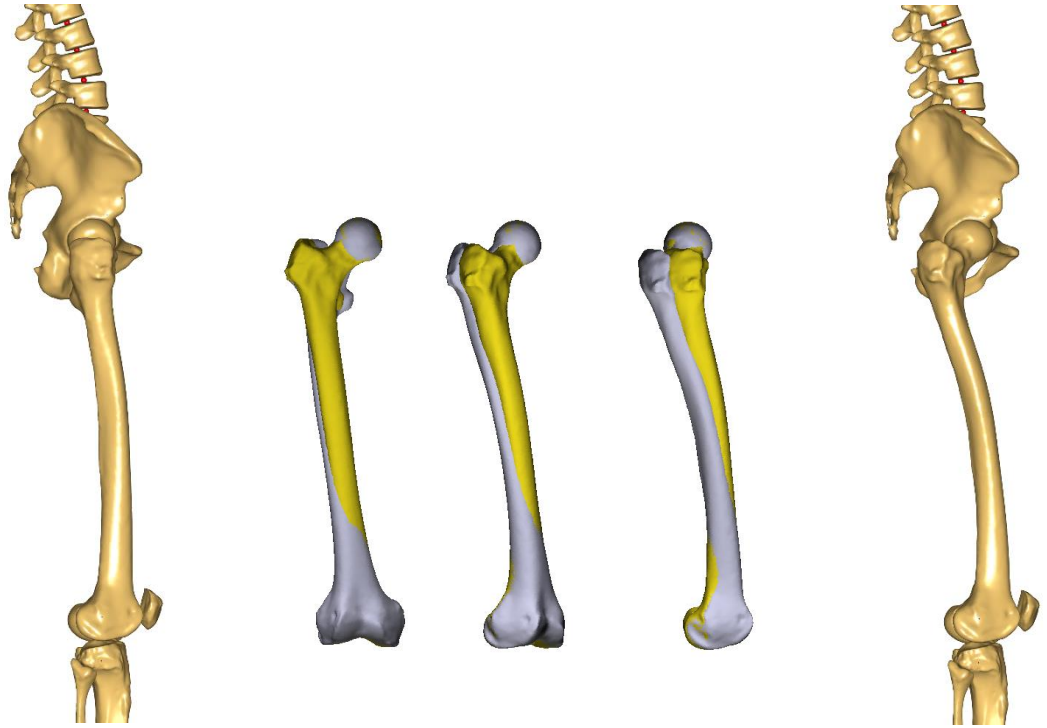
The webcast will begin shortly…

Modeling subject-specific femoral torsion for the analysis of lower-limb joint loads

November 18th, 2021



Outline

- General introduction to the AnyBody Modeling System
- Presentation by Dr. Enrico De Pieri
  - Modeling subject-specific femoral torsion for the analysis of lower-limb joint loads
- Upcoming events
- Question and answer session

Presenter:
Dr. Enrico De Pieri
Research Associate

Universitäts-Kinderspital beider Basel

The University of Basel Children's Hospital, Switzerland

Host(s):
Pavel Galibarov
Sr. Consultant

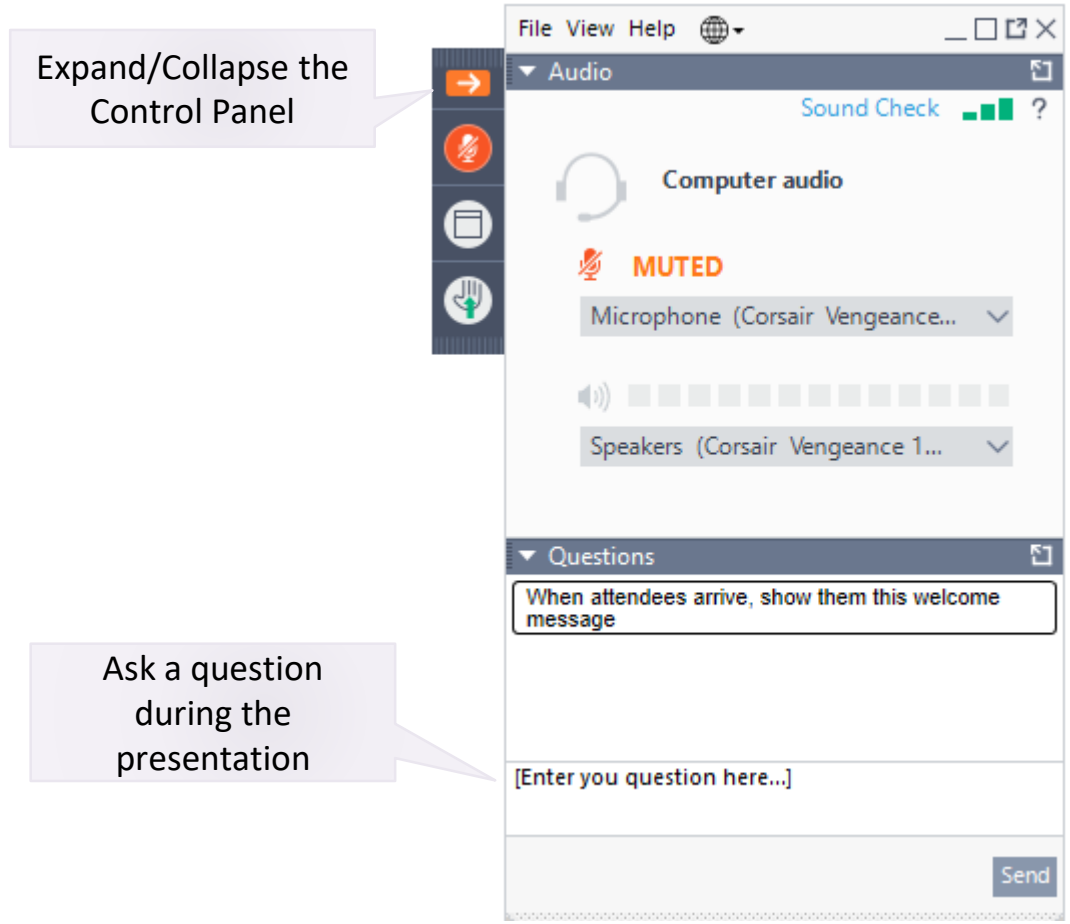
Kristoffer Iversen
Technical Sales Executive

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

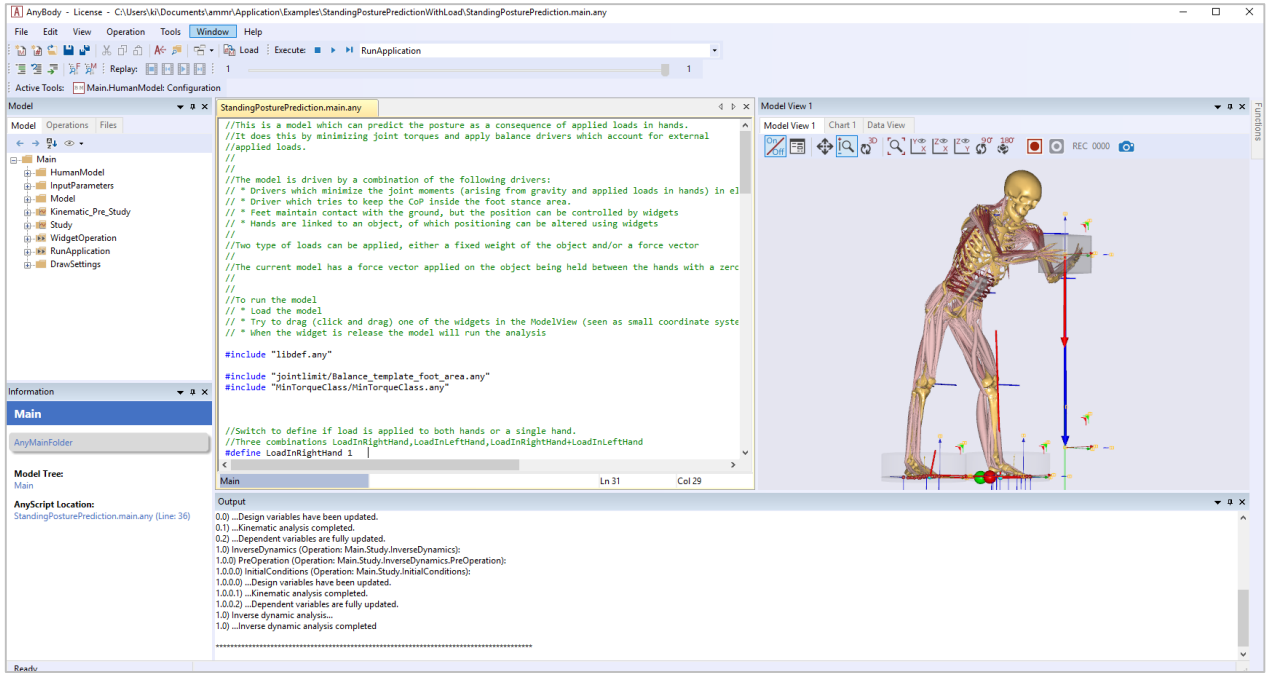
Kinematics and Forces

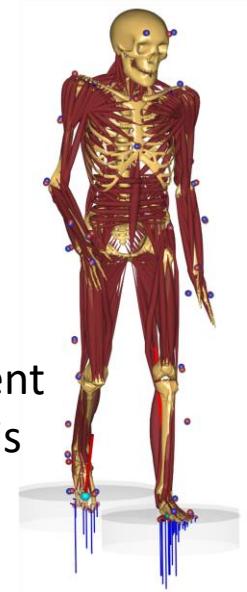
ANYBODY

Modeling System

Body Loads

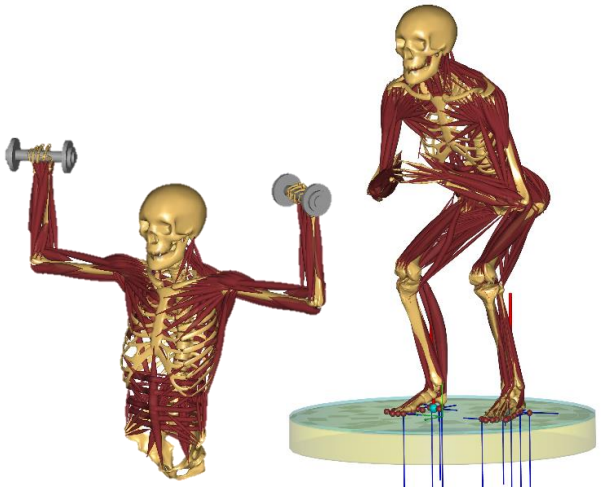
- Joint moments
- Muscle forces
- Joint reaction forces





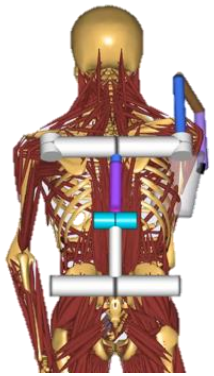
Movement Analysis

Product optimization design

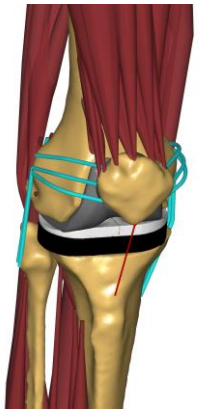


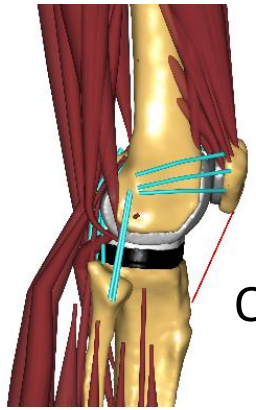
Sports

ANYBODY Modeling System



Assistive Devices





Orthopedics and rehab

AnyBody Modelling System

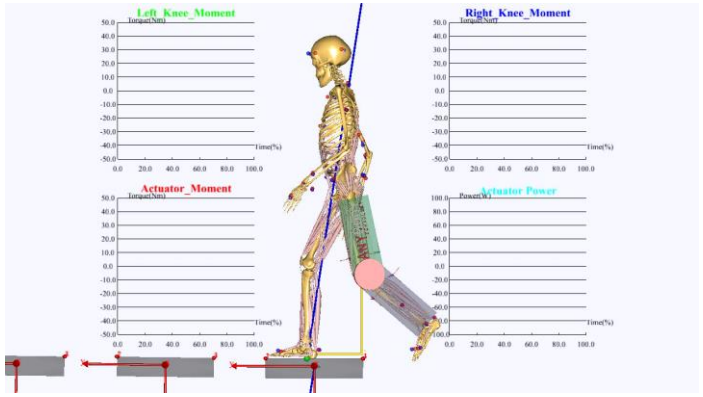
Motion and Forces

Body model

Environment model

Inverse dynamics
Muscle recruitment

Simulation



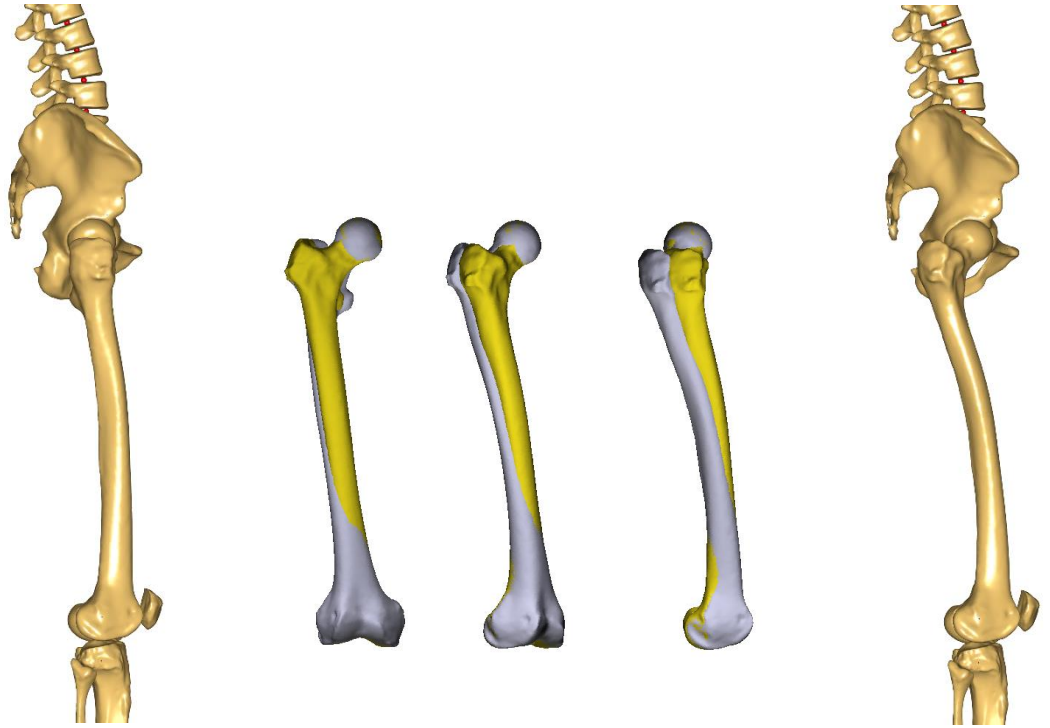
Internal body loads
- Muscle forces
- Joint moments

Design Optimization

Post Processing (e.g. Finite element tools)

Modeling subject-specific femoral torsion for the analysis of lower-limb joint loads

Presented by Dr. Enrico De Pieri



Enrico De Pieri

Modeling subject-specific femoral torsion for the analysis of lower-limb joint loads

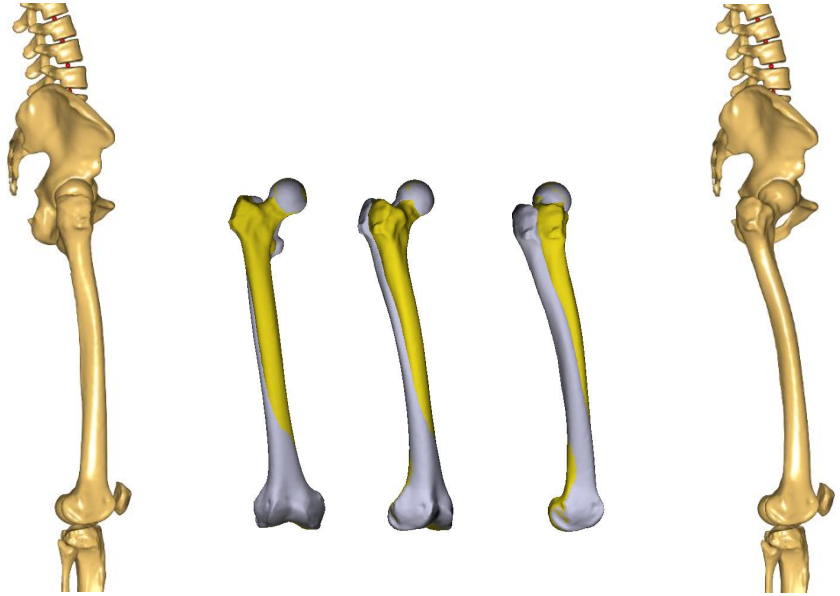
18.11.2021

Outlook

- Lower-limb alignment and load-induced pathologies
- Need for personalized musculoskeletal models

- Femoral torsion and hip loading in healthy subjects
- Joint loads in pathological populations
- Application in a clinical setting

- Demonstration: how to personalize your own models



Osteoarthritis as a disease of mechanics

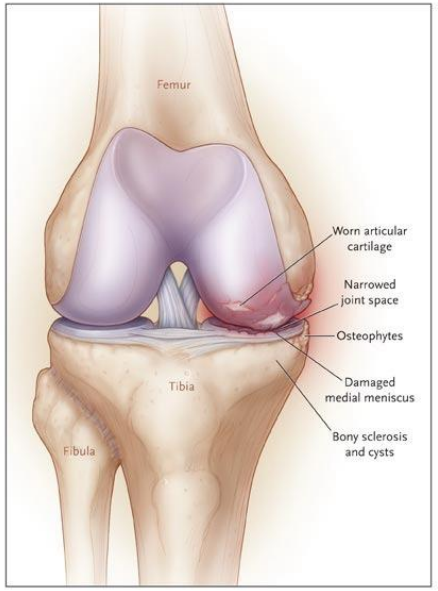
Osteoarthritis (OA)

- deterioration and loss of articular cartilage
- affects all structures within a joint

Risk factors include age, gender, genetics, obesity, overuse, trauma

OA is almost always caused by **increased intra-articular forces** causing damage

www.mayoclinic.org



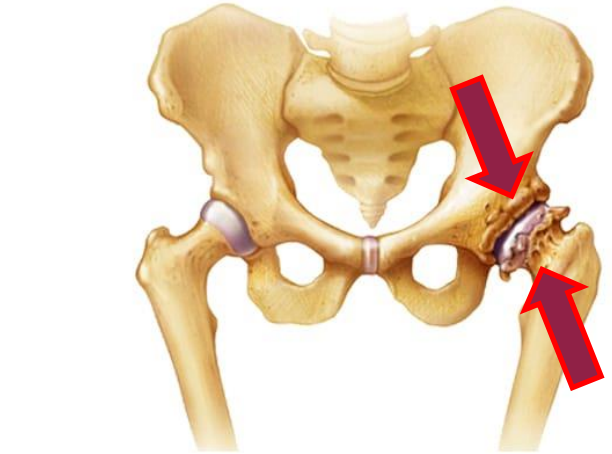
Felson DT, N Engl J Med 2006

Peat G et al, Ann Rheum Dis 2001
Felson DT, N Engl J Med 2006
Felson DT, Osteoarth Cartil 2013

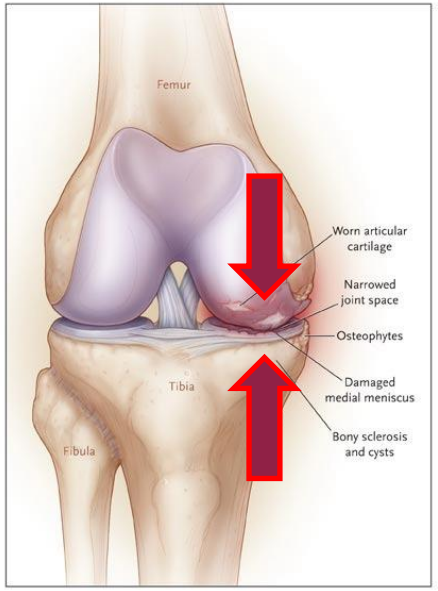
Loads and anatomy

Increased localized forces in the joint are due to:

- abnormal **anatomy** (congenital or acquired)
- excessive overall **load**:
  - demanding occupational tasks, obesity,
  - trauma and injuries.
- a combination of anatomy and excessive load



www.mayoclinic.org



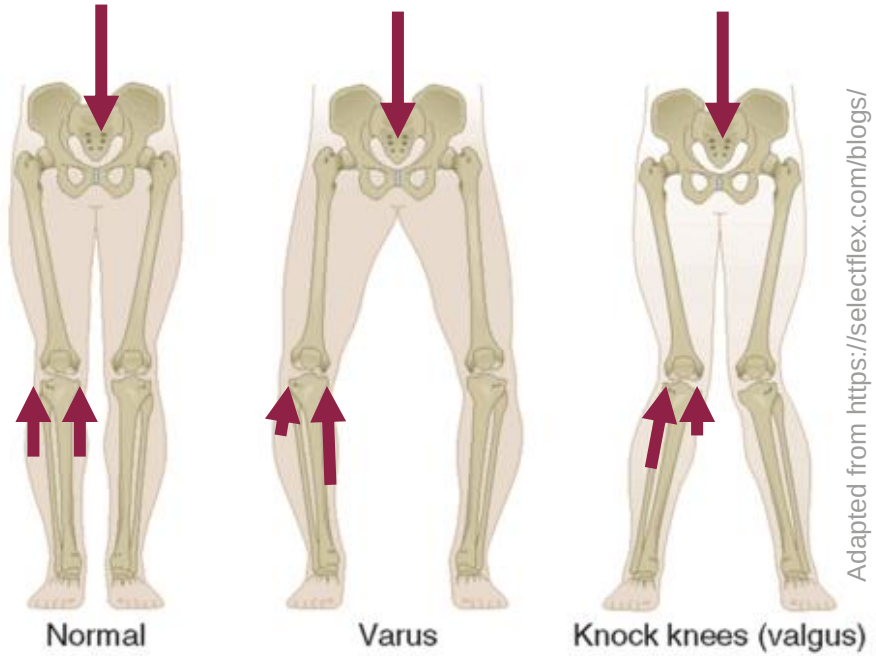
Felson DT, N Engl J Med 2006

Peat G et al, Ann Rheum Dis 2001
Felson DT, N Engl J Med 2006
Felson DT, Osteoarth Cartil 2013

Loads and anatomy

Joint malalignment causes increased loads on a localized area of the joint

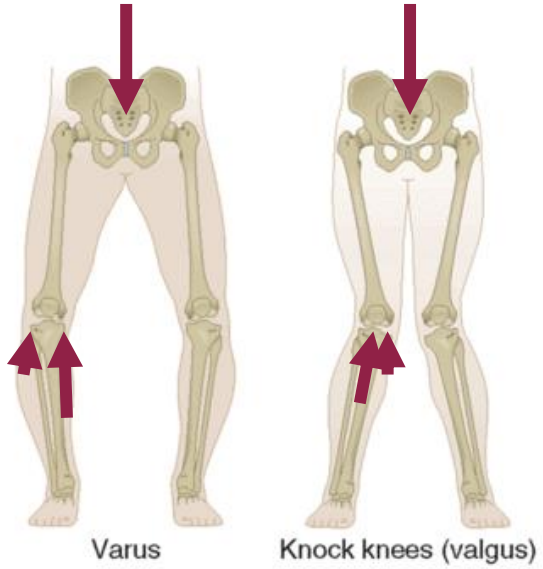
Knee varus alignment typically associated with the onset of medial compartment knee OA



Adapted from https://selectflex.com/blogs/

Felson DT, N Engl J Med 2006

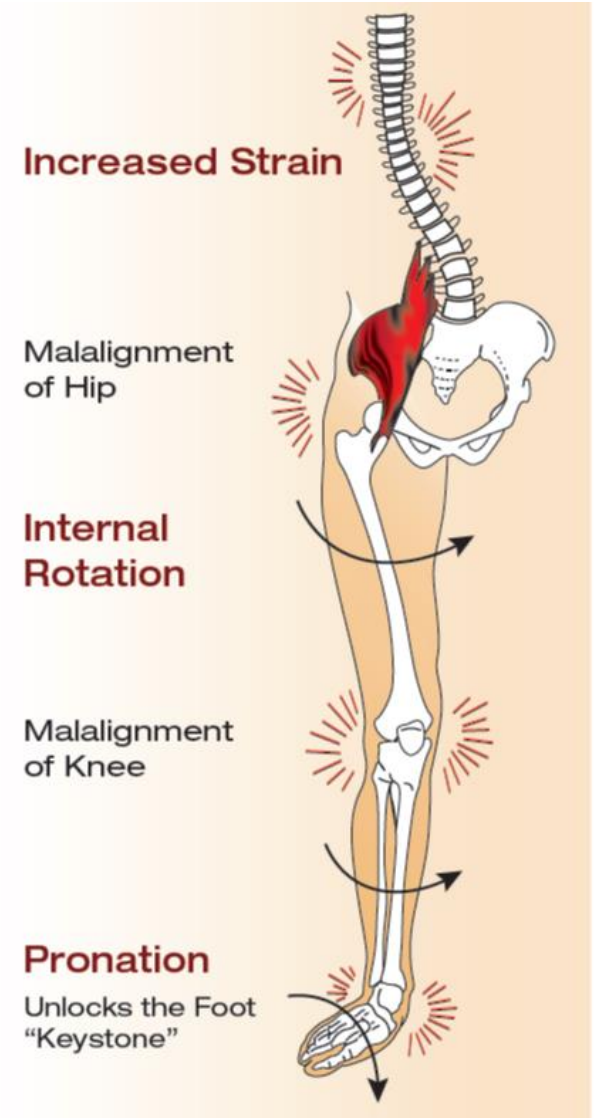
Malalignment



https://selectflex.com/blogs/

https://www.hopkinsmedicine.org/

www.southcoastfootsurgery.com.au

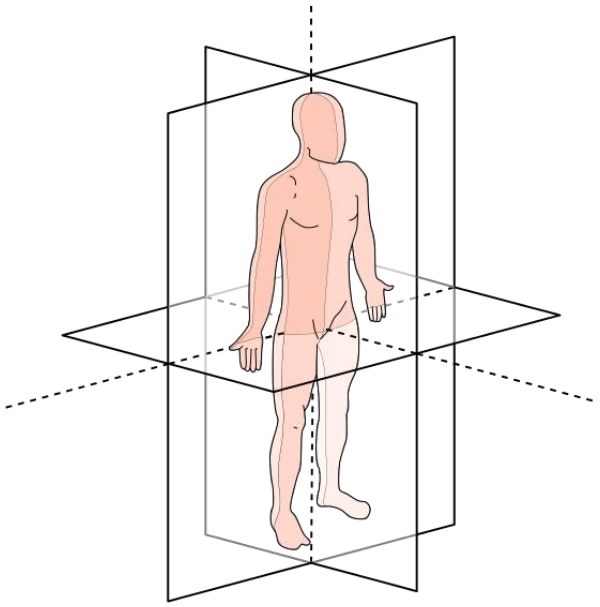


http://www.cambridgefootclinic.co.nz/

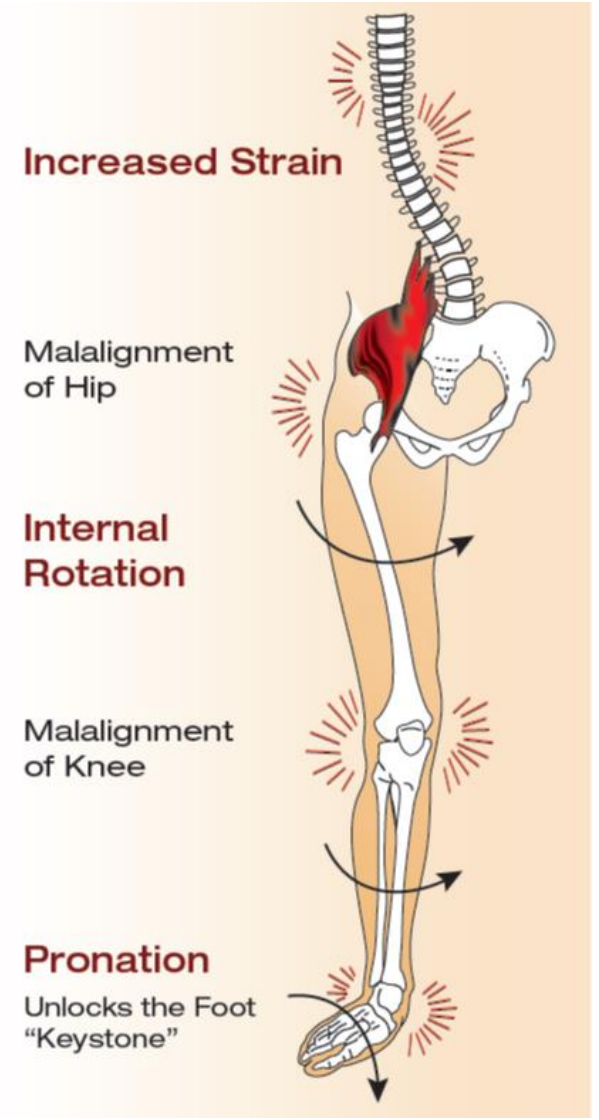
Malalignment

- It leads to postural (and kinematic) adaptations
- It affects multiple joints
- There is an interaction across different anatomical planes

What is the effect of limb alignment on joint loads?



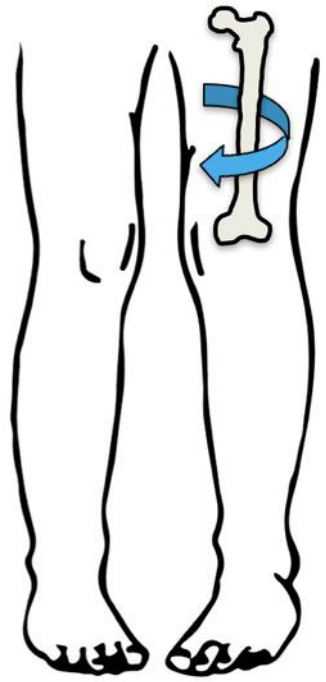
https://commons.wikimedia.org/



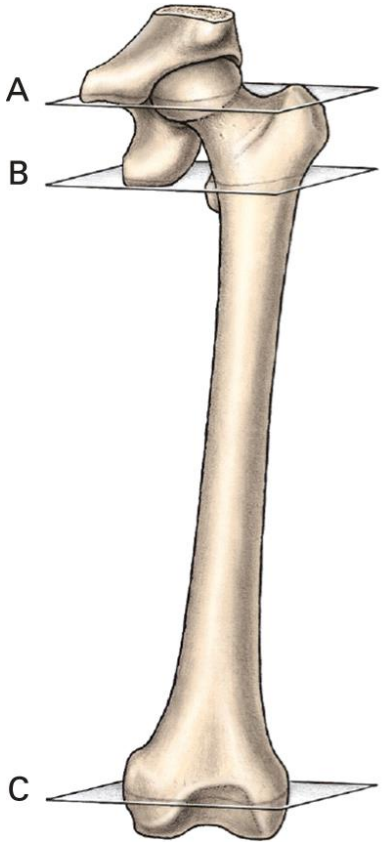
http://www.cambridgefootclinic.co.nz/

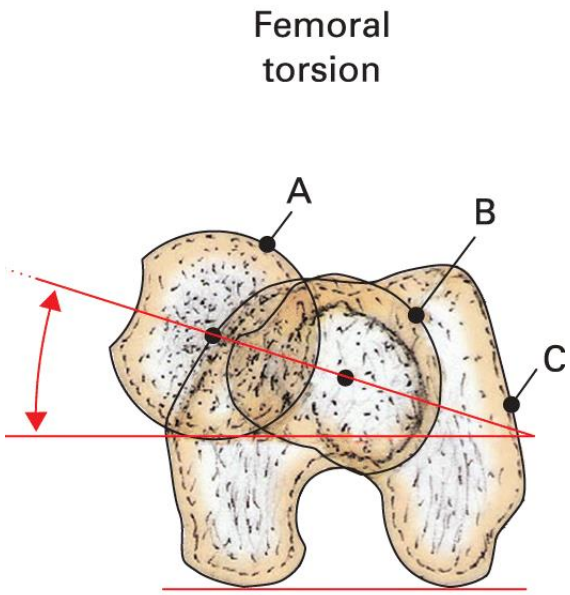
Femoral torsional alignment

Femoral torsion is defined as angle between femoral neck axis and the axis connecting the posterior contour of the femoral condyles in the transversal plane



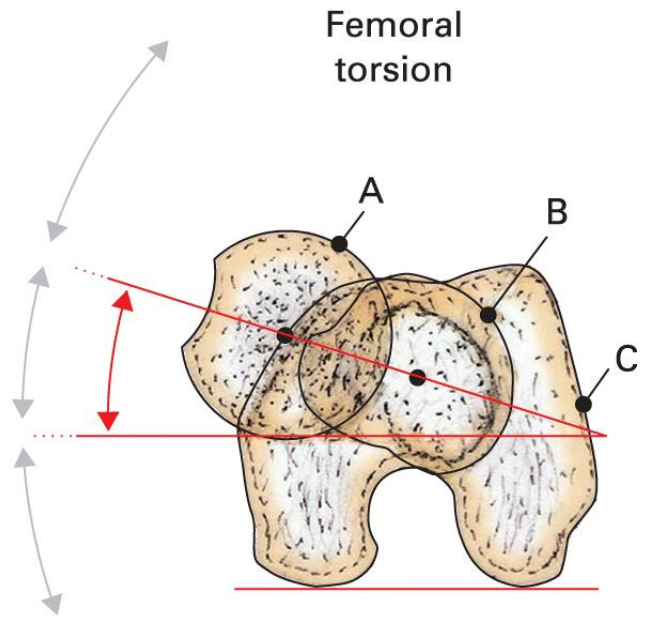
Goyala V et al, IEEE 2019





Lerch TD et al, Bone Joint Journal 2019

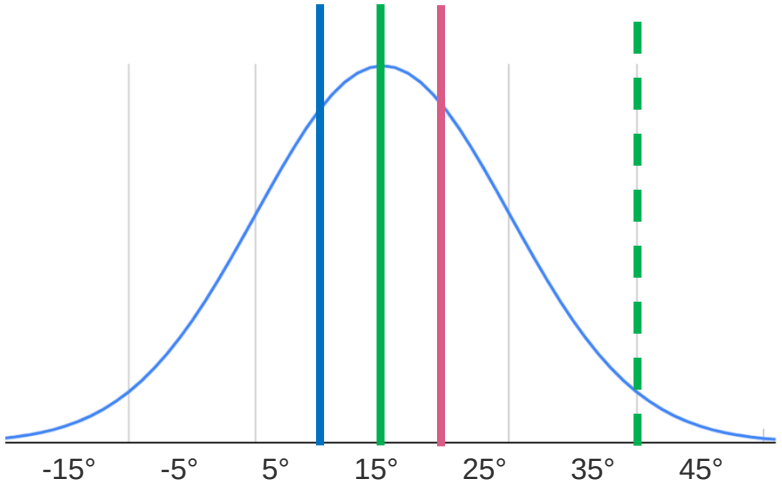
Femoral torsion



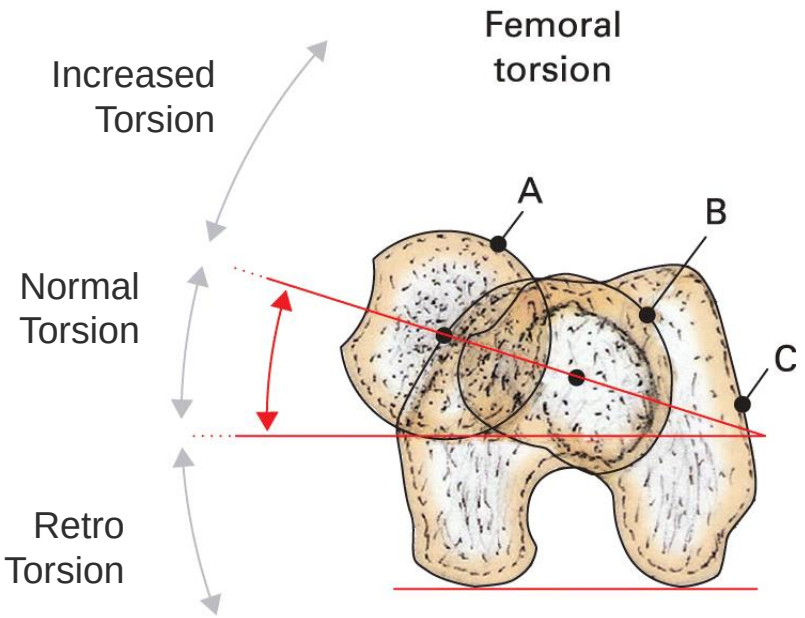
Lerch TD et al, Bone Joint Journal 2019

Large variability across the population:

- It normally decreases with growth
  - children ~ 40° → adults ~ 15°
- Sex differences
  - females present larger torsion than males
- Variations of normal human anatomy

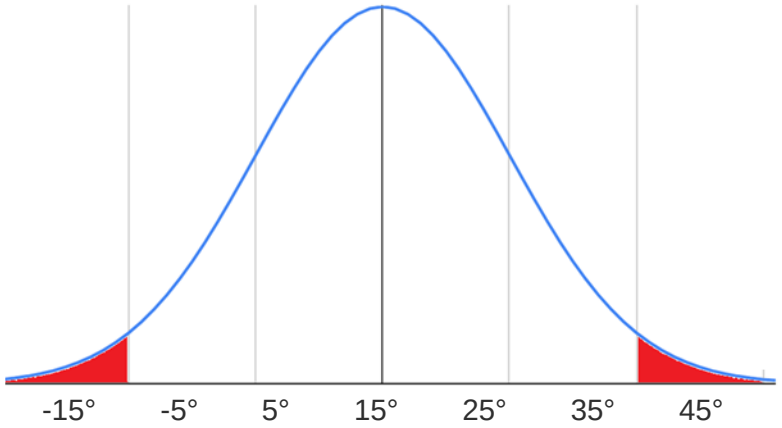


Femoral torsion



Lerch TD et al, Bone Joint Journal 2019

- Increase femoral torsion can persist during adulthood
- Large deviations are considered abnormal
- No consistent definition of what is considered excessive
  - thresholds ranging from >30° to >50°
- Retrotorsion can also lead to complications

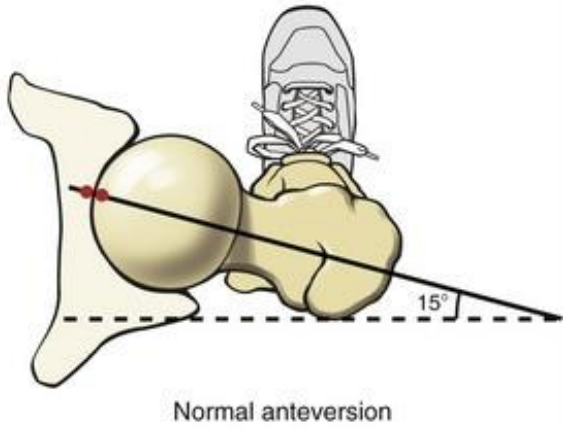


Femoral torsion

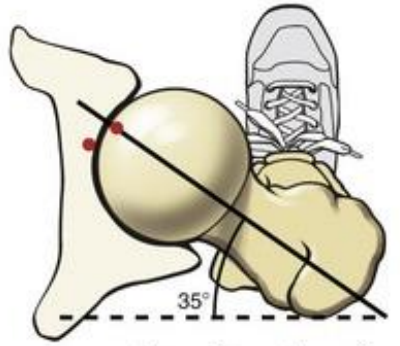
Excessive femoral torsion:

- Affect **muscle functionality** → lever arm dysfunction

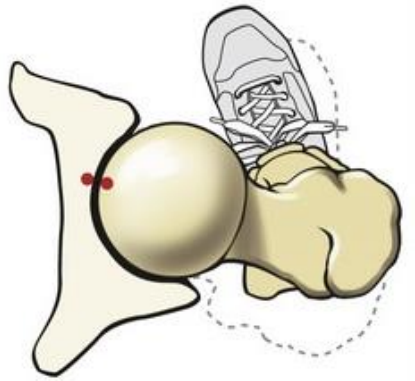
- Kinematic **compensatory mechanisms** → “in-toeing” gait, by rotating hip internally, allows:
  - To increase the moment arm of the hip abductor muscles
  - To guide antetorted femoral head directly into the acetabulum



Normal anteversion



Excessive anteversion



Excessive anteversion with “in-toeing”

https://clinicalgate.com/hip-5/

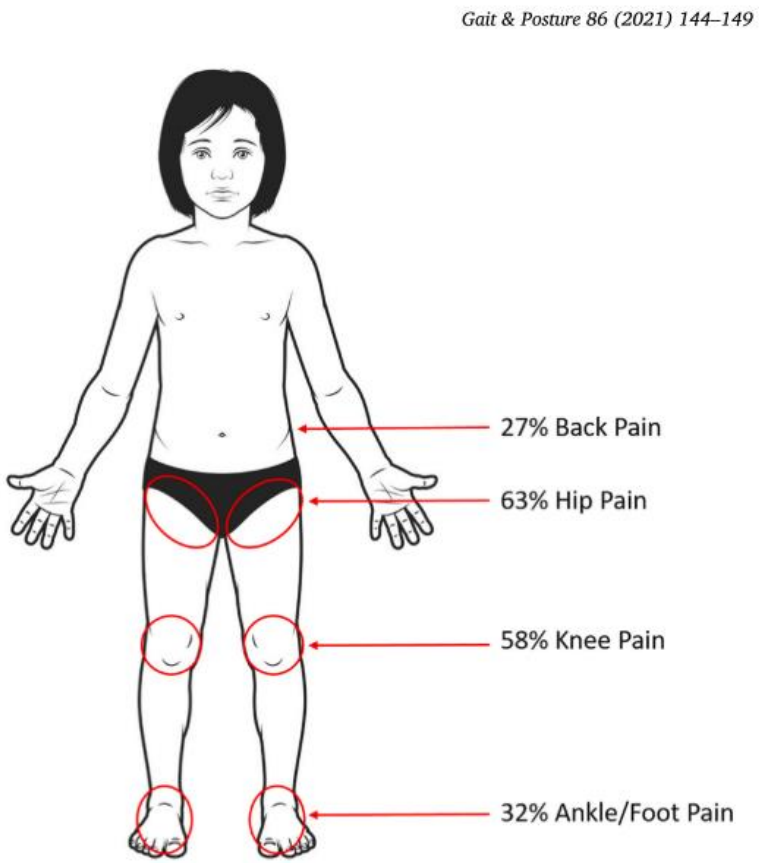
Arnold AS et al, Dev Med Child Neurol. 1997
Passmore E et al, Gait Posture 2018

Torsional malalignment

Femoral (and tibial) torsional deviations are associated with:

- Muscle functionality
- Cosmesis of gait (in-toeing)
- Joint pain
- Risk of hip dislocation
- Patellar instability

Altered joint loading?



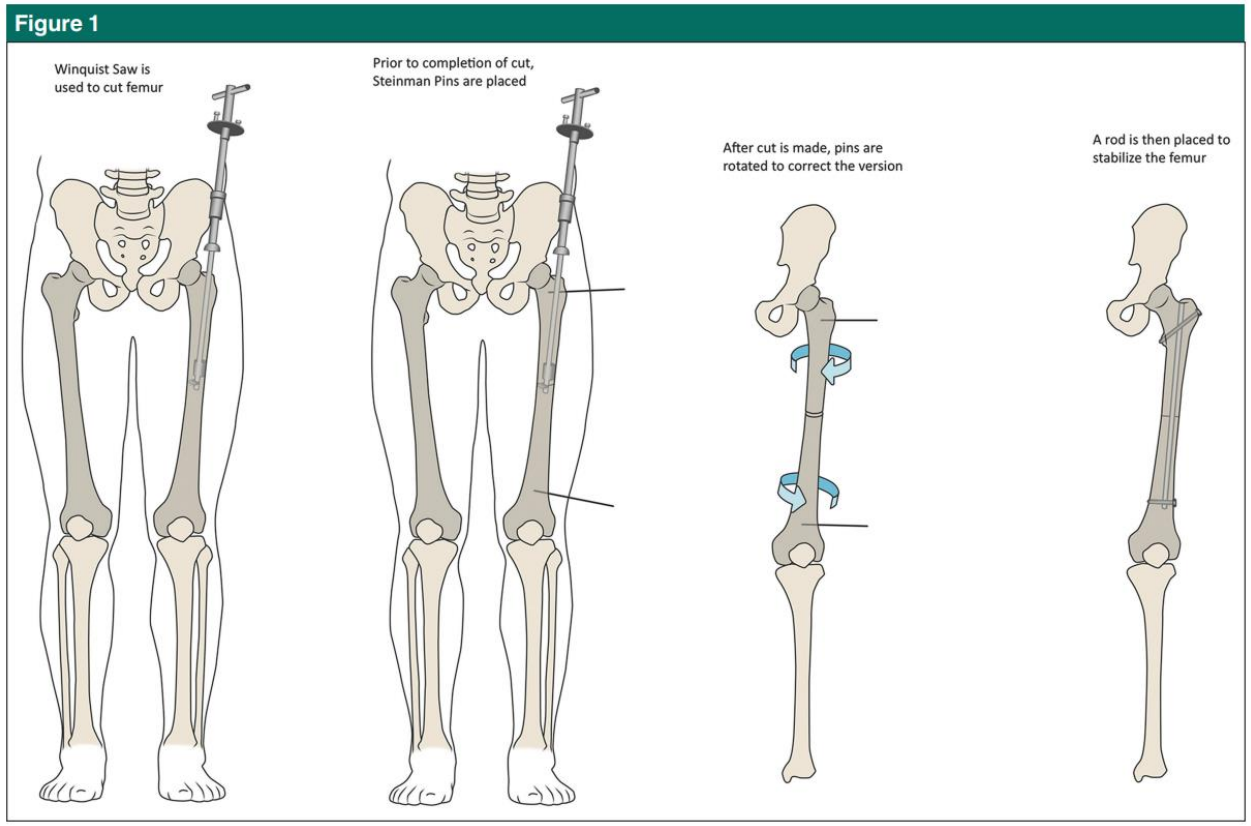
Mackay J et al, Gait Posture 2021
Fabry G et al, J Bone Joint Surg 1973
Upadhyay SS et al, J Bone Joint Surg. 1985
Powers CM, J Orthop Sports Phys Ther 2003

Femoral derotation osteotomy

Invasive surgery

In case of idiopathic torsional deformities:

- No consensus regarding indication for surgery:
  - Normally when patient is symptomatic
  - Often based on surgeon's experience
- No consensus regarding biomechanical outcome parameters:
  - **Joint kinematics?**
  - **Muscle functionality?**
  - **Joint loading?**



Buly RL et al, J Am Acad Orthop Surg 2018

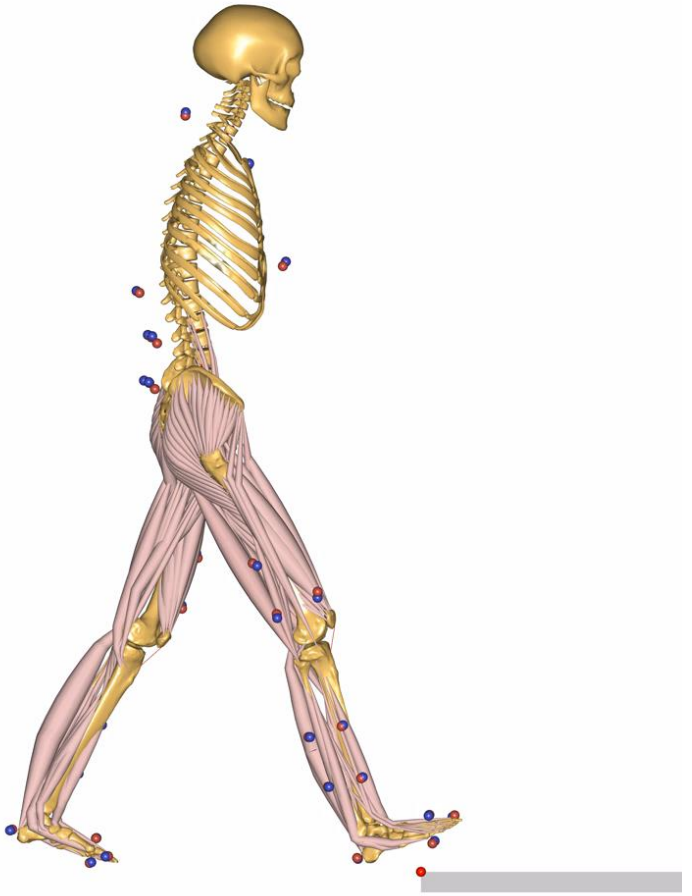
Buly RL et al, J Am Acad Orthop Surg 2018
Nelitz M, Curr Rev Musculoskelet Med. 2018

Musculoskeletal modelling

- **Joint kinematics?**
- **Muscle functionality?**
- **Joint loading?**

To understand the effect of femoral torsion on joint kinematics, muscle functionality, and joint loading,

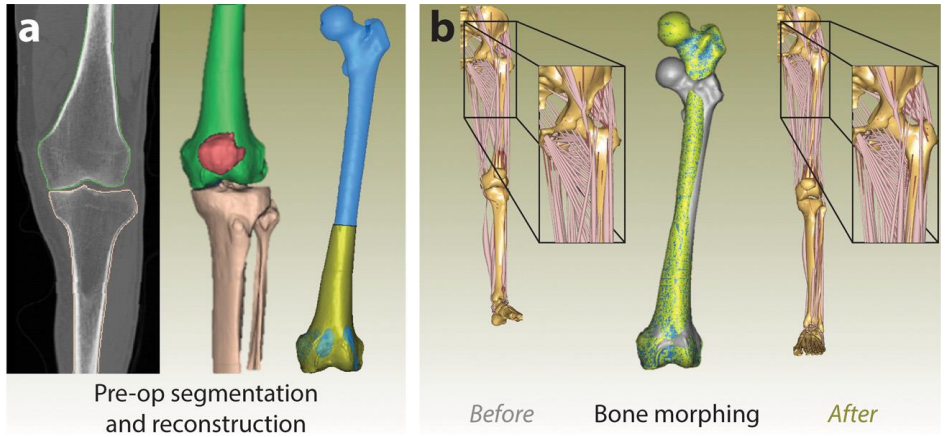
we need **subject-specific** data on both **morphometry** and **movement** data



Subject-specific modelling

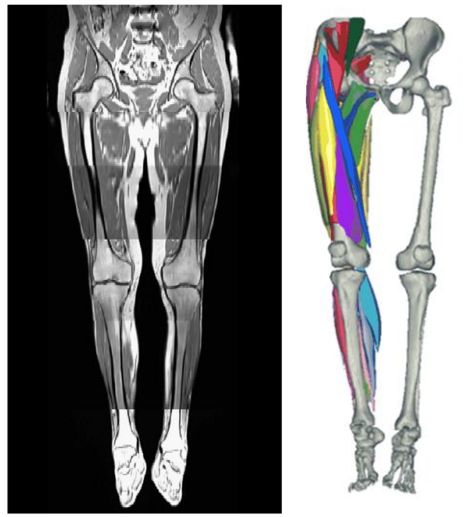
- Subject-specific models built from CT/MRI data

Marra MA et al, J Biomech Eng 2014

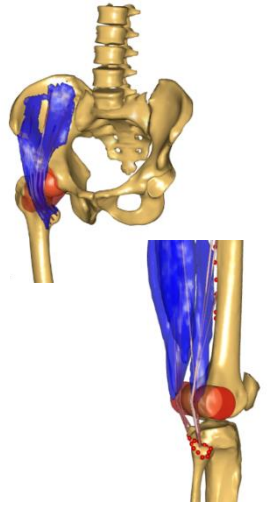


  - Imaging data not always available
  - Time-consuming
  - Uncertainties with muscle lines of action

- Generic models



Carbone V et al, J Biomechanics, 2015

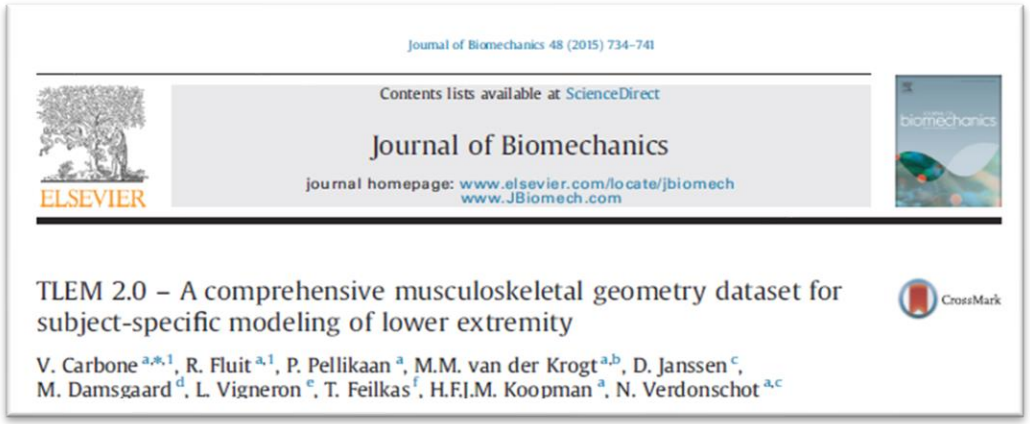


De Pieri E et al, PLoS ONE, 2018

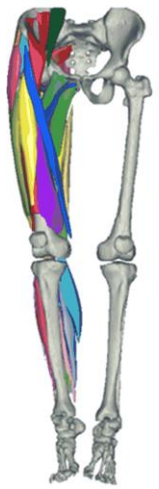
  - Ready-to-use and well-established
  - Based on a single cadaveric template
  - Not representative of the overall population

Marra MA et al, J Biomech Eng 2014
Carbone V et al, J Biomechanics, 2015
De Pieri E et al, PLoS ONE, 2018

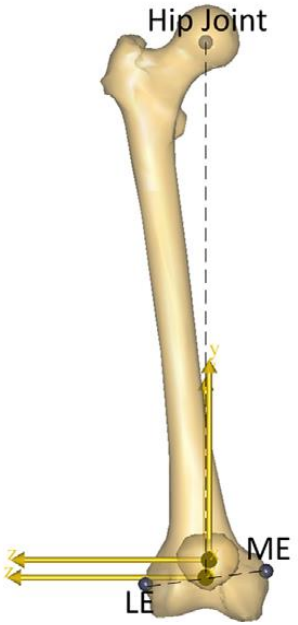
Generic models

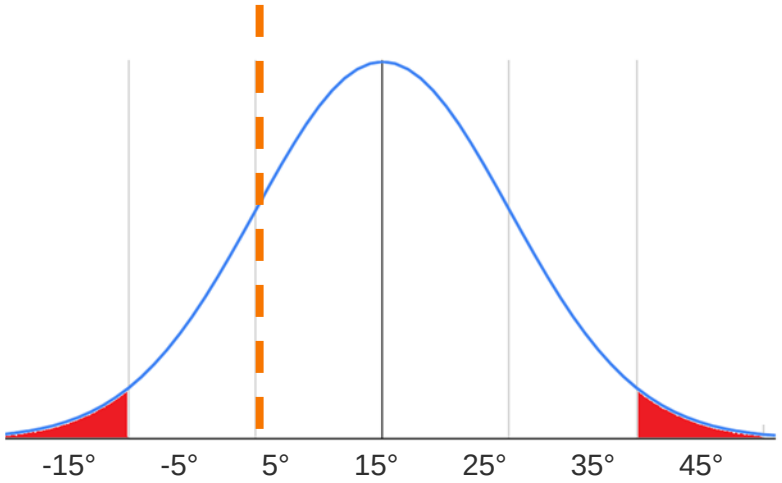


- TLEM 2.0
  - Single cadaveric specimen
  - Femoral torsion approximatively 5°
  - Not representative of the overall population



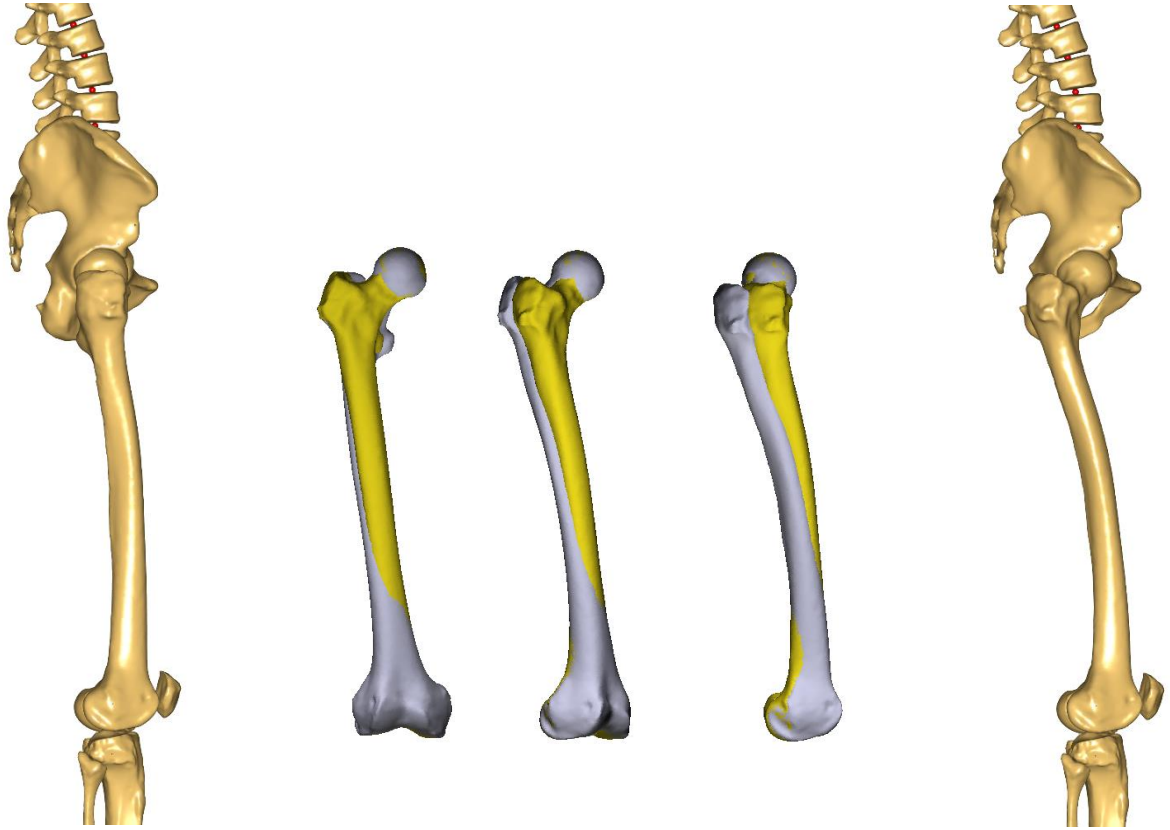
Carbone V et al, J Biomechanics, 2015





Personalized models

Morphing the musculoskeletal geometry of the generic model TLEM 2.1 by rotating distal and proximal sections to account for subject-specific values of femoral torsion



Personalized models

- Morphing tool included in the next official AMMR release

- Demonstration at the end of this webcast

ANY MODEL REPOSITORY

Quick search

Go

Table of Contents

- *Welcome to the AMMR documentation!*
- *Getting Started with AMMR*
- *Configuring the Body Model*
- *The Body Models*
- *Application Examples*
  - Daily activities and ergonomics
  - Motion Capture and gait analysis
  - Orthopedics and rehab
  - Other examples
  - Sports
  - Validation
- *Creating a Human model from scratch*
- *Introduction to Scaling*
- *The AnyMoCap Framework*
- *About the AMMR*

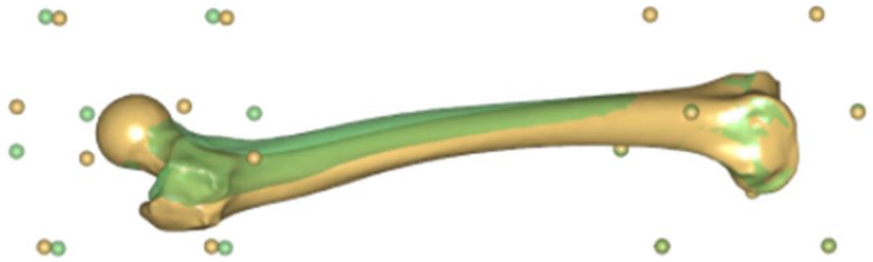
Femoral Torsion tool

This is an example of modifying the femoral torsion of the default leg ({ref}`TLEM 2.0 <tlem2>`) geometry by using a model utility tool included within the model repository. The model is the simple standing model where the femoral torsion has been altered to 20 degrees. The model is also a good example on how a similar morphing approach can be used to personalize different body segments.

Model location in AMMR:
Application ▸ Examples ▸ FemoralTorsion ▸ StandingModel.Main.any

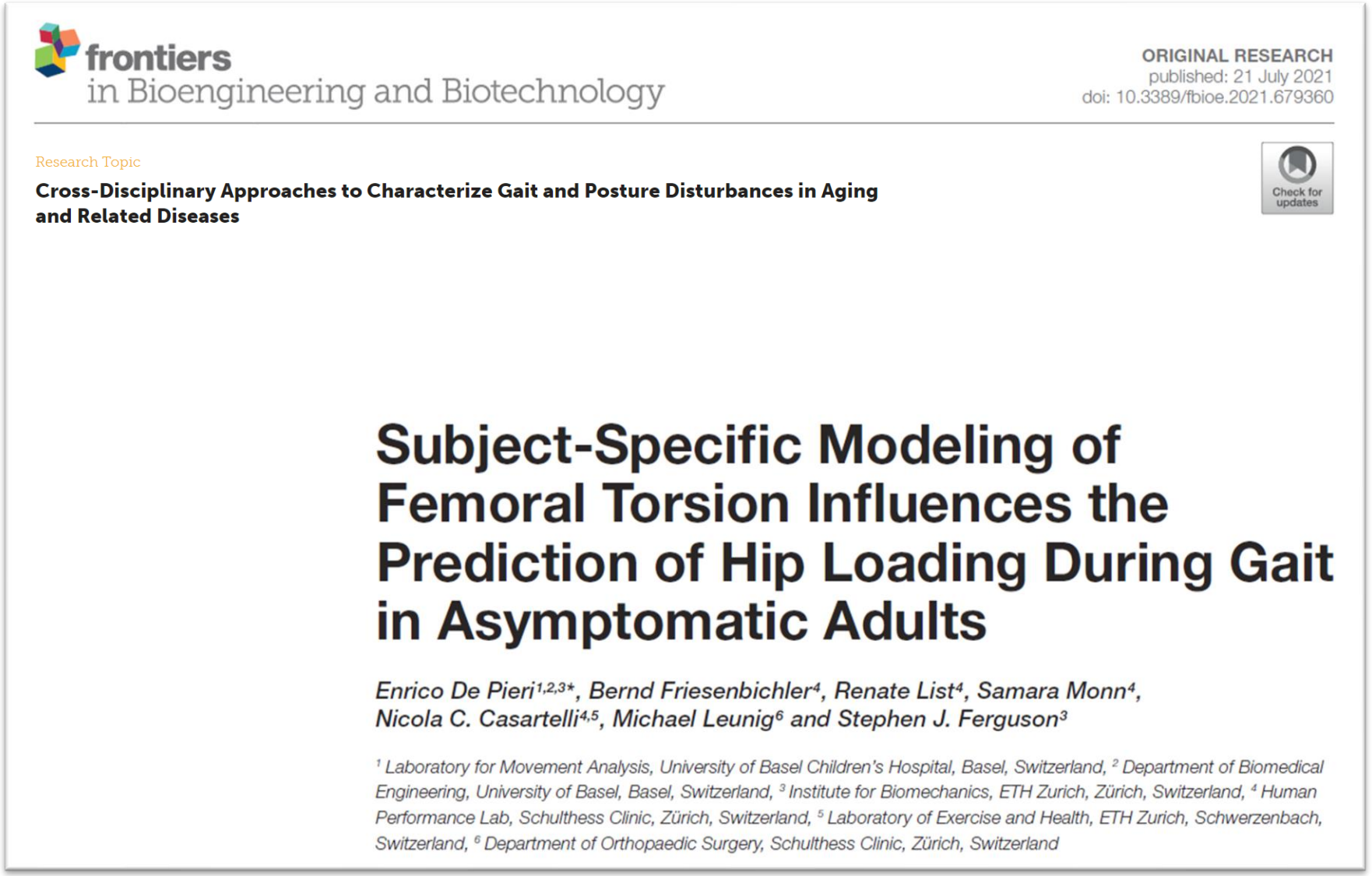
The tool was developed by Enrico De Pieri, from the University of Basel Children's Hospital (UKBB), and Morten E. Lund, from AnyBody Technology A/S.

This tool was made to generate personalized models that account for subject-specific values of femoral torsion, and investigate the effect of torsional alignment on hip loading. This work is published in 'Frontiers in Bioengineering and Biotechnology' [DFLM21]. Please cite this article when using this tool.



The tool works by adding a 8 control points around the hip center and knee center, which control a RBF scale function. The control points are scaled with the default model scaling, while the femoral torsion is added on top.

Femoral torsion and hip loading



frontiers in Bioengineering and Biotechnology

ORIGINAL RESEARCH
published: 21 July 2021
doi: 10.3389/fbioe.2021.679360

Research Topic
Cross-Disciplinary Approaches to Characterize Gait and Posture Disturbances in Aging and Related Diseases

Subject-Specific Modeling of Femoral Torsion Influences the Prediction of Hip Loading During Gait in Asymptomatic Adults

Enrico De Pieri[1,2,3], Bernd Friesenbichler[4], Renate List[4], Samara Monn[4], Nicola C. Casartelli[4,5], Michael Leunig[6] and Stephen J. Ferguson[3]*

[1] Laboratory for Movement Analysis, University of Basel Children's Hospital, Basel, Switzerland, [2] Department of Biomedical Engineering, University of Basel, Basel, Switzerland, [3] Institute for Biomechanics, ETH Zurich, Zürich, Switzerland, [4] Human Performance Lab, Schulthess Clinic, Zürich, Switzerland, [5] Laboratory of Exercise and Health, ETH Zurich, Schwerzenbach, Switzerland, [6] Department of Orthopaedic Surgery, Schulthess Clinic, Zürich, Switzerland

Aim

What is the effect of femoral torsion on hip loads?

To evaluate:

- hip kinematics and kinetics,
- muscle forces,
- hip contact forces (HCFs)

during **gait** in a group of **asymptomatic adults** presenting a heterogeneous range of femoral torsion

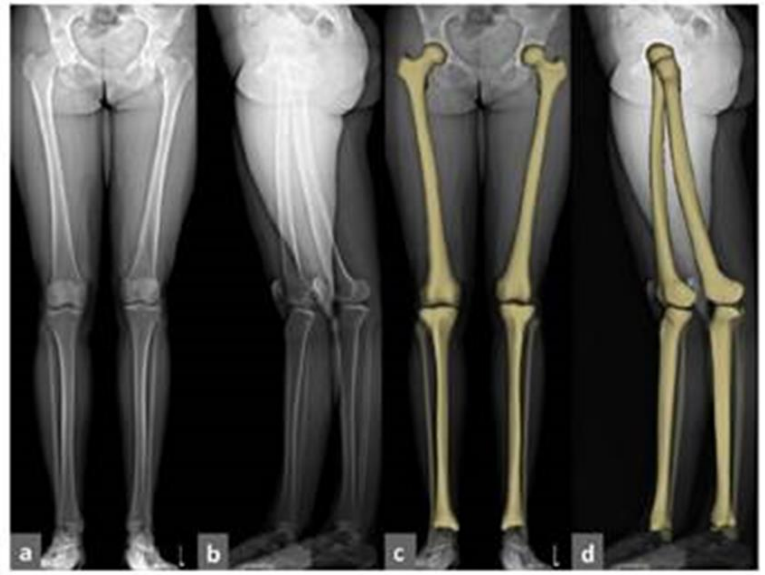
Personalized musculoskeletal models were created based on subject-specific motion-capture and radiographic data

Participants and radiographic data

37 healthy volunteers

- 27.7 ± 4.6 years old, 15 females
- BMI = 23.0 ± 2.6
- no back or lower-extremity pain or injury
- no previous hip surgeries

Low dosage, biplanar radiographs of the lower limbs acquired with EOS system (EOS Imaging Inc., France)

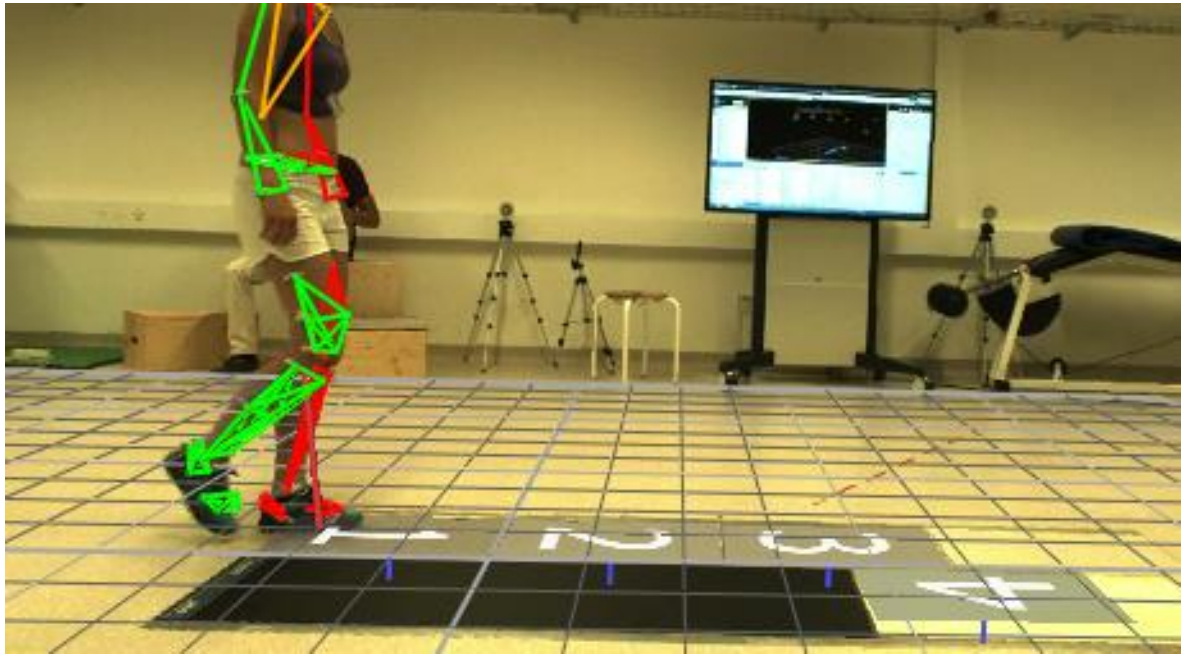


Femoral torsion assessed on **3D reconstructions** of the femur

- Ranged from -7° of retrotorsion to +38° of antetorsion
- mean value 16.2° ± 10.0°

Gait analysis

- Kinematic data (marker trajectories)
- Kinetic data (ground reaction forces – GRF)

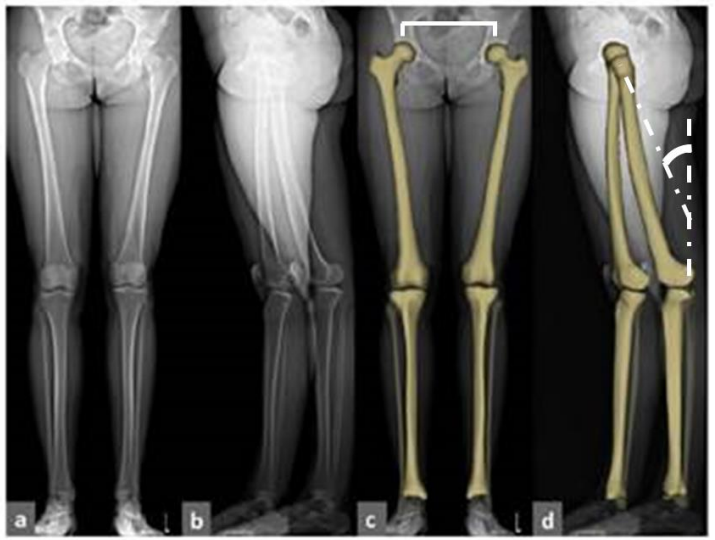


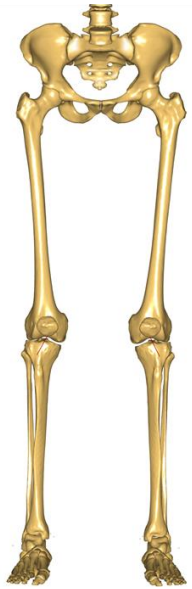
- 1 static standing trial
- 3-5 gait cycles at self selected gait speed
  (controlled to be within ±10% of first trial)

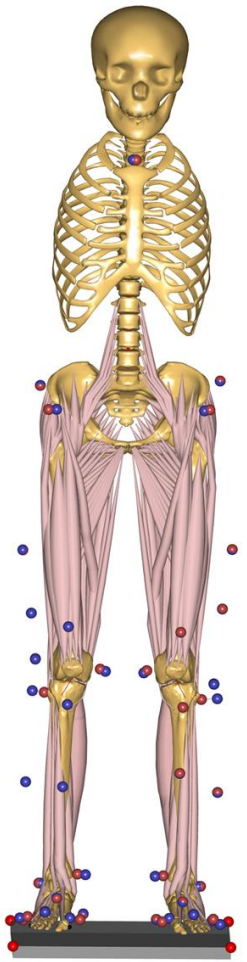
- Data used as input for inverse dynamics analysis

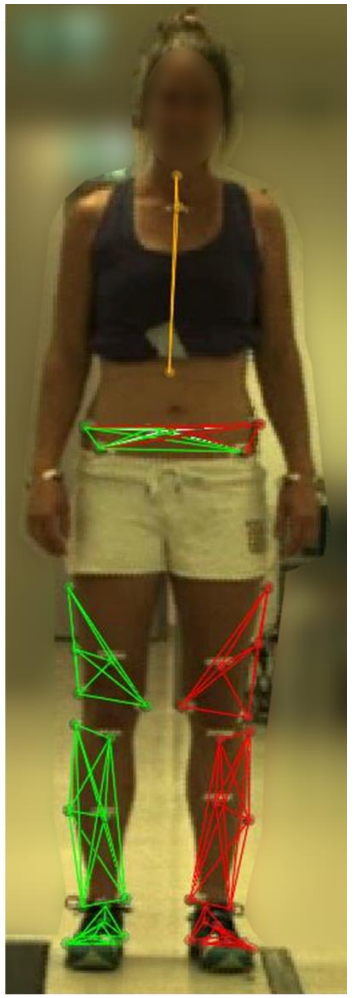
Personalized musculoskeletal models

- **Model scaling** to match markers' data during static trial
- Radiographic distance between hip joint centers used to scale **pelvis width**
- **Femurs morphed** to match the subject's radiographic femoral torsion values

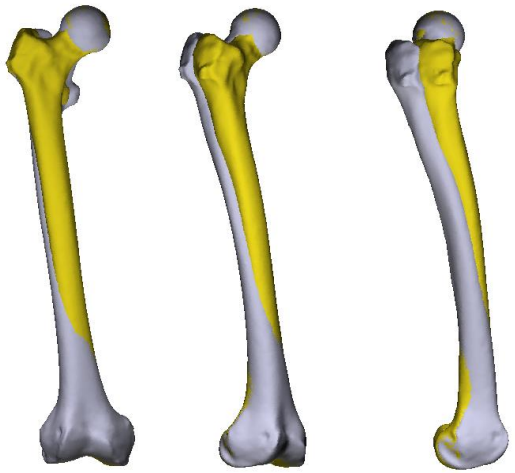








Muscle lever arms

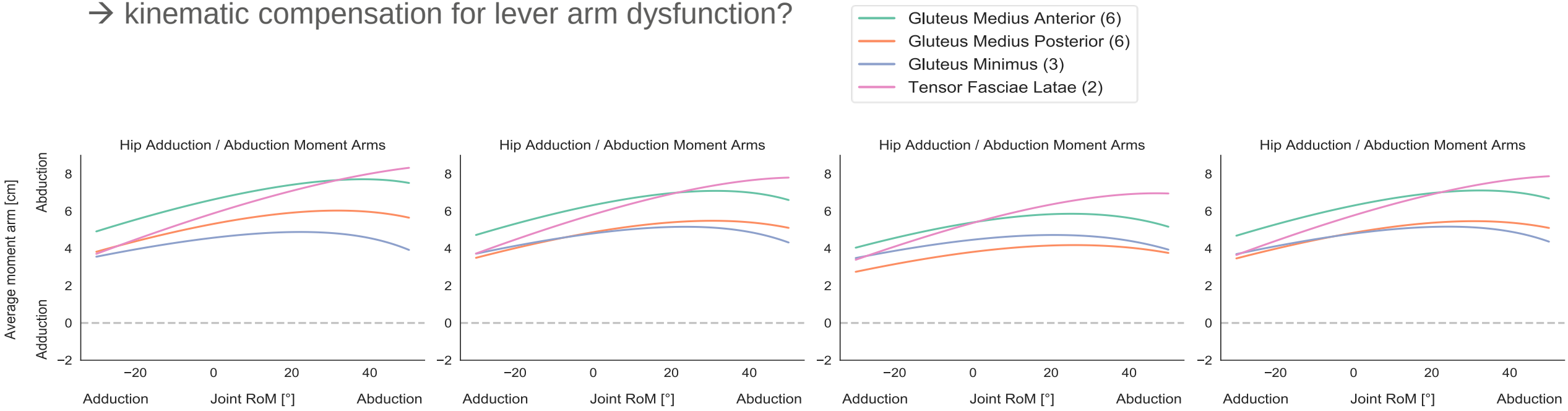


- Muscles’ lines of action follow morphed geometry
- Qualitative evaluation of **muscle lever arms** for different values of femoral torsion

Muscle lever arms

- Muscle lever arms evaluated for different femoral morphologies over arbitrary ranges of motions
- Hip abductors' lever arms decrease for higher femoral torsion
- Abductive capacity restored with 20° hip internal rotation

→ kinematic compensation for lever arm dysfunction?



5.5° antetorsion (baseline)

25° antetorsion

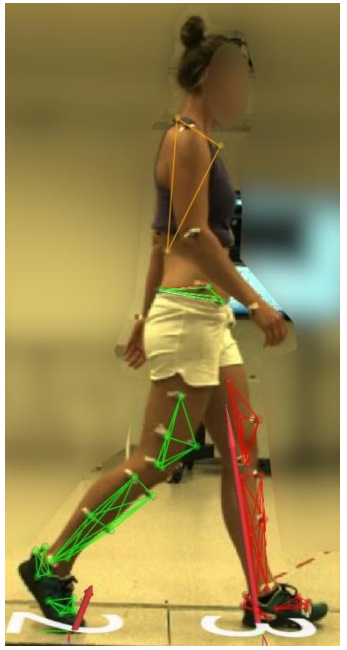
45° antetorsion

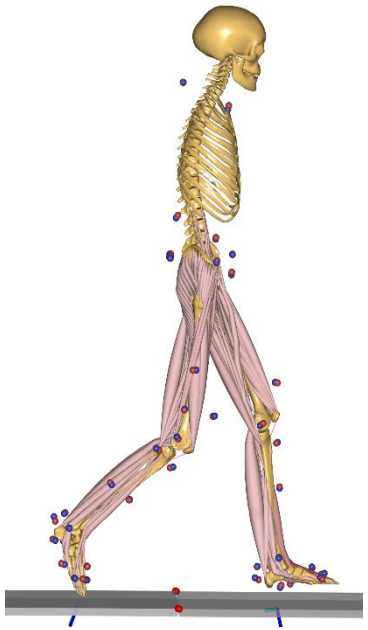
45° antetorsion
+ 20° int. rot.

Gait data – processing and analysis

- Gait trials processed with AnyPyTools

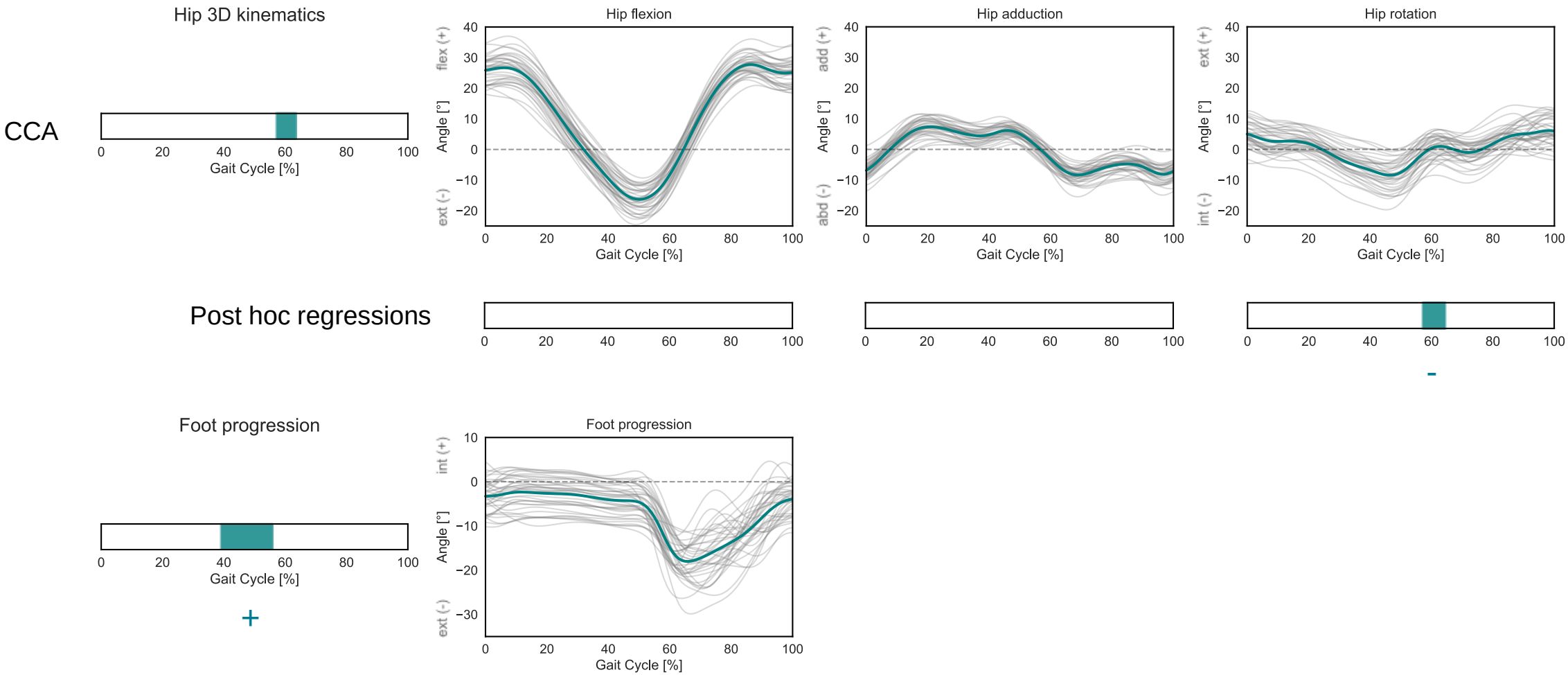
  - Hip rotations
  - Foot progression angle
  - Hip internal net moments
  - Muscle forces (femur-spanning muscles)
  - Hip contact forces



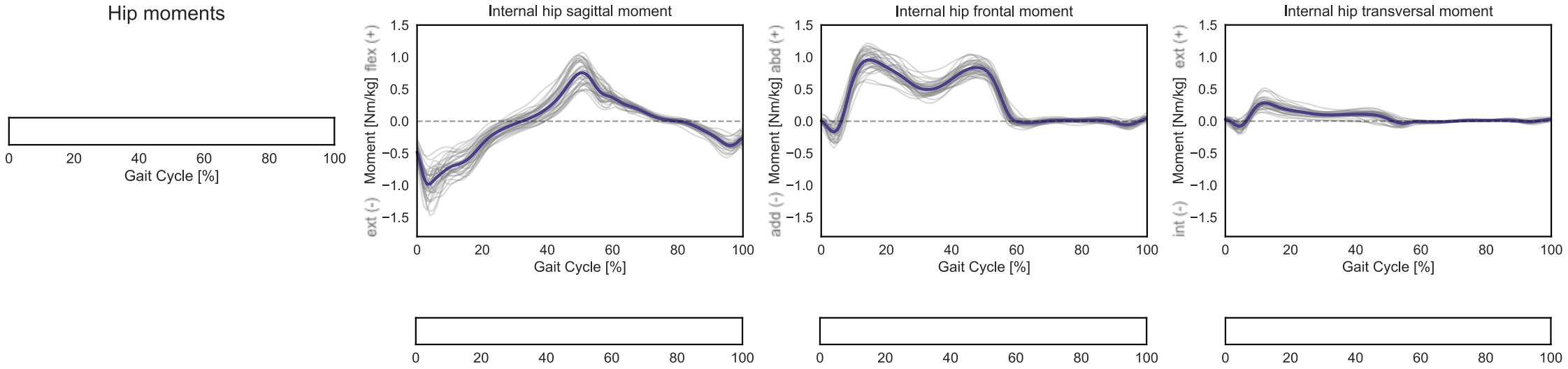


- Correlation with femoral torsion through statistical parametric mapping (SPM)
  - Canonical correlation analysis (CCA) for vectorial quantities
  - Regression analyses for individual scalar components

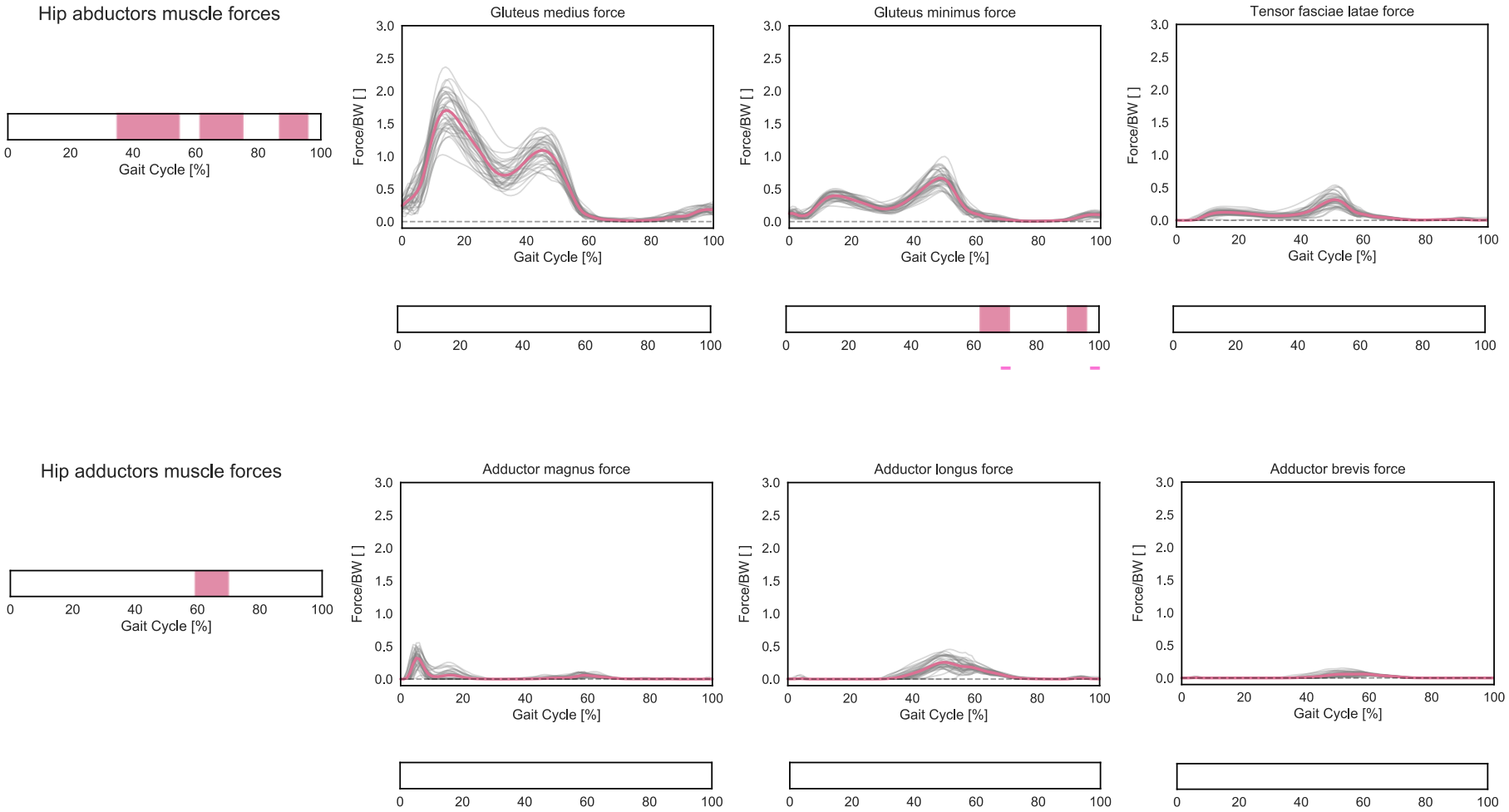
Results – kinematics



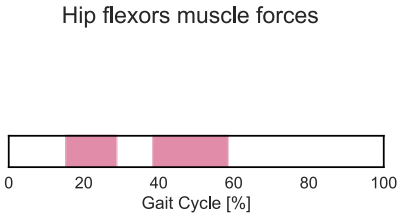
Results – kinetics

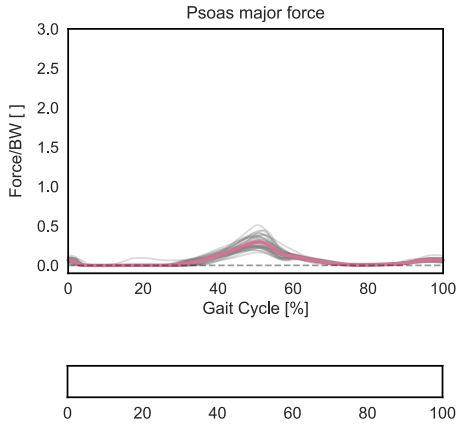


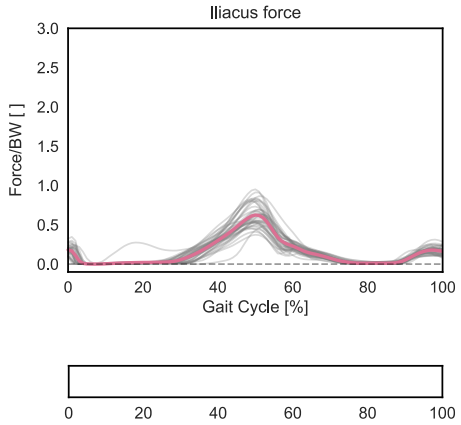
Results – muscle forces

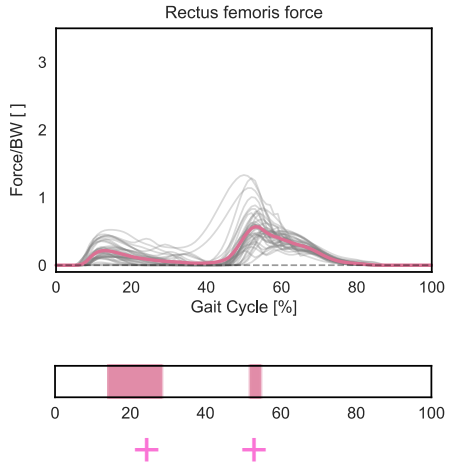


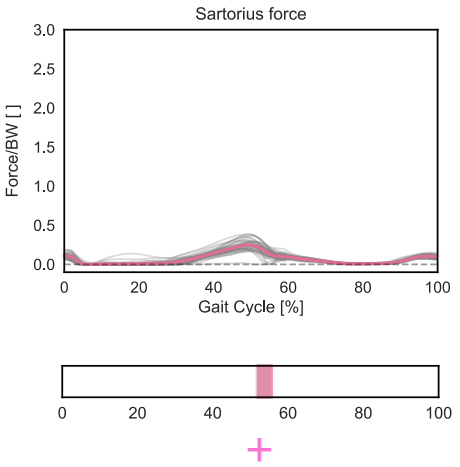
Results – muscle forces

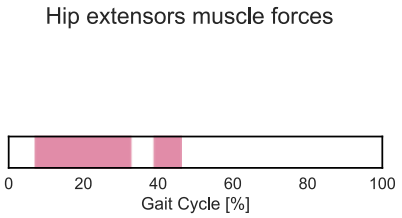


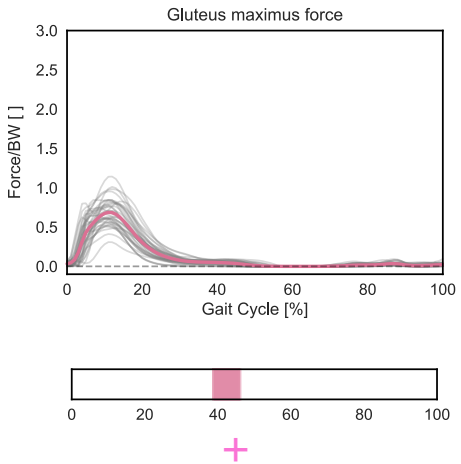


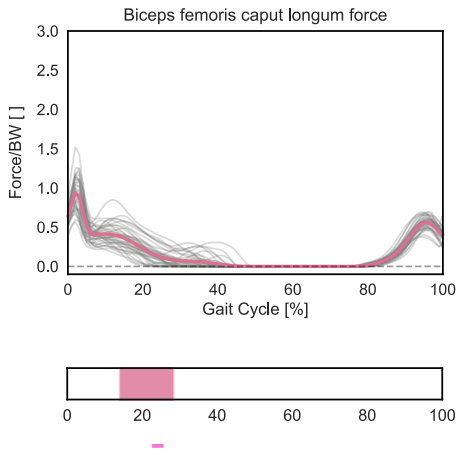


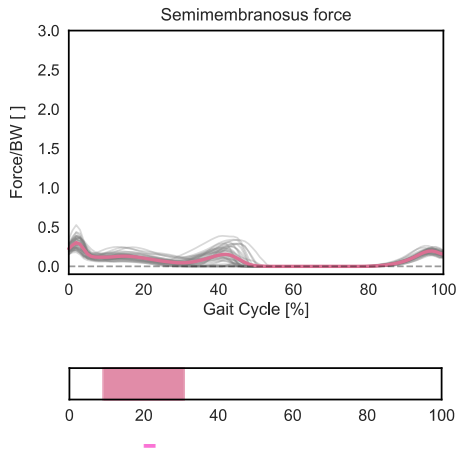


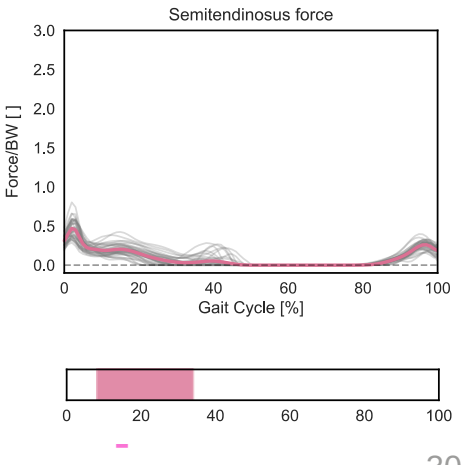




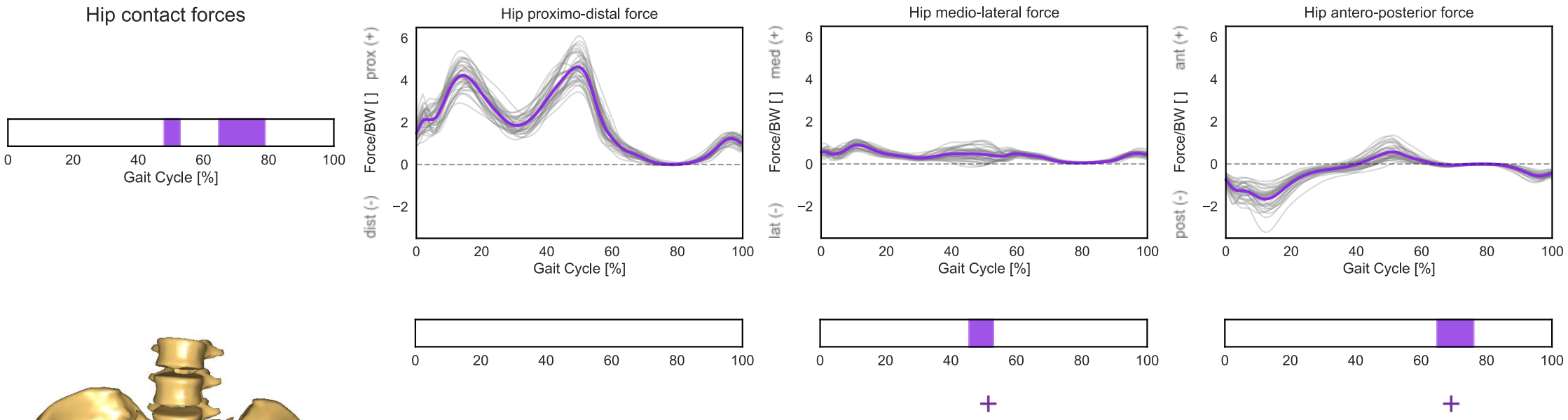


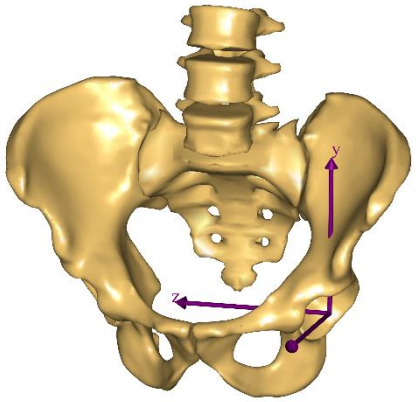






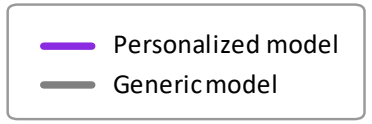
Results – hip contact forces

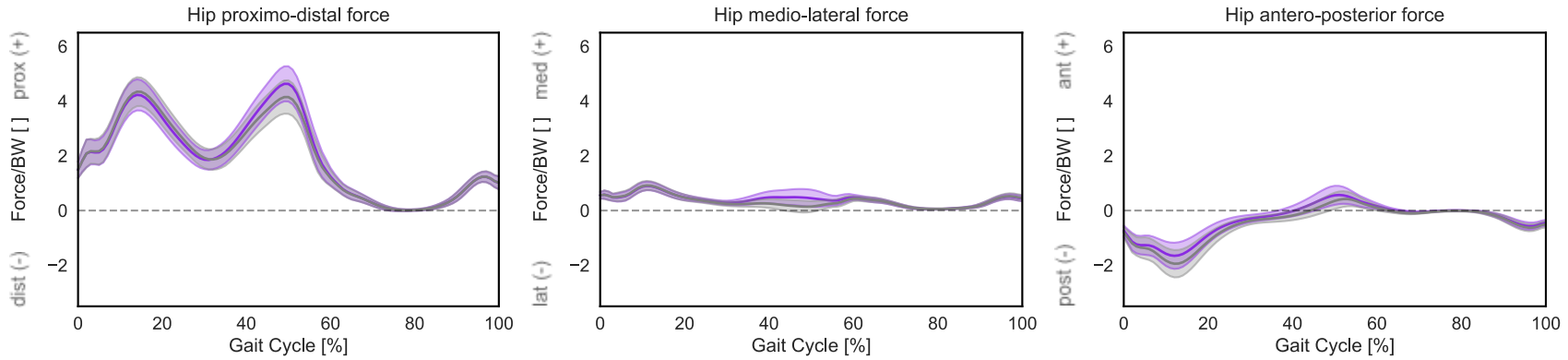


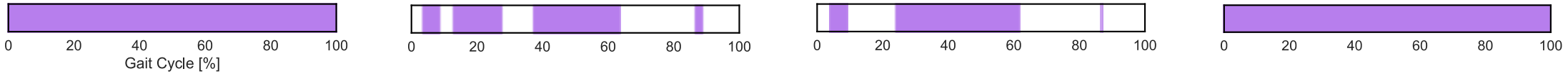


Pelvis-based reference frame according to ISB standards

Personalized vs generic models' predictions

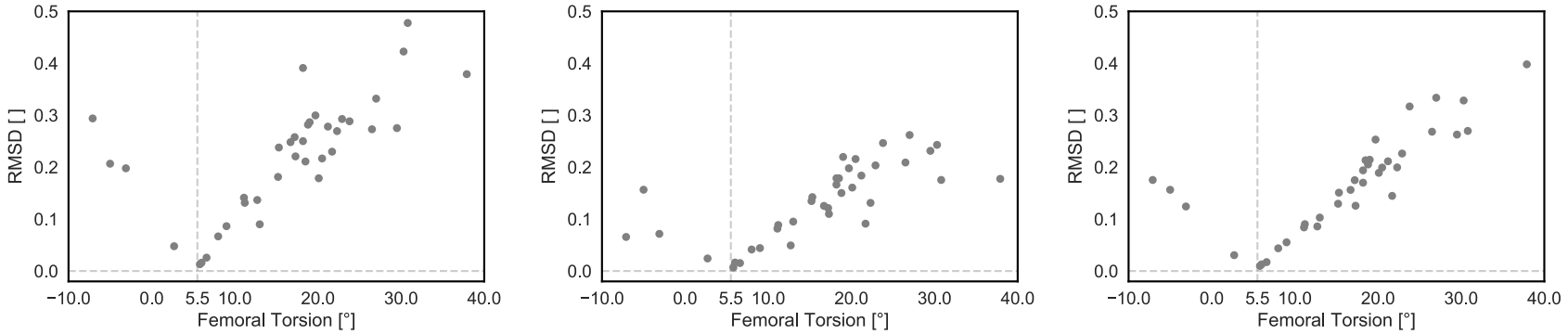






Paired Hotelling T^2

Post hoc paired t-tests



Conclusions

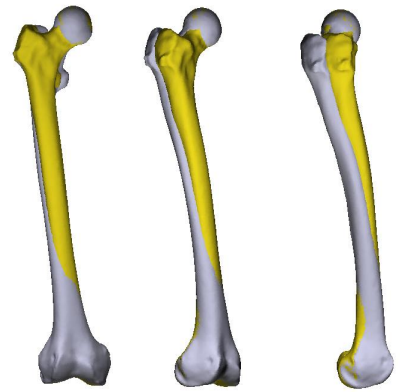
- Femoral torsion affects **muscle lever arms** and therefore **muscle recruitment and forces**
- Compensatory mechanisms (i.e. hip internal rotation) can restore lever arm capacity

- Correlations between femoral torsion and **hip and foot kinematics**
- Correlations between femoral torsion and **hip contact forces**

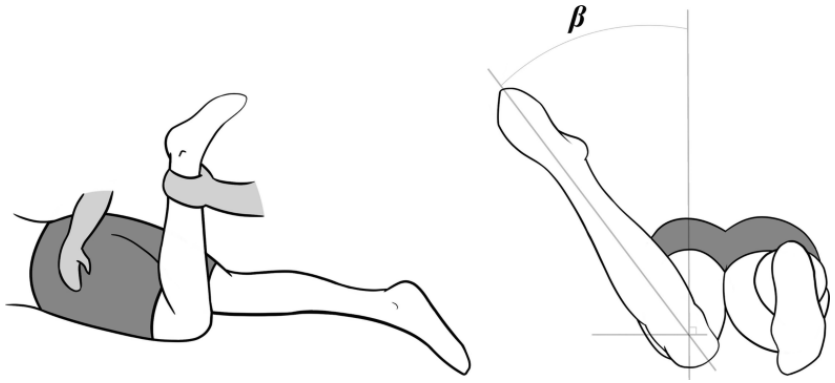
→ Analysis of joint loads should account for **both subject-specific kinematics and morphology**

Conclusions

- **Personalized modelling** leads to significantly different force predictions
- Subject-specific morphology is important, especially when it largely deviates from baseline model



- Morphing femoral geometry is a quick and effective solution
  - from low-dosage imaging data
  - from **physical examination**



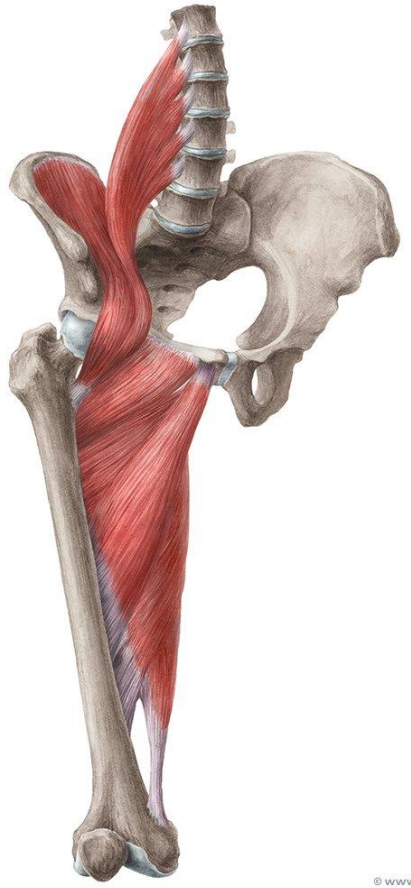
Po-Jung Chen B, Cerebral Palsy. Springer 2018

Outlook: loads and anatomy

- Femoral torsion is just one parameter affecting hip mechanics

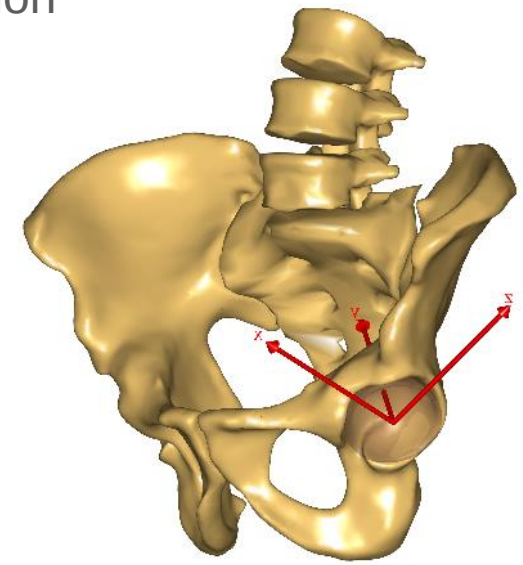
- Femoral neck-shaft angle could similarly affect muscle lever arms and resultant joint loads

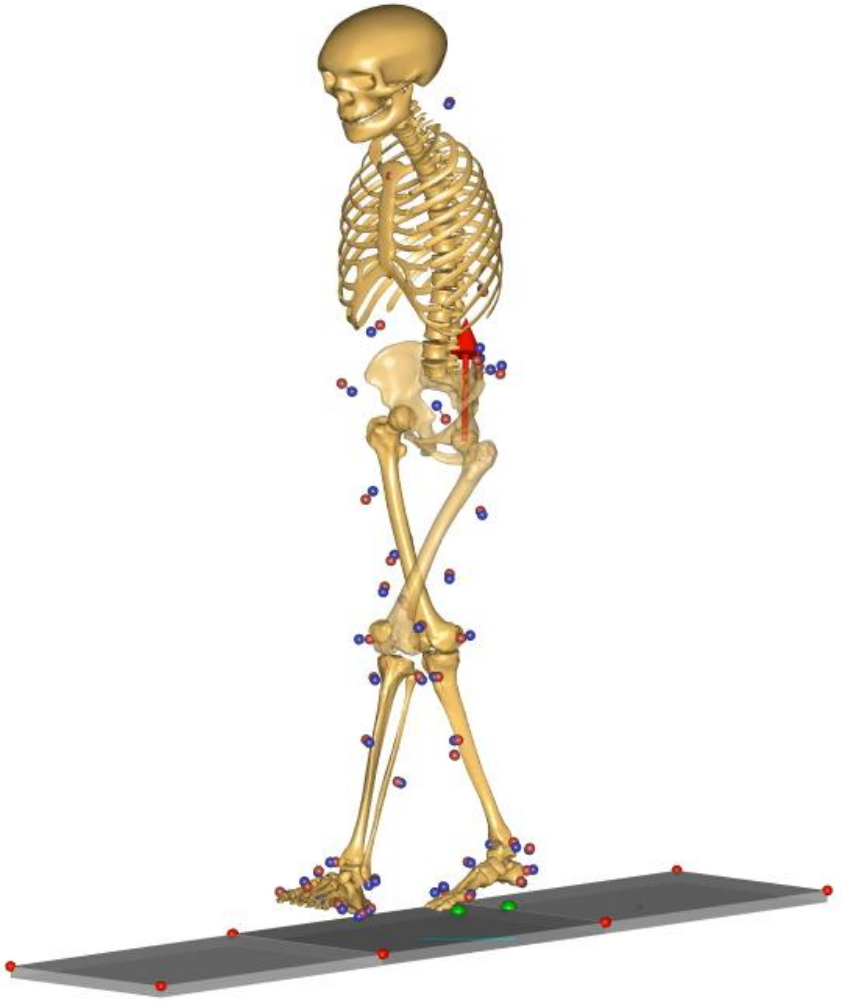
- Acetabular coverage, acetabular retroversion, and presence of cam/pincer deformities could
  - lead to overall kinematic and kinetic deviations (e.g. pain avoidance)
  - affect contact mechanics and **load distribution** within the joint



Acetabular load distribution

- Intersection of HCF vector and hemisphere representing an idealized acetabulum
  - 45° inclination
  - 20° version





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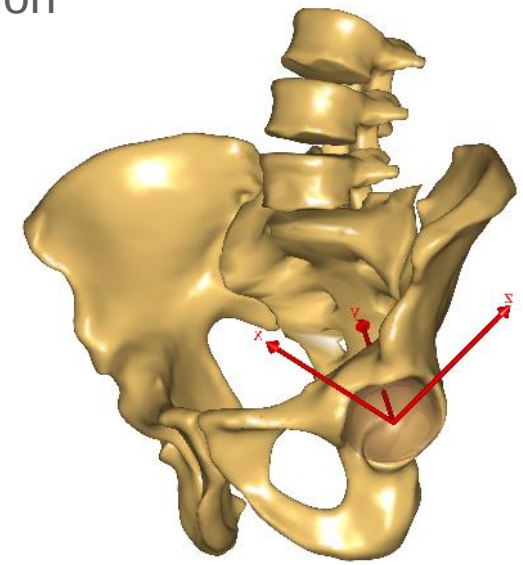
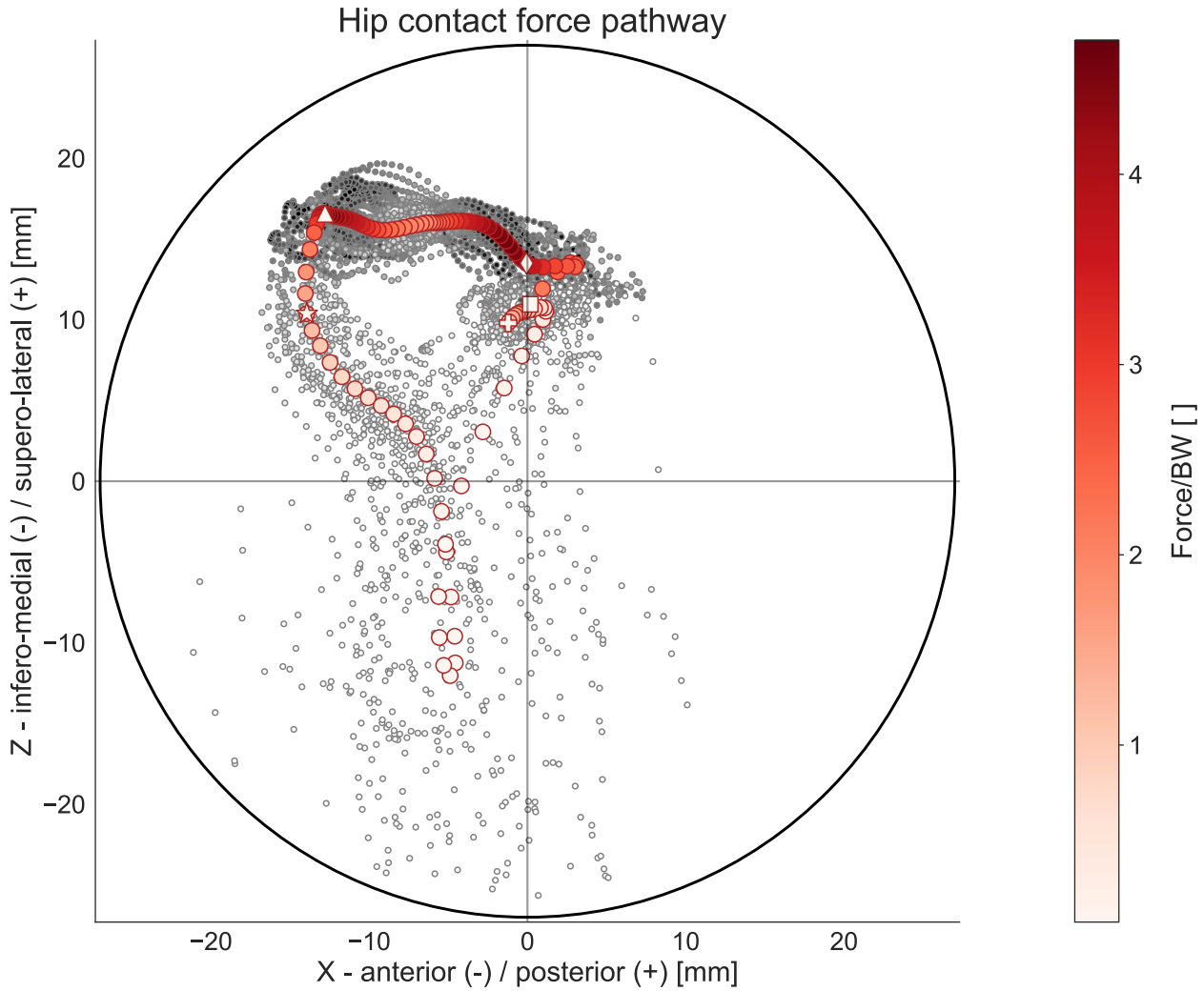


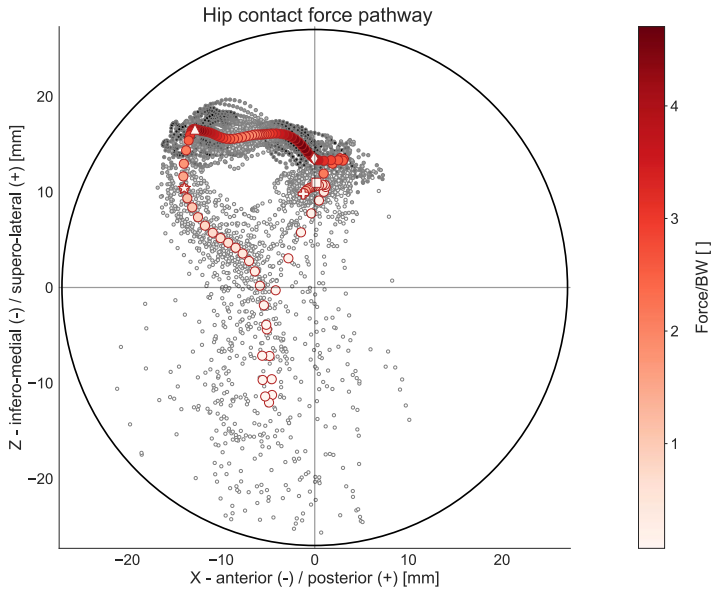
Loads during gait are mostly transmitted from the femur to the **anterior supero-lateral quadrant of the acetabulum**

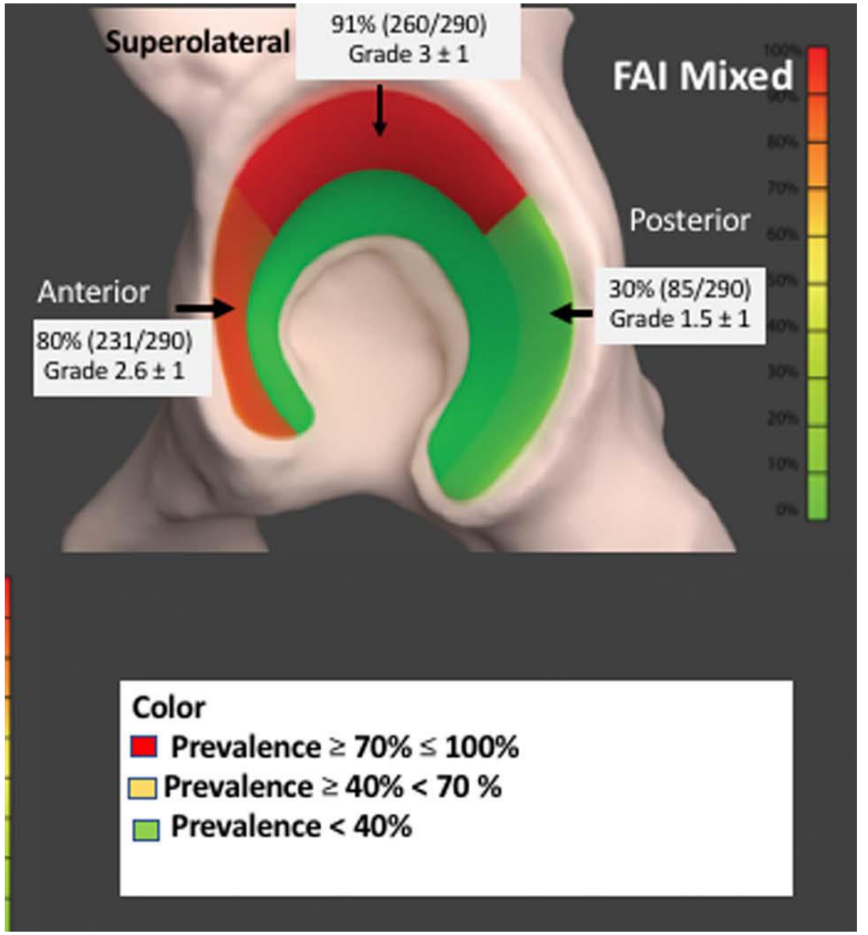


Acetabular load distribution

Patients affected by femoro-acetabular impingement:

→ high incidence of both anterior and superolateral peripheral cartilage lesions





Pascual-Garrido C et al, Clin Orthop Relat Res 2019

Subject-specific analysis of **load distribution**, accounting for acetabular morphology, may help identifying **patients at risk**

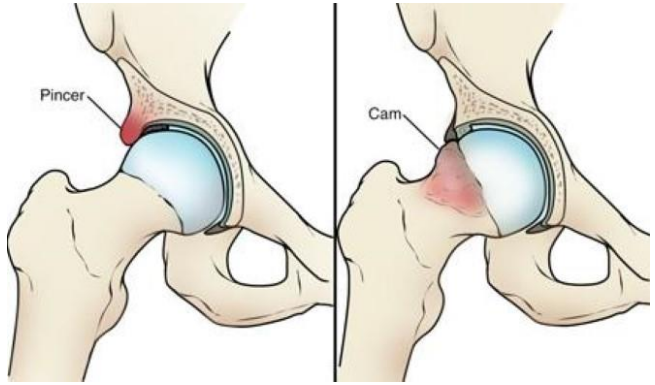
Pascual-Garrido C et al, Clin Orthop Relat Res 2019

Outlook I: femoro-acetabular impingement

Cam/pincer deformities

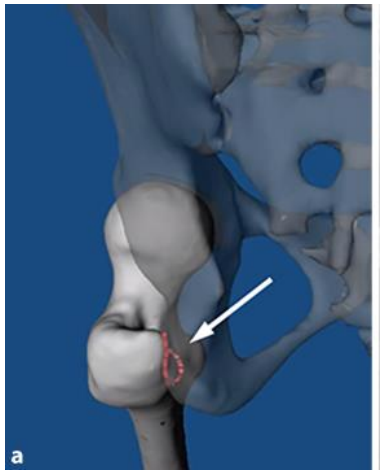
→ **femoro-acetabular impingement (FAI)**

→ Onset of hip OA



https://orthoinfo.aaos.org

- Alignment parameters, such as femoral torsion:
  - may aggravate or compensate the effect of existing deformities
  - may affect impingement-free hip range of motion

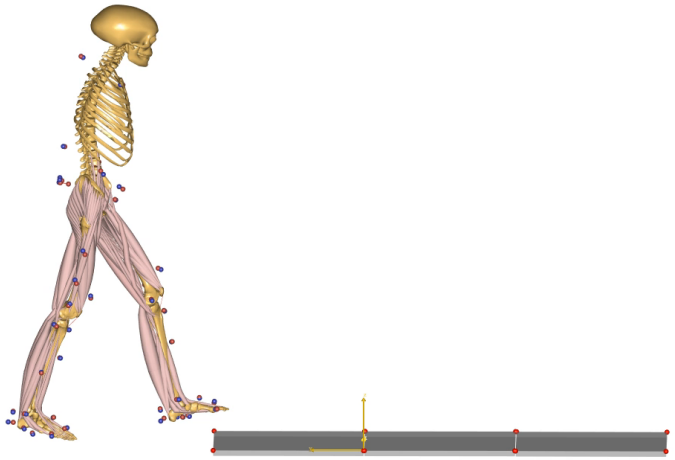


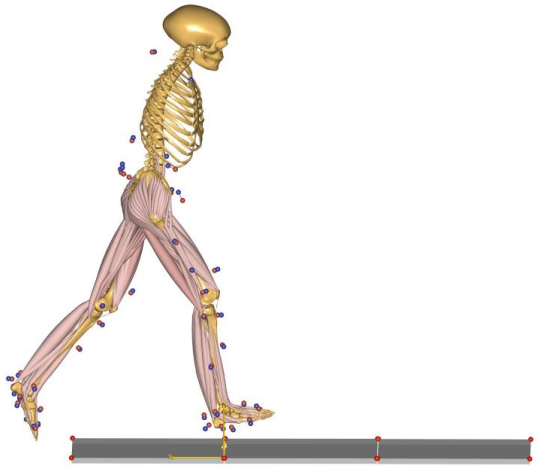
Lerch TD et al, Der Orthopäde 2019

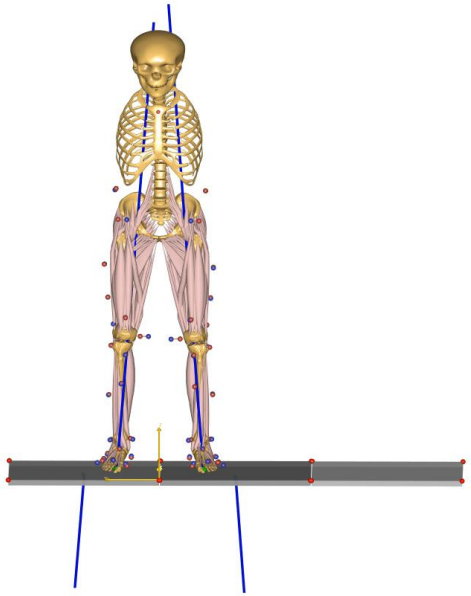
→ To characterize the hip loading environment in FAI patients while accounting for relevant patient-specific morphological and kinematic characteristics

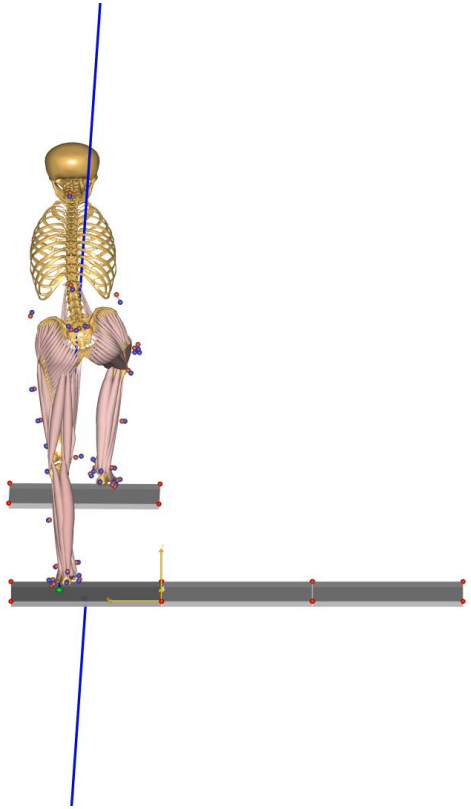
Felson DT, Osteoarth Cartil 2013
Zeng WN et al, Sci Rep 2016
Schmaranzer F, Clin Orthop Relat Res 2019
Ejnisman L et al., Orthopedics 2013

Realistic loading scenarios

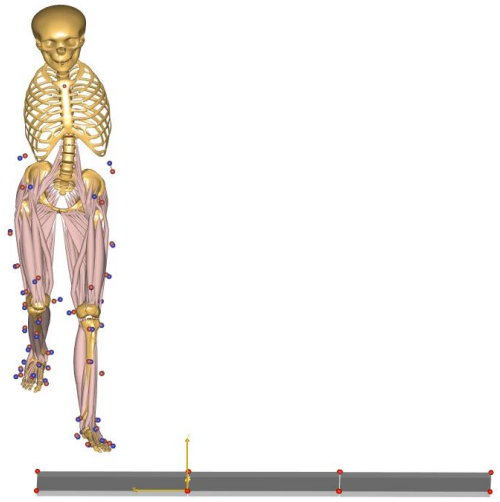


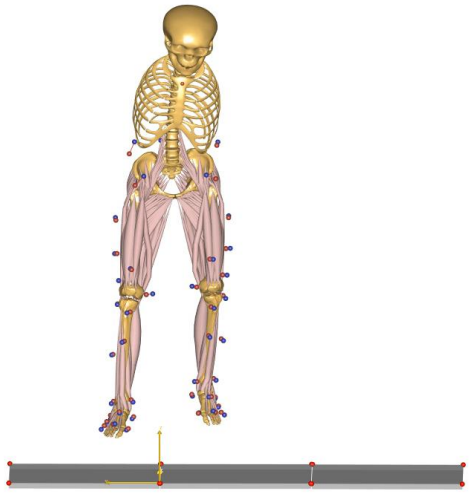


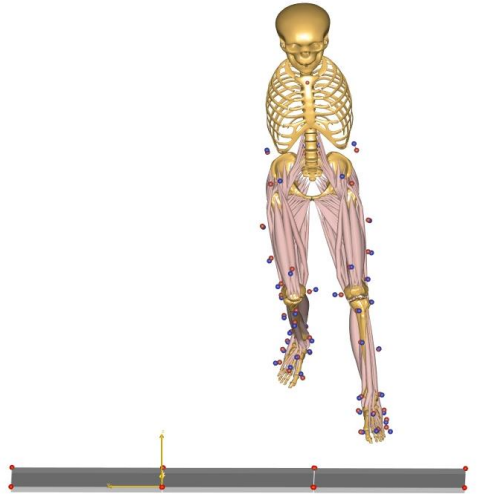




Challenging loading scenarios



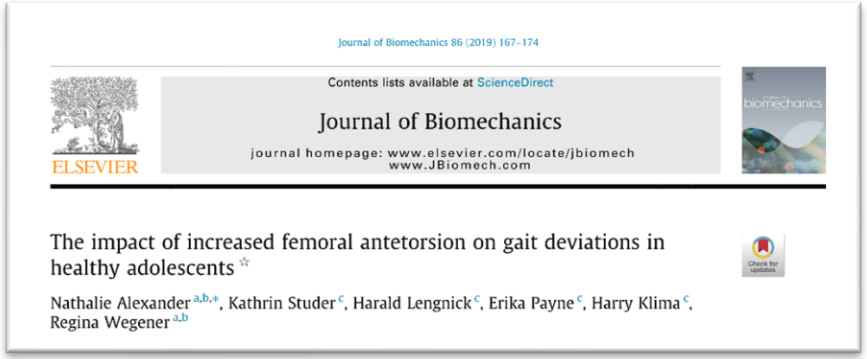




Outlook II: increased femoral torsion

- 42 pediatric patients with idiopathic, CT-confirmed increased femoral antetorsion >30°

- Analysis of joint loads and muscle functionality during gait


Journal of Biomechanics 86 (2019) 167–174
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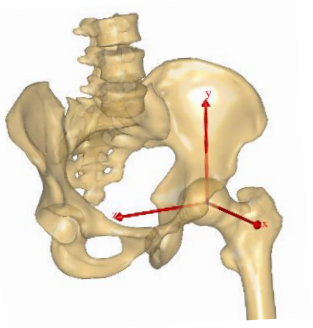
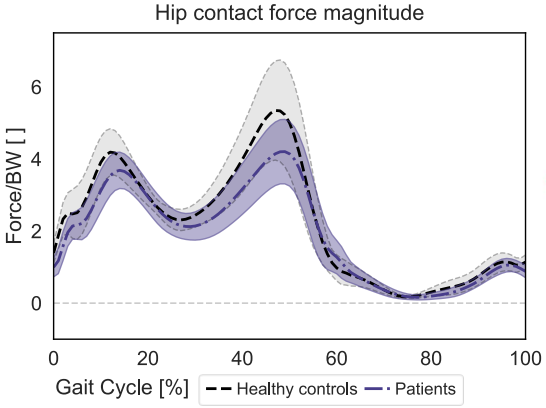
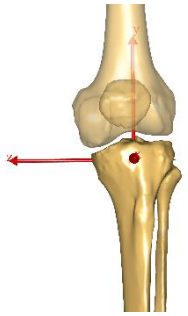
www.JBiomech.com

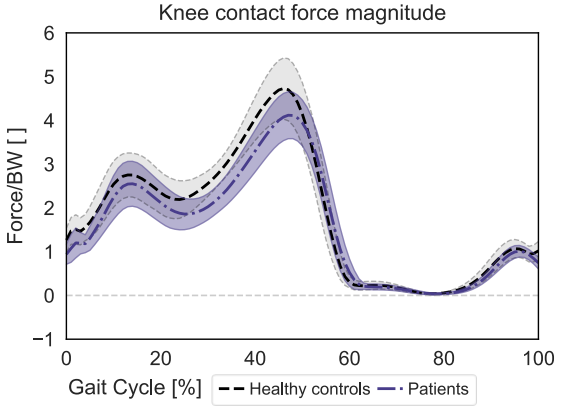
The impact of increased femoral antetorsion on gait deviations in healthy adolescents ☆

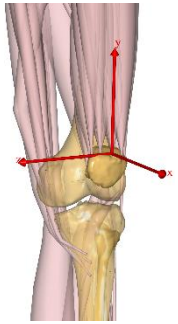
Nathalie Alexander [a,b,*], Kathrin Studer [c], Harald Lengnick [c], Erika Payne [c], Harry Klima [c], Regina Wegener [a,b]

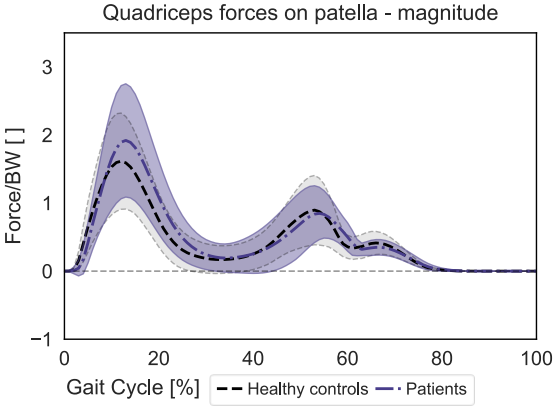






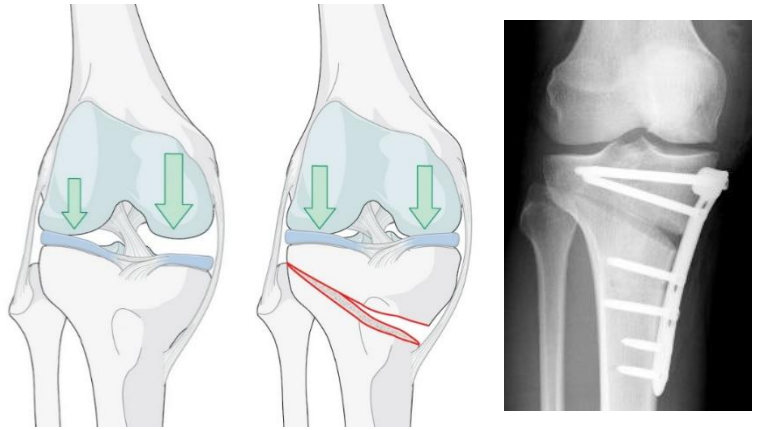




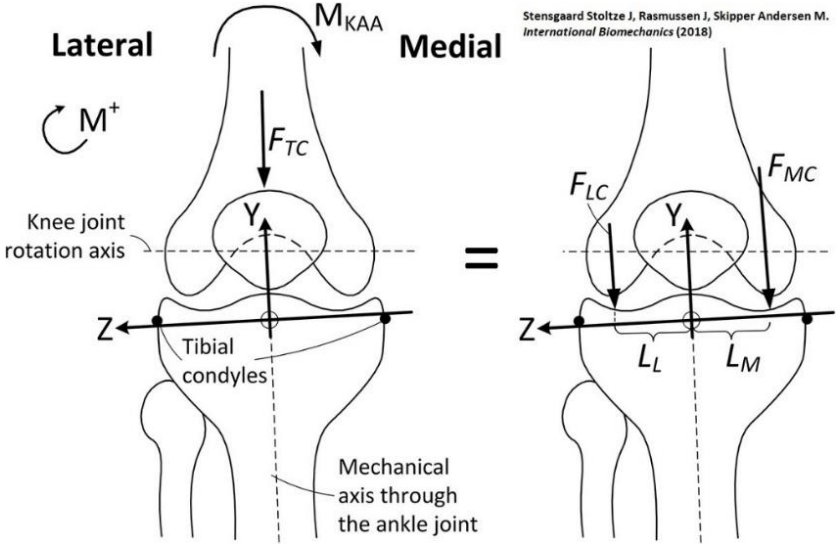


Outlook III : knee surgical realignment

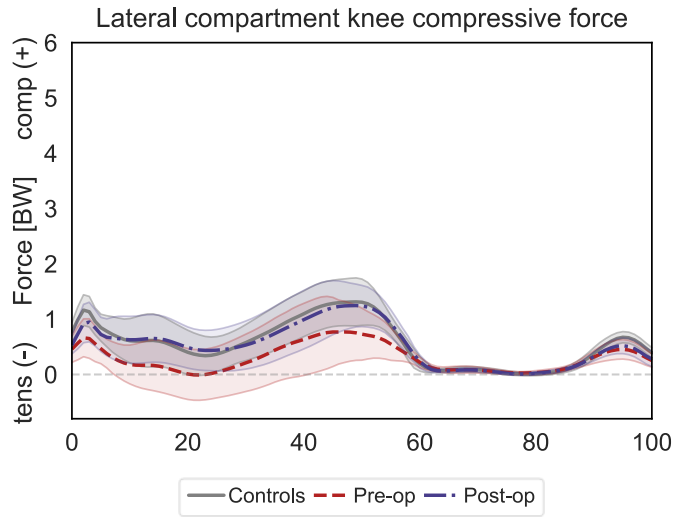
- **High tibial osteotomy** (HTO) is a surgical procedure that aims at realigning the tibia to reduce loads in the medial compartment associated with varus alignment
- Pre- and post-op analysis of knee loads during gait in patients who underwent HTO

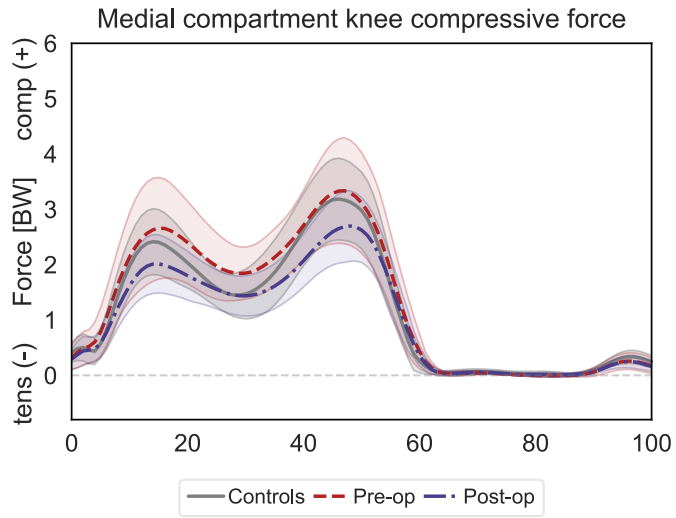


https://aorecon.aofoundation.org/education/surgical-insights/228.html



Stensgaard Stoltze J, Rasmussen J, Skipper Andersen M. *International Biomechanics* (2018)





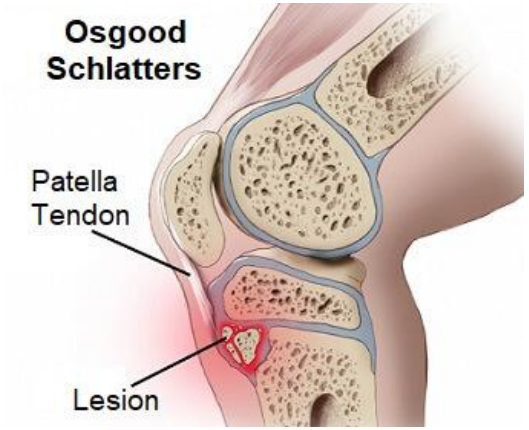
Outlook IV: alignment and overuse injuries

EFORT open reviews

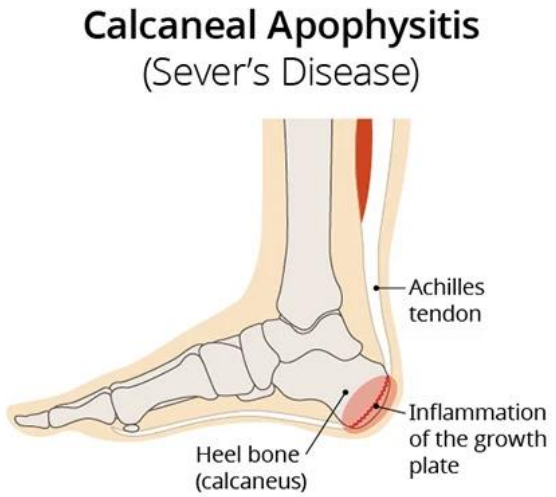
Torsional deformities and overuse injuries: what does the literature tell us

Gherardo Pagliazzi, Enrico De Pieri, Michèle Kläusler, Morgan Sangeux, Elke Viehweger

Accepted for publication



https://www.knee-pain-explained.com/osgood-schlatter.html



https://shoesfeetgear.com.au/pages/severs-disease

Outlook V: clinical application

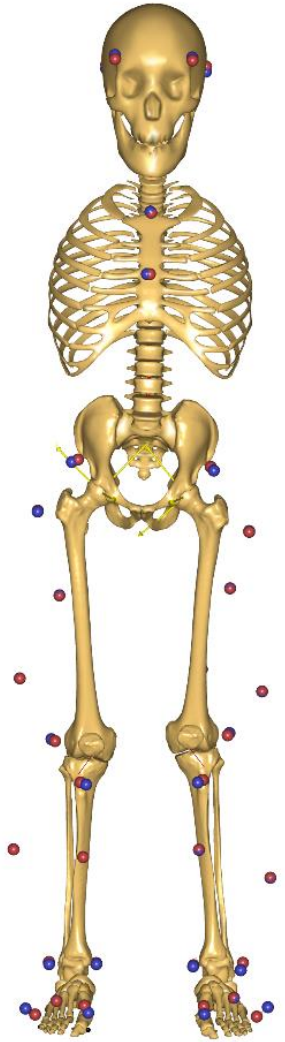
Incorporating musculoskeletal modelling into our routine clinical gait analysis

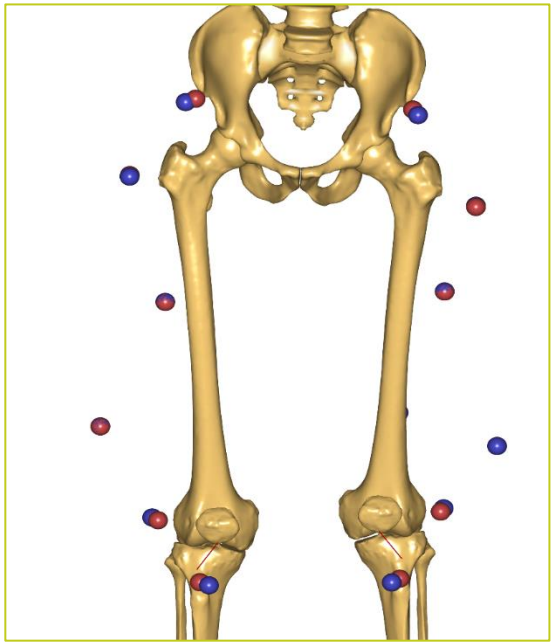
to better inform clinicians about joint loads experienced by patients with malalignment

Clinical application

15-year-old patient with:

- bilateral knee pain
- bilateral knee valgus (left > right)
- Bilateral femoral retrotorsion
  - MRI-confirmed left = -14°, right = -5°
- Restricted range of hip internal rotation
  - (>left side)
- Normal tibial torsion
  - MRI-confirmed left = 28°, right = 30°

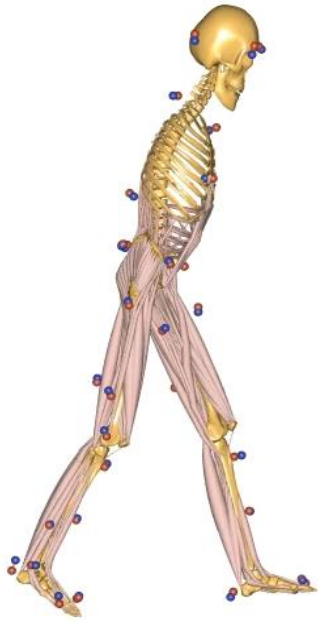


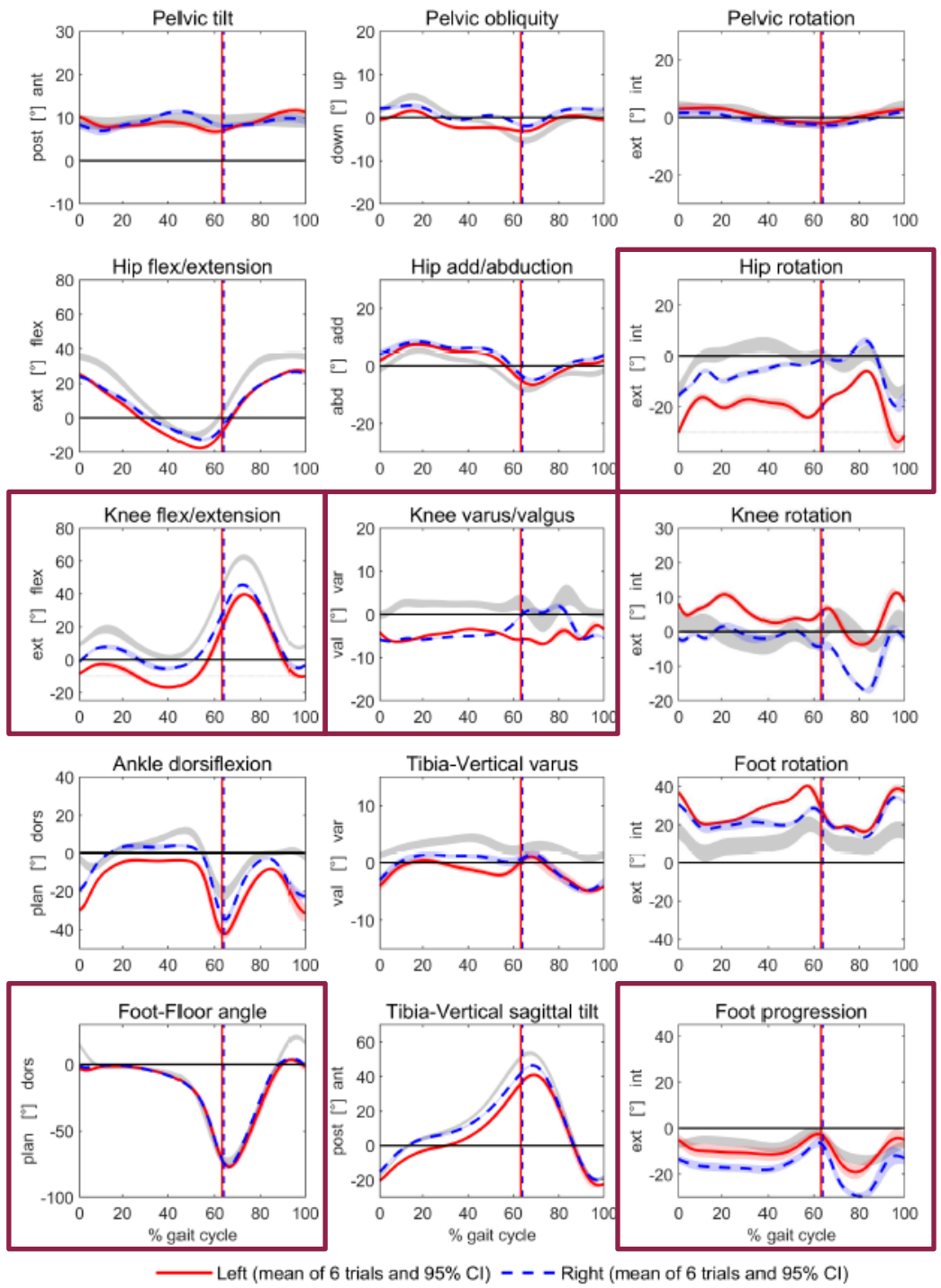


Clinical application

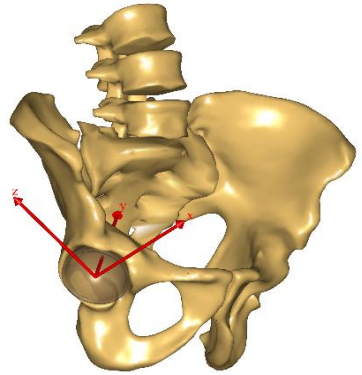
Gait pattern characterized by:

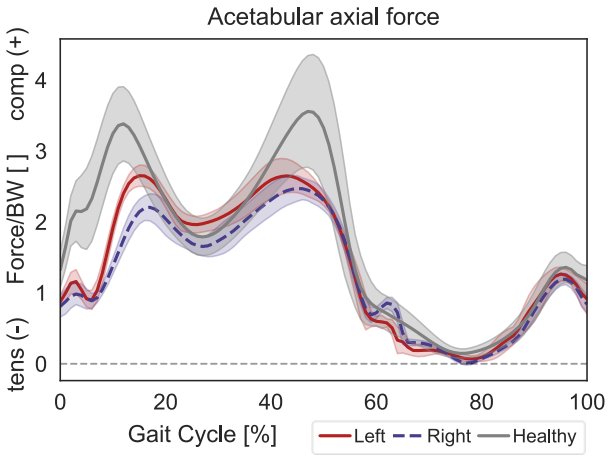
- forefoot contact,
- knee hyper-extension,
- knee valgus alignment,
- externally rotated hips,
- externally rotated feet

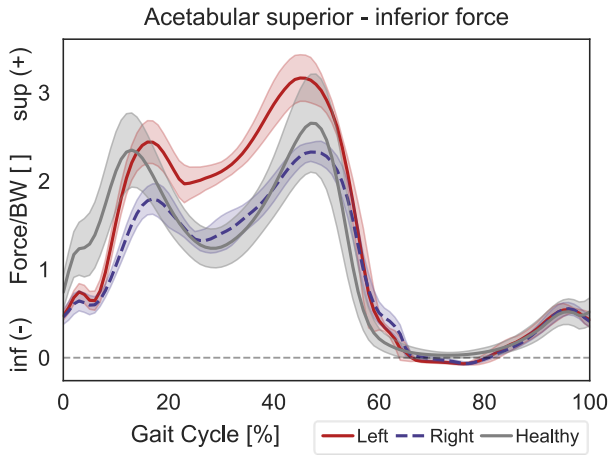


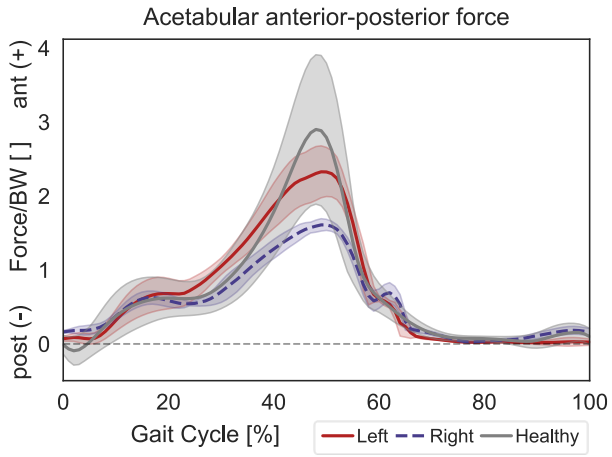


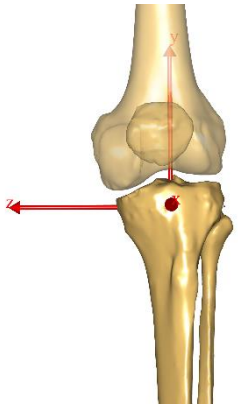
Clinical application

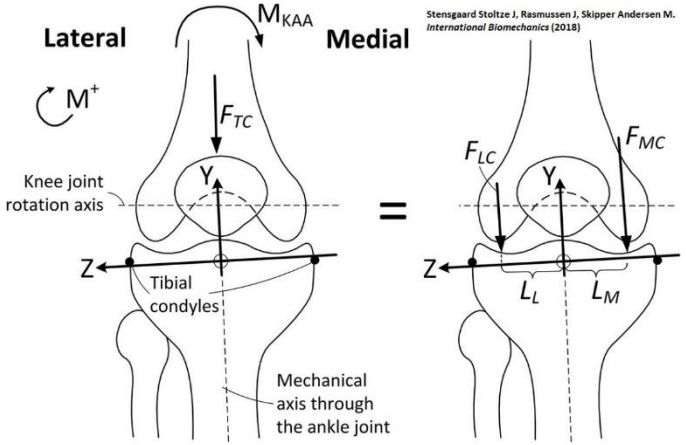


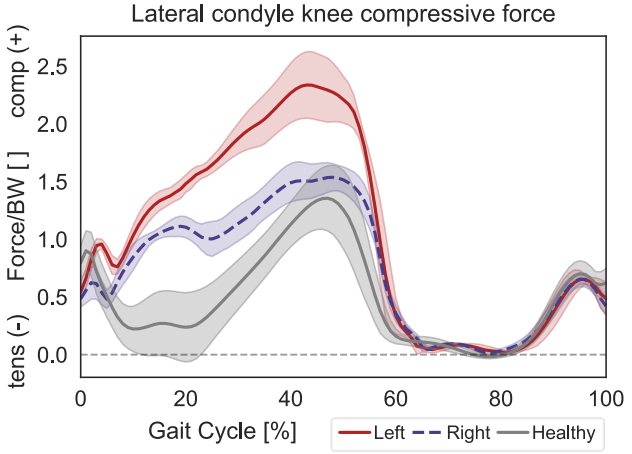


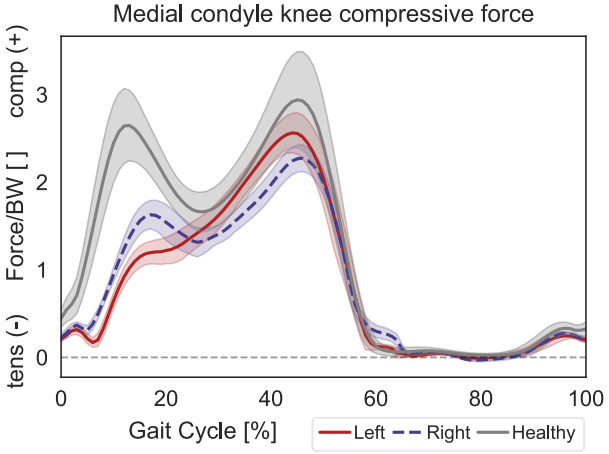












Clinical application

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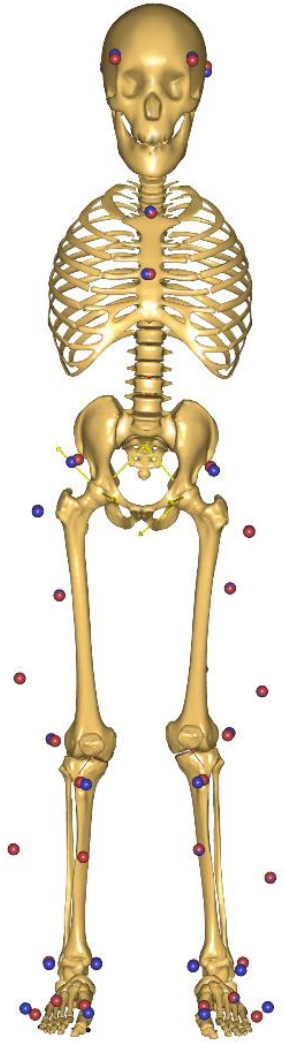


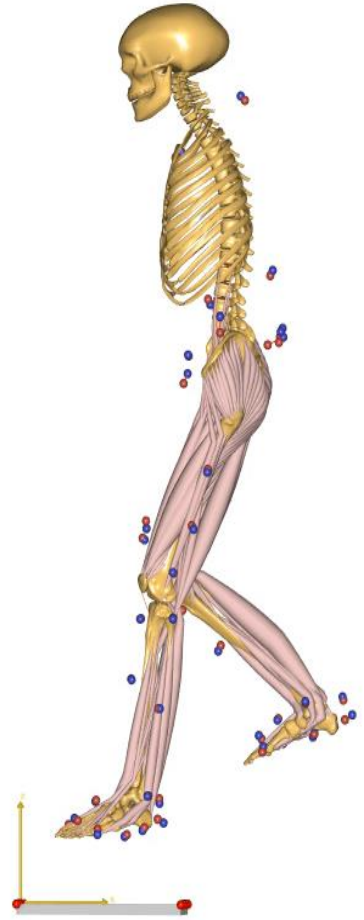
- **Conservative treatment**
  - Improve knee alignment and gait pattern through insoles
- Decision based on complete clinical picture
- Regular monitoring of hip and knee health (with joint loads in mind)

Take home messages

- Limb alignment plays an important role: from foot to spine!
- Joint loads are influenced by **anatomy** and **motion**

- Modelling of relevant morphological parameters is important both in healthy and pathological subjects

- Model personalization through geometrical morphing is an effective method



Acknowledgments

Morten Lund

Elke Viehweger, Reinald Brunner, Gherardo Pagliazzi, Michele Kläusler, Christoph Heidt, Bernhard Speth, Marco Odorizzi, Katrin Bracht-Schweizer, Jacqueline Romkes, Morgan Sangeux, Beat Göpfert, Regine Lohss, Stefanie Albrecht, Christian Wyss

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Financial support

Morphing femoral geometry in AnyBody

ANY MODEL REPOSITORY

Quick search

Go

Table of Contents

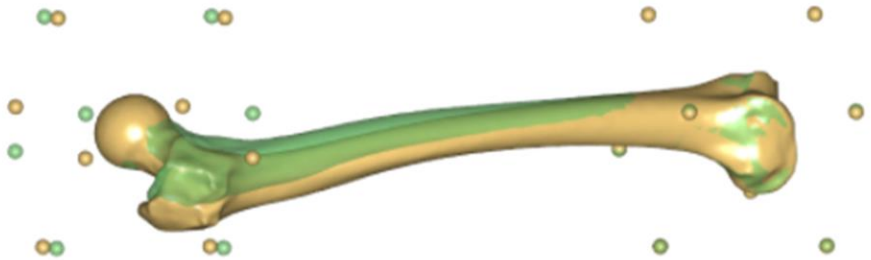
Femoral Torsion tool

This is an example of modifying the femoral torsion of the default leg ({ref}`TLEM 2.0 <tlem2>`) geometry by using a model utility tool included within the model repository. The model is the simple standing model where the femoral torsion has been altered to 20 degrees. The model is also a good example on how a similar morphing approach can be used to personalize different body segments.

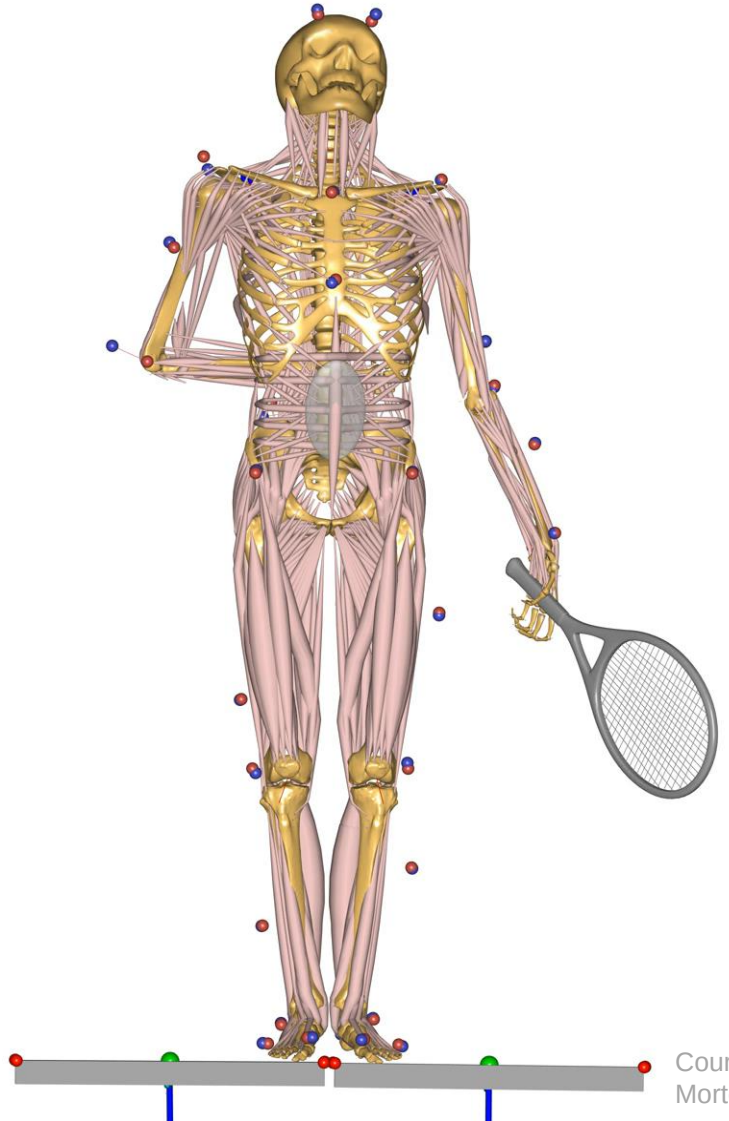
Model location in AMMR:
Application ▸ Examples ▸ FemoralTorsion ▸ StandingModel.Main.any

The tool was developed by Enrico De Pieri, from the University of Basel Children's Hospital (UKBB), and Morten E. Lund, from AnyBody Technology A/S.

This tool was made to generate personalized models that account for subject-specific values of femoral torsion, and investigate the effect of torsional alignment on hip loading. This work is published in 'Frontiers in Bioengineering and Biotechnology' [DFLM21]. Please cite this article when using this tool.



The tool works by adding a 8 control points around the hip center and knee center, which control a RBF scale function. The control points are scaled with the default model scaling, while the femoral torsion is added on top.



Courtesy of
Morten Lund

Thank you for your attention

Questions?

enrico.depieri@unibas.ch

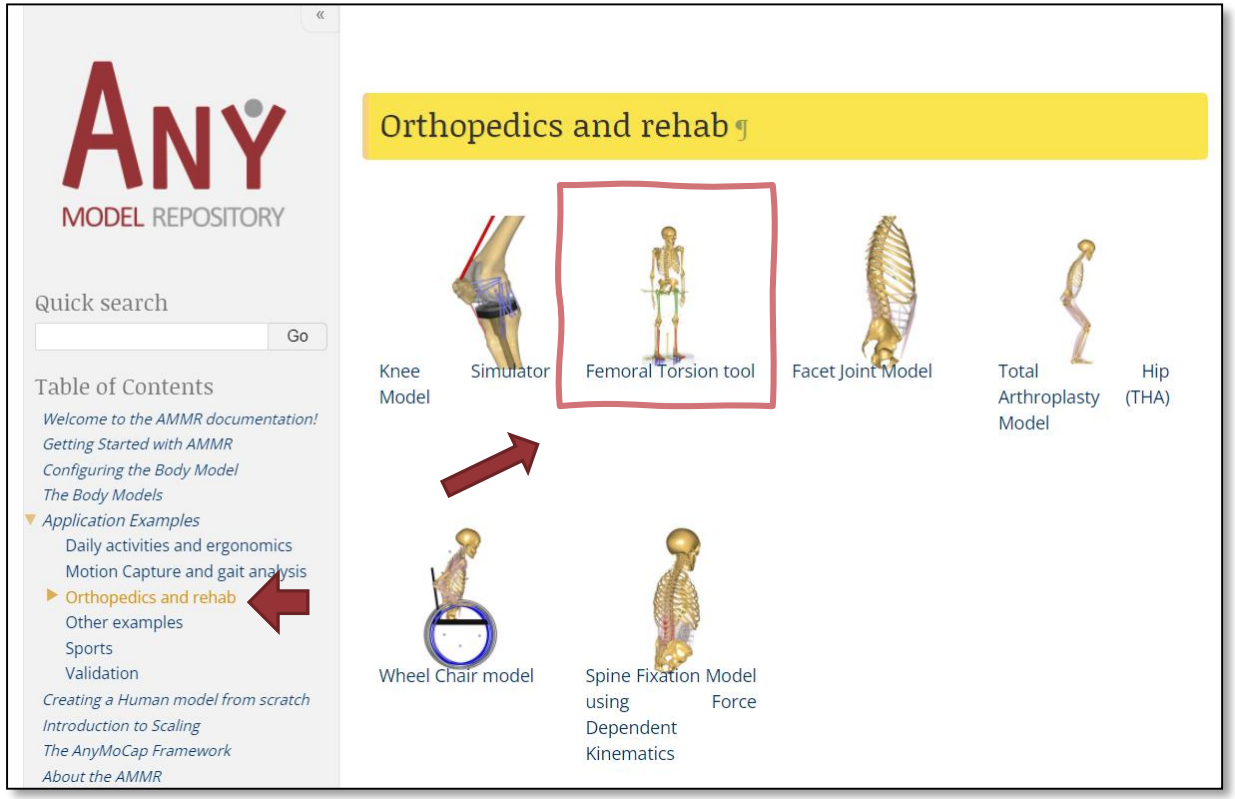
How get the femur torsion tool?

- New example model in Model Repository (AMMR)

Model location in AMMR:
Application ▸ Examples ▸ FemoralTorsion ▸ StandingModel.Main.any

- Included with the next release of AnyBody
  - Wait for next AnyBody release (AMMR 2.4)
  - Probably 2-4 month

- **For the impatient**
  - Join our development repository on GitHub



How get the femur torsion tool?

Development repository on GitHub

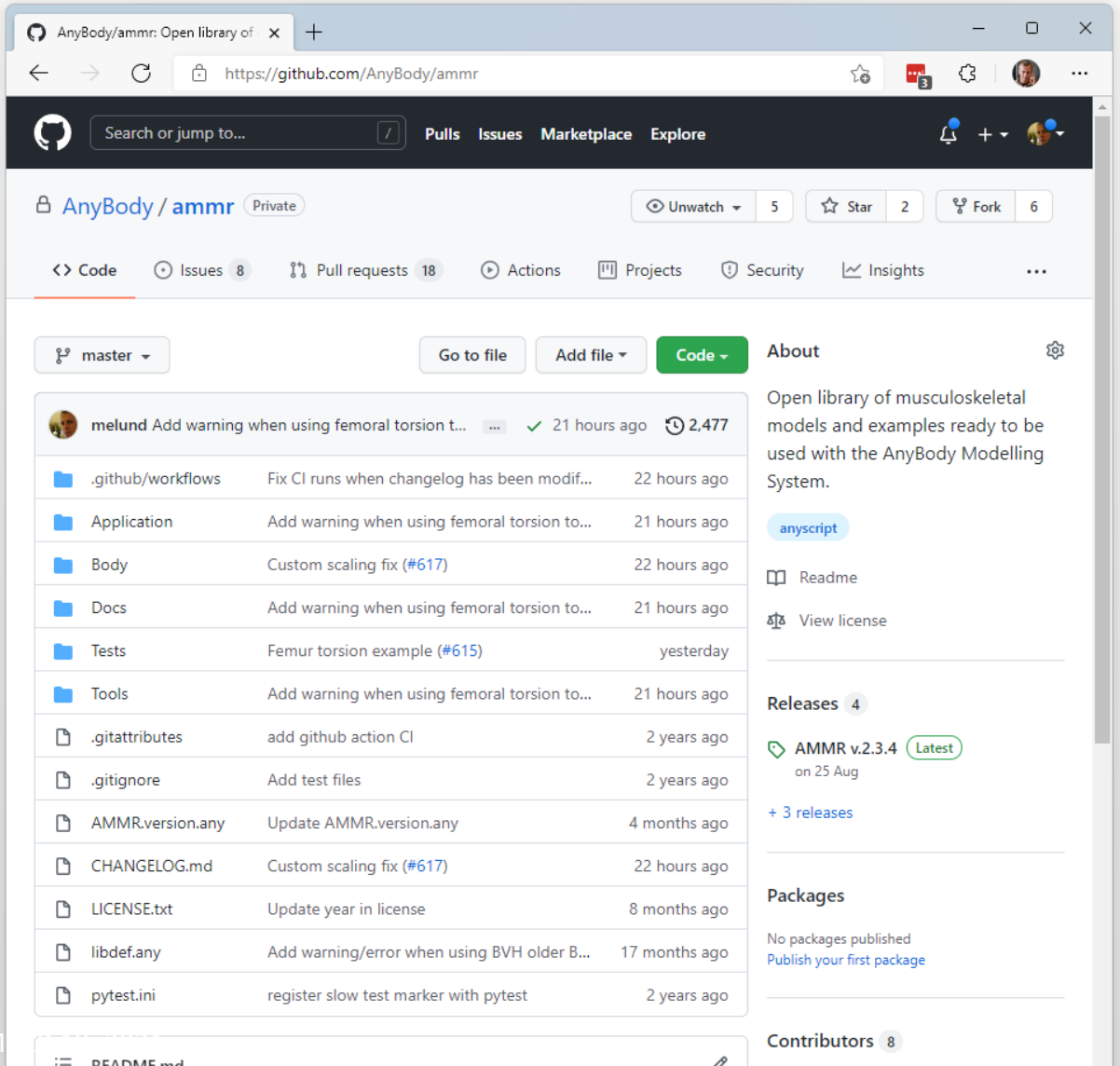
- Semi-private repository on GitHub
- Bleeding edge models

Join our development repository on GitHub

- Everyone can get access to our beta program.

Apply for access here:
https://github.com/AnyBody/ammr-doc

Or send us an email….



Find us:

www.anybodytech.com

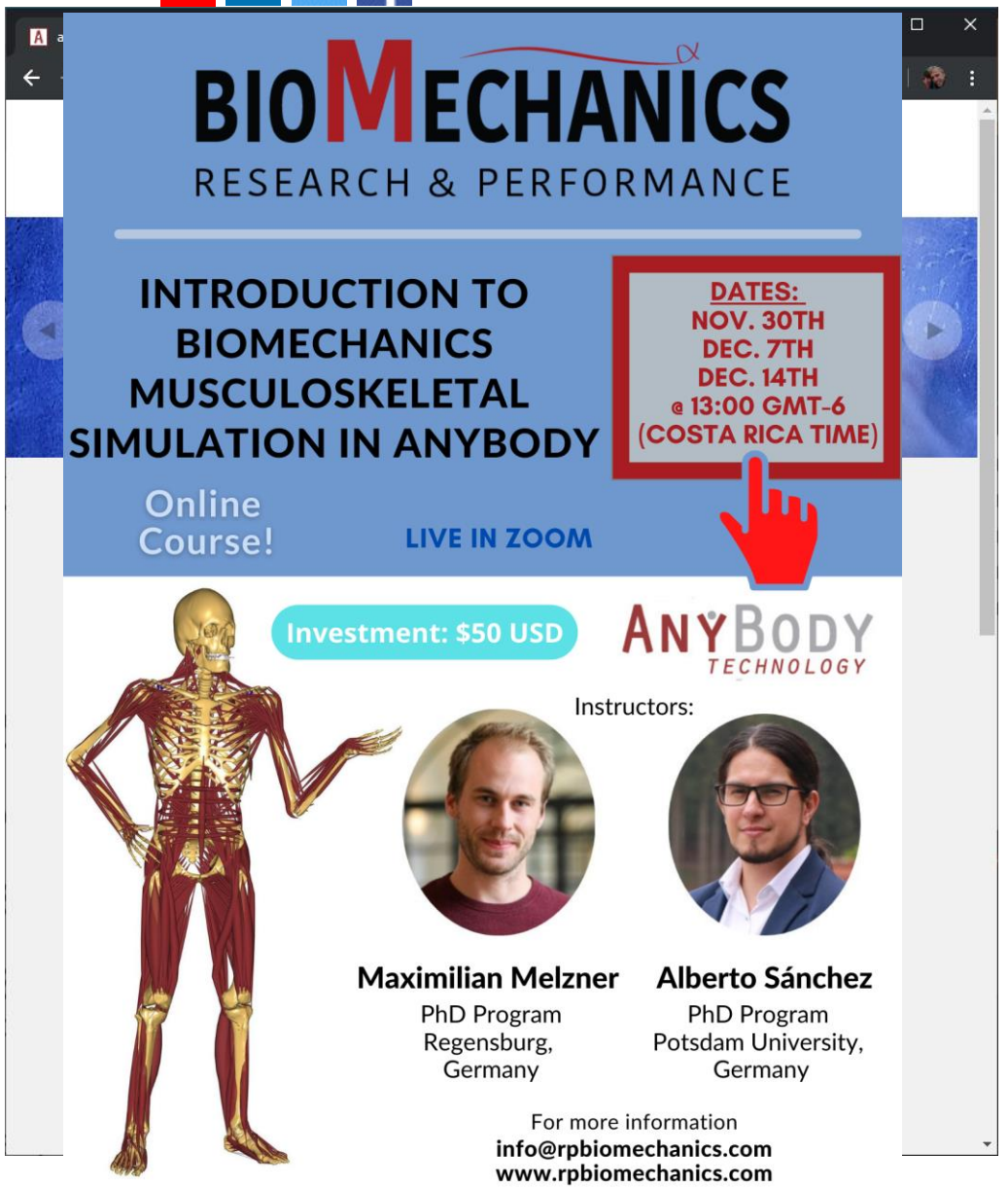
- Events, Dates, Publication list, ...

www.anyscript.org

- Wiki, Blog, Repositories, Forum

Events

- **Online course: Introduction to biomechanics musculoskeletal simulation in AnyBody**
  - Hosted by our South and Central America distributor, Research & Performance Biomechanics
  - The course language is English, but with live Spanish support, as the course is targeted at potential users in Latin America.
  - Sign up: https://forms.gle/eYDCf9R368f4RGL88



Meet us? Send email to sales@anybodytech.com

Want to present? Send email to ki@anybodytech.com

Thank you for your attention - Time for questions