

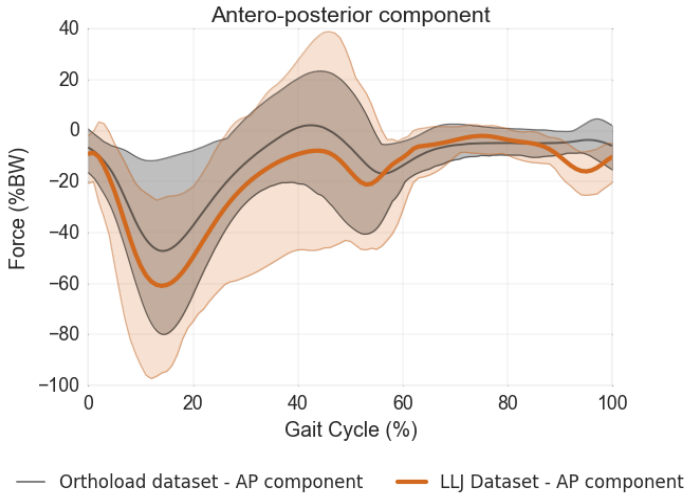


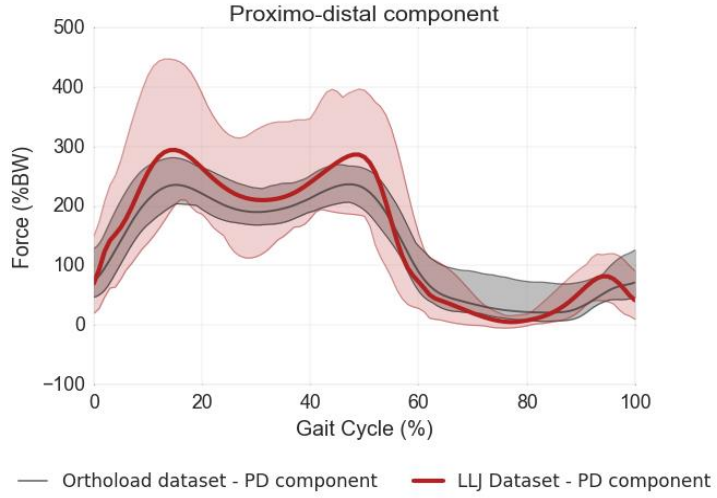


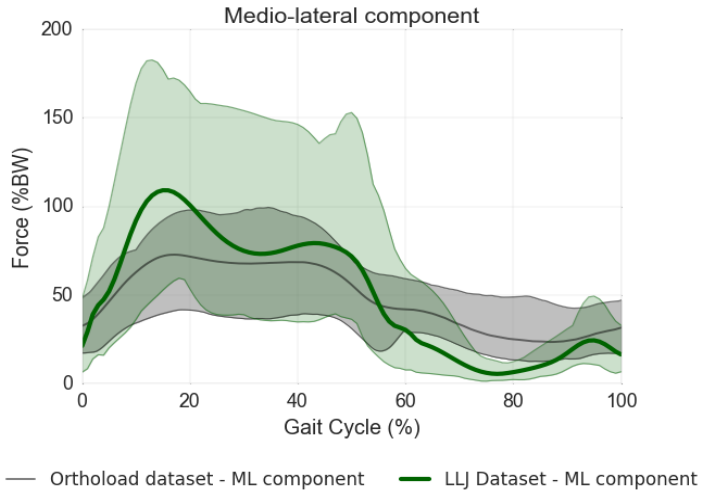


Qualitative comparison against Orthoload dataset



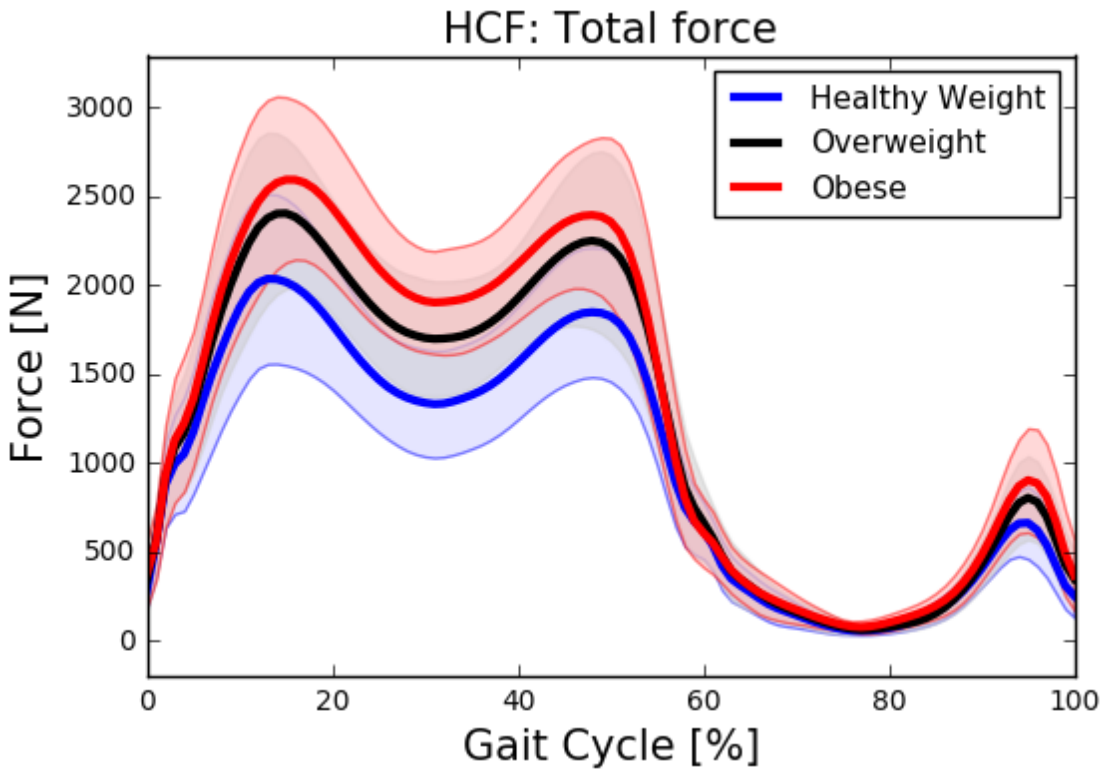


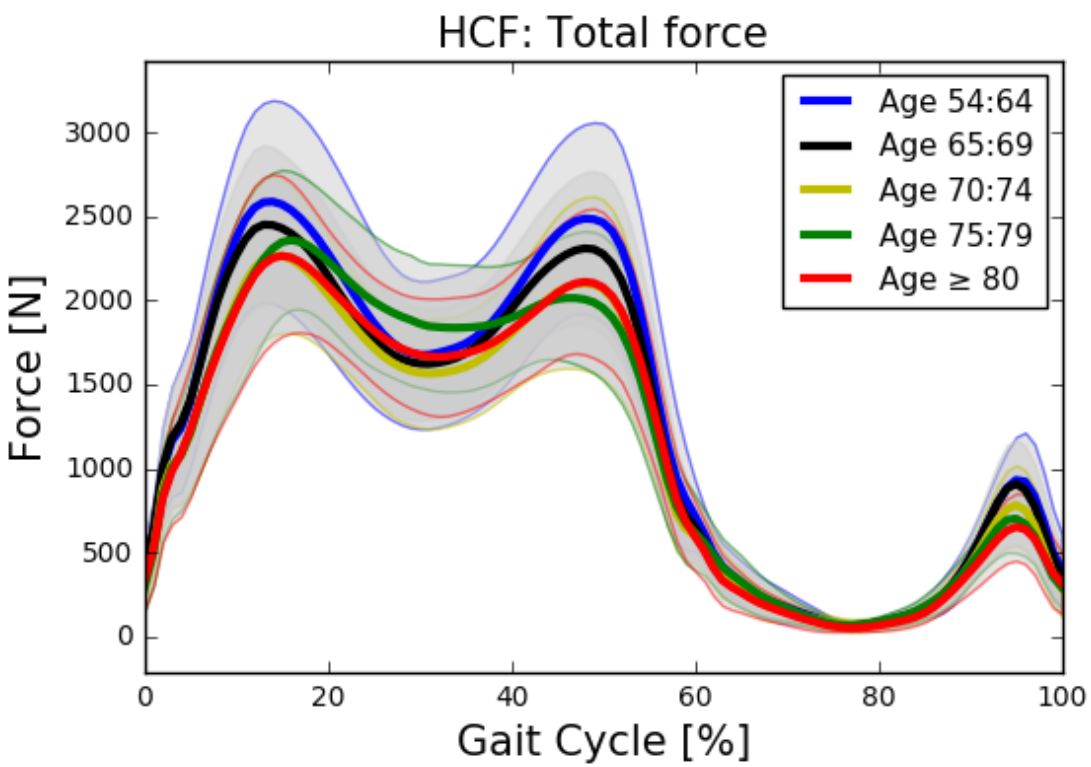




- Predictions' mean within Orthoload dataset range
- Larger variability

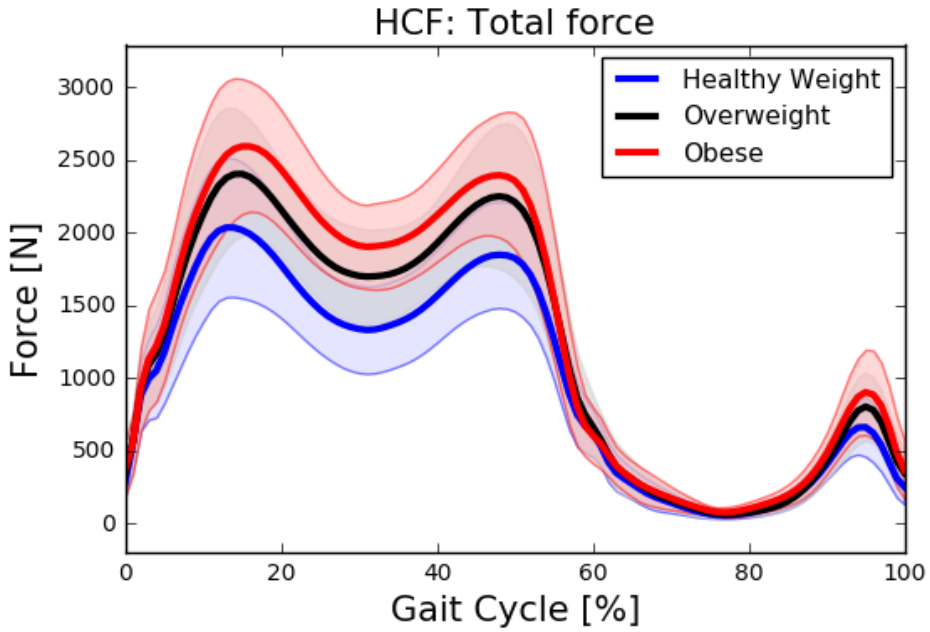
Effect of Patients' Characteristics on HCF

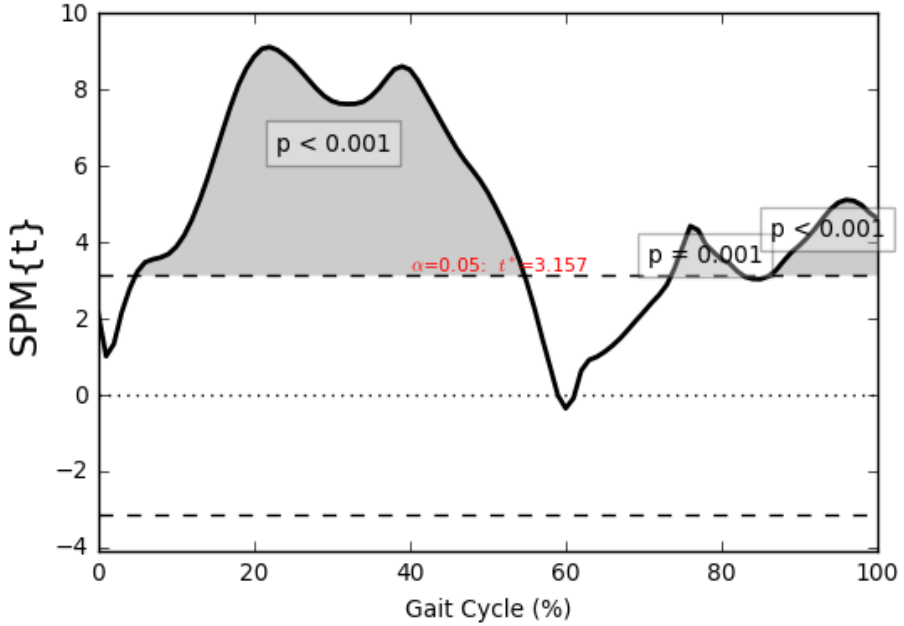




Population Stratification using Statistical Parametric Mapping (SPM)

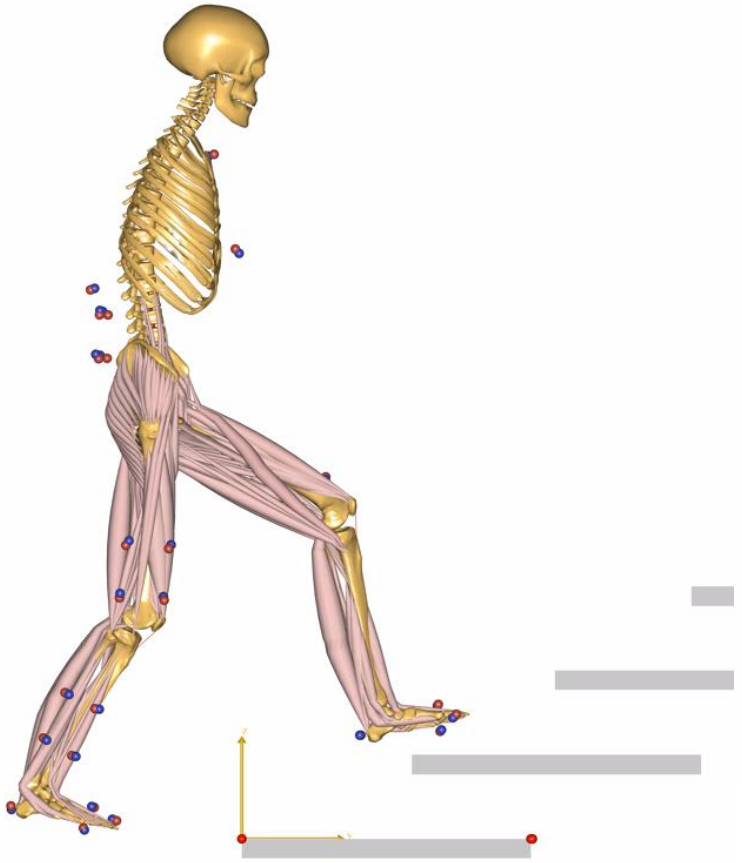
There are significant differences in HCF, whether we stratify them BMI, age, or gait speed

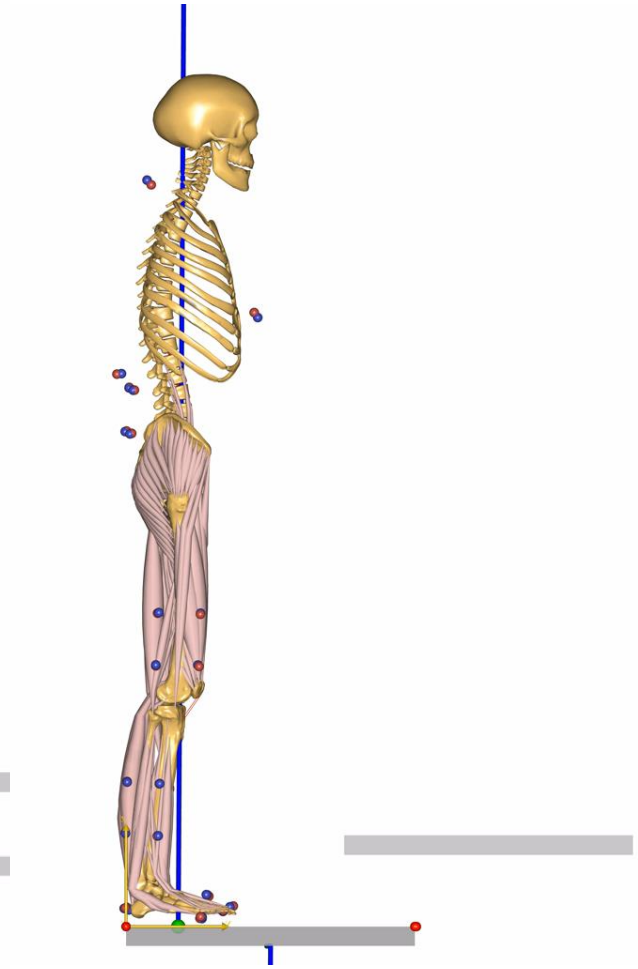


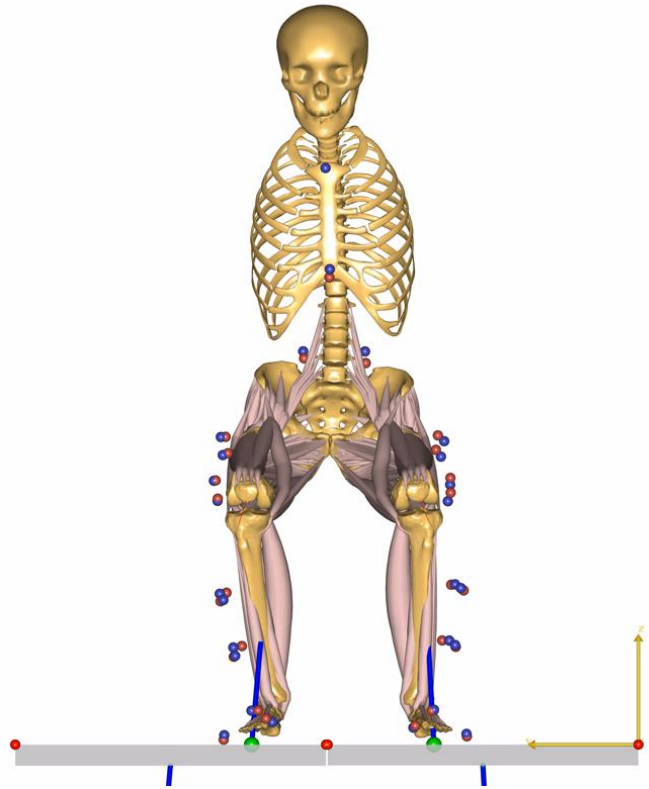


LIFE LONG JOINTS

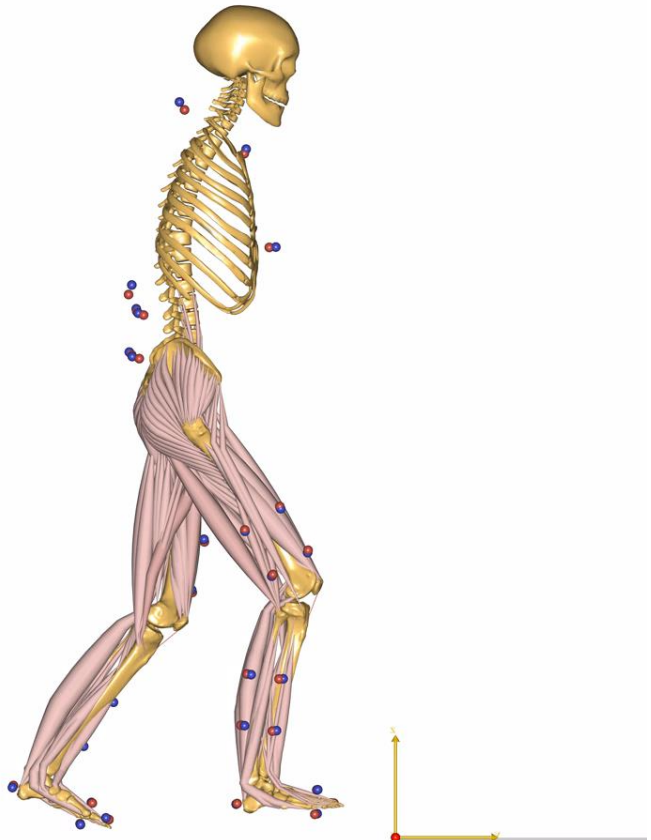
Routine Activities of Daily Living

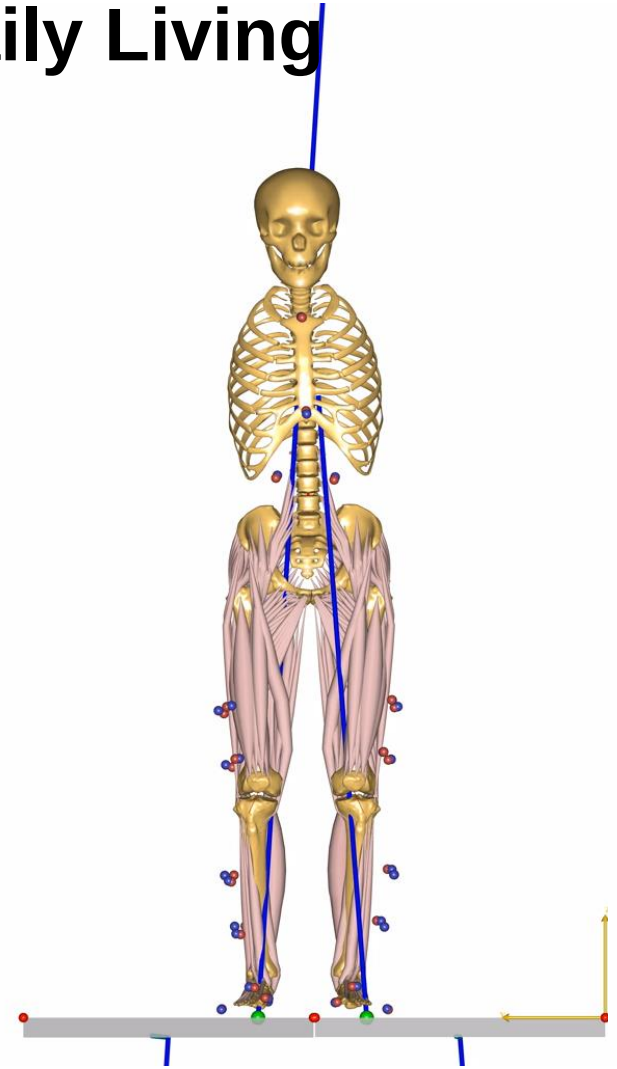


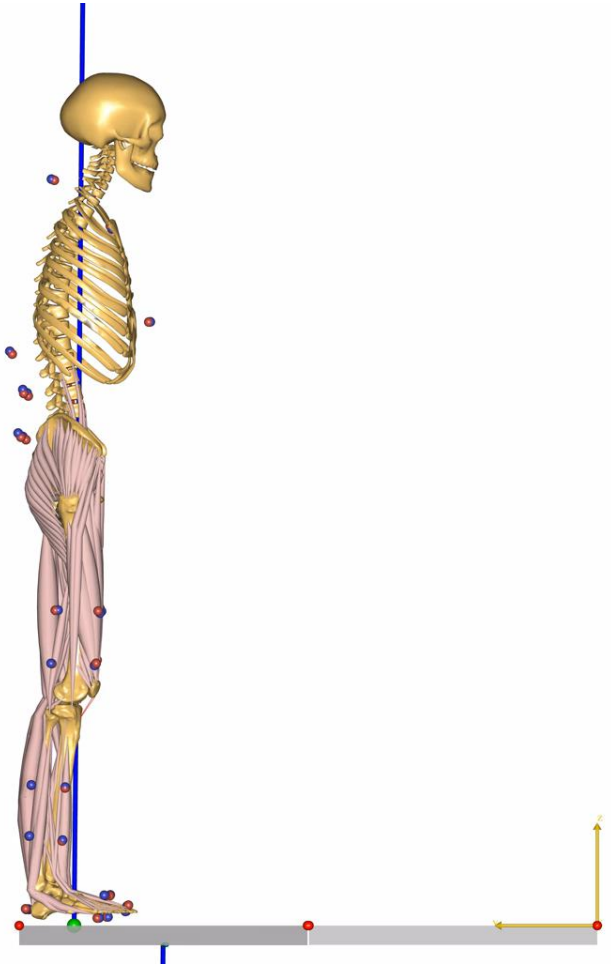




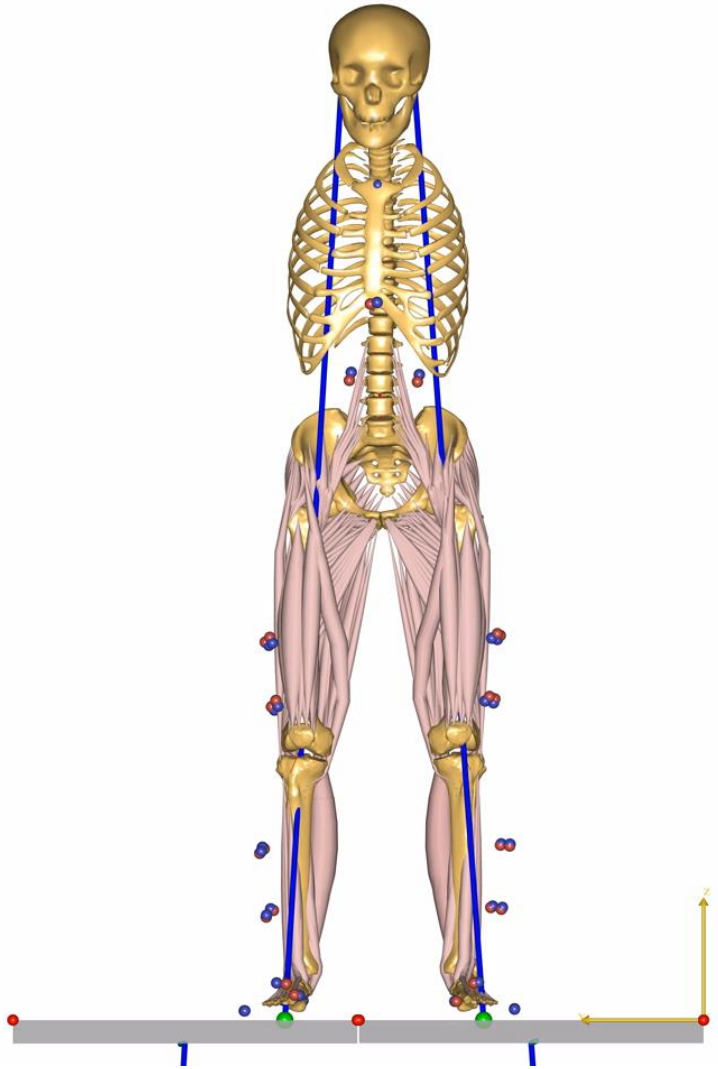
Adverse Activities of Daily Living

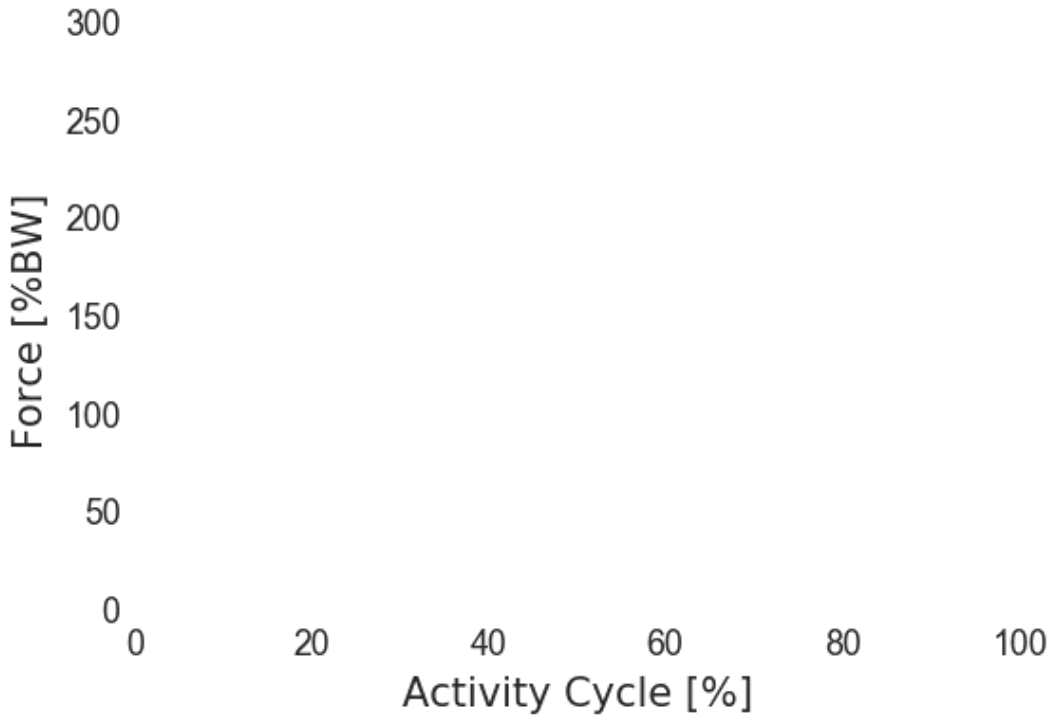




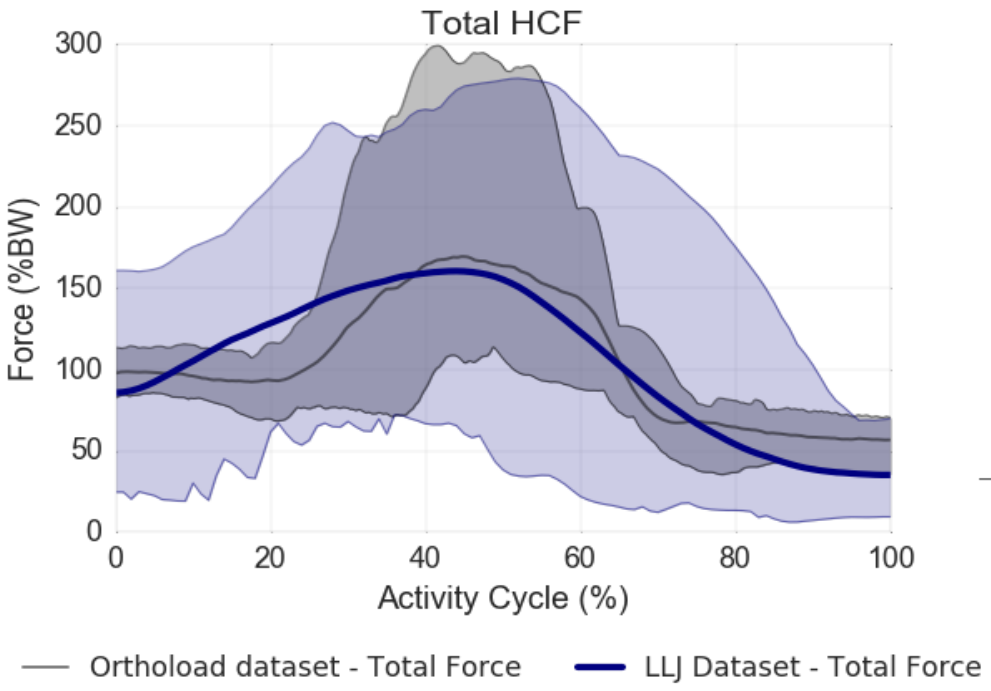


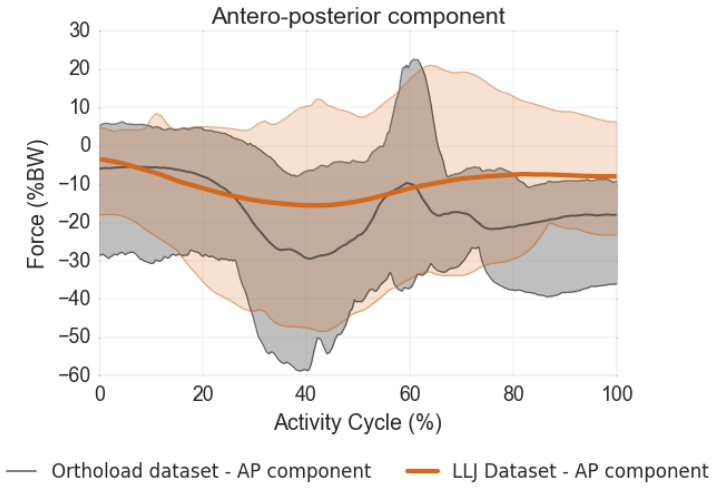
Activities of Daily Living – Sit Down

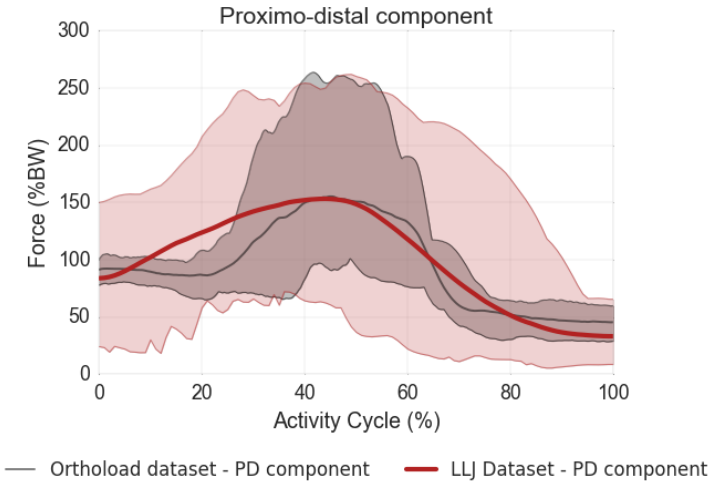


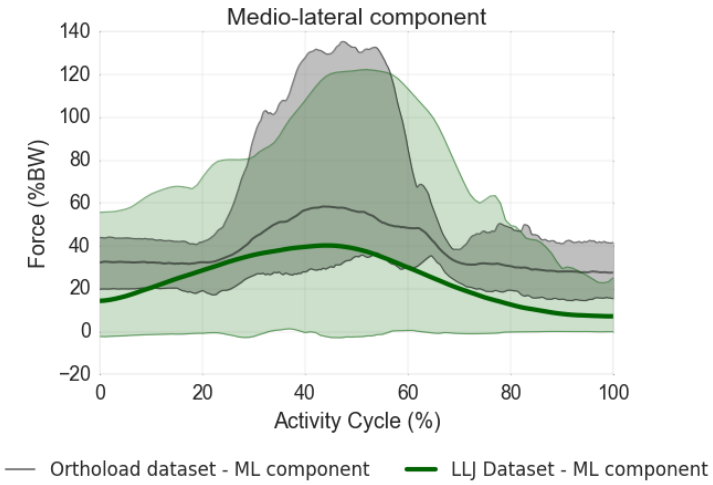


Qualitative comparison against Orthoload dataset – Sit Down



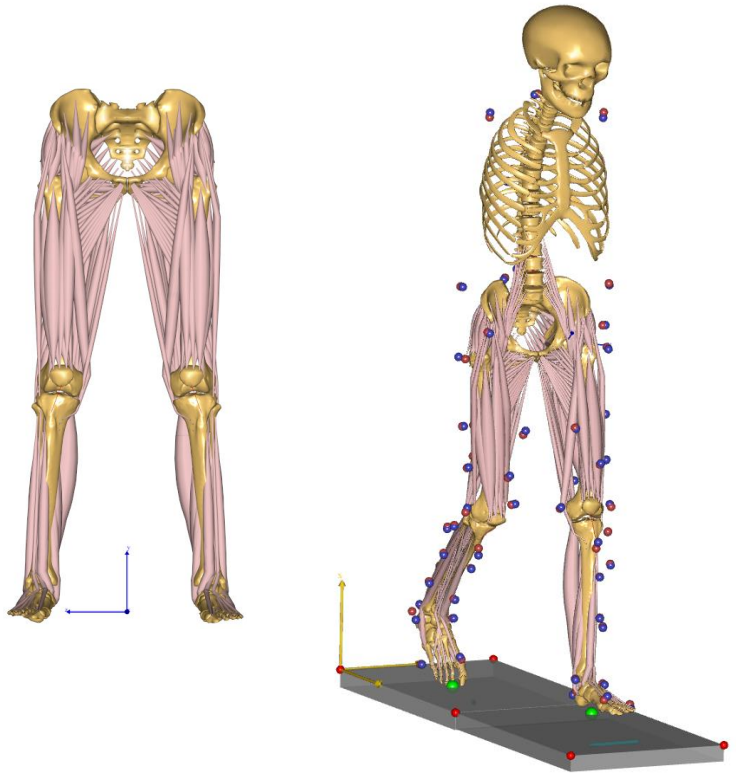


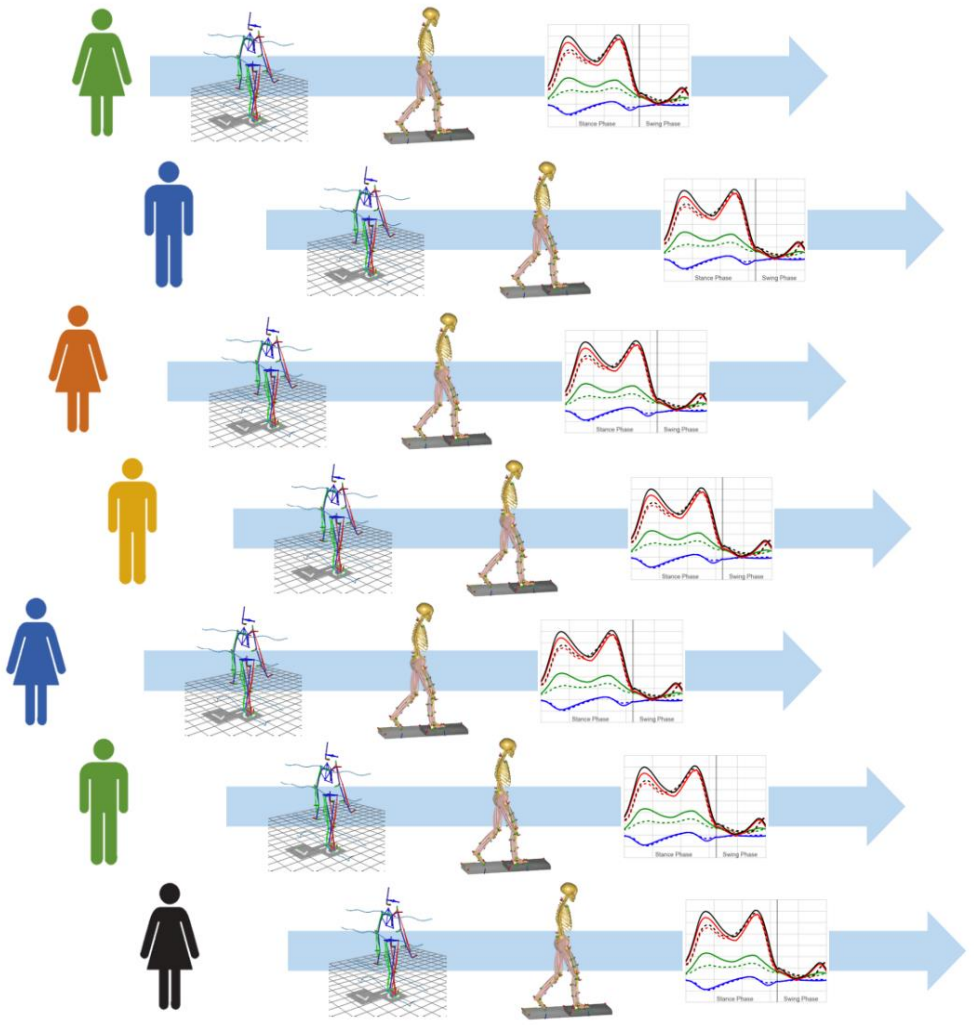




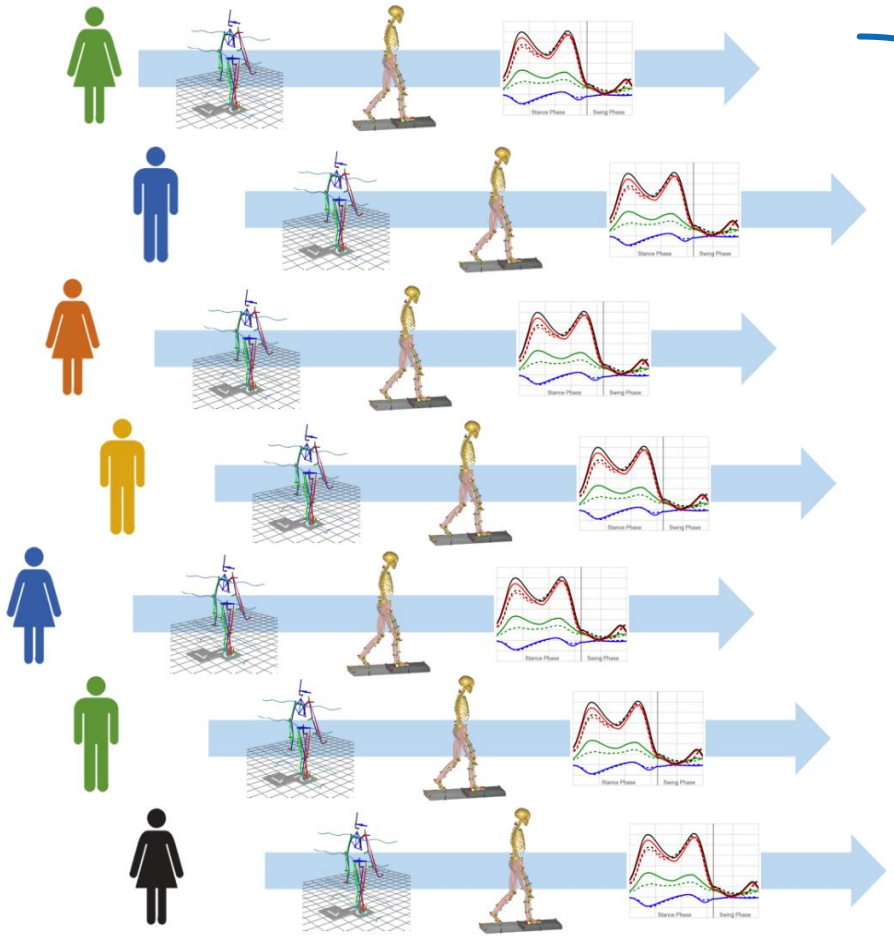
- Predictions' mean within Orthoload dataset range

Conclusion

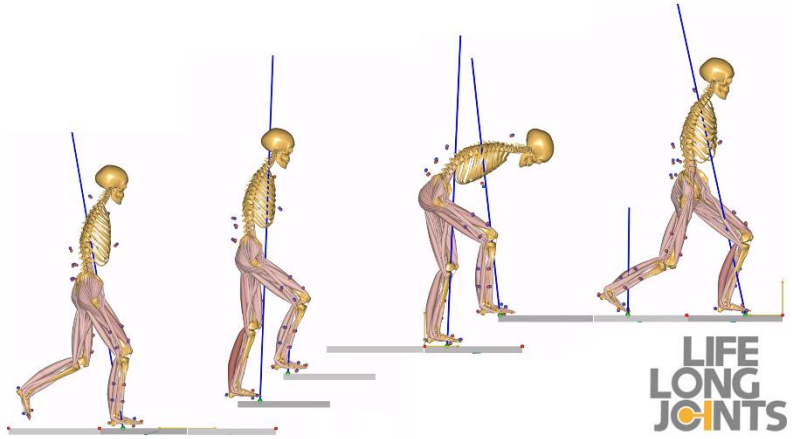


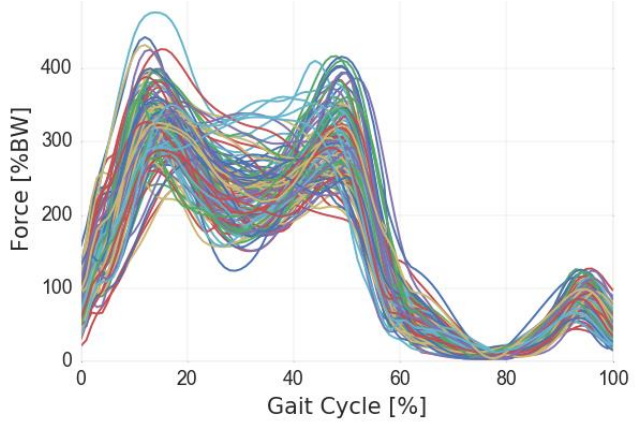


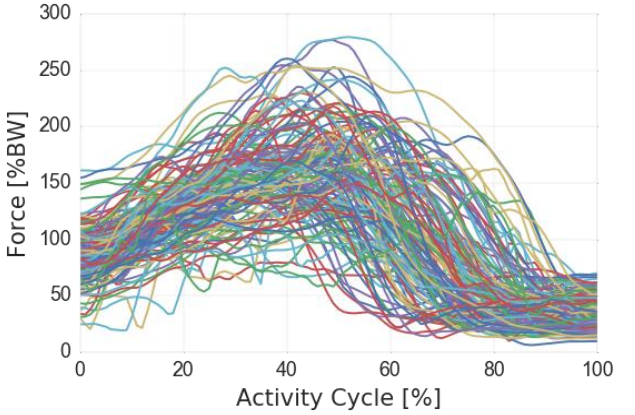
> 130 patients



> 130 patients



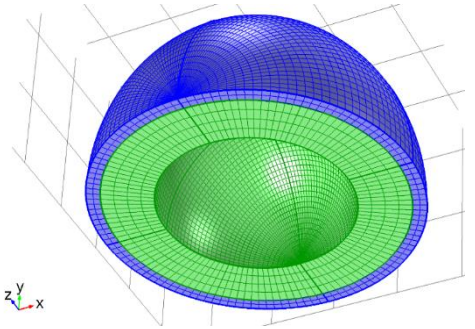


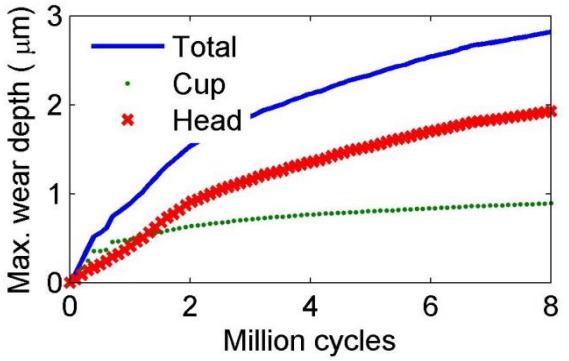


Imperial College London

UNIVERSITY OF LEEDS

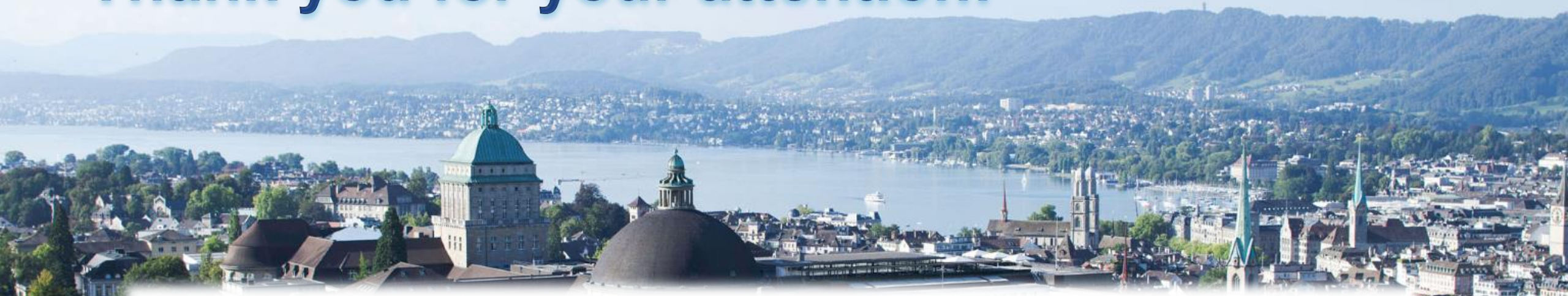
Wear Modelling





ETH zürich

Thank you for your attention!



Acknowledgments:

Morten E. Lund
Anantharaman Gopalakrishnan
Kasper P. Rasmussen

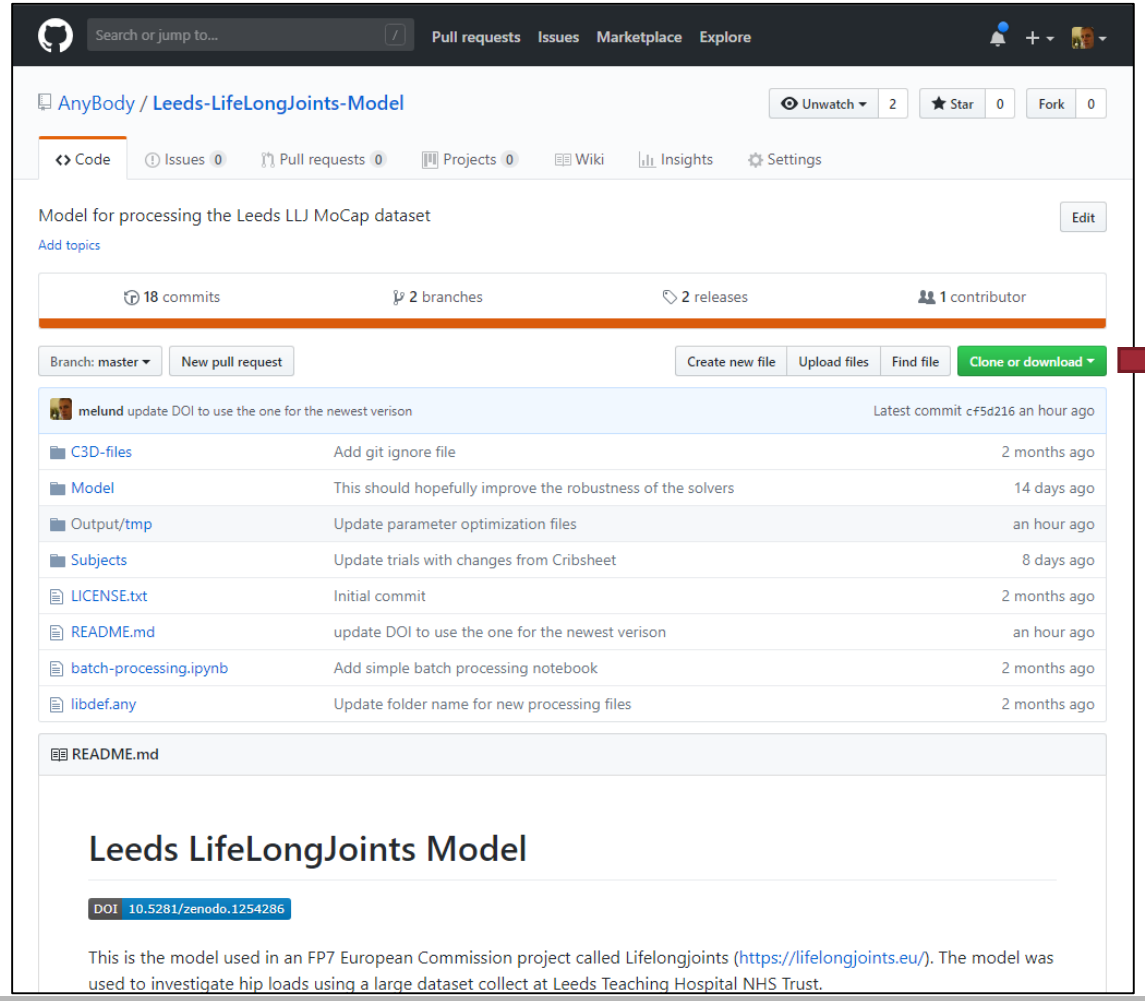
David E. Lunn
Anthony Redmond

Financial support:

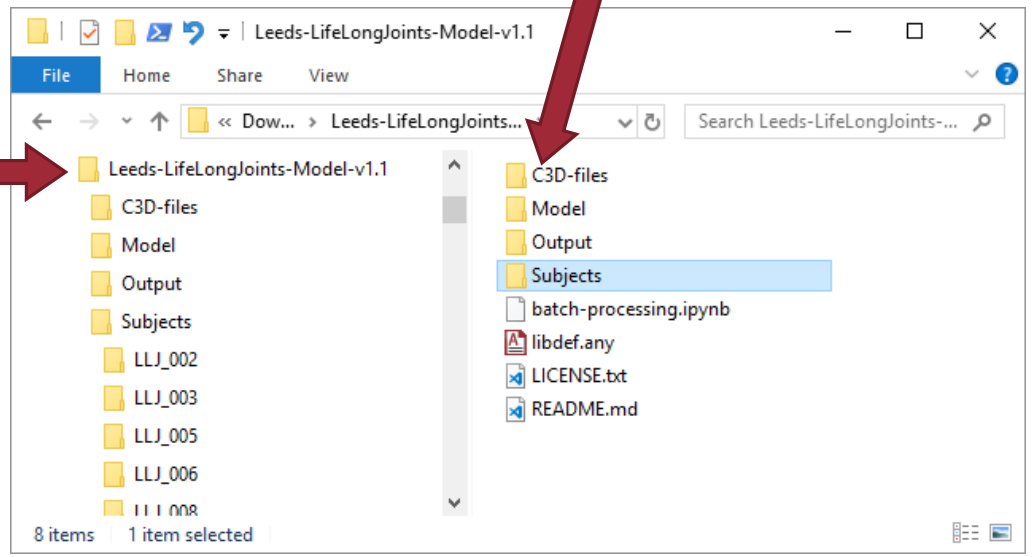
7th Framework Programme
Life Long Joints project

Released: Leeds LifeLongJoints Model

https://github.com/AnyBody/Leeds-LifeLongJoints-Model



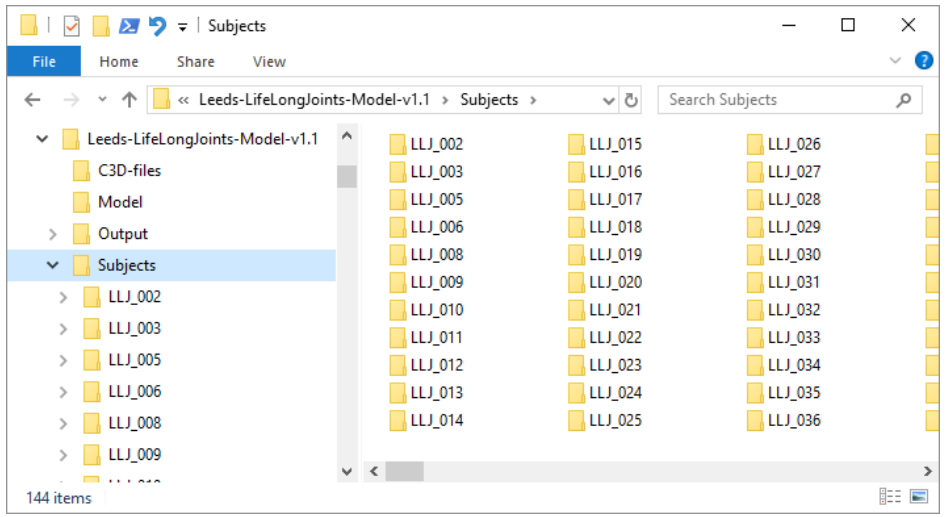
Data from *Leeds LLJ dataset* goes into "`C3D-files/`"

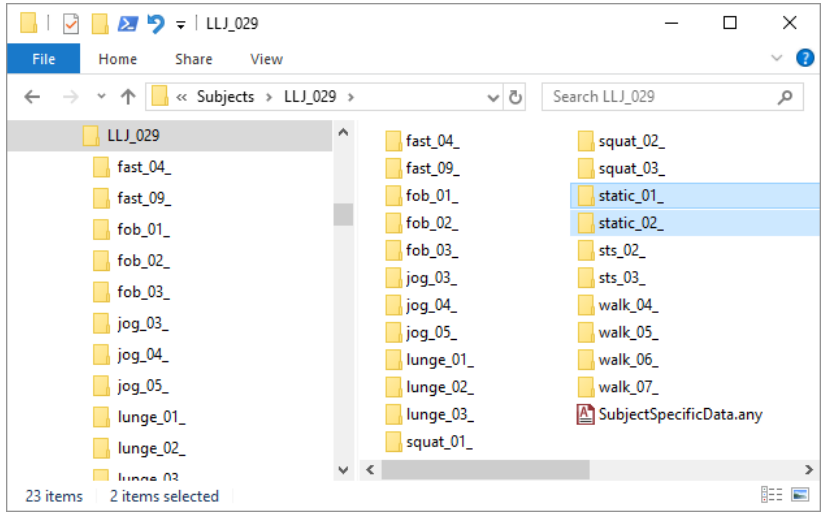


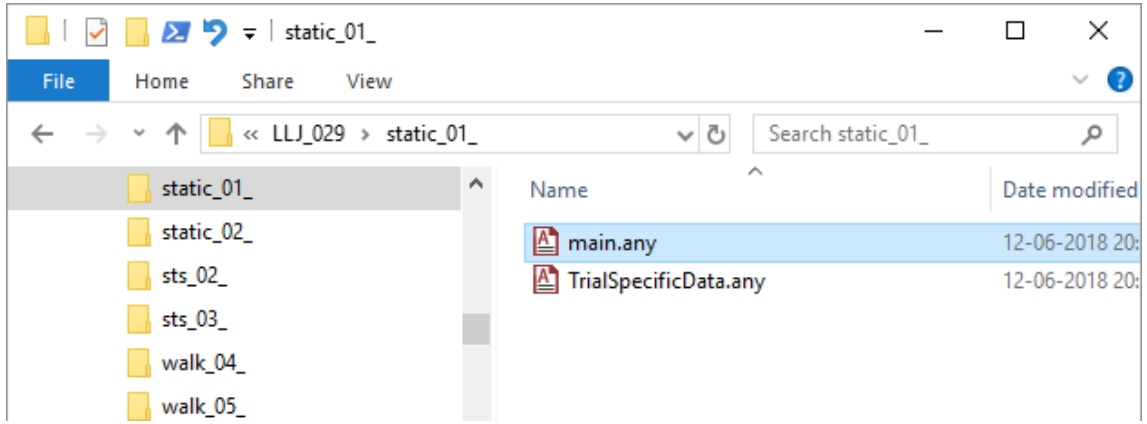
Notice: Data must be downloaded separately…

https://doi.org/10.5518/345

Released: Leeds LifeLongJoints Model



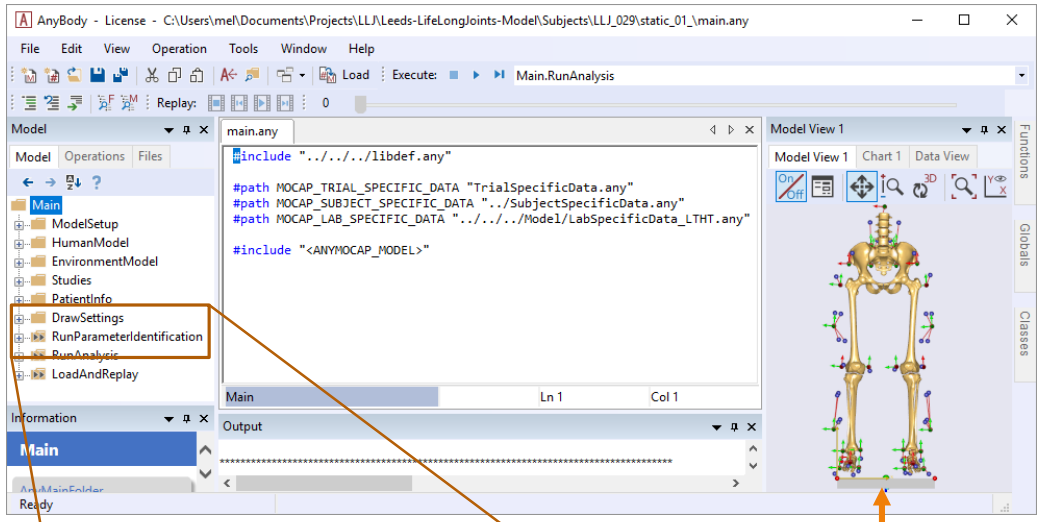


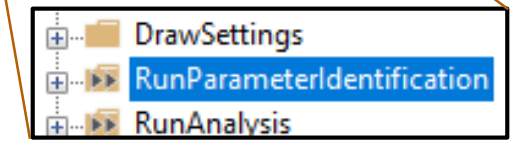


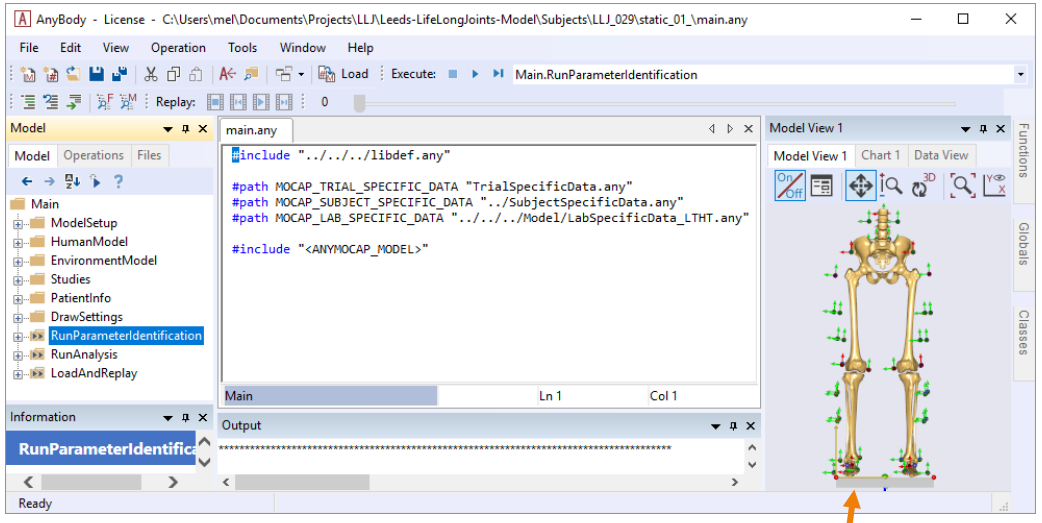
trial	Activity
static	Standing reference
fast	Fast gait
walk	Normal gait
lunge	Lunge
sts	Sit to stand/stand to sit
squat	Squat
fob	Foot on bench
jog	Jogging

Released: Leeds LifeLongJoints Model

Must run for all 237 trials…. Not a manual task.







Model is not scaled
Markers not located correctly

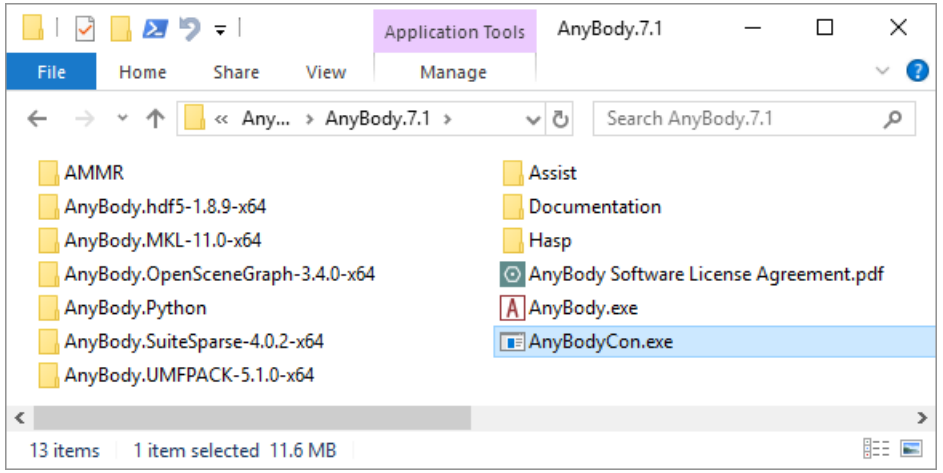
Segment length and marker positions are optimized

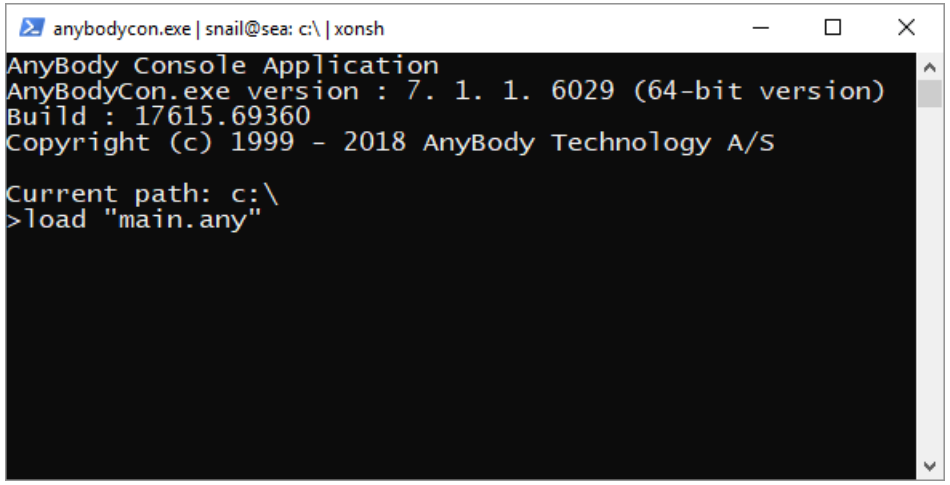
The console application and macros

- The AnyBody Modeling System without the graphical user interface (GUI)

AnyScript Macros commands

```
load <"file name"> [arg]

operation <opr_name>

run

classoperation <obj> <cmd> [arg]

exit
```



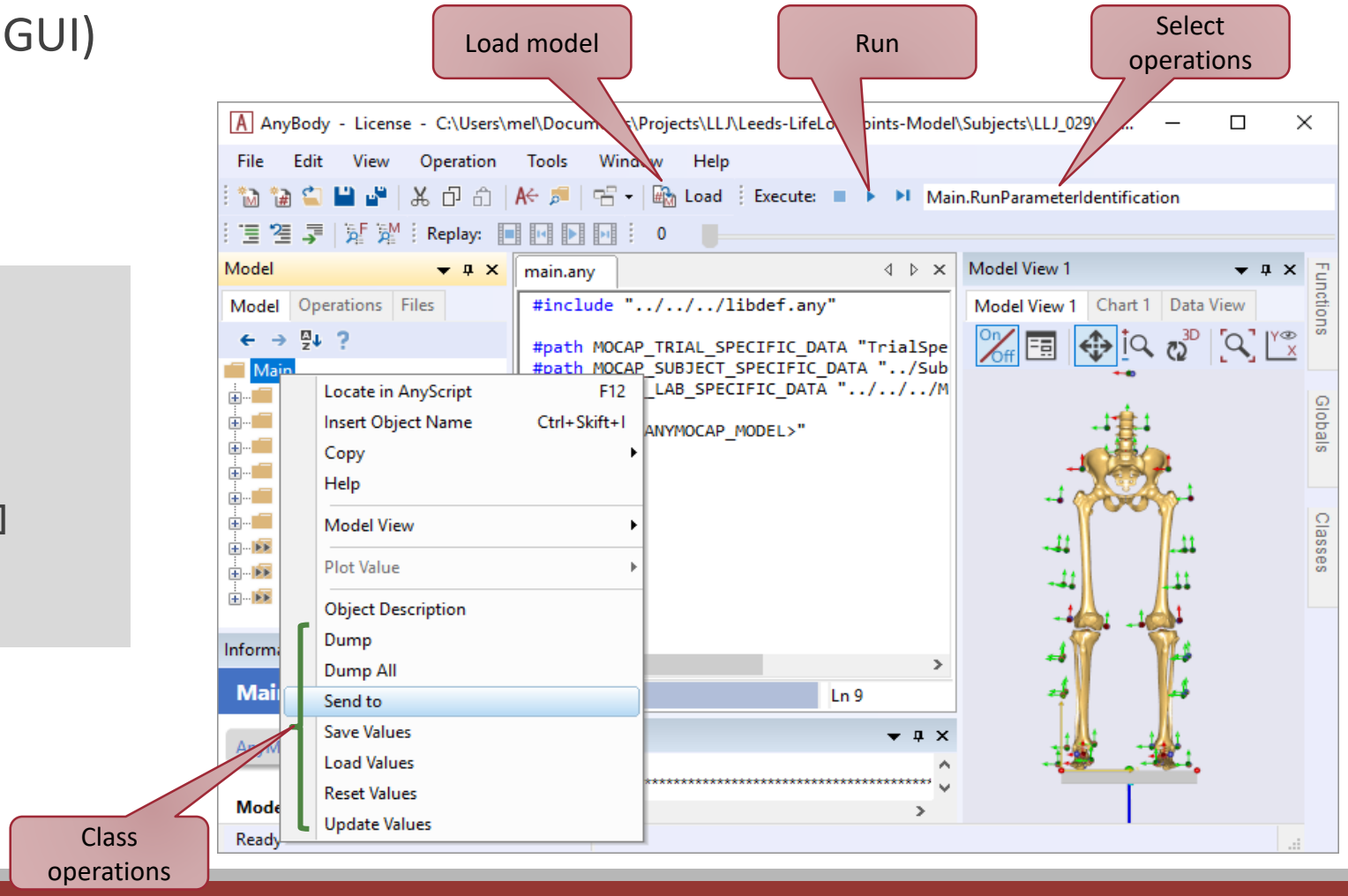


The console application and macros

- The AnyBody Modeling System without the graphical user interface (GUI)

AnyScript Macros commands

```
load <"file name"> [arg]

operation <opr_name>

run

classoperation <obj> <cmd> [arg]

exit
```



Batch processing with Python

- Running macro is easily automated with the *AnyPyTools* library.

In [1]:
```
from anypytools import AnyPyProcess
from anypytools.macro_commands import Load, OperationRun, Dump
```

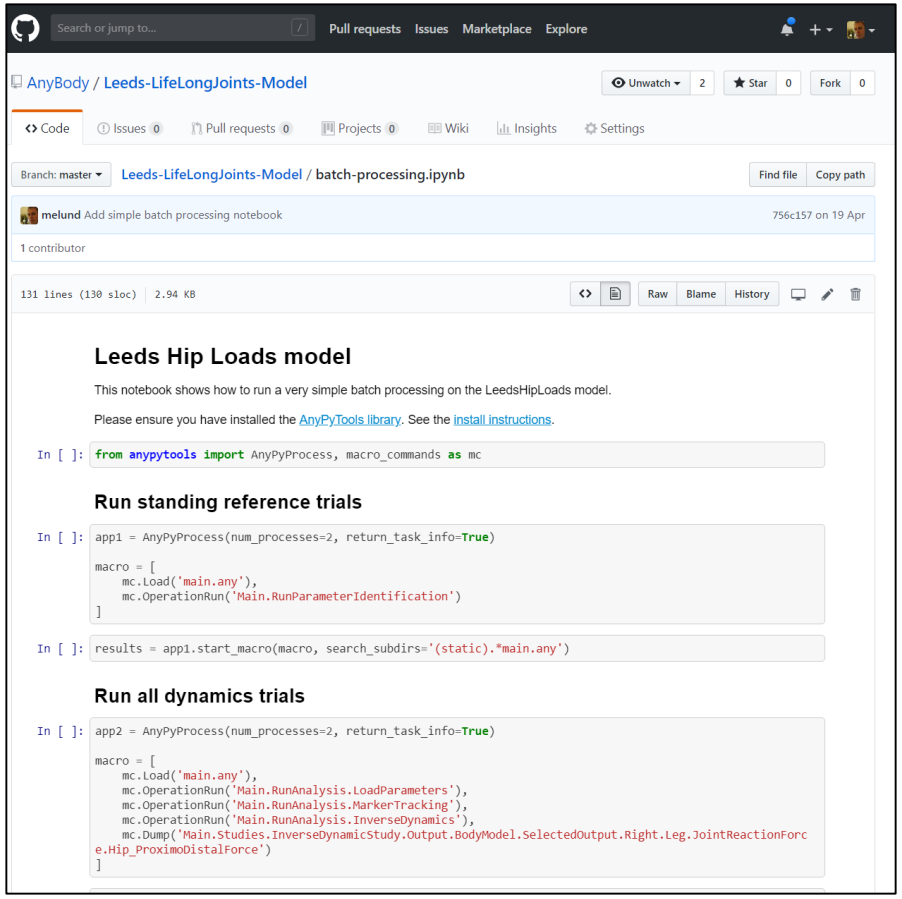
In [2]:
```
app1 = AnyPyProcess(num_processes=2)

macro = [
    Load('main.any'),
    OperationRun('Main.RunParameterIdentification')
]
```

In [ ]:
```
results = app1.start_macro(macro, search_subdirs='(static).*main.any')
```

14 of 237

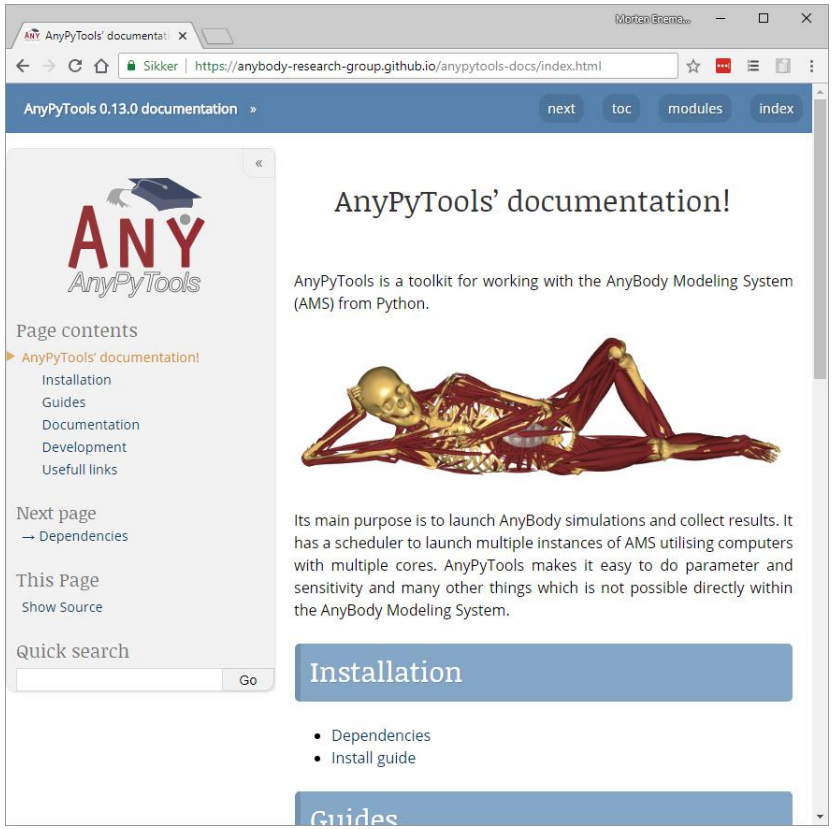
More on batch processing

Complete example with the Leeds-LifeLongJoints-Model:



https://github.com/AnyBody/Leeds-LifeLongJoints-Model

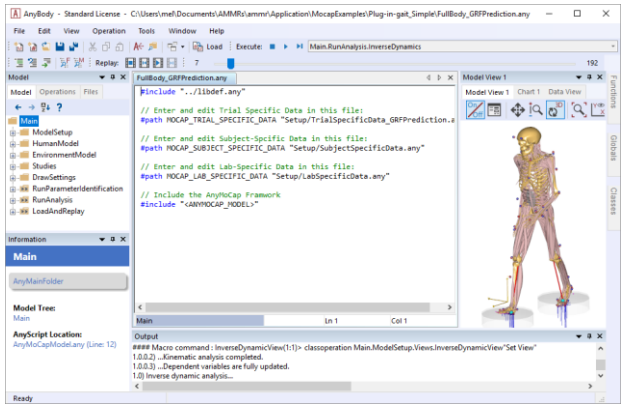
How to install and use AnyPyTools:



https://anybody-research-group.github.io/anypytools-doc

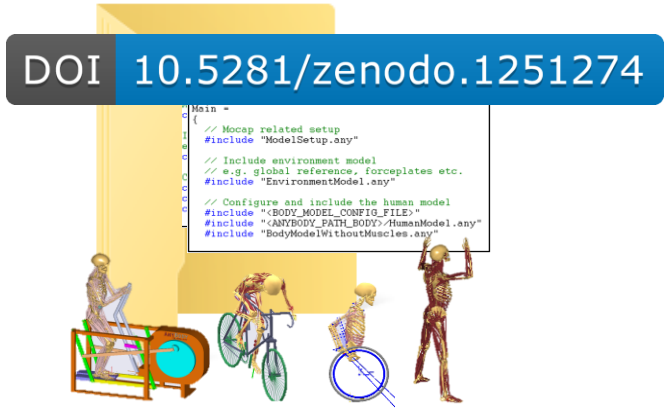
New releases are online:

ANYBODY Modeling System 7.1.2

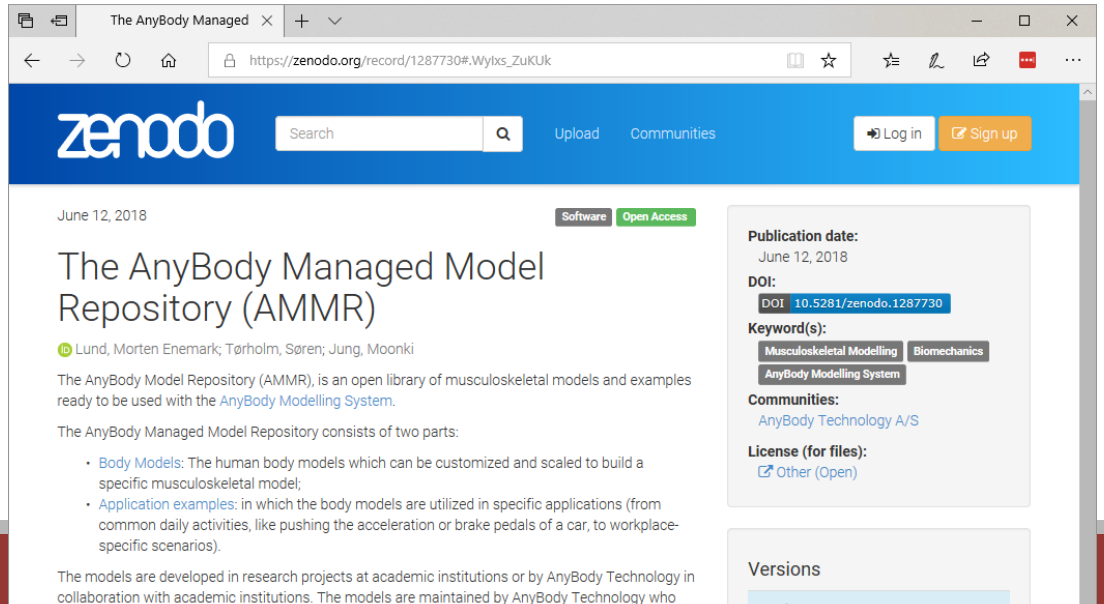


Minor release:
Smaller changes and bug fixes.

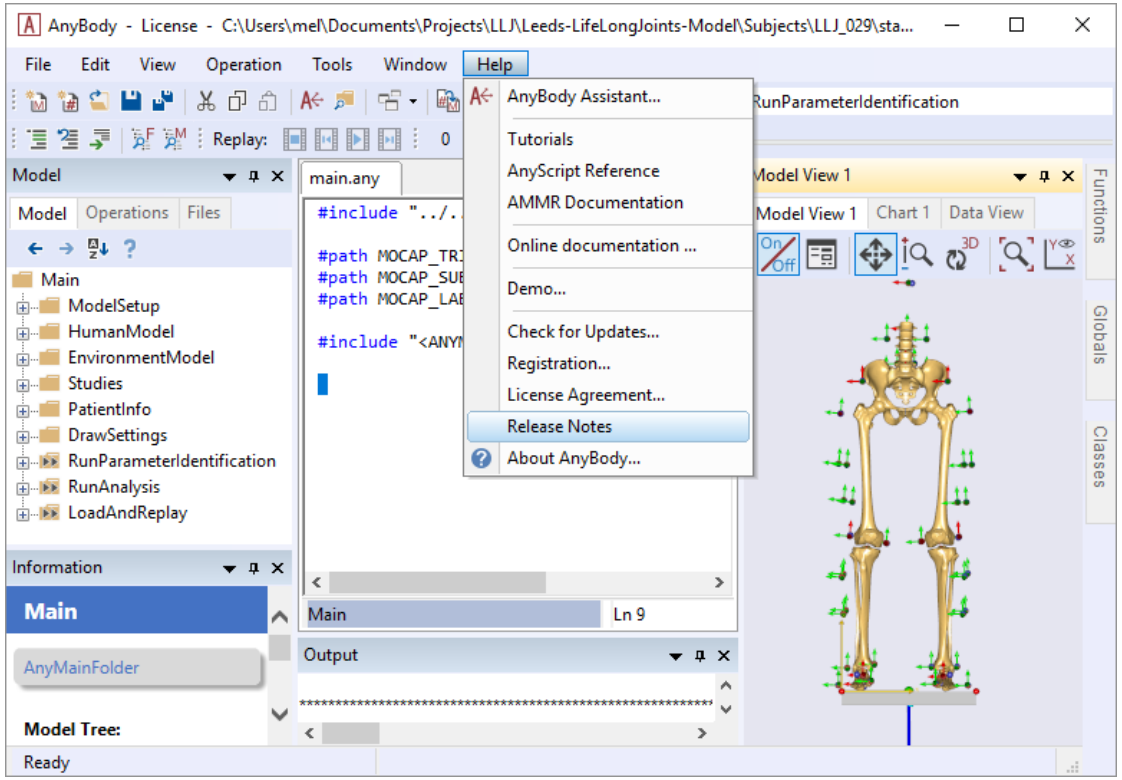
Model Repository (AMMR 2.1.1)



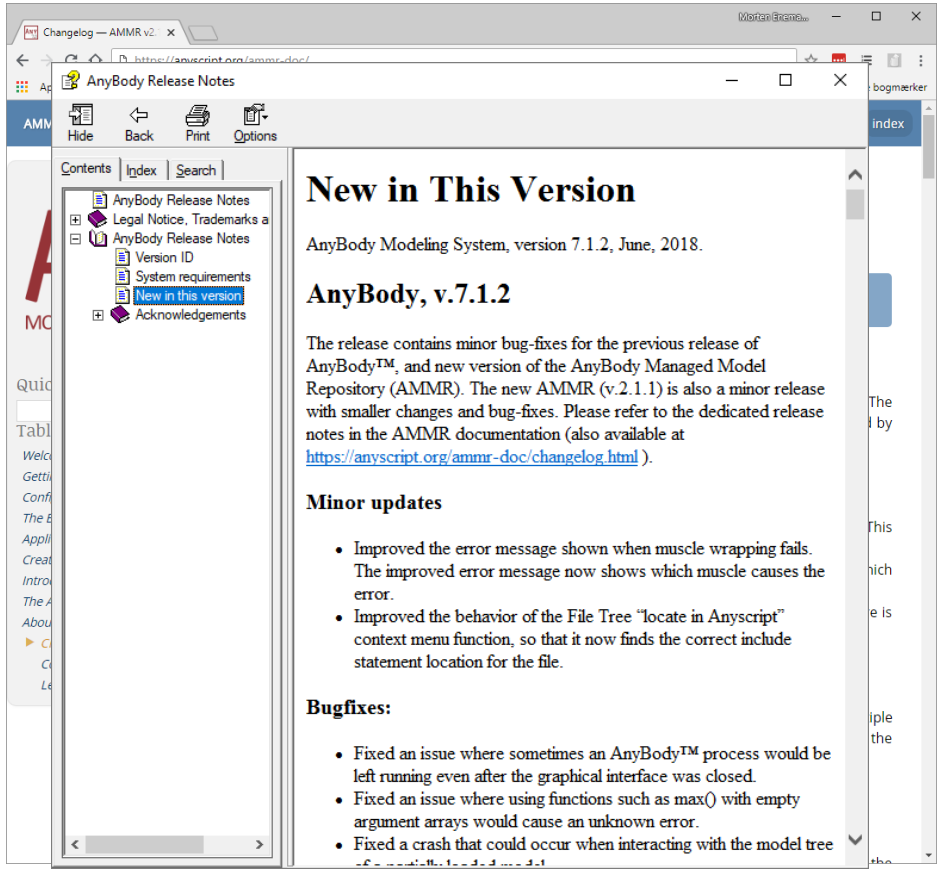
Open Science platform hosted at CERN



Check release notes:



https://anyscript.org/ammr-doc/changelog.html



www.youtube.com/anybodytech

- Previous webcasts

www.anybodytech.com

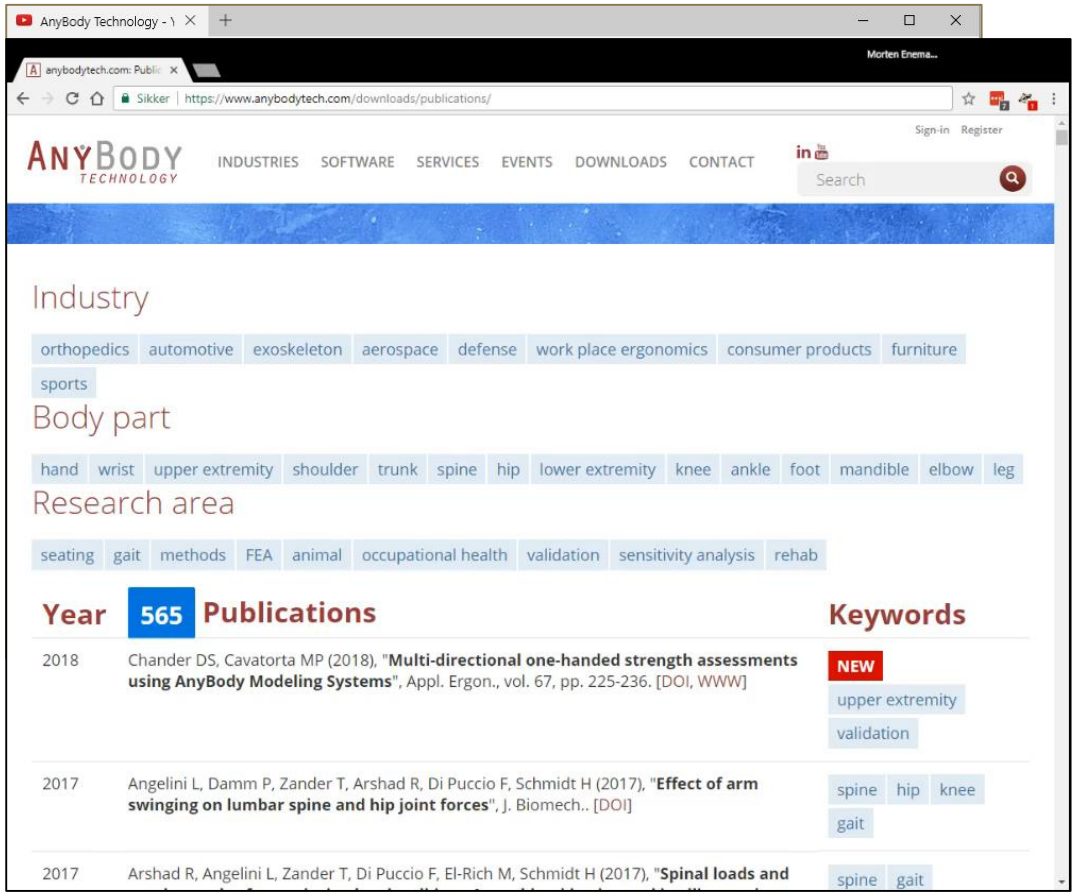
- Events, dates, publication list, ...

Events:

8-12 Jul: WCB in Dublin, Ireland.
See you on booth #42 at and for our session with Xsens

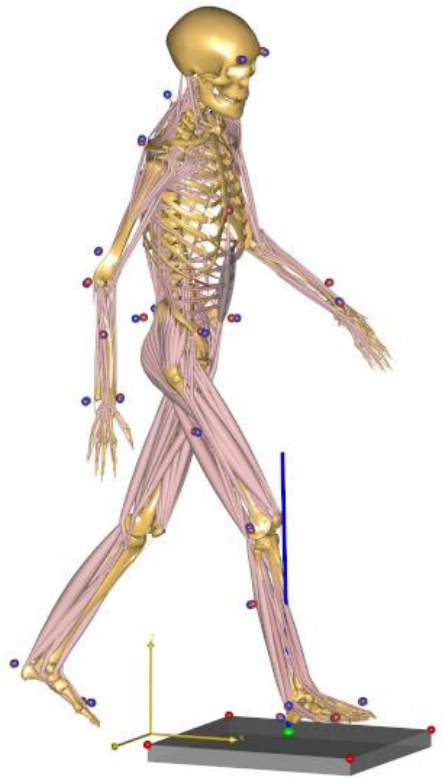
We are hiring:

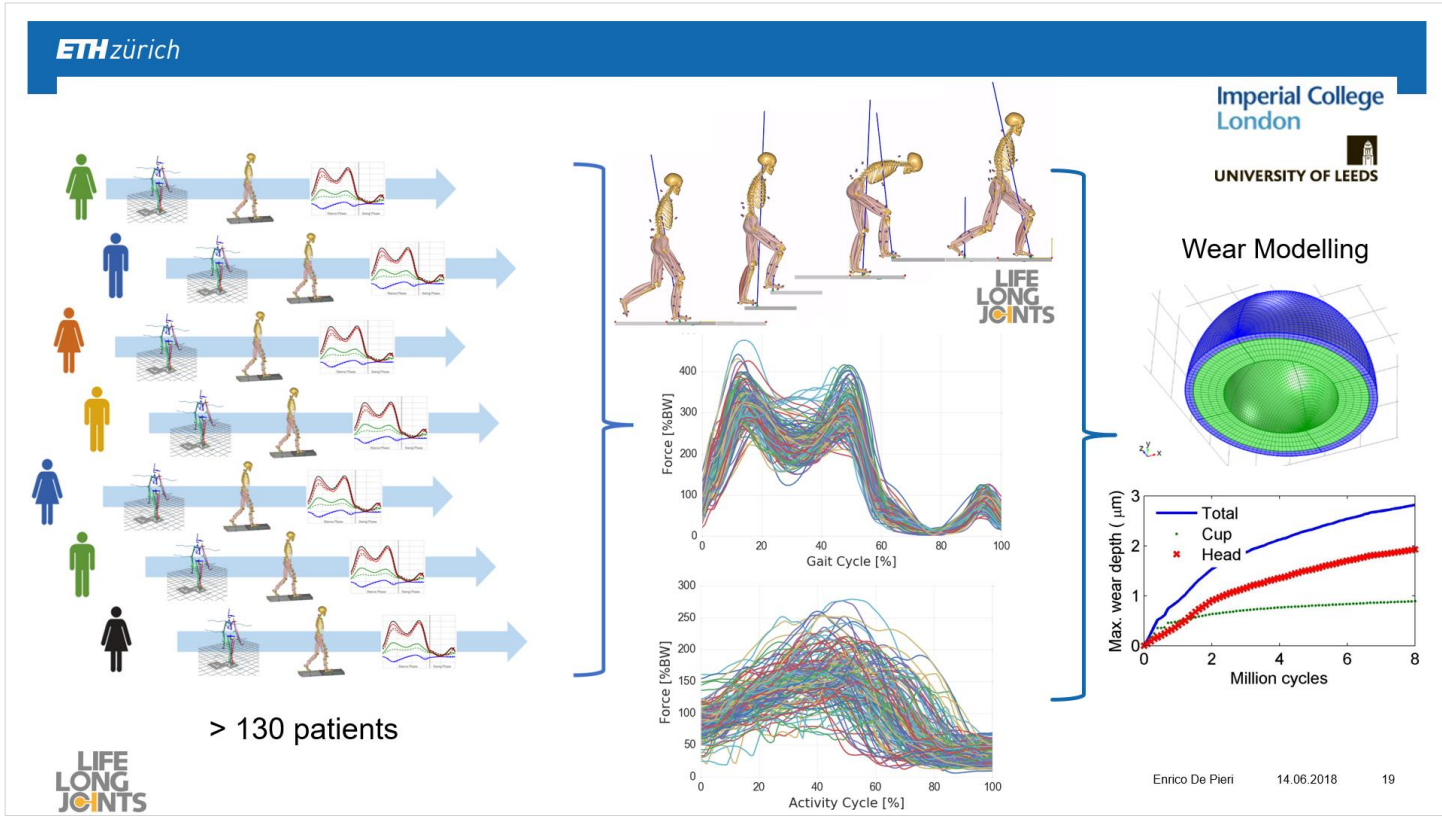
- Biomechanics Specialist and Simulation Core Developer

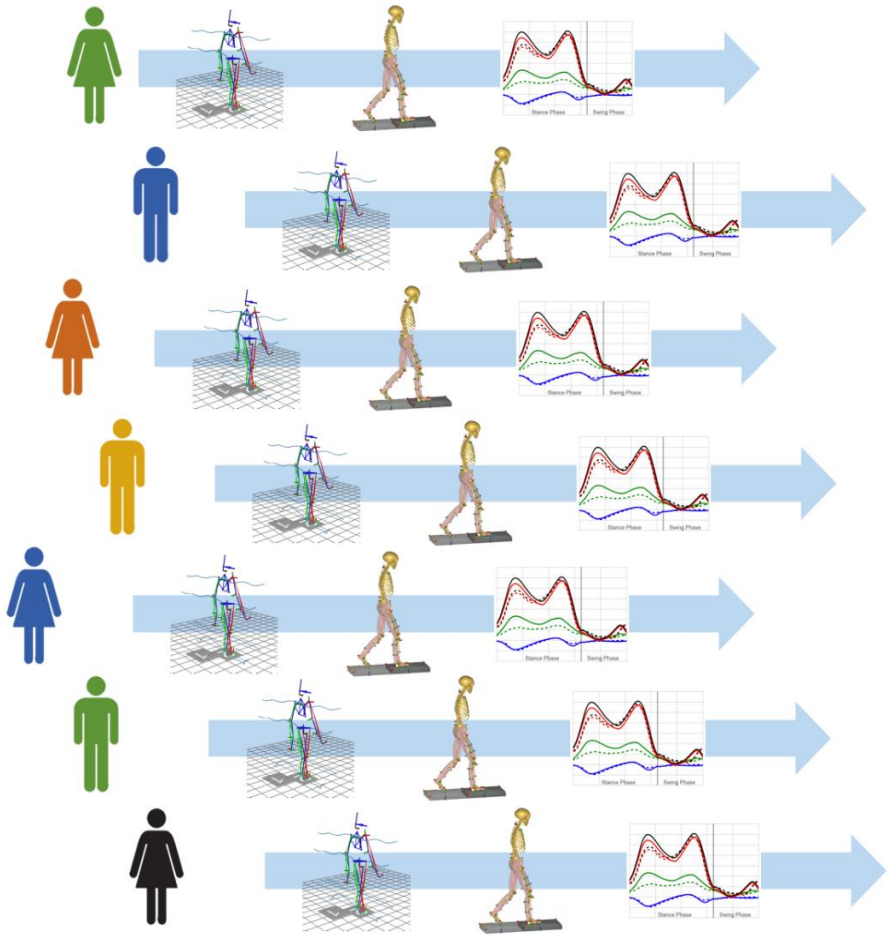


Meet us? Send email to sales@anybodytech.com

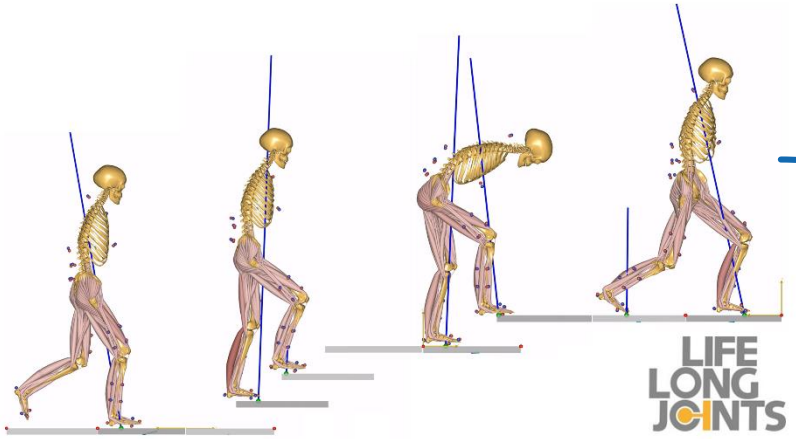
Time for questions:

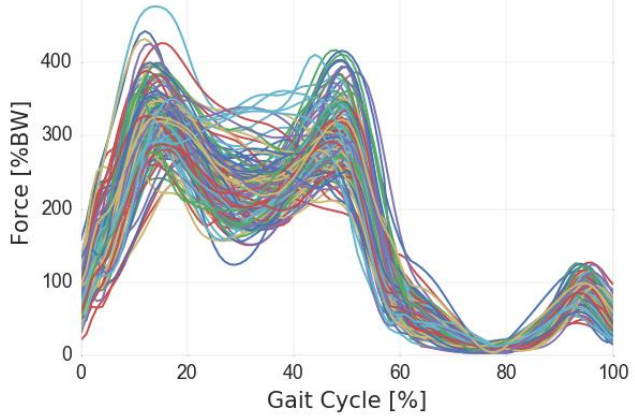


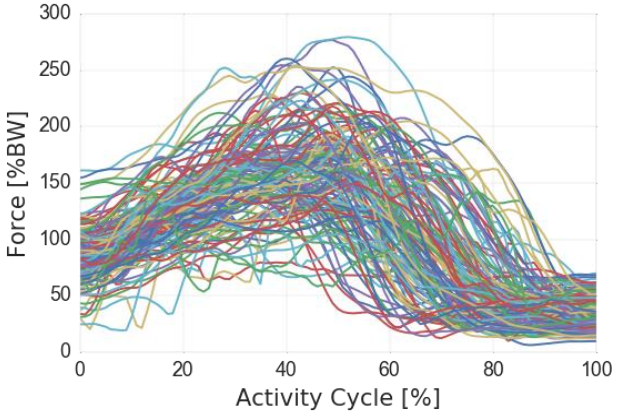




> 130 patients







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Wear Modelling