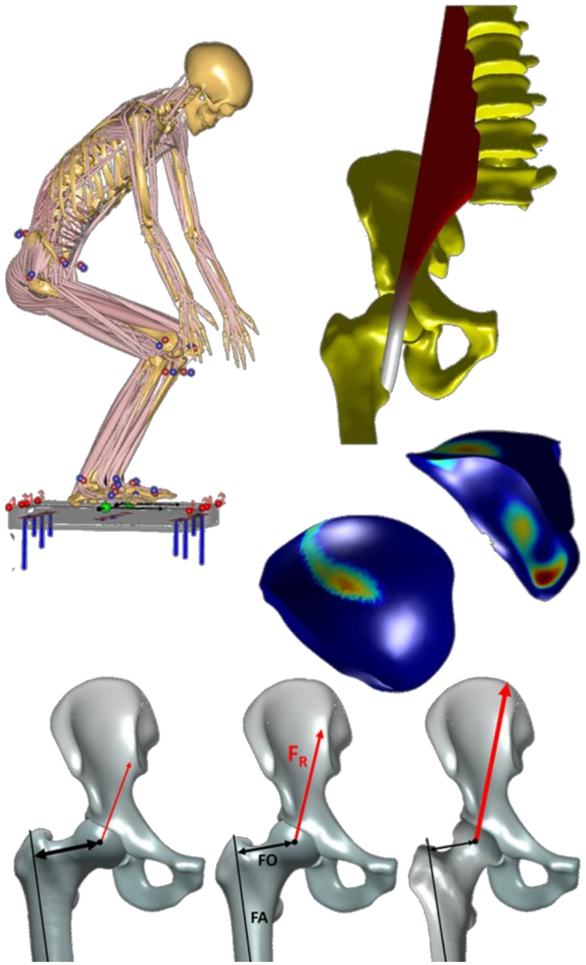
The webcast will begin shortly…

Undestanding the mechanical environment of the hip joint

November 25th, 2020



Outline

- General introduction to the AnyBody Modeling System
- Presentation by Jan Van Houcke
  - *Understanding the mechanical environment of the hip joint*
- Question and answer session

Presenter:
Jan Van Houcke, MD, PhD
Hip Surgeon at OLV Hospital, Aalst, Belgium

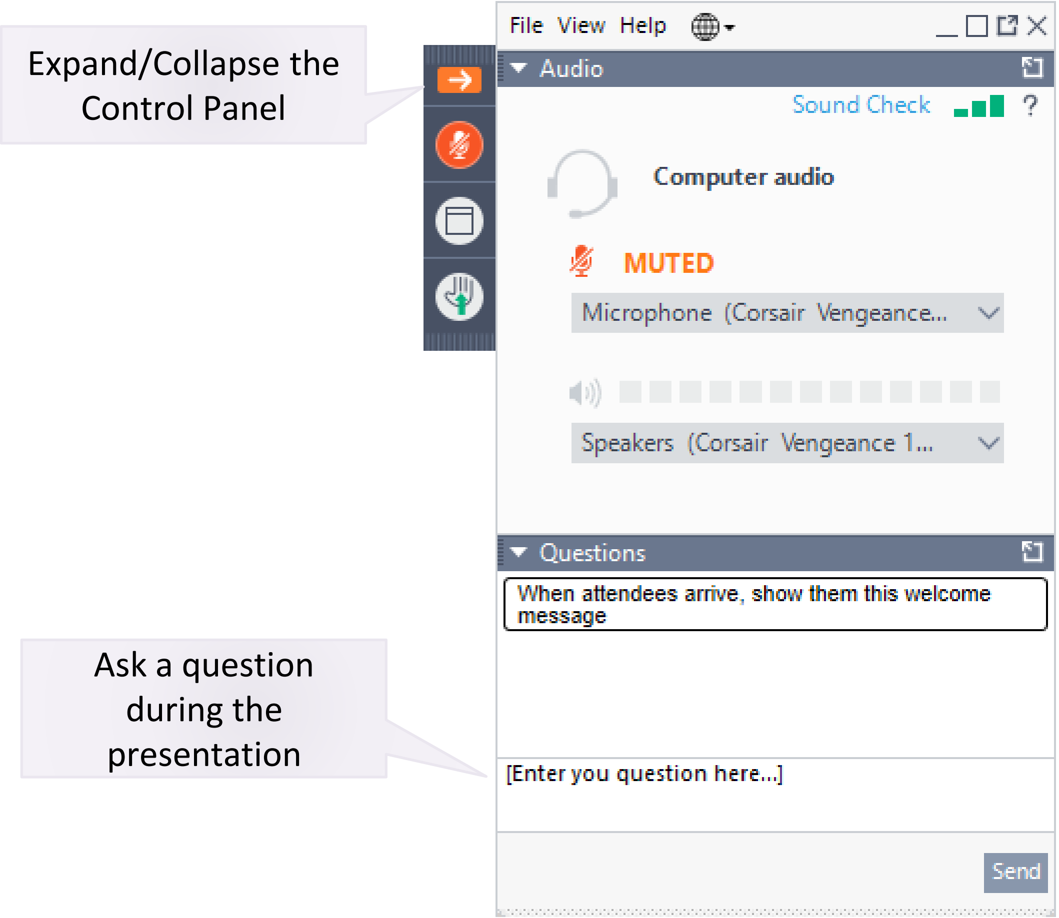
Host:
Pavel Galibarov
Senior Engineer
AnyBody Technology

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.

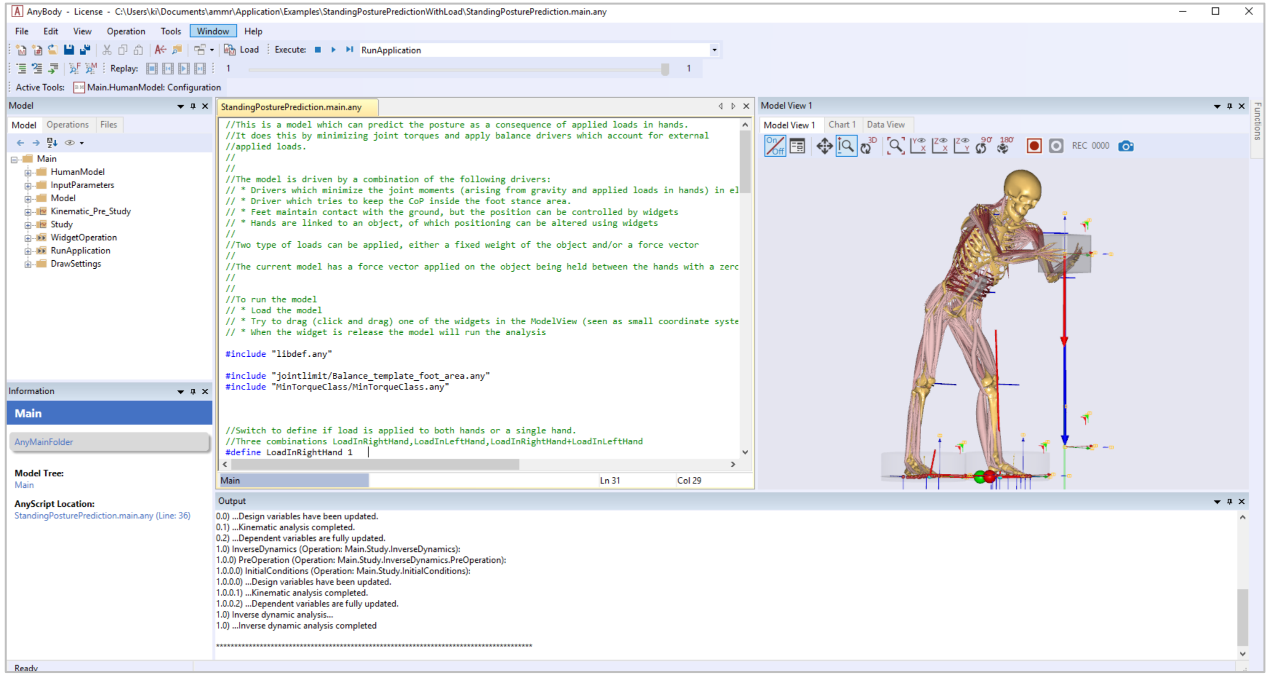


Musculoskeletal Simulation

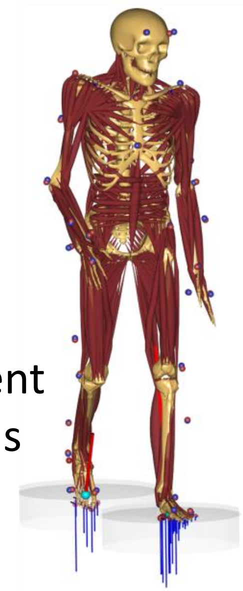
Motion Data
Kinematics and Forces

ANYBODY
Modeling System

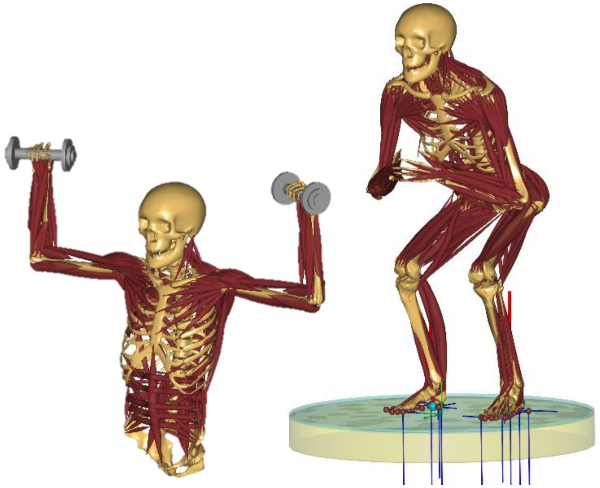
Body Loads
- Joint moments
- Muscle forces
- Joint reaction forces



Product optimization design

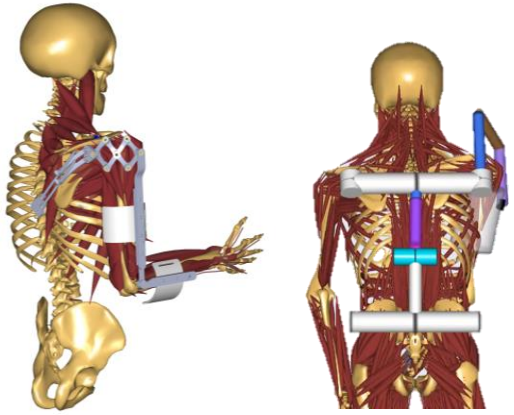


Movement Analysis

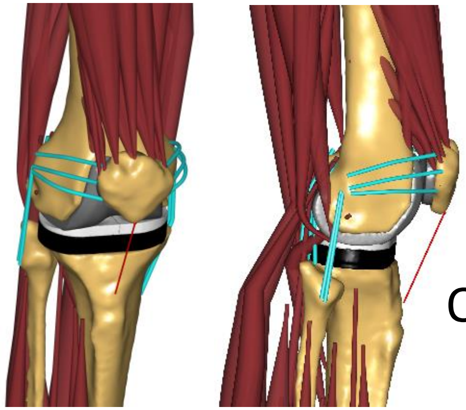


Sports

ANYBODY
Modeling System



Assistive Devices



Orthopedics and rehab

AnyBody Modelling System

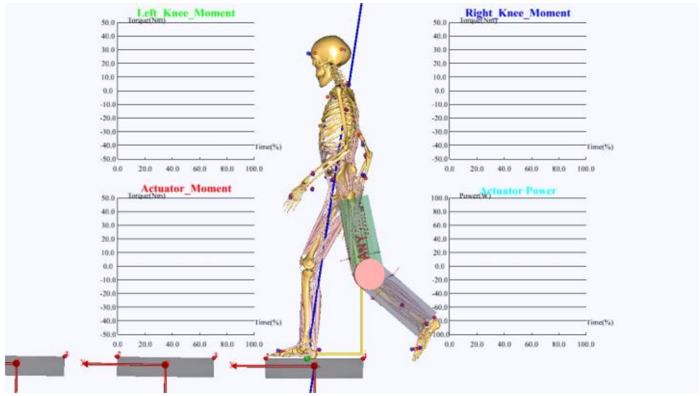
Motion and Forces

Body model

Environment model

Inverse dynamics
Muscle recruitment

Simulation

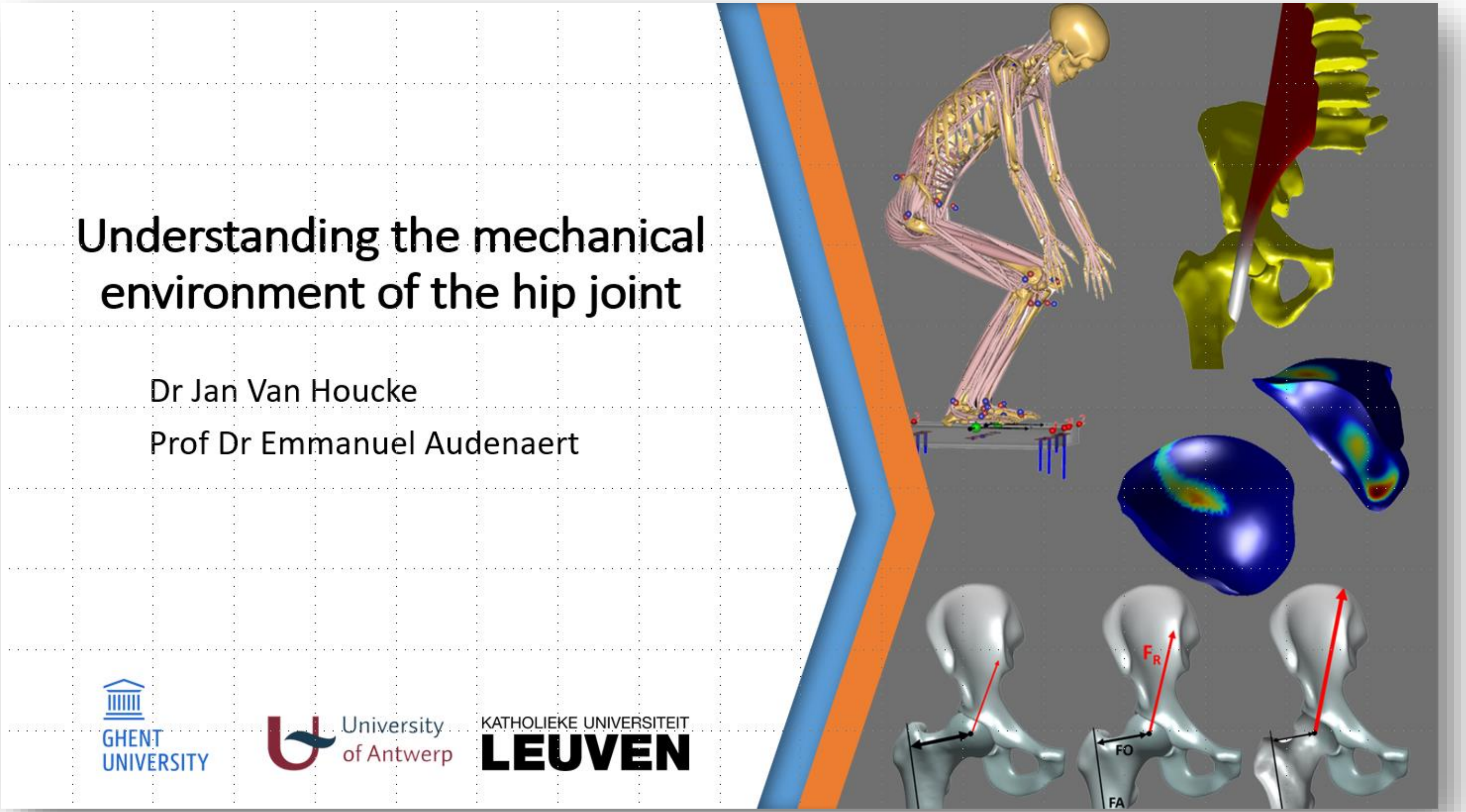


Internal body loads
- Muscle forces
- Joint moments

Design Optimization

Post Processing (e.g. Finite element tools)

Presentation



www.anybodytech.com

- Events, Dates, Publication list, ...

www.anyscript.org

- Wiki, Repositories, Forum

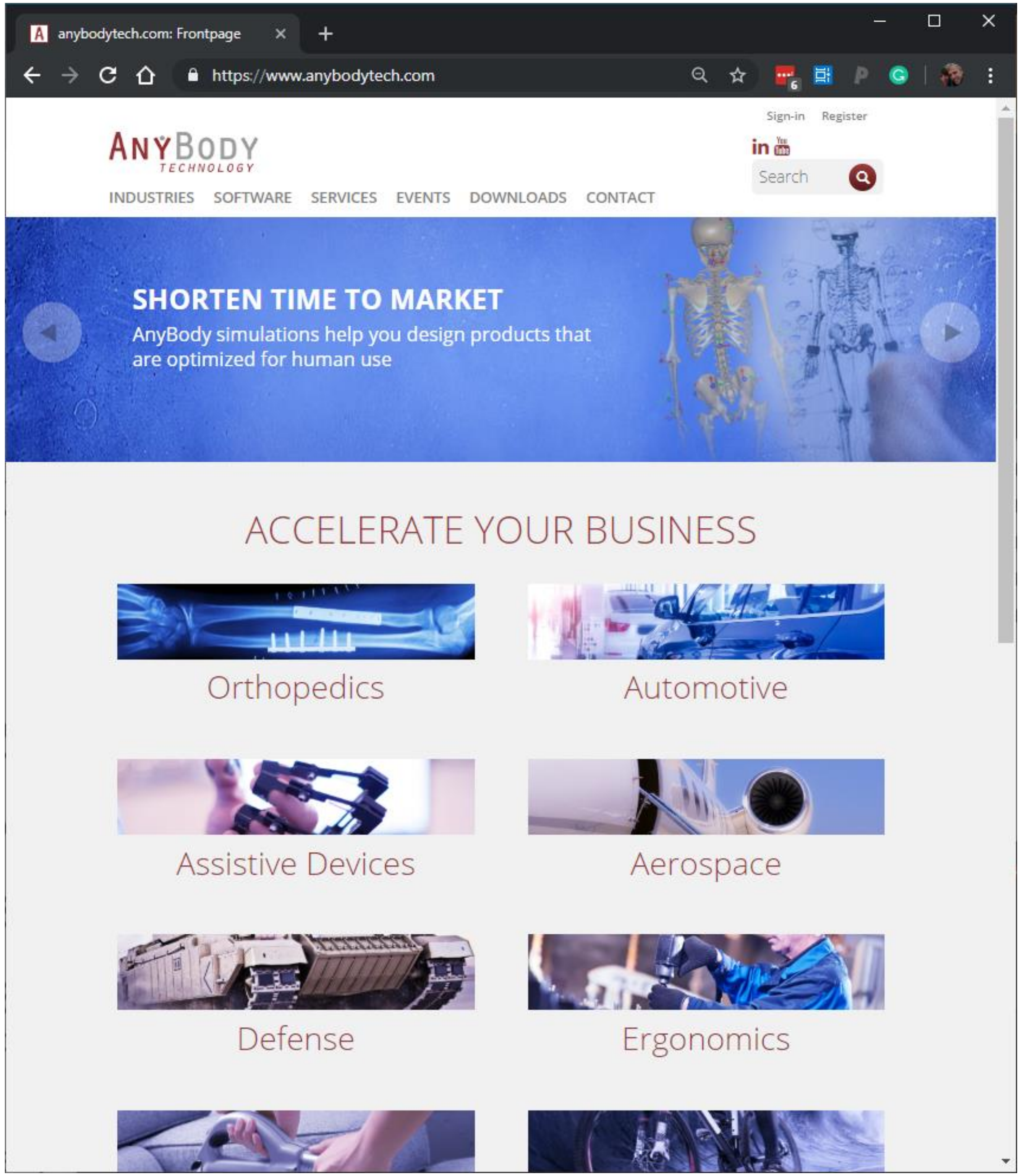
Webcast

- Dec 1: A new musculoskeletal AnyBody detailed hand model. A joint presentation by Scientific Computing Centre Ulm and OTH Regensburg

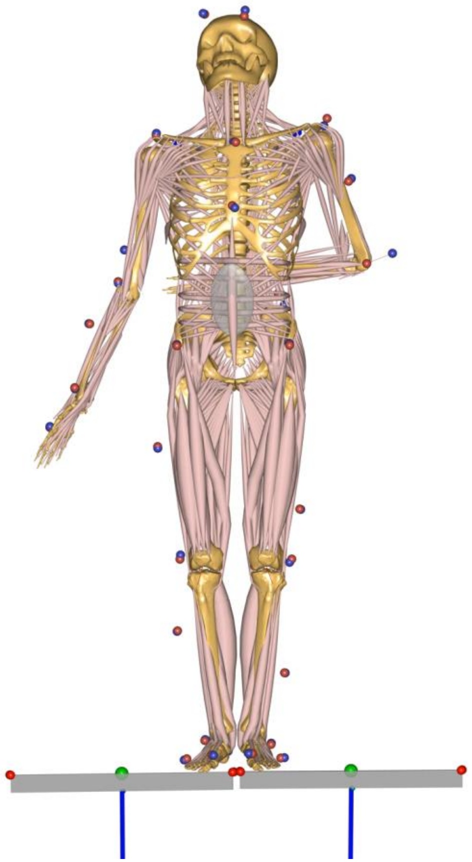
Meet us? Send email to sales@anybodytech.com

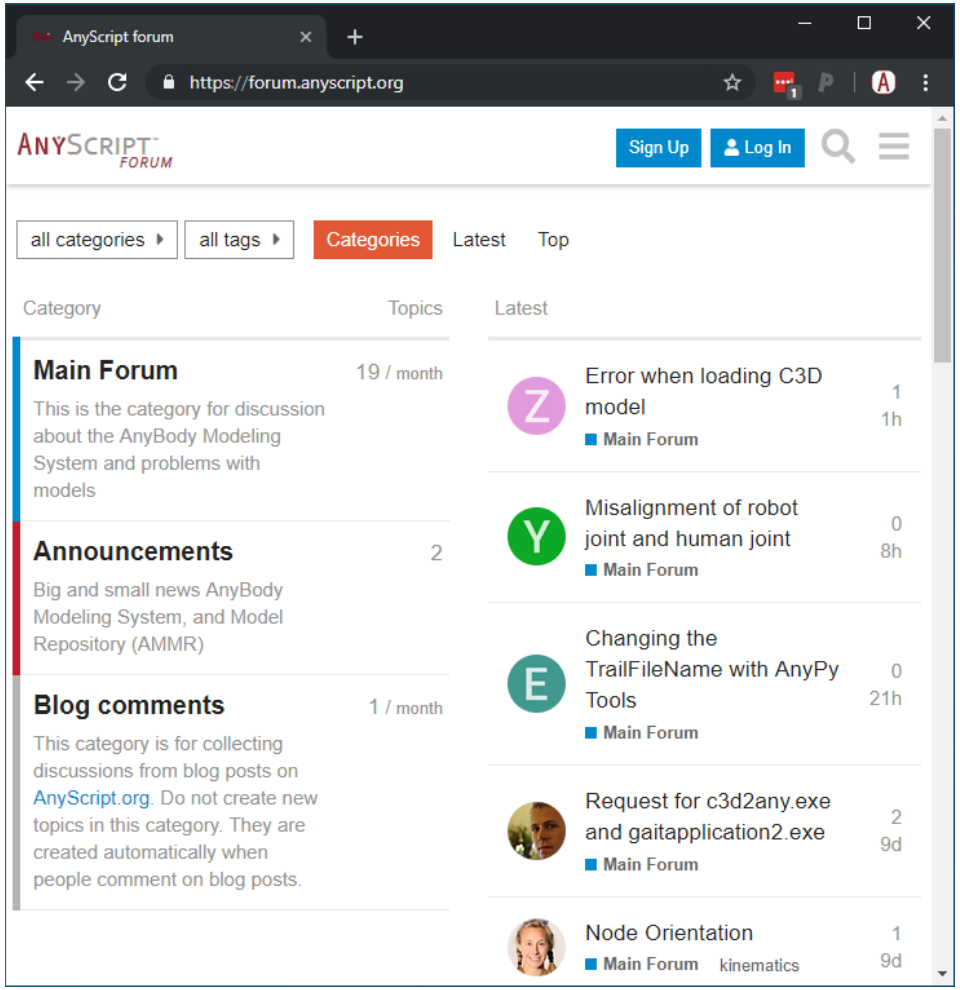
Want to present? Send email to ki@anybodytech.com

Find us:



Time for questions:





Understanding the mechanical environment of the hip joint

Dr Jan Van Houcke

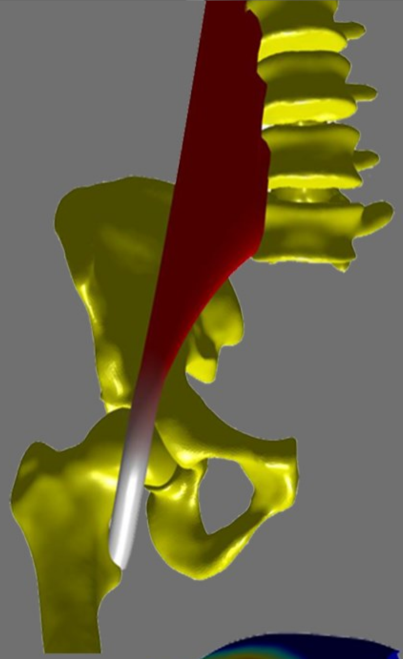
Prof Dr Emmanuel Audenaert

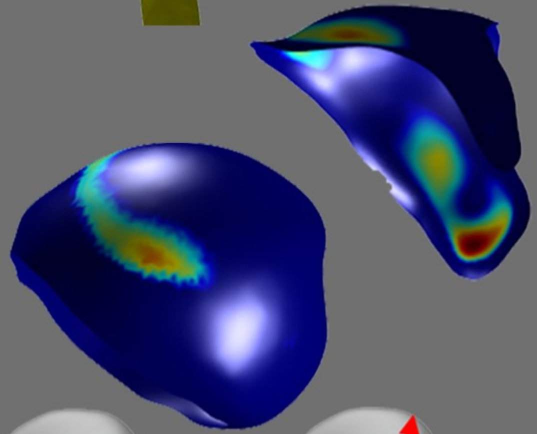
ANYBODY TECHNOLOGY

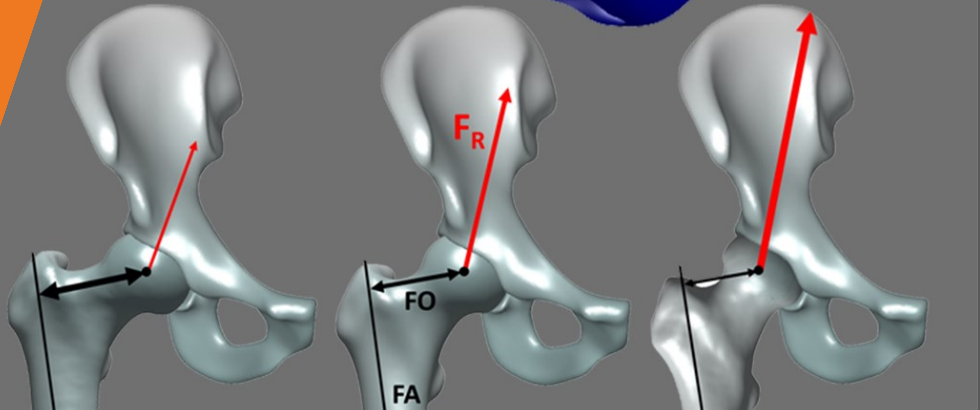
GHENT UNIVERSITY

University of Antwerp

KATHOLIEKE UNIVERSITEIT LEUVEN



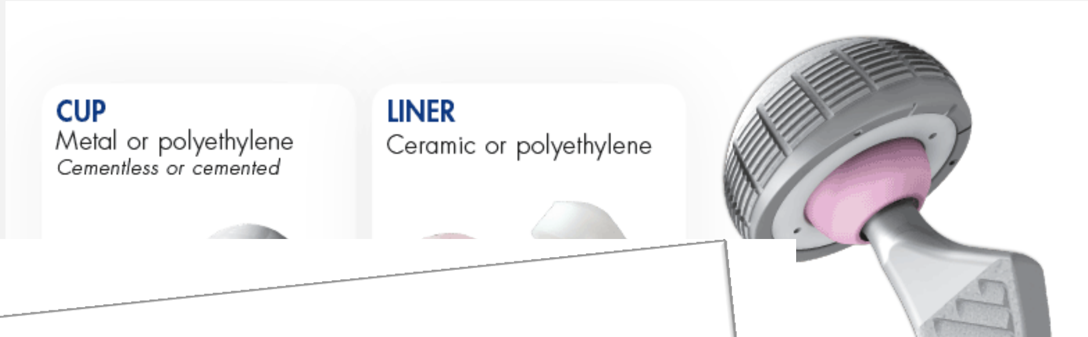




UZ
GENT

The Problem

Not quite a problem?




THE LANCET

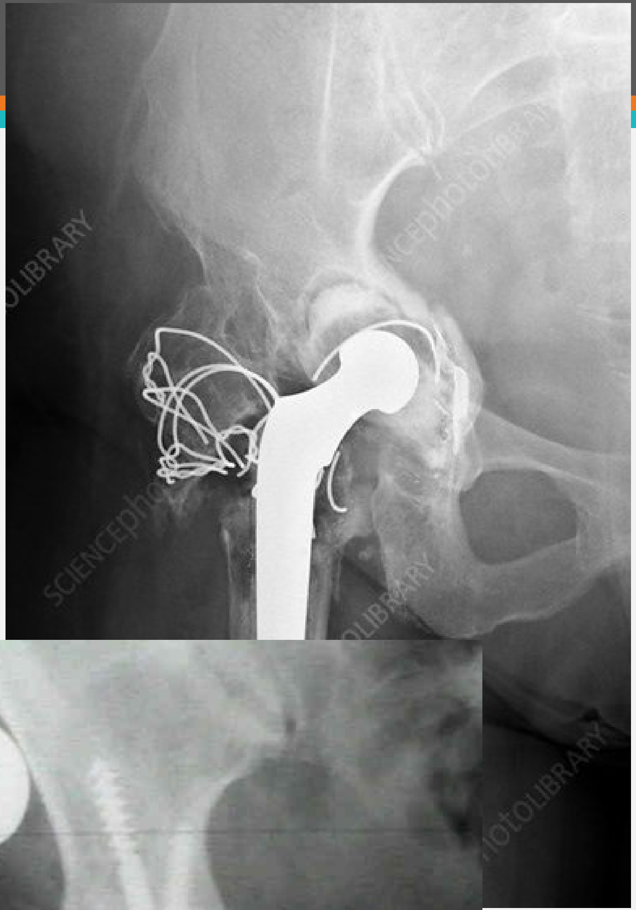
ccess provided by Ghent University

REVIEW | VOLUME 370, ISSUE 9597, P1508-1519, OCTOBER 27, 2007

The operation of the century: total hip replacement

Prof Ian D Learmonth, FRCS • Claire Young, FRCS • Prof Cecil Rorabeck, FRCS

Published: March 29, 2007 • DOI: https://doi.org/10.1016/S0140-6736(07)60457-7



What causes hip OA?

Major health problem

Hip OA

Primary (85%)

Secondary (15%)

Lifetime risk 25%

FAI

(True primary arthrosis of the hip)

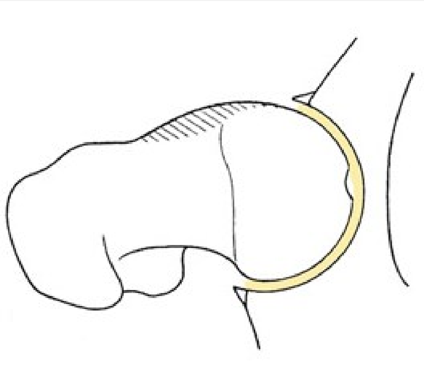
* *Ganz et al., Clin Othop Relat Res, 2008*
Harris WH, Clin Orthop Relat Res, 1986

Shape

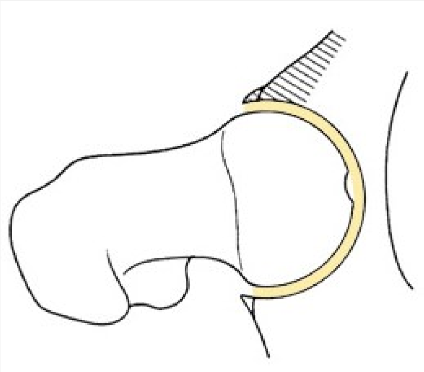
- FAI

  Femoroacetabular impingement (FAI) is a **mechanical** hip disorder defined as **early and/or repetitive** contact between the acetabular rim and the proximal femur, potentially resulting in **damage** to the hip joint cartilage and labrum in young adults.

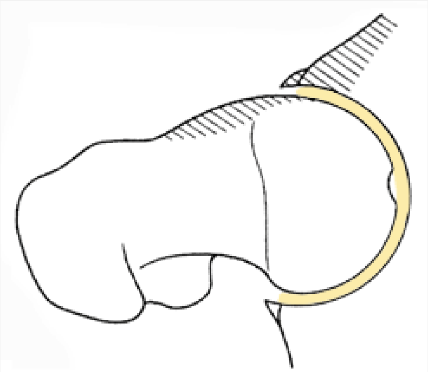
- Types



Cam

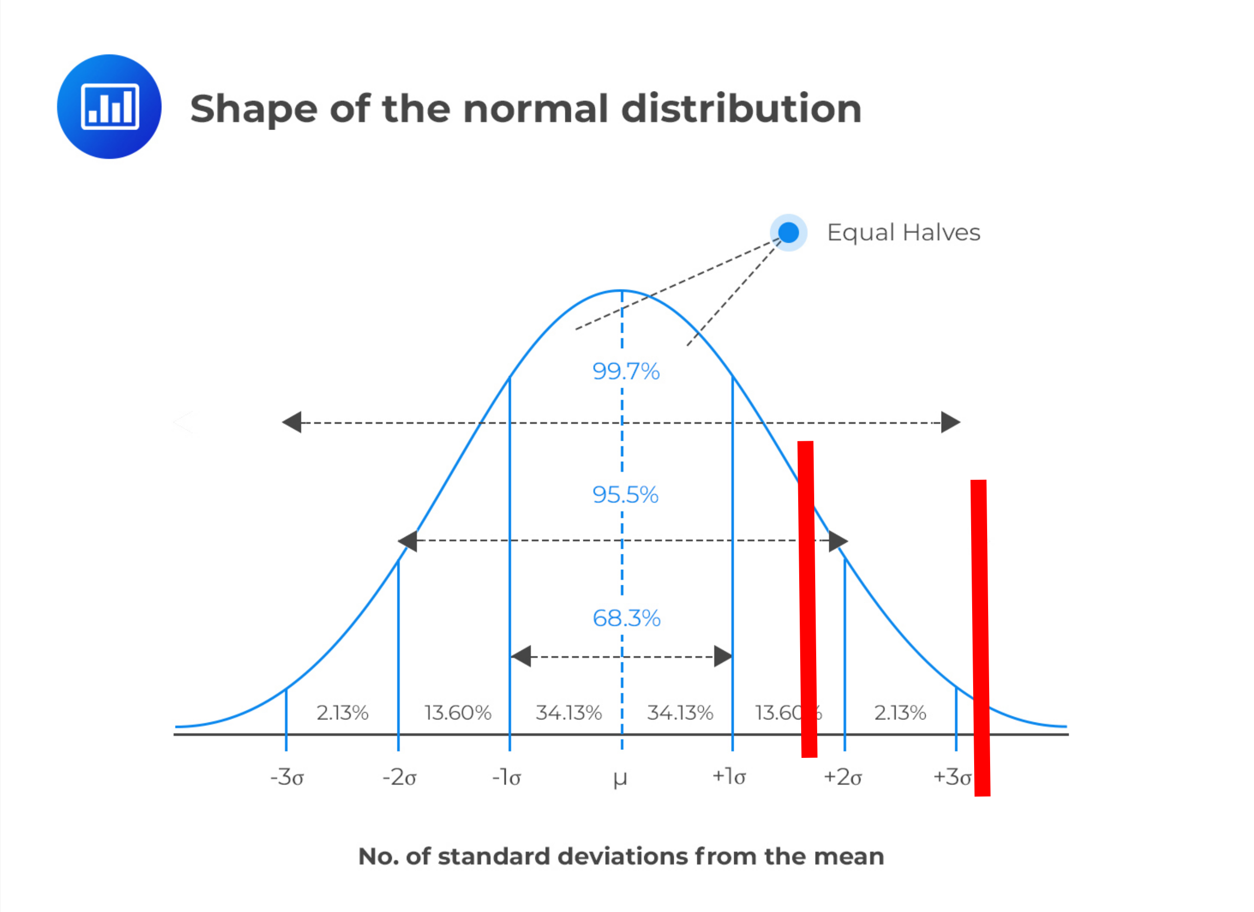


Pincer

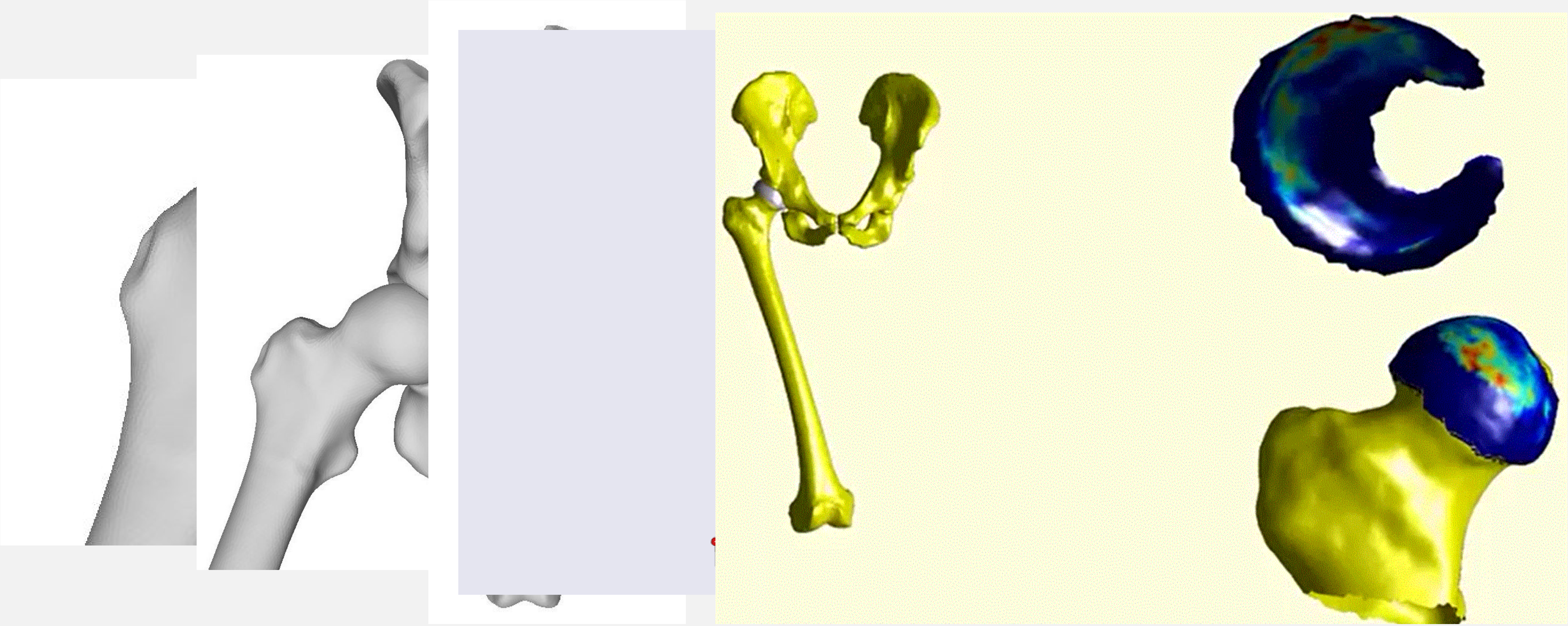


Mixed

The questions we all have



There is more than meets the eye



Aim

- Develop a pipeline for **exploring** the impact of **shape variation** and related **surgery** on **contact stresses** of the **hip** joint

1. Explore peak static and dynamic hip joint reaction forces
2. Explore hip joint contact stress patterns
3. Explore the impact of cam resection surgery on hip joint contact stress

1. Mapping Variation in Joint Reaction Forces

- Understanding hip joint loading during relevant static and challenging dynamic activities
- Experimental computational modeling design:
  - Musculoskeletal model in Anybody
  - Inverse dynamics

Static sitting configurations

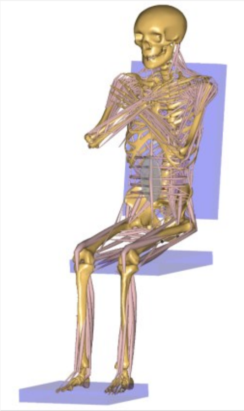
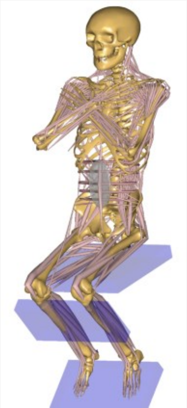
- ❑ Rationale
  - Prolonged, deep seated sitting triggers hip pain in FAI patients
  - Prominent bumps: contact > 60° hip flexion
  - Median sitting time in Western society around 5h/day
  - No data on joint loading during kneeling chair sitting
- ❑ Aim
  - Quantify resulting joint loading and required hip flexion during 3 distinct sitting configurations: Car seat – simple chair – kneeling chair

Static sitting configurations

❑M&M

- Anybody
- Average adult Caucasian male (1.74 m, 75kg)
- Validated seated application model AMMR *(Rasmussen et al, 2009)*
- Validation:
    - Orthoload HJRF library
    - 3 male subjects
    - Good agreement for chair and car seat



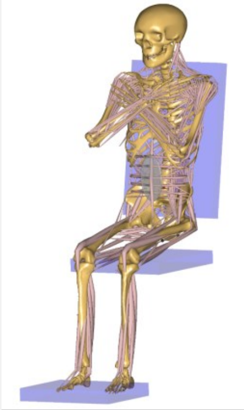
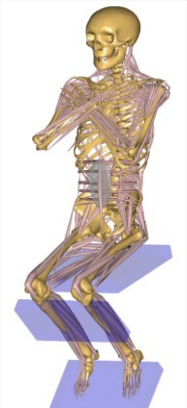





Results & conclusion*

- Chair – car seat – kneeling chair
  - HJRF: 22%BW – 22%BW – 9%BW
  - Hip flexion: 63° - 79° - 50°

- Kneeling chair:
  - Relative reduction of 50% in reaction force in kneeling chair
  - Lower hip flexion, under threshold for femoracetabular conflict
  - Greatest ergonomic potential in case of FAI




**Van Houcke et al., Computer-based estimation of the hip joint reaction force and hip flexion angle in three different sitting configurations, Applied Ergonomics, 2017*

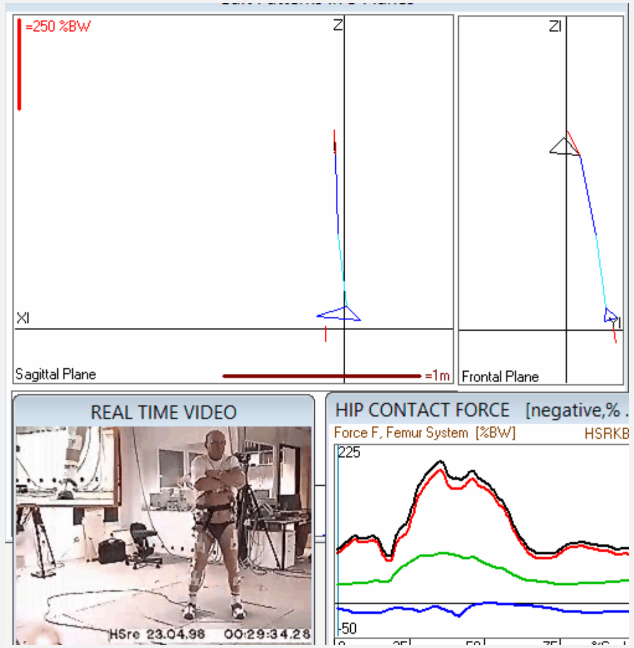
Dynamic deep squat

❑Rationale

- Available hip kinetics = Orthoload database = >60yrs

< 50° hip flexion and < 80° knee flexion

> 100° knee and hip flexion



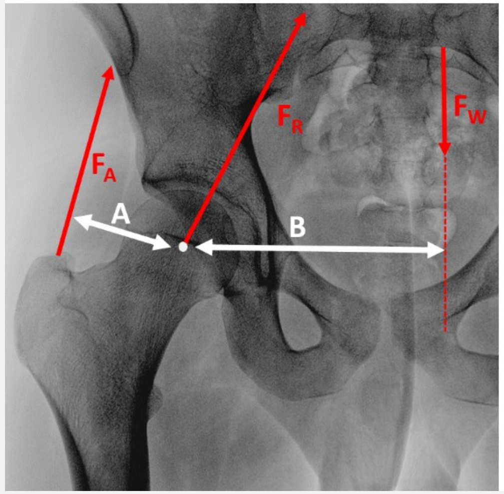
vs

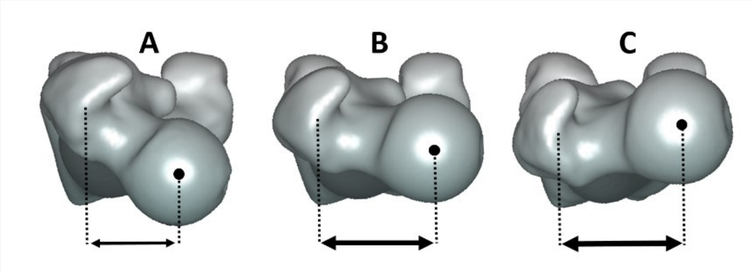
Bergmann et al., 2001, Journal of Biomechanics

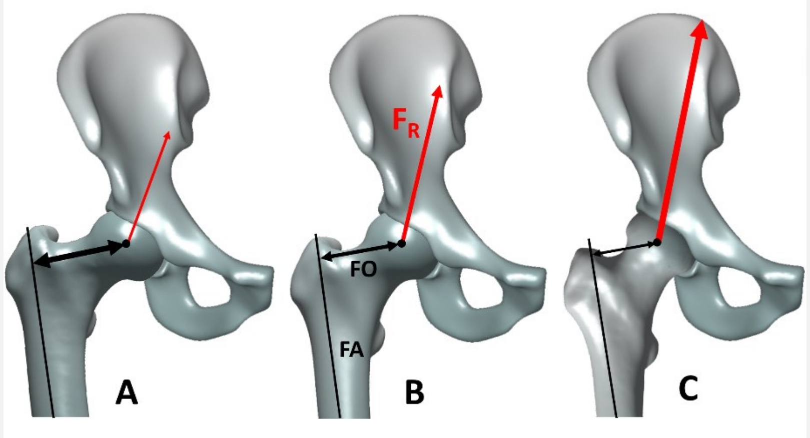
Dynamic deep squat

❑Rationale

- Anatomical extra-articular variation
  - Varus valgus
  - Femoral version
  - Pelvic width
  - …







Aim

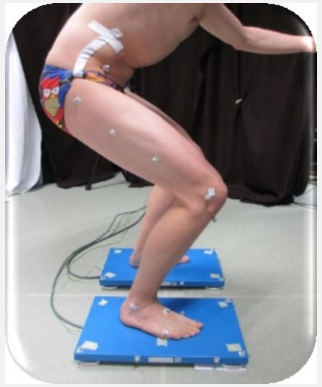
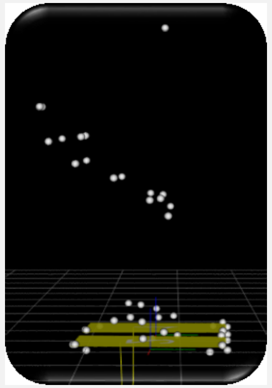
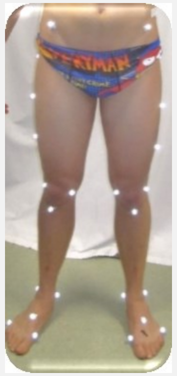
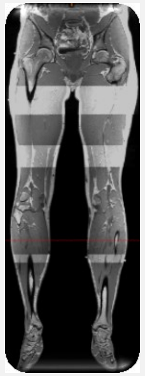
- Report functional ROM and hip joint loading in young athletic males
- Provide personalized model solution for estimating hip joint loading during deep squat

M&M

❑ Data collection

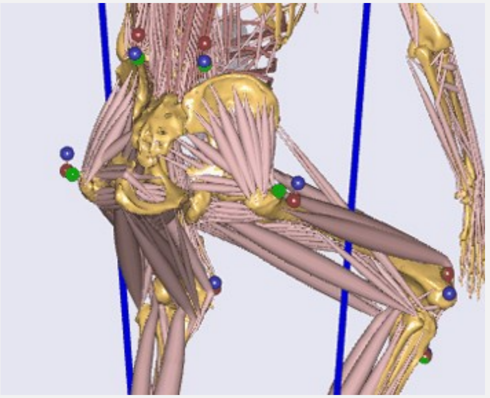
- Athletic males (18-25 yrs old)
- Exclusion criteria:
  - history of hip pain/surgery
  - inflammatory/neuromuscular joint diseases
  - FADIR+ and/or FABER asymmetry >5cm

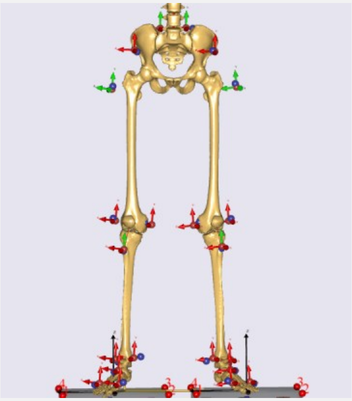
- Maximal squat gaitlab (OptiTrack®, Kistler®)
- MRI lower limb + skin marker position
- Segmentation pelvis, femur, shank
  Position skin marker relative to bones

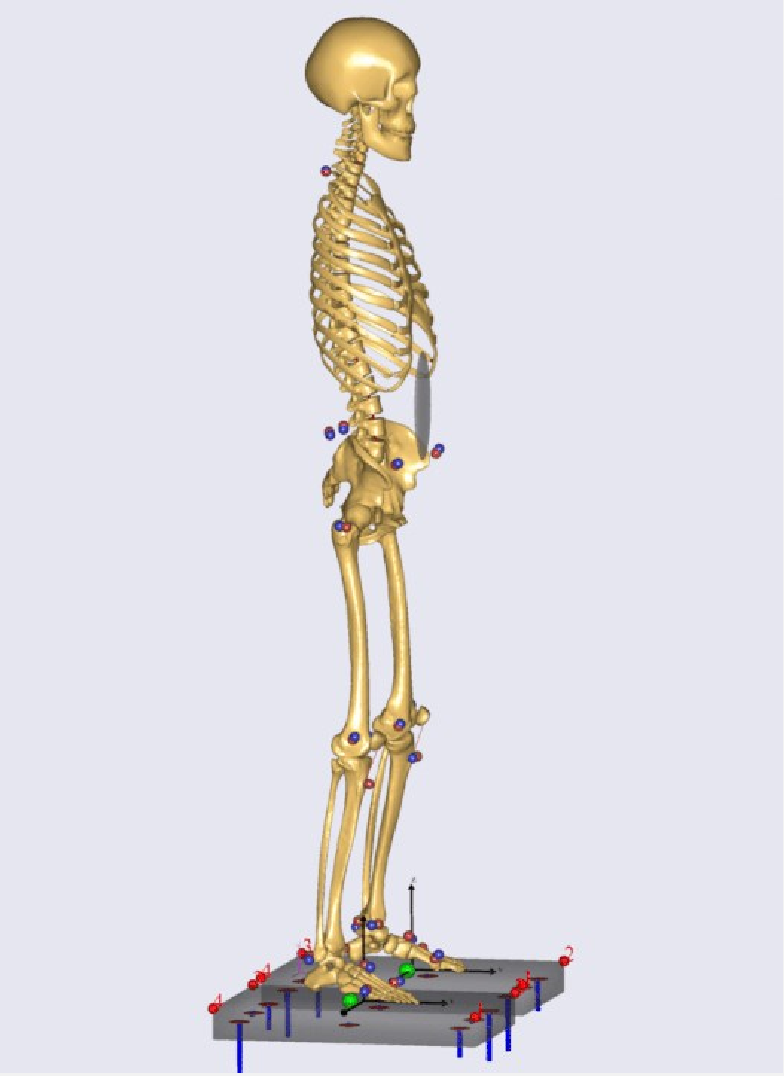





M&M

- ❑Data analysis
- AnyBody Modelling System
- TLEM 2.0 muscle definitions
- Gluteal wrapping definition
- Inverse Dynamics - Polynomial solver
- Morphed muscle-bone geometry
- Direct skin marker position from MRI







M&M

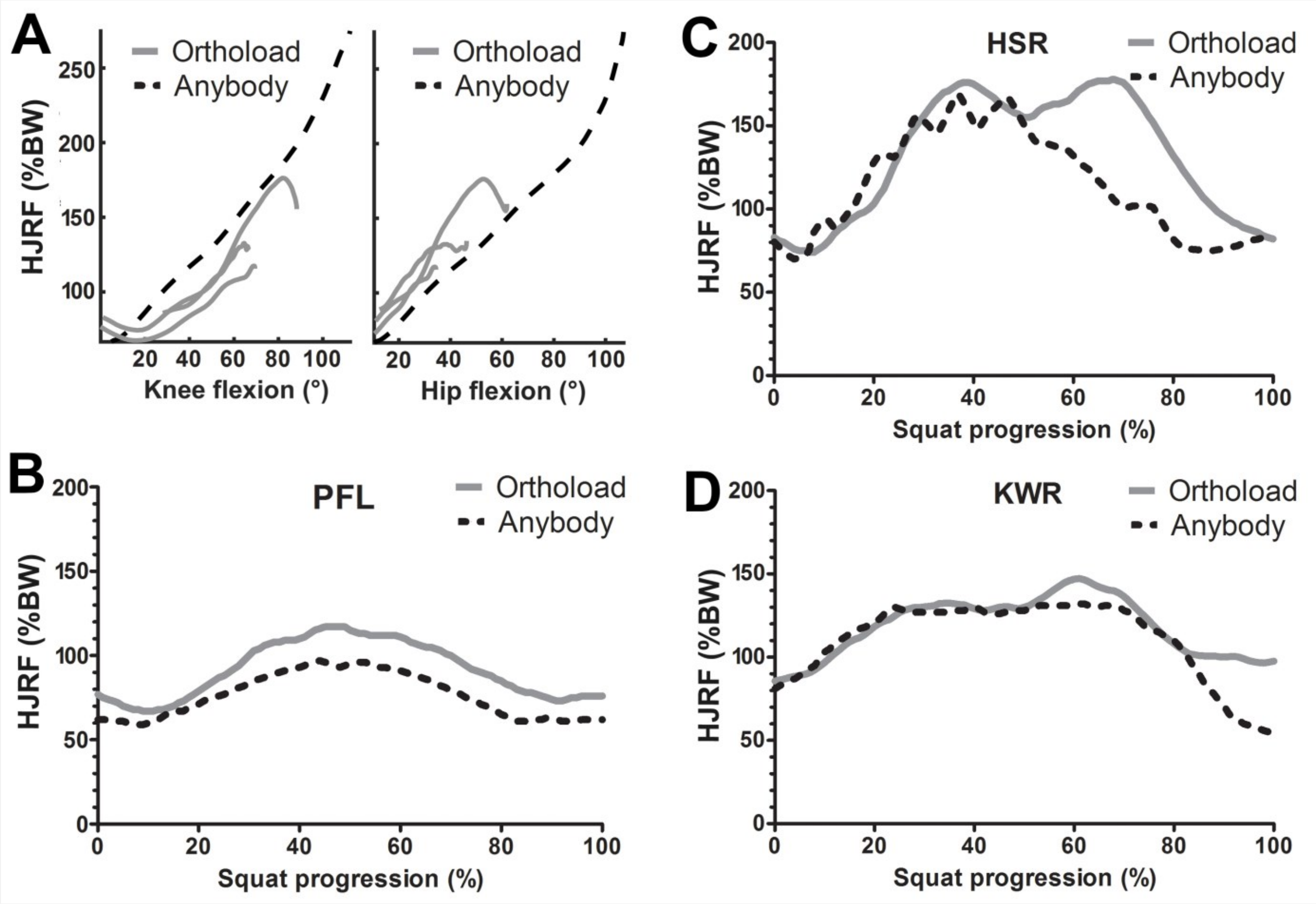
❑NORMALIZATION

- Reaction forces in % bodyweight
- Squat deepest point = peak knee flexion at 50% - quadratic interpolation
- Squat time – PLS regression

❑VALIDATION

- Orthoload
- Knee Bend trials
- Hip joint reaction force, hip flexion and knee flexion

Results

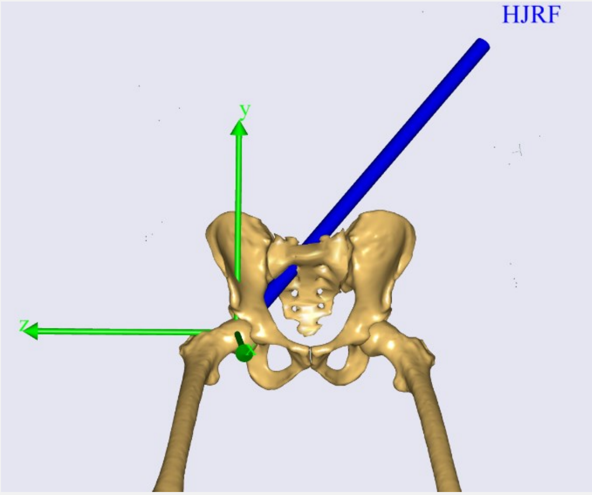

A
Orthoload
Anybody
HJRF (%BW)
Knee flexion (°)
Hip flexion (°)
B
PFL
Squat progression (%)
C
HSR
D
KWR

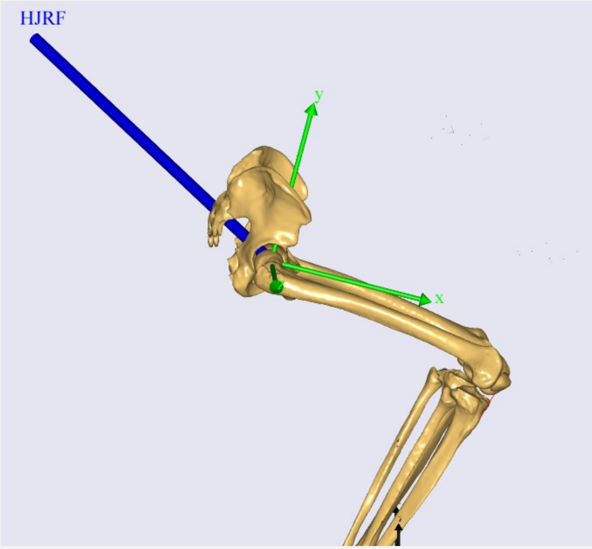
Results

Table 1. Demographics, anthropometrics and kinetical results during full squat cycle from study group of 35 young, athletic subjects.

	Mean (95 CI)
Age (years)	21.9 (21.2–22.7)
Height (cm)	182 (180–184)
Weight (kg)	70.7 (68.0–73.4)
BMI (kg/m^2)	21.4 (20.8–22.0)
Sports (hours per week)	3.8 (3.1–4.5)
Neck-shaft angle (°)	129.6 (128.0–131.2)
Femoral version (°)	9.5 (7.0–11.9)
Duration squat (s)	4.2 (4.17–4.24)
Peak knee flexion (°)	112 (108.1–116.5)
Peak hip flexion (°)	107 (104.6–109.4)
Peak anterior pelvic tilt (°)	27 (24.2–30.2)
Peak hip abduction (°)	17 (15.1–19.6)
Peak hip internal rotation (°)	11 (9.0–13.6)
Peak hip joint reaction force (%BW)	274 (251.5–297.9)
Peak hip extension moment (Nm/kg)	0.56 (0.506–0.617)
Peak hip adduction moment (Nm/kg)	0.22 (0.184–0.248)
Peak hip internal rotation moment (Nm/kg)	0.12 (0.081–0.151)

95CI: 95% confidence interval between brackets. The neck shaft angle (Boese et al. 2016) was defined as the angle between the femoral neck axis (line connecting the centre of best fitting sphere of the femoral head and the centre of the femoral neck) and the anatomical femoral shaft axis (line connecting the centres of the best fitting circle of the proximal and distal diaphyseal femur). The femoral version (Victor et al. 2009; Casciaro and Craiem 2014) was defined as the angle between the femoral neck axis and the femoral transverse axis (line connecting the centres of the best fitting spheres of the medial and lateral femoral condyles).



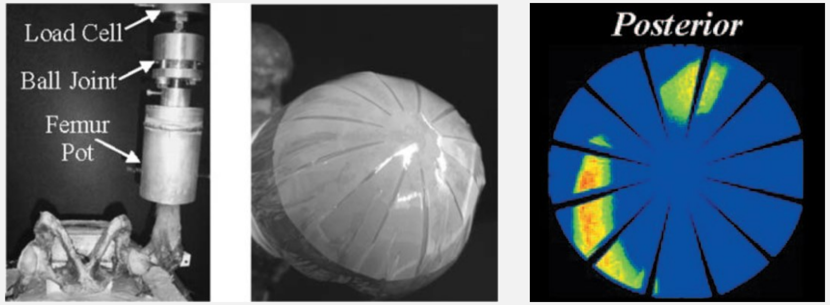


Conclusion*

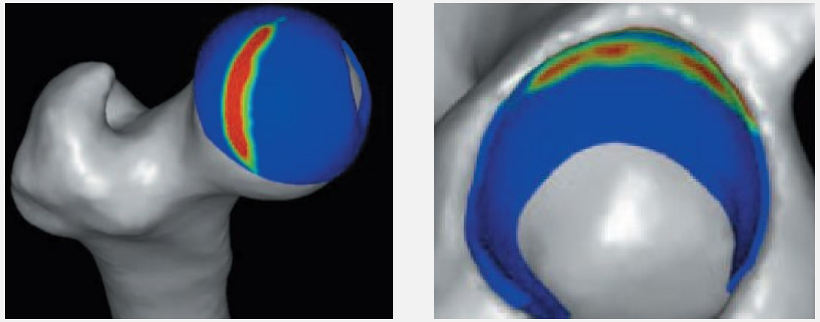
- Hip joint kinetics young athletic adult ≠ THA middle aged patient
- Enables personalized kinetical evaluation of extra-articular variation
- Milestone for population wide modelling

**Van Houcke et al., Personalized hip joint kinetics during deep squatting in young, athletic adults, Comput Methods Biomech Biomed Engin, 2019*

2. Mapping Variation in Cartilage Stress



- Rationale
  - Contact stress in the hip joint
    - In vitro: cadaveric experiments
      - Expensive, in vivo unfeasible
    - In silico: Finite Element Analysis (FEA)
      - Accurate but time consuming and CPU intensive
  - Cartilage geometry
    - Manually segmented outperforms parametric
      - Very labour intensive



- Aim
- Develop and validate straightforward tools for evaluation of hip joint stresses

M&M

- Population-averaged cartilage anatomy prediction:
  - Cartilage thickness defined per node on the acetabular/femoral surface
  - Extrusion along surface normal
  - Based on 10 manually segmented cartilage geometry
  - Comparison with parameterized alternatives:
    - Constant thickness
    - Spherical fit

- Discrete element analysis (DEA)
  - 2 layer spring model
  - Only compressive forces, non-linear and linear
  - Verification and validation

M&M

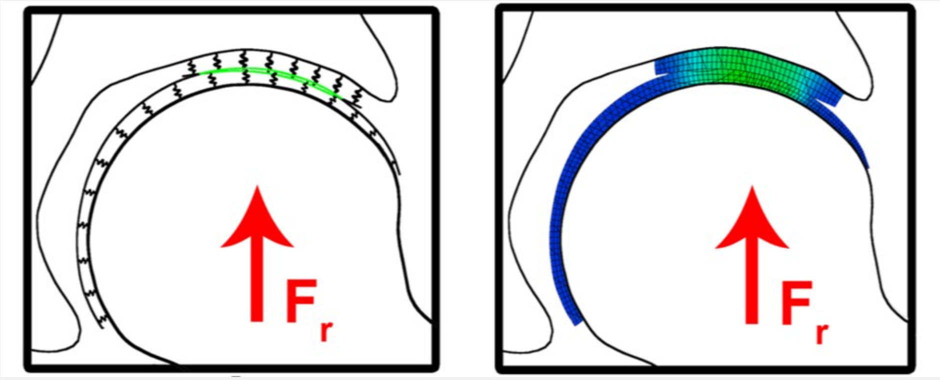
- Validation study group*:
  - 10 healthy adults; reconstructed CT hip joint morphology
  - 3 Orthoload loading scenarios: Heel strike during walking, ascending and descending stairs
  - FEA evaluation with manually segmented cartilage geometry

- Evaluation of:

  Golden standard FEA with manually segmented cartilage

  versus

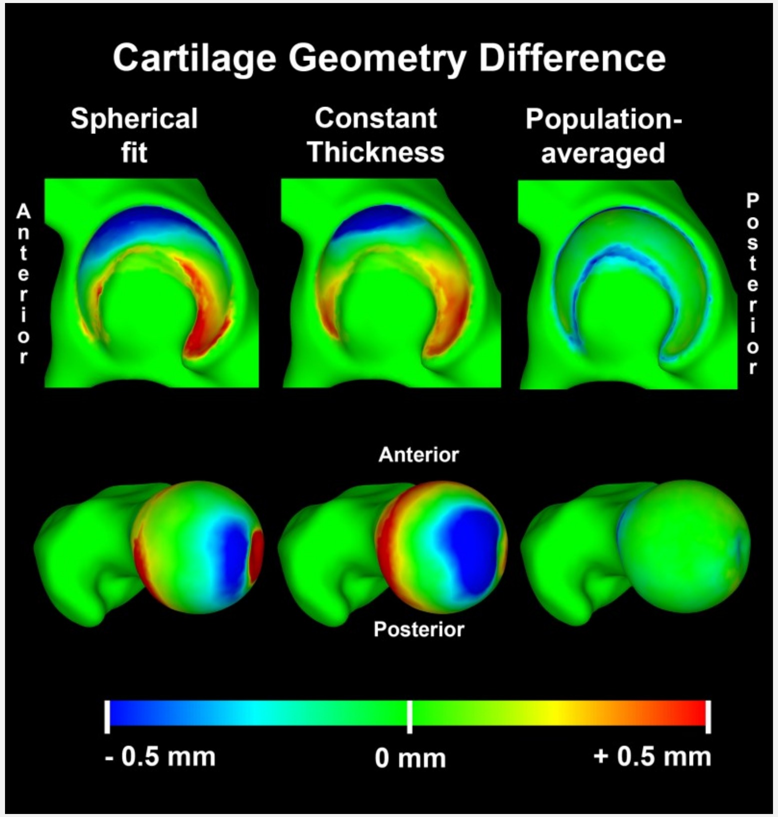
  DEA with automatically predicted cartilage geometry



Harris et al., Finite element prediction of cartilage contact stresses in normal human hips, J. Orthop. Res., 2012

Results

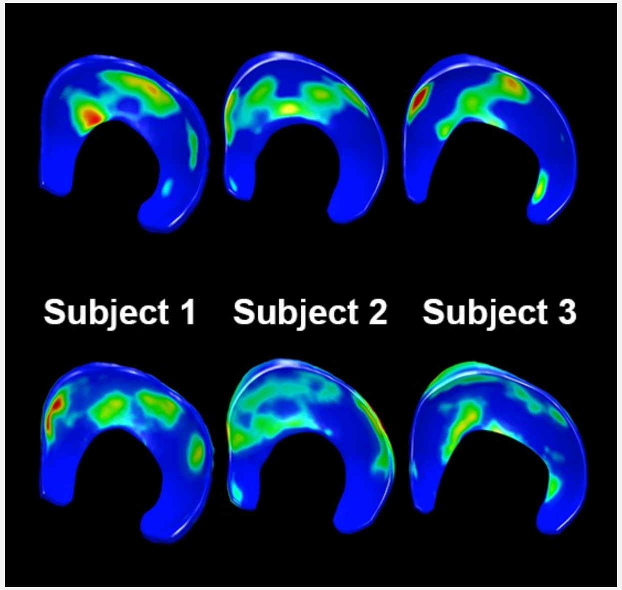
Cartilage prediction: RMSE 0.31 ±0.08 mm



Autom DEA+cart pred

vs

Manual FEA



- Peakstress ≠ : 1.68 ± 2.63 MPa
- Contact area ≠ : -20.6 ± 7.4 %
- 50sec vs one hour

Conclusion*

- DEA with population averaged cartilage prediction method offers a suitable alternative compared to subject-specific FEA models
- Consistent underestimation of contact area and overestimation of peak and average contact stress
- Important computational advantage

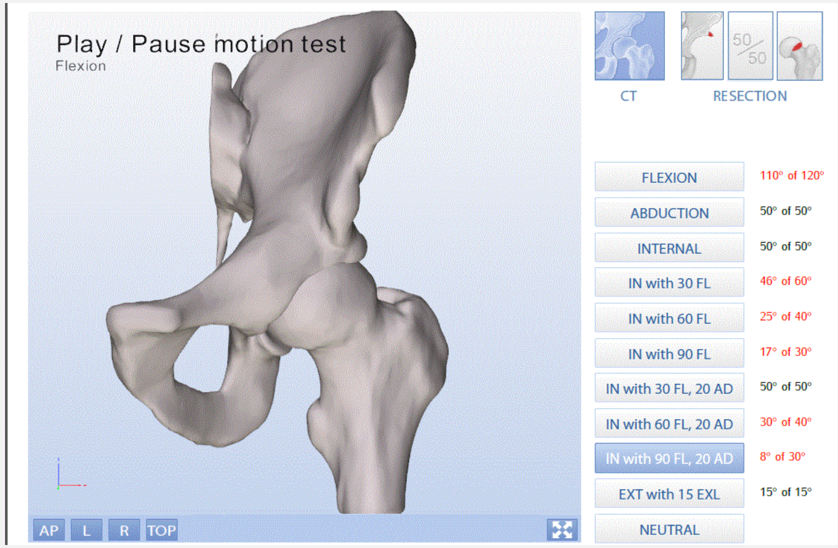
**Van Houcke et al., A combined Geometric Morphometric and Discrete Element Modeling Approach for Hip Cartilage Contact Mechanics, Frontiers in Bioengineering and Biotechnology, 2020*

3. Clinical translation

❑Rationale

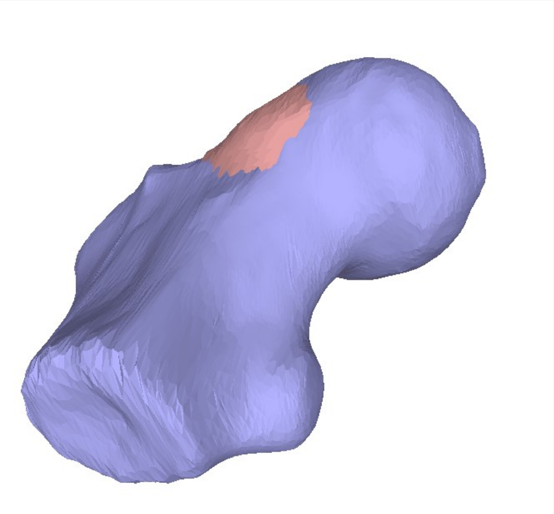
- Cam FAI associated with hip OA
- Cam resection surgery aimed to alleviate pain and prevent/delay hip OA

- Current state of the art:
  - ROM collision simulation
  - Planning resection volume and area
  - No information cartilage stresses



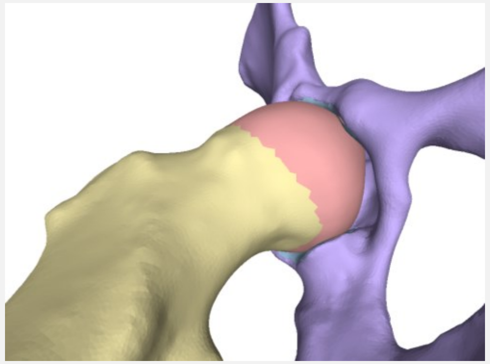
❑Aim

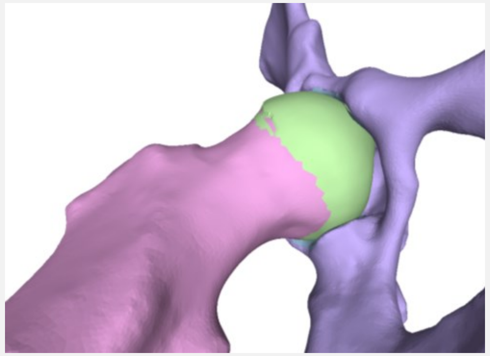
- Evaluate contact mechanical impact of cam resection in cam FAI patients

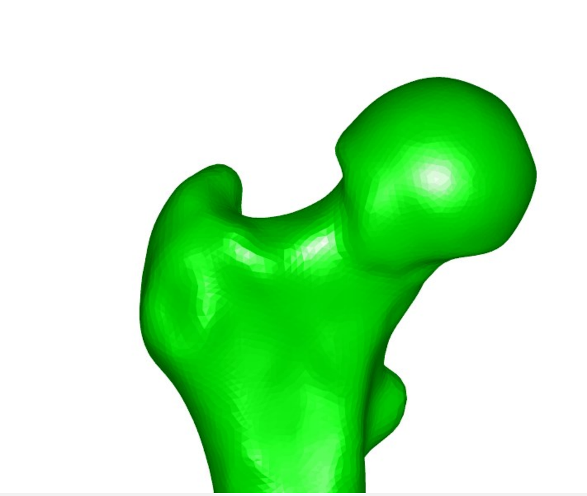


M&M

- Case-control study design
  - 10 cam FAI patients (male, 18-40yrs old, Alpha-angle >55°)
  - Impingement test loading
  - Patient-specific discrete element models of
    1. Preoperative cam
    2. Postoperative cam resection
    3. Matched virtual control

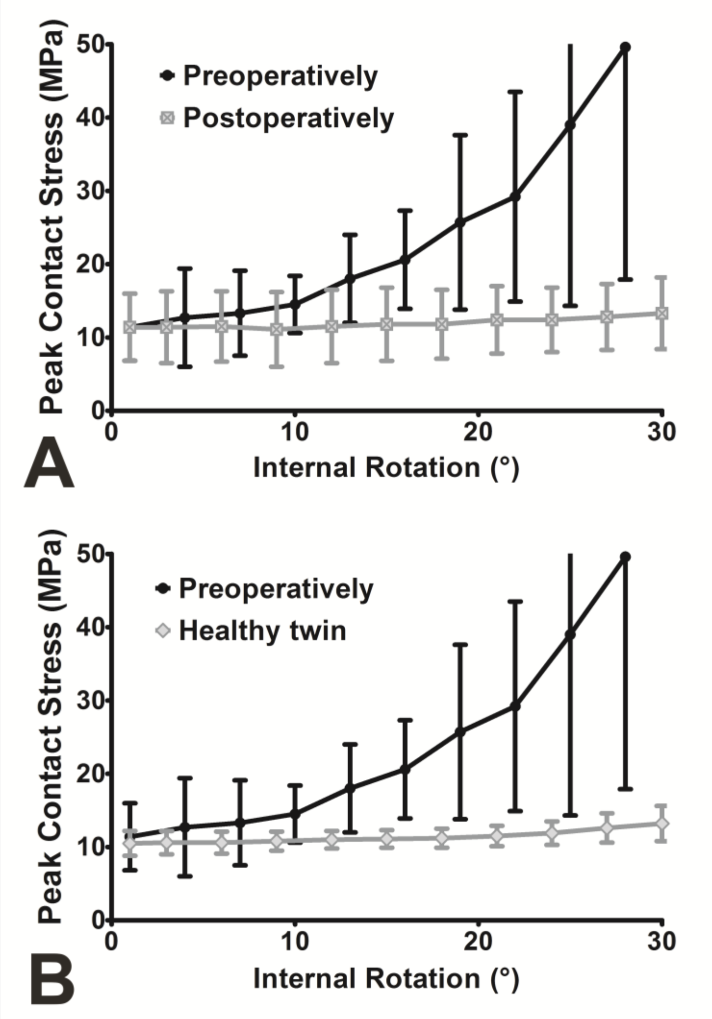






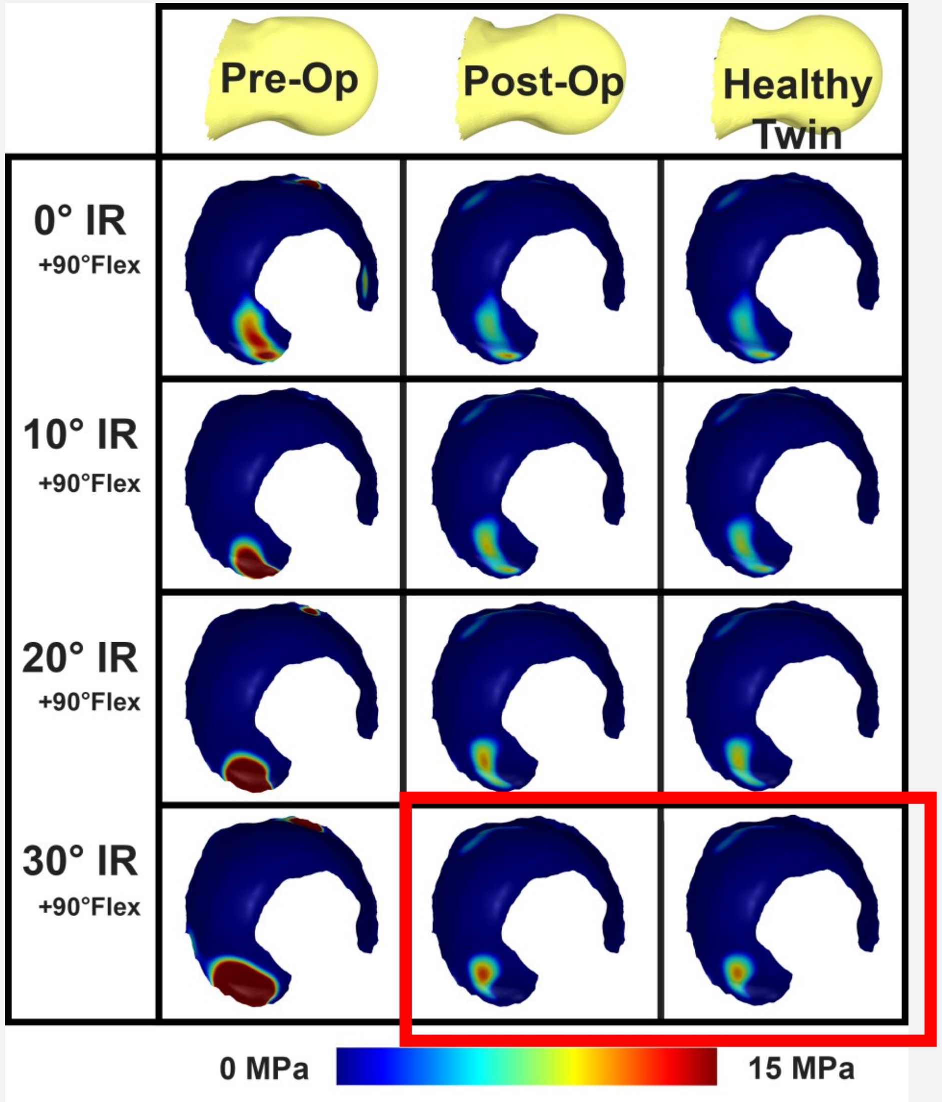
Results

	Preoperative (n = 10)	Postoperative (n = 10)	Healthy Twin (n = 10)
Alpha angle (°)			
12 o’ clock	57.4 (50.0-64.8)	44.6 (42.9-46.3)**	43.3 (40.9-45.7)**
1 o’ clock	73.7 (70.6-76.8)	49.3 (47.8-50.8) ***	47.4 (45-49.8)***
2 o’ clock	69.3 (66.0-72.6)	46.2 (43.9-48.5) ***	45.6 (42.1-49.1) ***
3 o’ clock	56.3 (51.7-60.9)	47.6 (44.4-50.8) ***	42 (37.9-46.1) ***
Peak contact stress (MPa) in 90° hip flexion and increasing degrees of internal rotation			
0° IR	11.3 (8.5-14.1)	11.2 (8.4-14.0)	10.4 (9.4-11.4)
5° IR	12.4 (9.2-15.7)	11.5 (8.5-14.5)	10.7 (9.7-11.6)
10° IR	14.5 (12.1-16.9)	11.2 (8.0-14.3)	11.0 (10.2-11.7)*
15° IR	19.9 (15.6-24.2)	11.8 (8.7-14.9)**	11.1 (10.3-11.8)**
20° IR	26.6 (19.4-33.8)	12.1 (9.2-14.9)**	11.4 (10.5-12.2)**
25° IR	39.0 (23.7-54.2)	12.4 (9.7-15.1)**	12.2 (11.1-13.2)**
30° IR	60.9 (34.0-87.9)	13.3 (10.3-16.3)**	13.2 (11.7-14.7)**



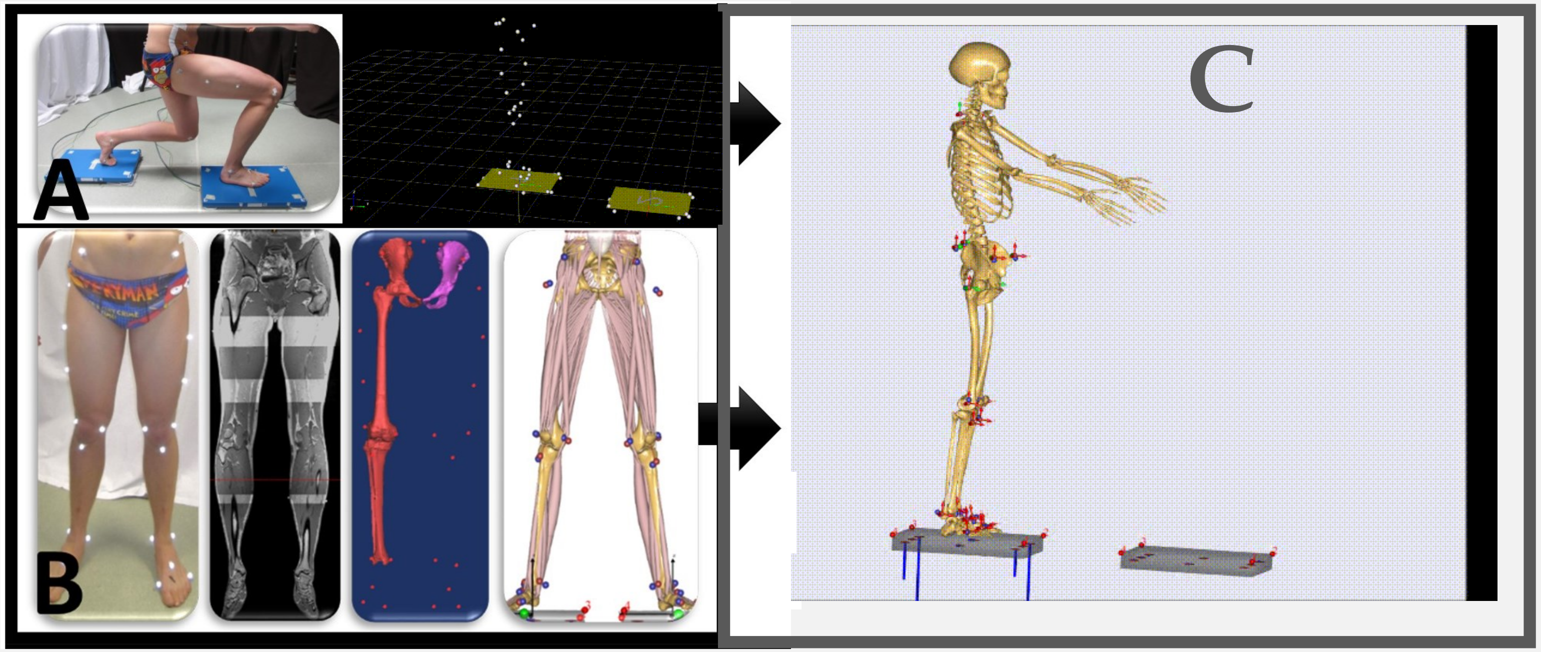
Results & conclusion

- Complete and accurate resection of a cam deformity can restore healthy articular cartilage contact mechanics
- This cannot be extrapolated in the presence of extensive articular cartilage damage and therefore does not allow for long term outcome predictions



Future perspectives

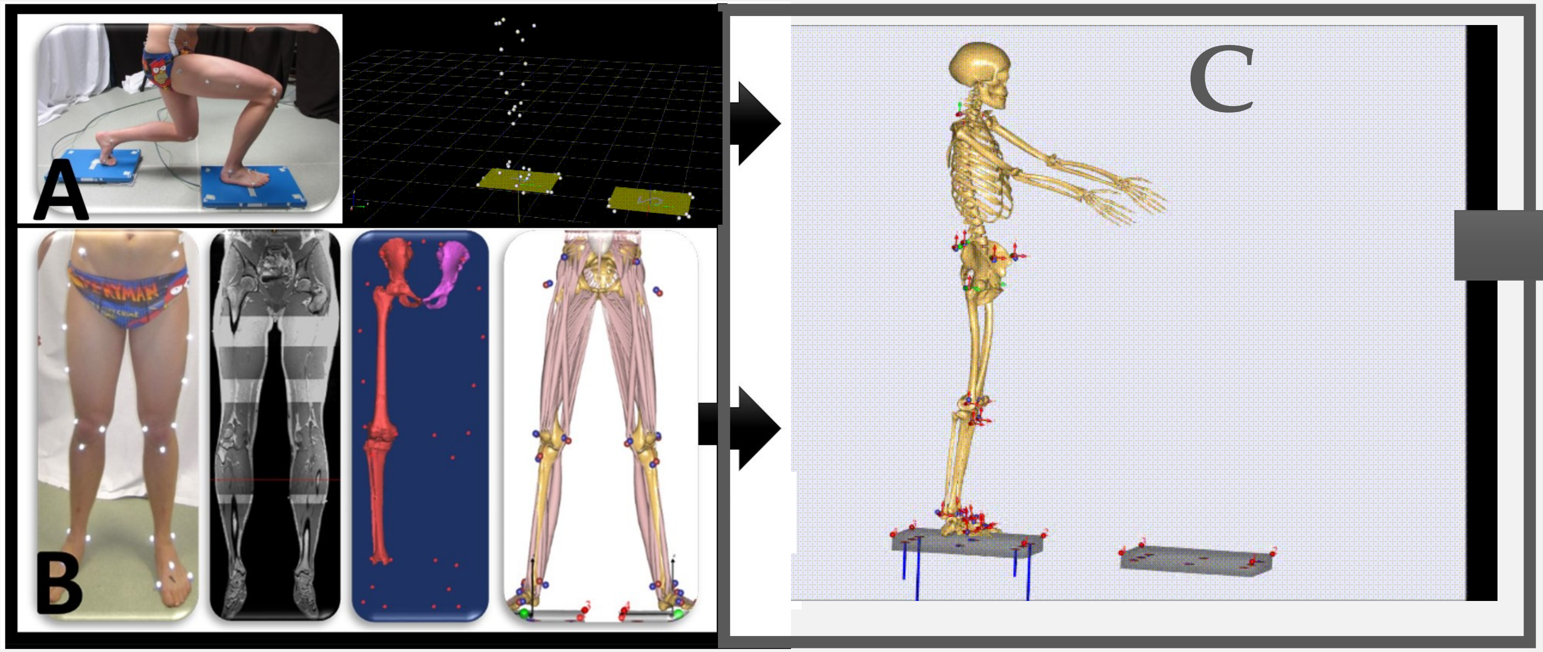
- Lunge



Future perspectives

- Lunge

AnyBody output



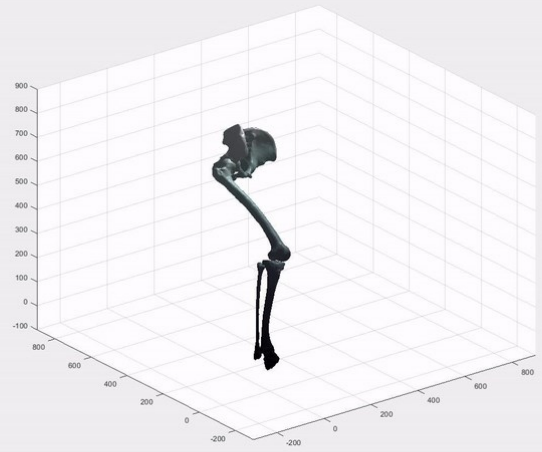
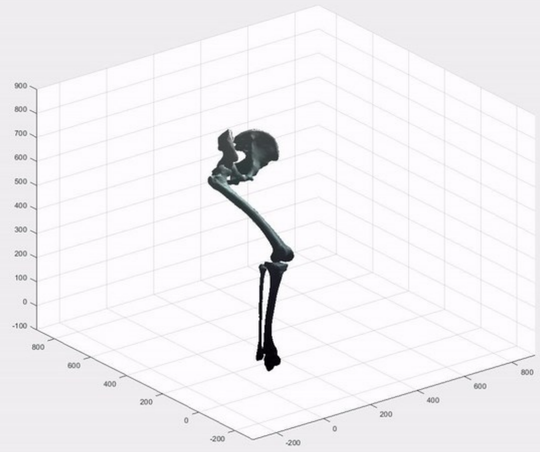
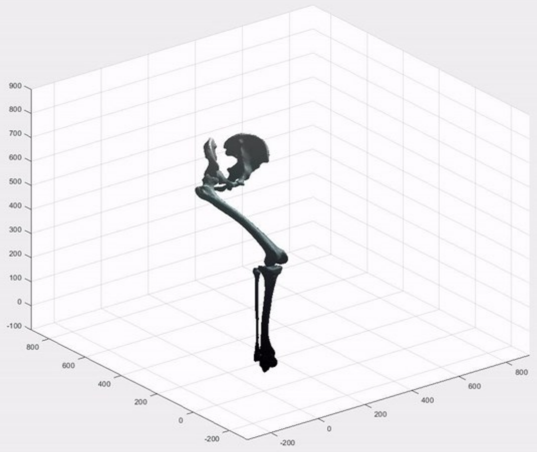
Non-linear data
Hip
flexion/abduction/rotation
Knee flexion
Ankle flexion

Post-processing: searching modes of variance (MoV)

Principal component analysis on residuals to analyse
inter-subject variance

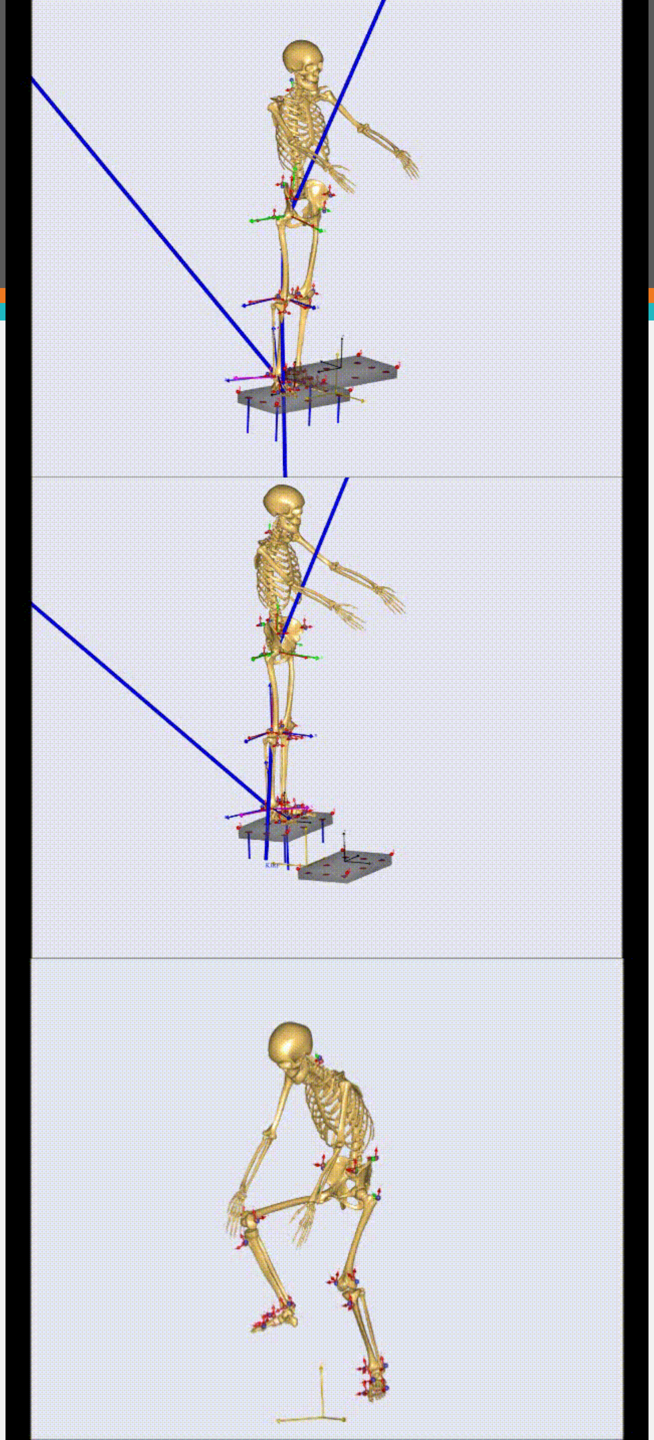
Statistical model of lunge

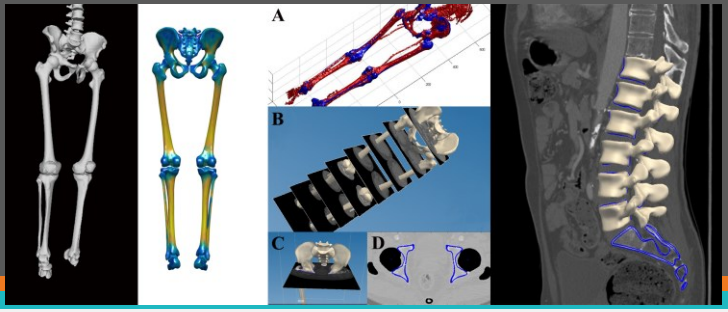
- First mode: lunge depth
- Second mode: internal rotation and adduction during lunge
- Third mode: variation in ankle dorsiflexion during lunge

Mean – 2 standard deviations component	**Mean**	**Mean + 2 standard deviations component**
		

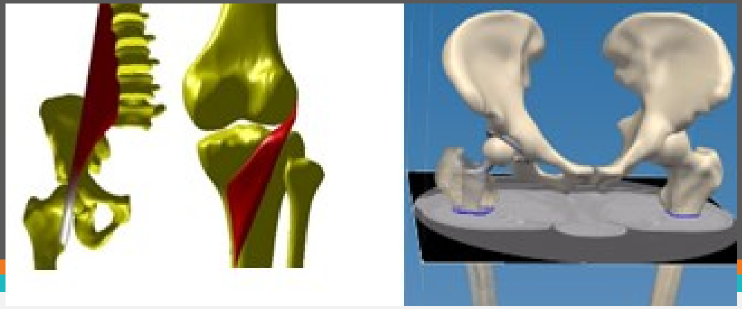
Future Kinetics of

- Upstairs/downstairs
- Cycling in different positions

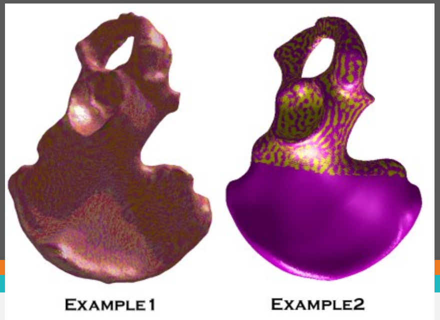




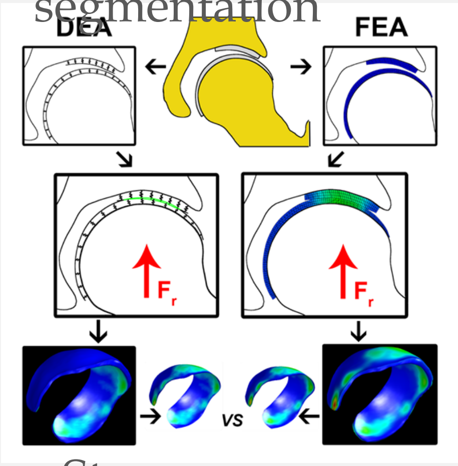
Automated segmentation



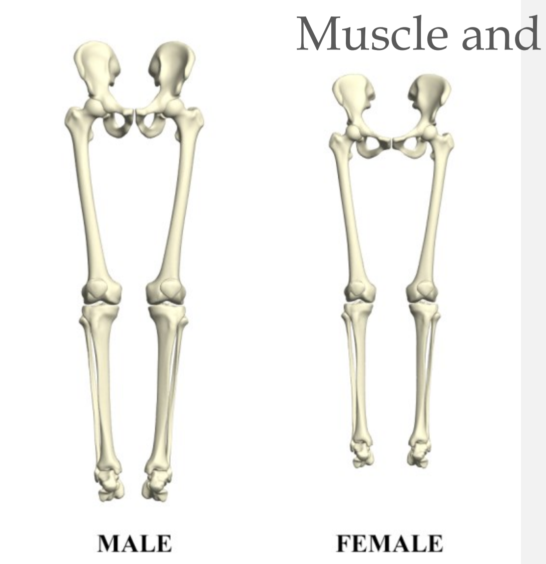
Muscle and ligament wrapping



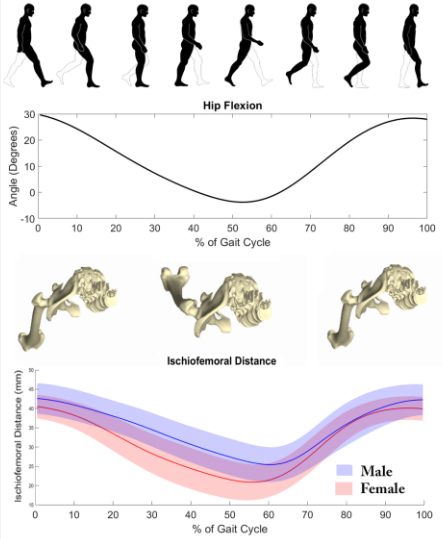
Nonrigid registration



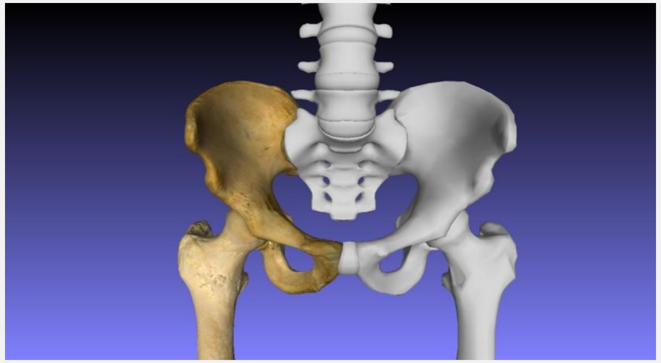
Stress



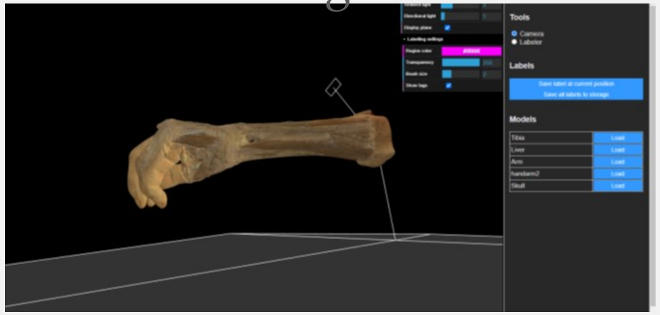
Gender specific shape analysis

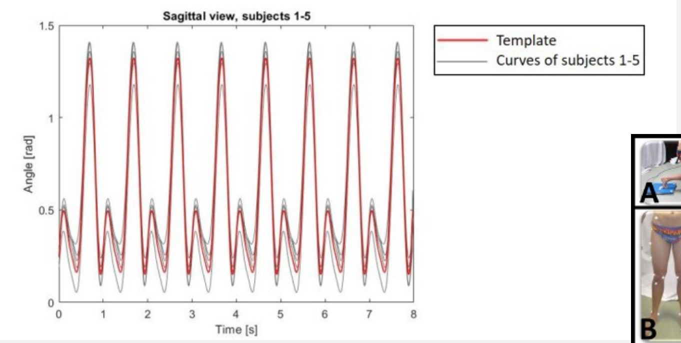


Monte Carlo Sampling Virtual Population Simulations

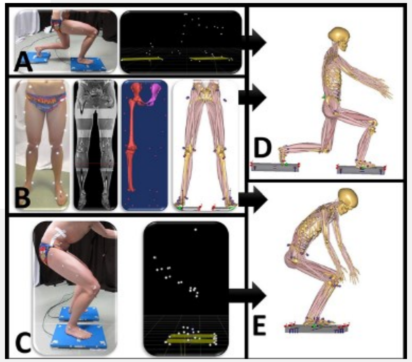


Anatomical Modelling

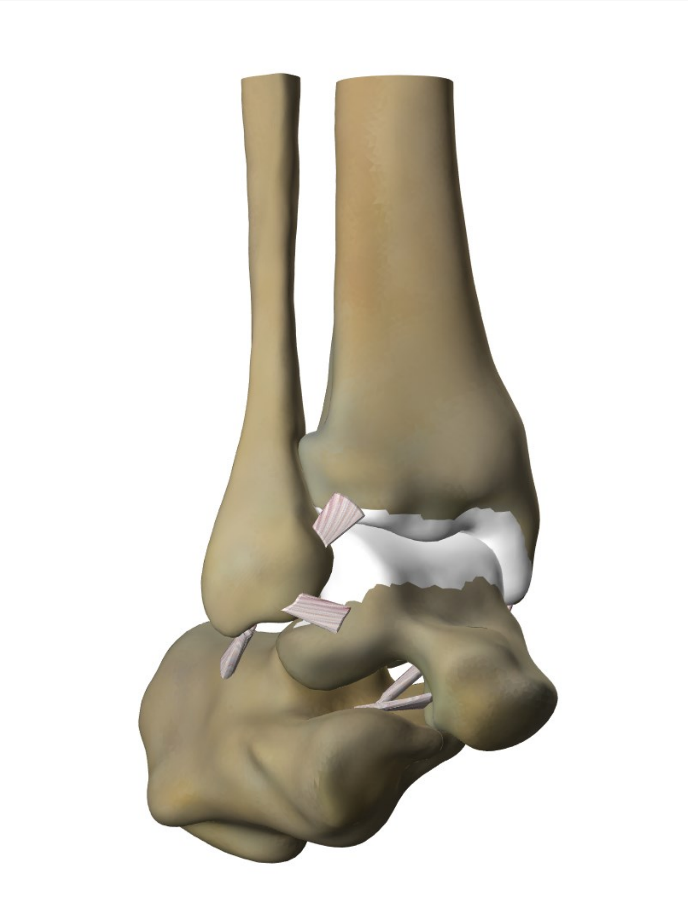


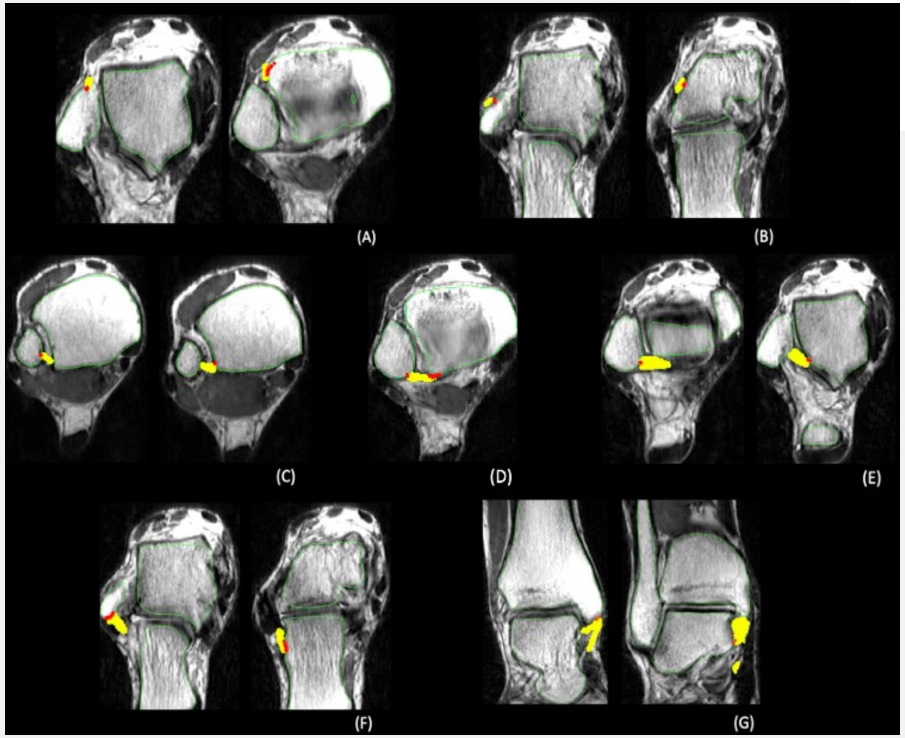


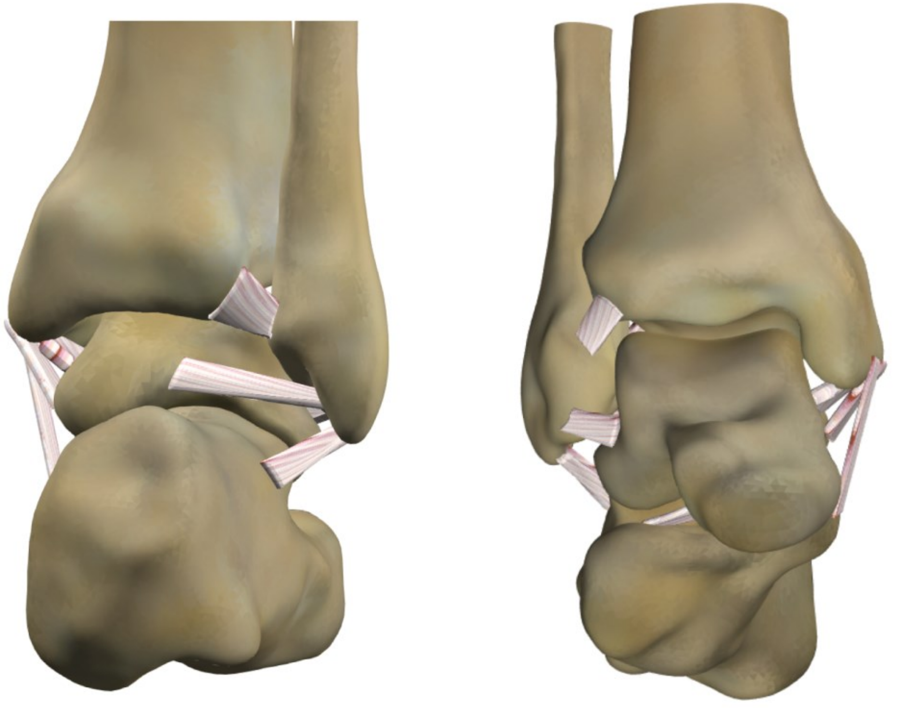
Statistical Kinematic Models

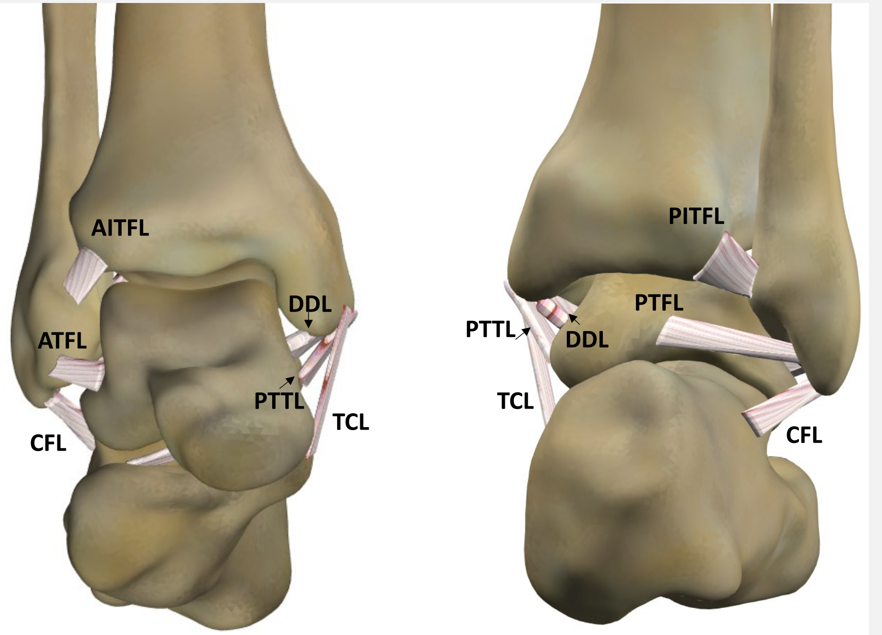


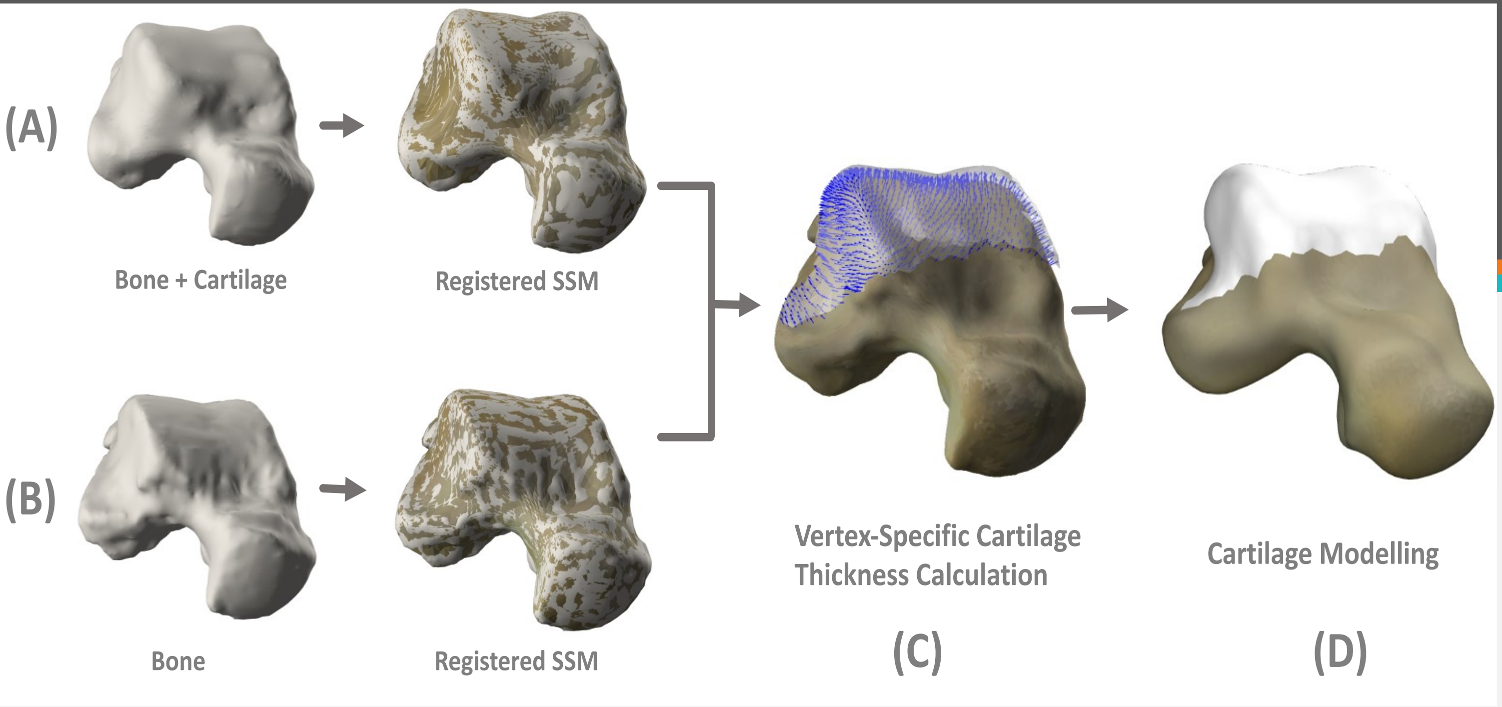
Combined SSM-DEA Ankle

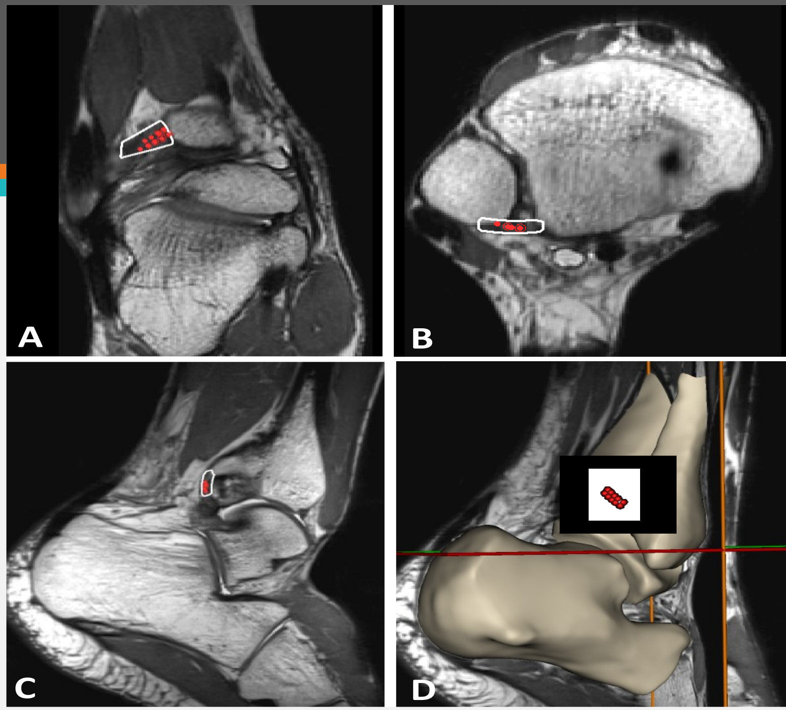








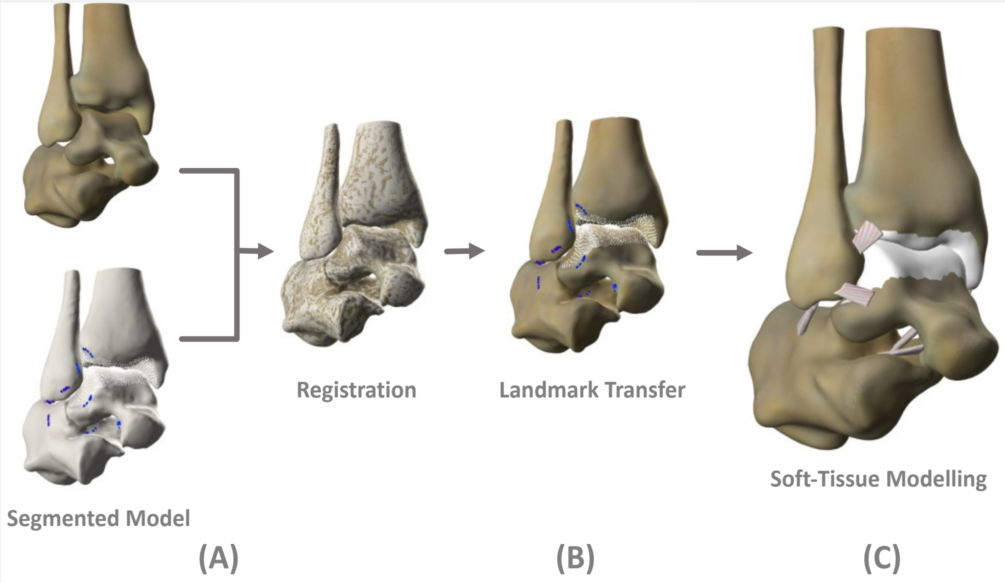


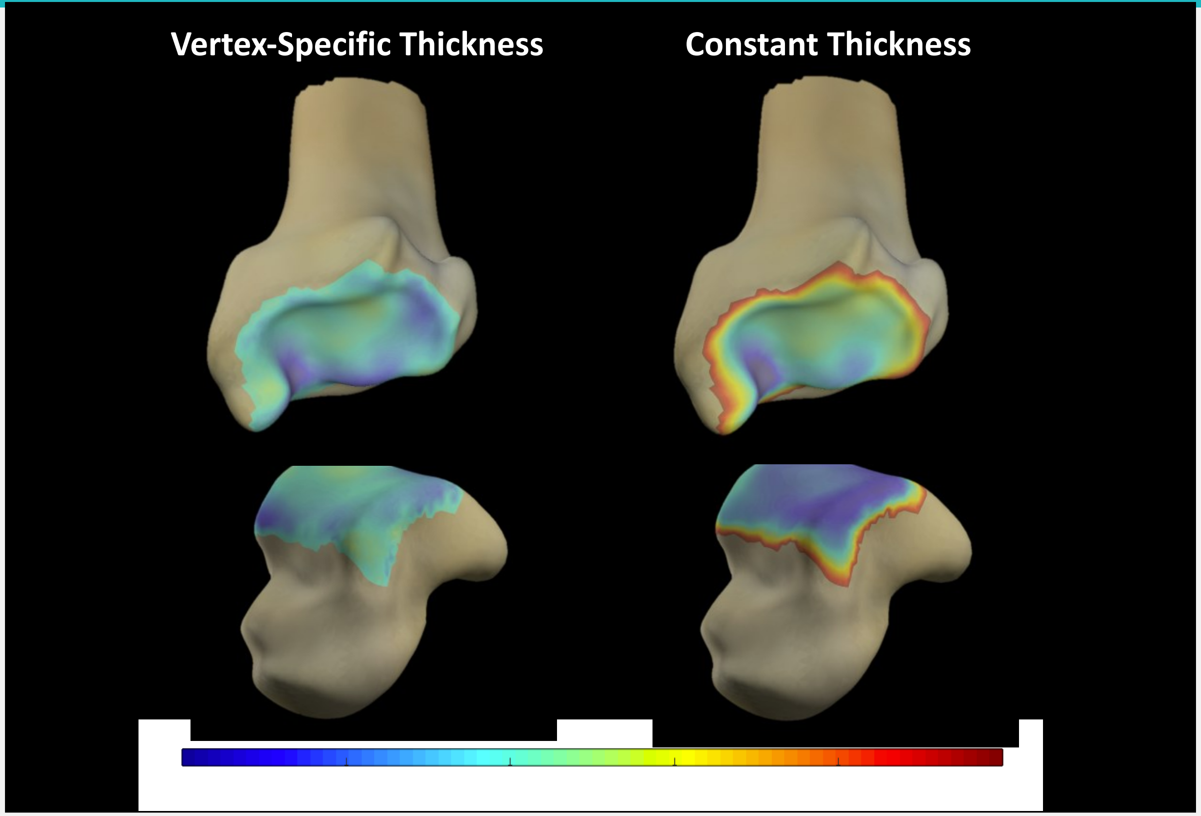


- Force dependent kinematics

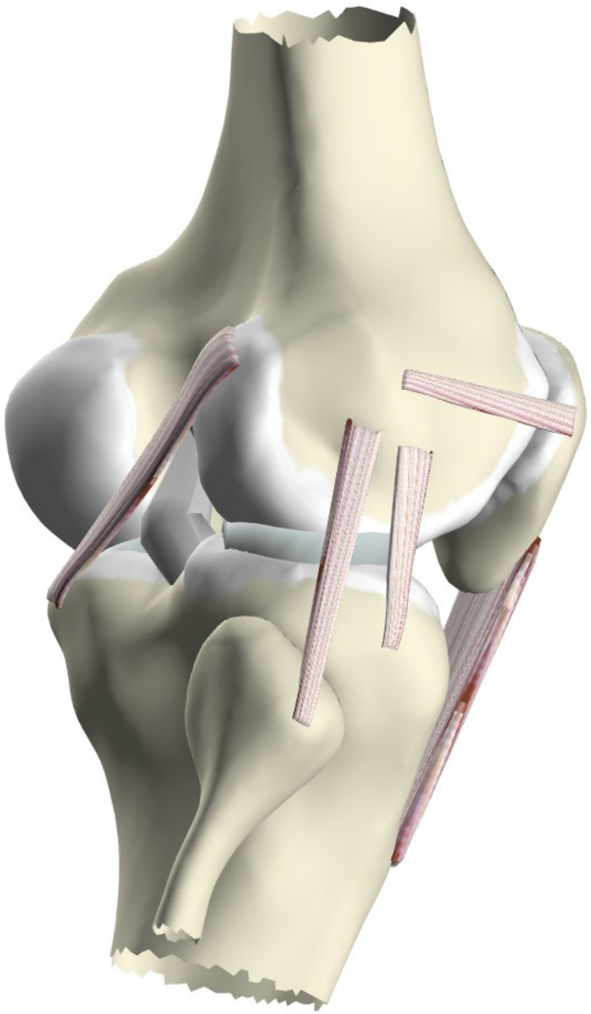
vs

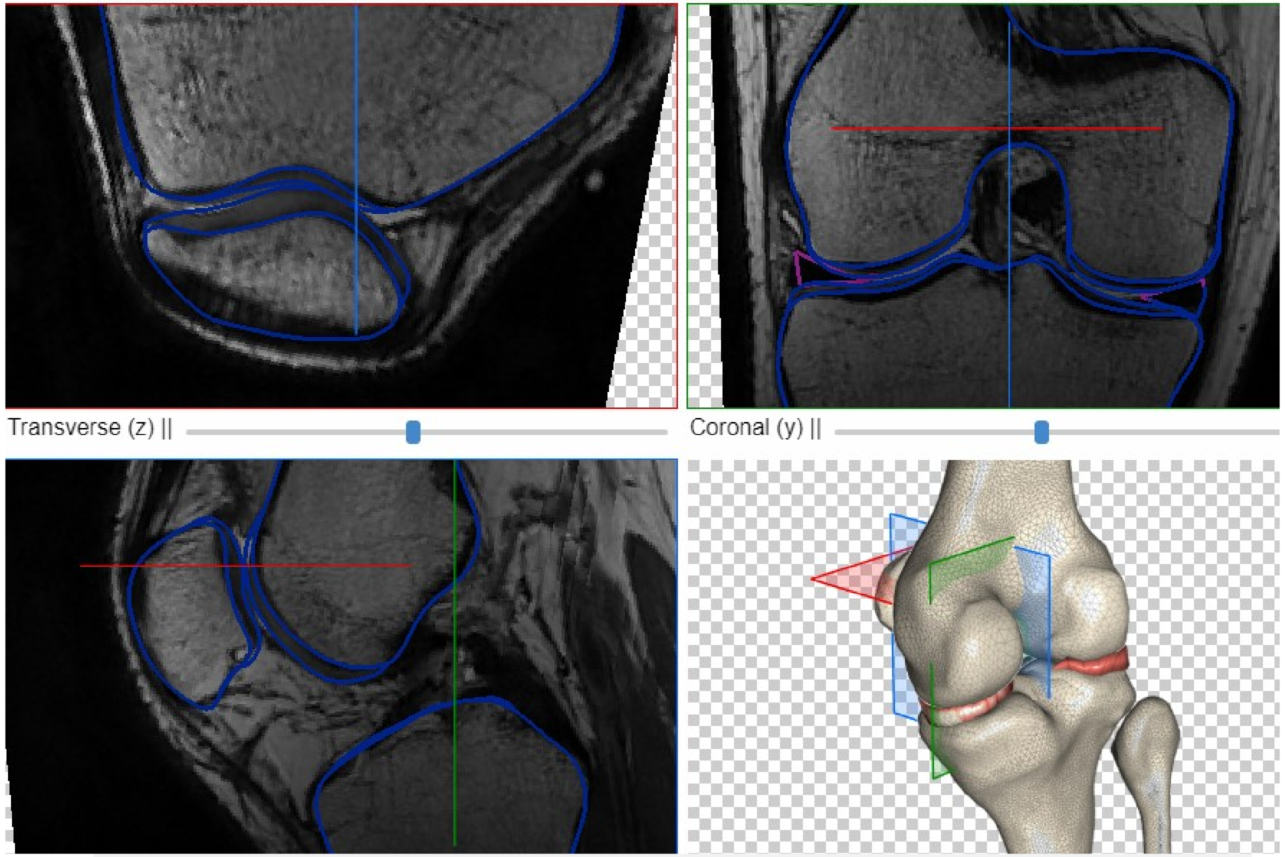
Shape dependent kinematics

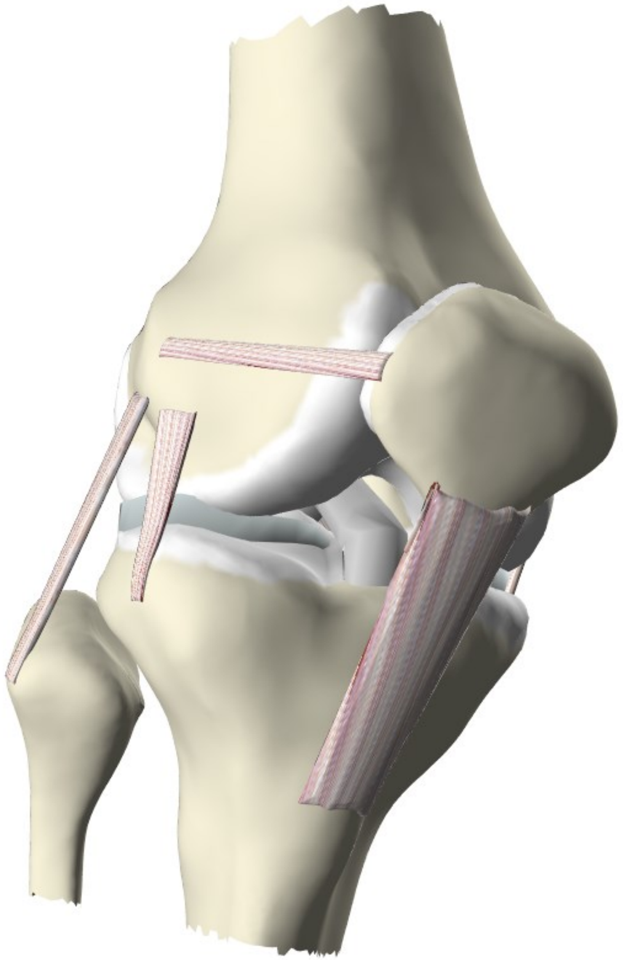



Vertex-Specific Thickness
Constant Thickness

Combined SSM-DEA Knee







Future

- Personalized identification of hip at risks for OA
- Planning for surgical femoroplasty-reorientational osteotomies

- Evaluation of daily life activity kinetics
- Integration in statistal population wide models

Thank you for your attention