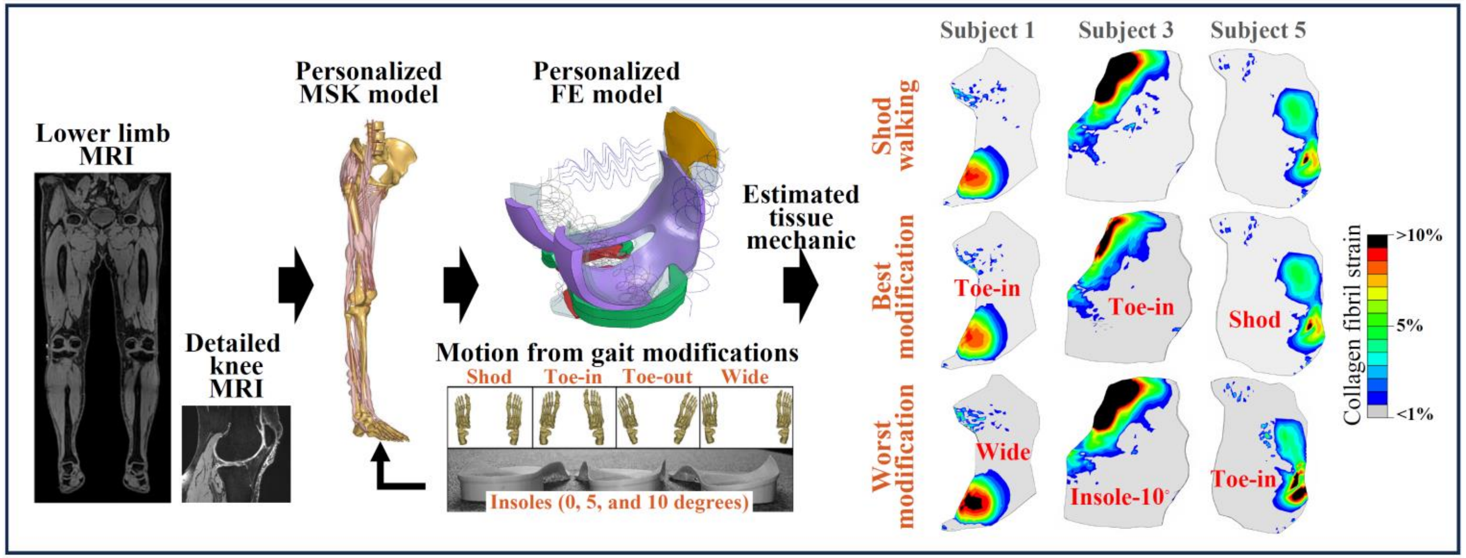
ANYBODY TECHNOLOGY

The webcast will begin shortly…

In silico approach for personalized gait modification to decelerate knee osteoarthritis progression

November 22 , 2023



Outline

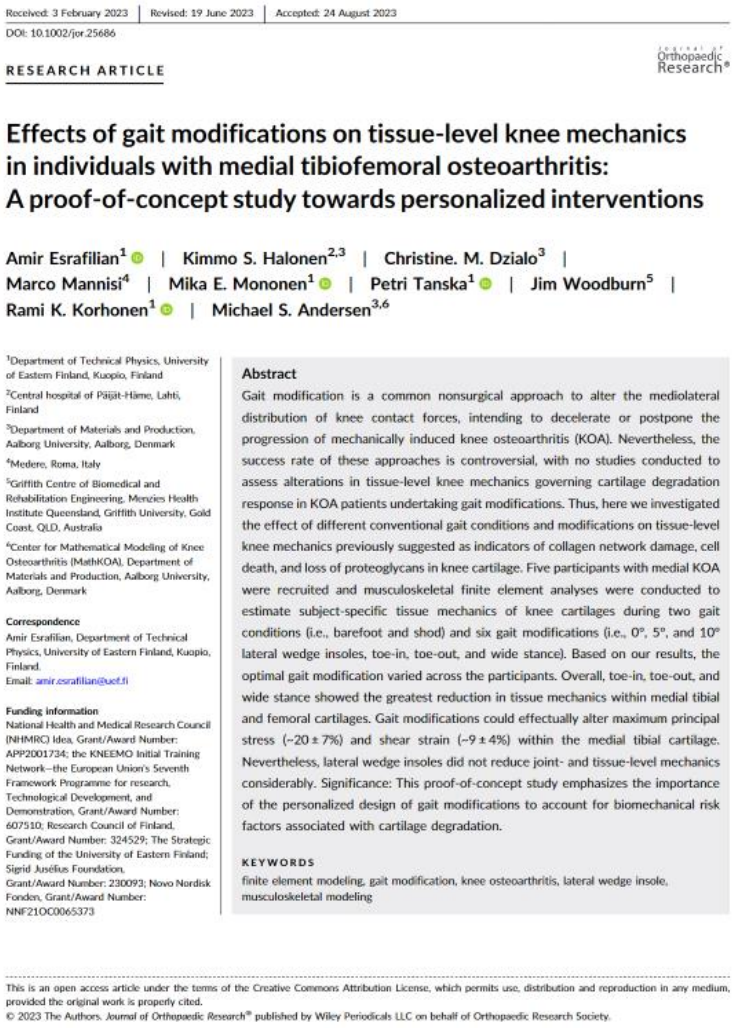
- Introduction to the AnyBody Modeling System
- Presentation by Dr. Amir Esrafilian
- Upcoming events
- Question and answer session

Presenter:
Dr. Amir Esrafilian

Department of Technical Physics, University of Eastern Finland, Kuopio, Finland

Host:
Kristoffer Iversen
Technical Sales Executive
AnyBody Technology

Outline



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Journal of Orthopaedic Research®

RESEARCH ARTICLE

Effects of gait modifications on tissue-level knee mechanics in individuals with medial tibiofemoral osteoarthritis: A proof-of-concept study towards personalized interventions

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[3]Department of Materials and Production, Aalborg University, Aalborg, Denmark
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[5]Griffith Centre of Biomedical and Rehabilitation Engineering, Menzies Health Institute Queensland, Griffith University, Gold Coast, QLD, Australia
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Abstract
Gait modification is a common nonsurgical approach to alter the mediolateral distribution of knee contact forces, intending to decelerate or postpone the progression of mechanically induced knee osteoarthritis (KOA). Nevertheless, the success rate of these approaches is controversial, with no studies conducted to assess alterations in tissue-level knee mechanics governing cartilage degradation response in KOA patients undertaking gait modifications. Thus, here we investigated the effect of different conventional gait conditions and modifications on tissue-level knee mechanics previously suggested as indicators of collagen network damage, cell death, and loss of proteoglycans in knee cartilage. Five participants with medial KOA were recruited and musculoskeletal finite element analyses were conducted to estimate subject-specific tissue mechanics of knee cartilages during two gait conditions (i.e., barefoot and shod) and six gait modifications (i.e., 0°, 5°, and 10° lateral wedge insoles, toe-in, toe-out, and wide stance). Based on our results, the optimal gait modification varied across the participants. Overall, toe-in, toe-out, and wide stance showed the greatest reduction in tissue mechanics within medial tibial and femoral cartilages. Gait modifications could effectually alter maximum principal stress (~20 ± 7%) and shear strain (~9 ± 4%) within the medial tibial cartilage. Nevertheless, lateral wedge insoles did not reduce joint- and tissue-level mechanics considerably. Significance: This proof-of-concept study emphasizes the importance of the personalized design of gait modifications to account for biomechanical risk factors associated with cartilage degradation.

KEYWORDS
finite element modeling, gait modification, knee osteoarthritis, lateral wedge insole, musculoskeletal modeling

Presenter:
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Host:
Kristoffer Iversen
Technical Sales Executive
AnyBody Technology

Control Panel

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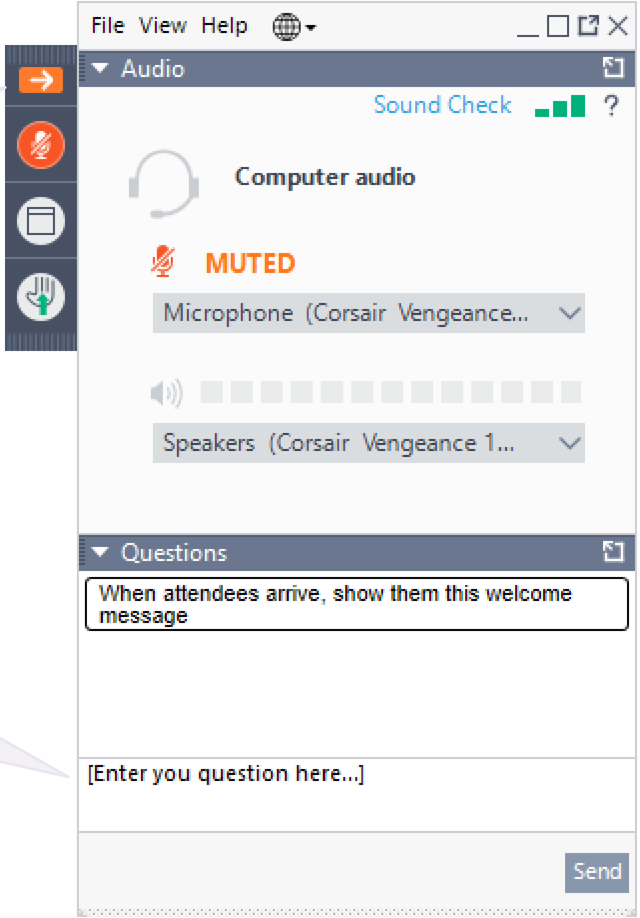


ANYBODY TECHNOLOGY

Musculoskeletal Simulation

Motion Data

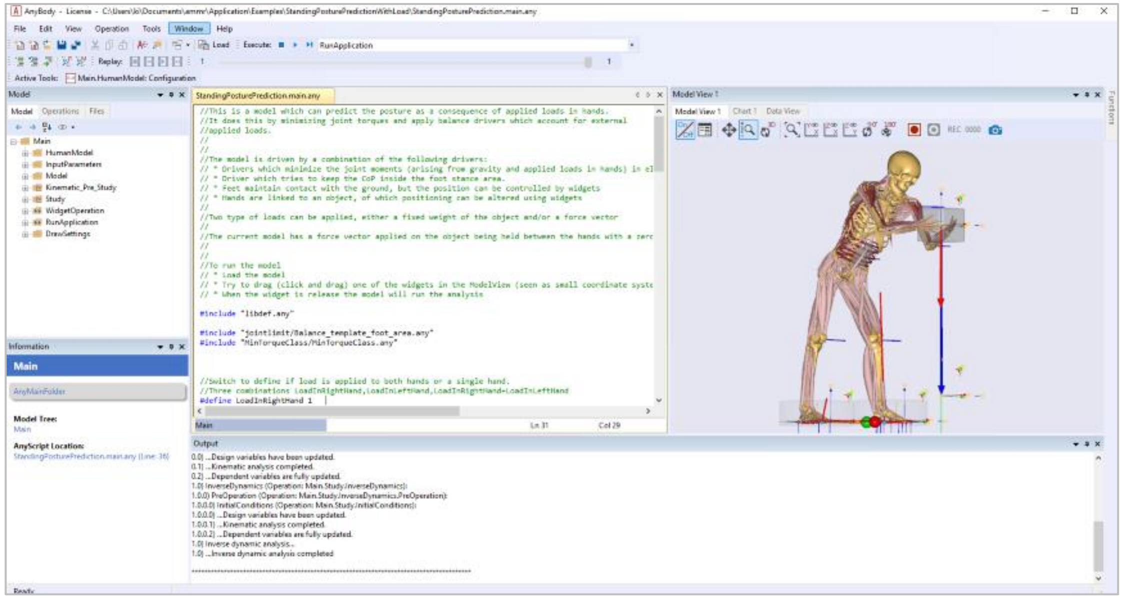
Kinematics and Forces

ANYBODY

Modeling System

Body Loads

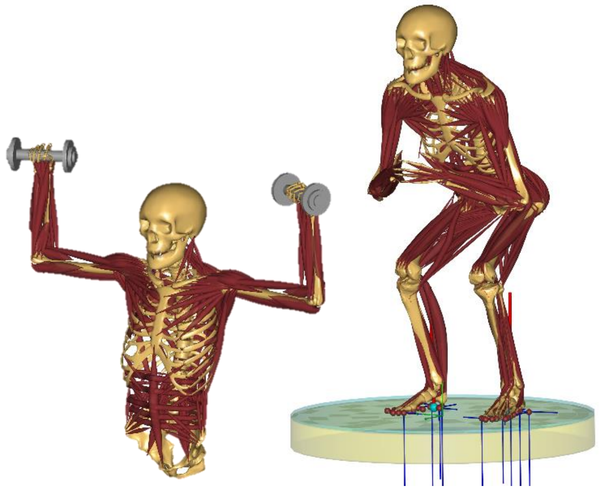
- Joint moments
- Muscle forces
- Joint reaction forces



AnyBody Technology

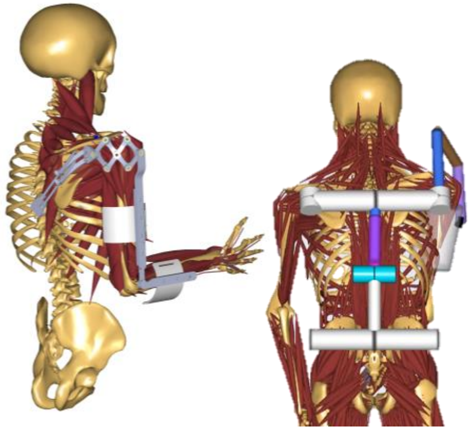
Product optimization design

Movement Analysis

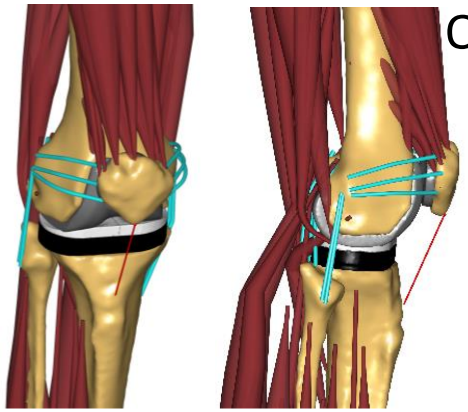


Sports

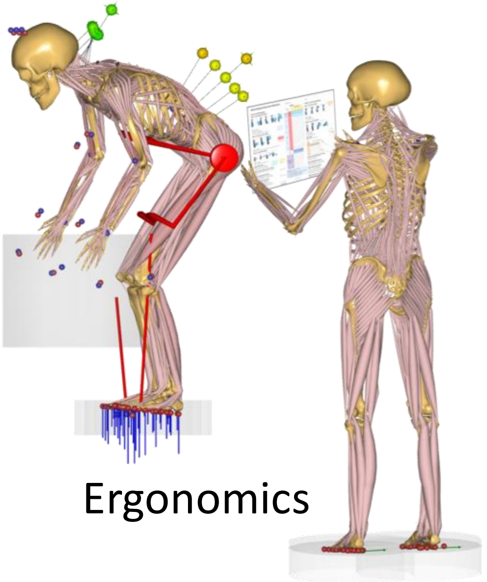
AnyBody Modeling System



Assistive Devices

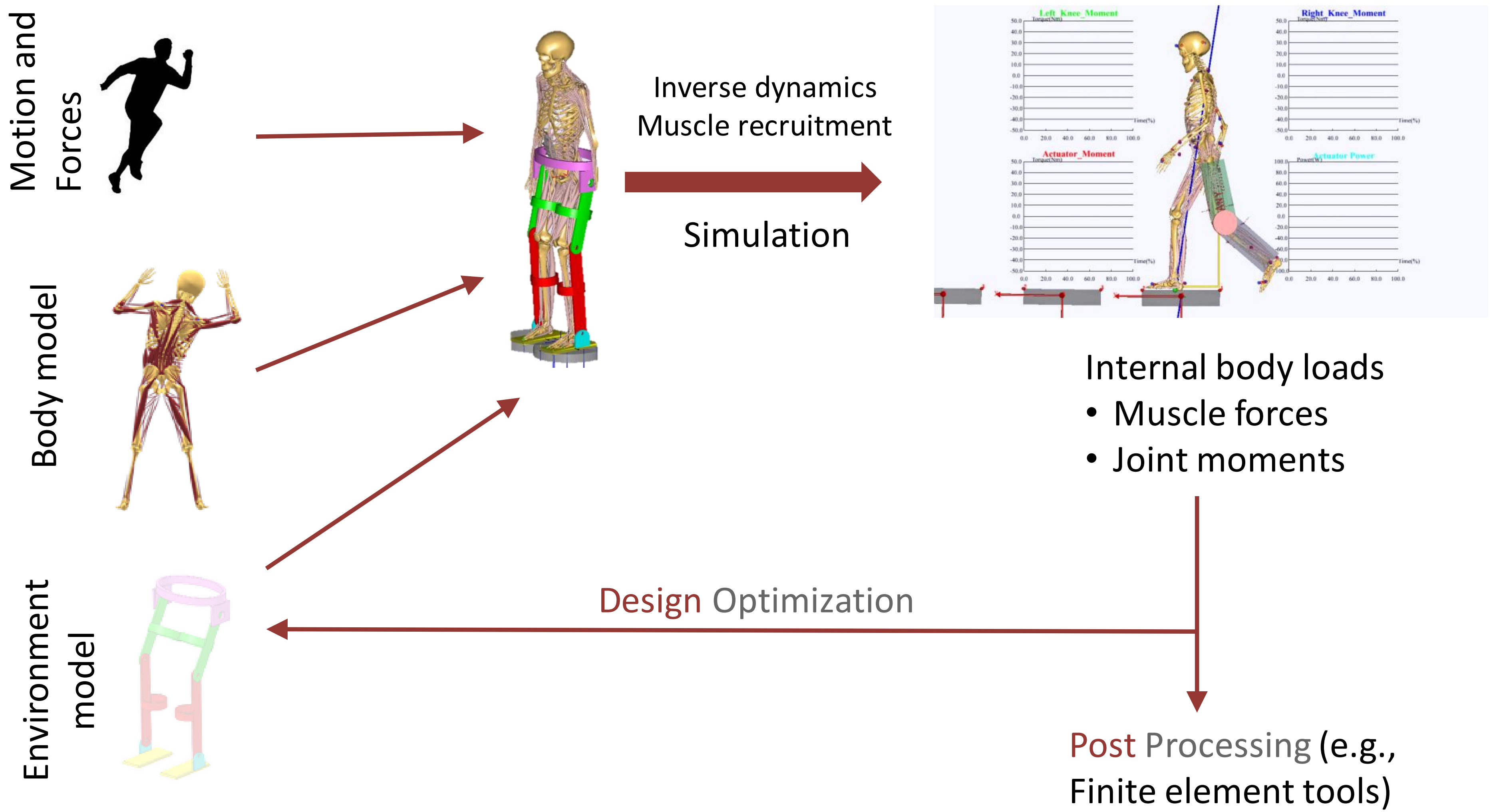


Orthopedics and rehab



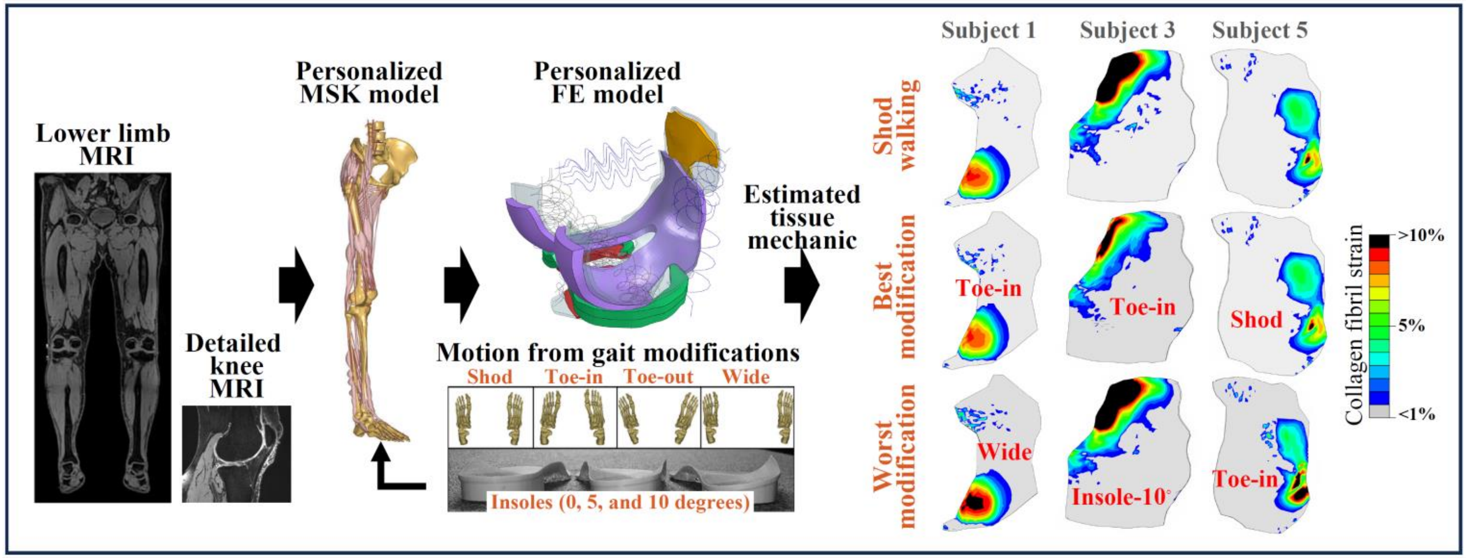
Ergonomics

AnyBody Modeling System



In silico approach for personalized gait modification to decelerate knee osteoarthritis progression

Presented by Dr. Amir Esrafilian



Workflow of the study. The contour maps on the right illustrate collagen fibril strain within the medial tibial cartilage of three study participants at the peak of tibiofemoral joint contact force for the shod walking (top row) and modifications causing the greatest decrease (middle row) and greatest increase (bottom row) in collagen fibril strain. Subchondral bones are excluded in contour maps to enhance clarity.

In silico approach for personalized gait modification to decelerate knee osteoarthritis progression

Presented by: Amir Esrafilian, PhD
Department of Technical Physics
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A brief introduction about me

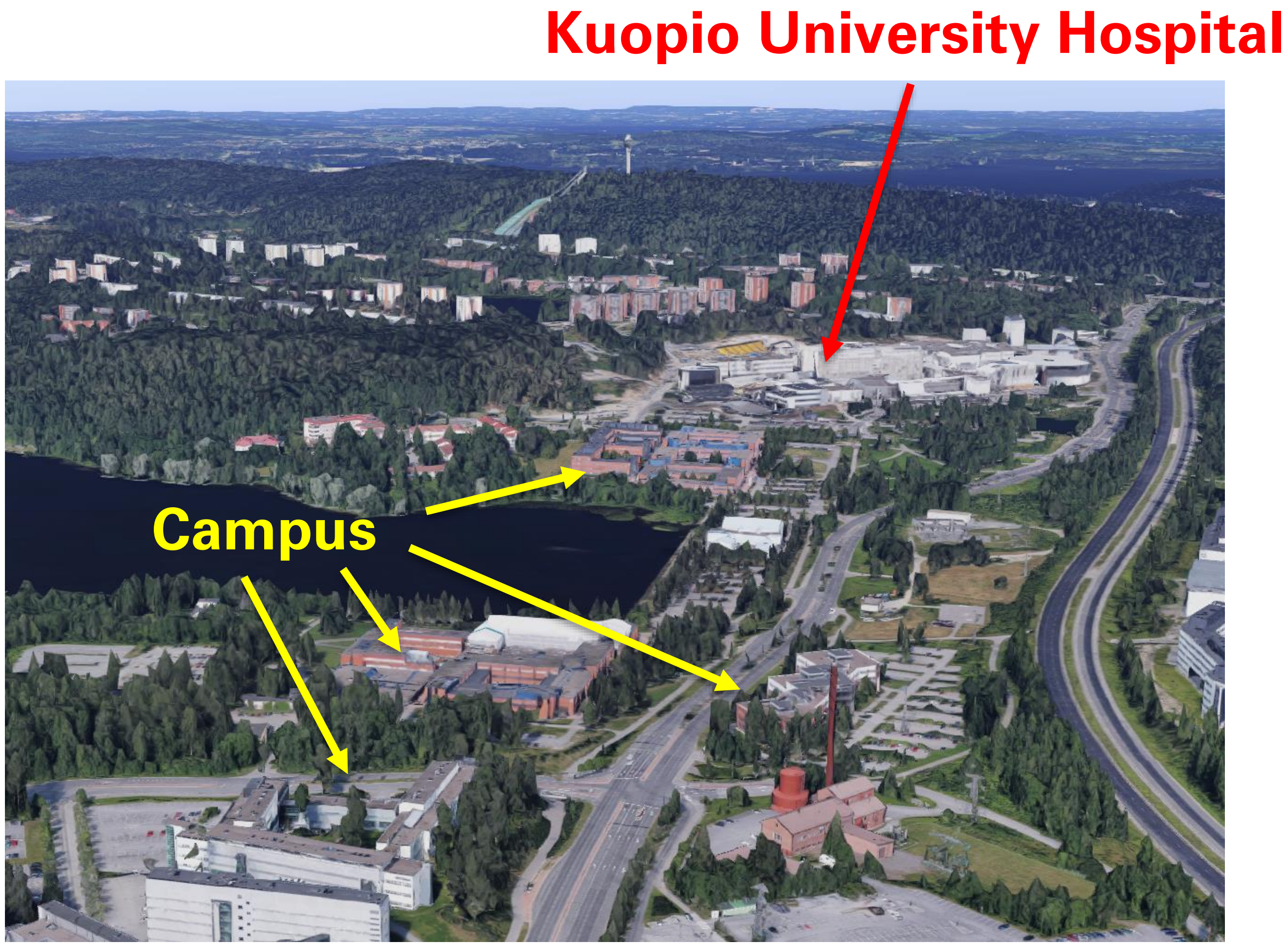
- BSc and MSc in mechanical engineering

- PhD at the University of Eastern Finland (2017-2021), Biophysics of Bone and Cartilage group

- Currently: postdoctoral researcher

  Multiscale modeling of the knee joint with a focus on knee osteoarthritis

Here we are


Kuopio University Hospital
Campus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Sweden
Finland
Norway
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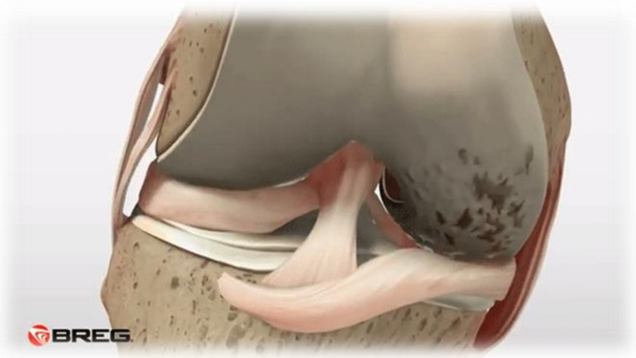
Ireland
Belarus
Poland
Germany
Ukraine
Austria
France
Romania
Bay of Biscay

Intro: Knee osteoarthritis (KOA)

Knee injuries are reported as the second most frequent musculoskeletal disease [1].

Knee osteoarthritis affects ~400 million people globally [2]

knee osteoarthritis



WHO: Osteoarthritis (OA) is a long-term chronic joint disease, primarily characterized by the deterioration of joint cartilage and underling bone.

KOA has different phenotypes:

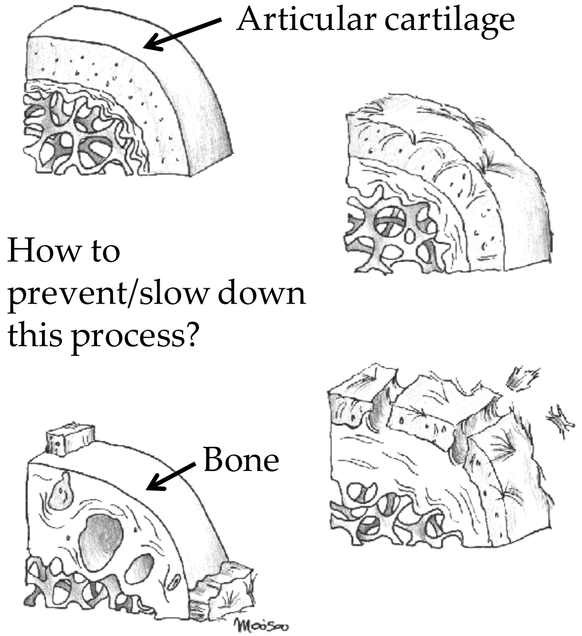
- Mechanical loading
- Metabolic
- Aging
- Inflammation
- Etc.

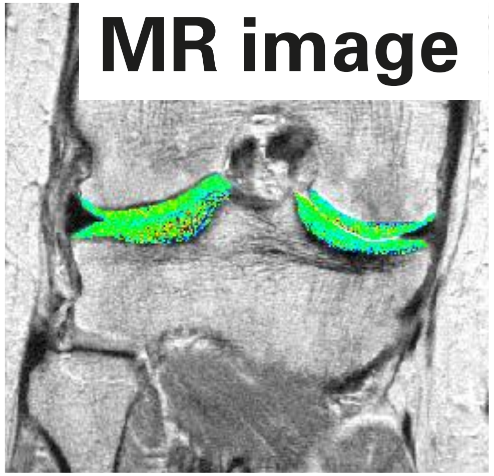
[1] Grinsven et al., knee surg., 2010 [2] Leifer et al., OA & cart., 2022

But what are the mechanisms?

Motivation

Osteoarthritis





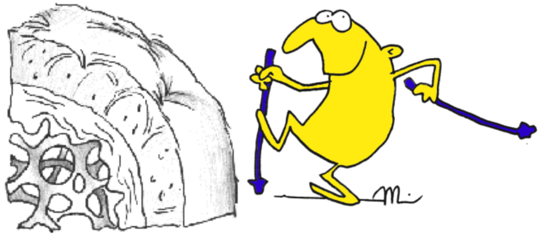
Intro: Modeling knee joint for prediction and prevention

Current situation

Different KOA phenotypes

Cartilage structure and function need to be taken in to account

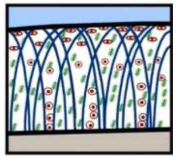
?



In 10 years

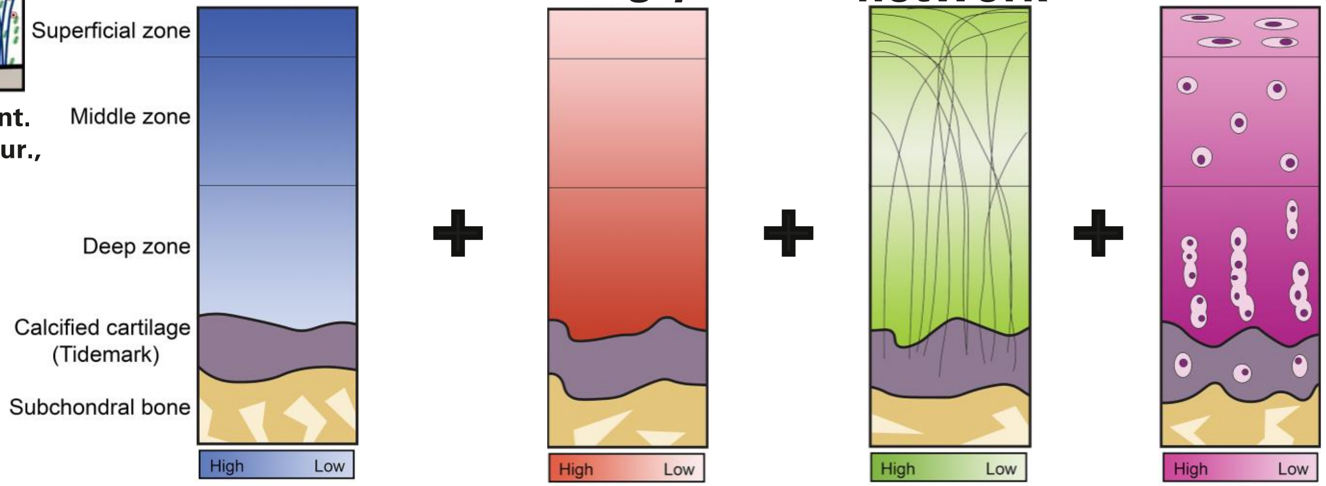
Intro: Knee cartilage structure and function

Healthy cartilage



Matzat, Quant. Timg. Med. Sur., 3(3) 2013

Fluid	+	Proteoglycan	+	Collagen network	+	Cell



70% - 80%	5% - 10%	20% - 30%	< 1%
Rate and time dependency	Compressive strength Swelling properties	Tensile strength	Tissue synthesis

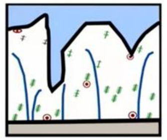
Reduced loading:

- Cartilage softening [3]
  - Collagen damage [4]
  - Rise in breakdown enzymes and inflammatory cytokines [5]
  - Increase in catabolic response [2]

Excessive loading: Excessive shear strain / Excessive tensile stress / Excessive shear strain

- Reduced load-bearing capacity
  - Increased permeability [1]
- Rise in breakdown enzymes and inflammatory cytokines [2]
- Increase in catabolic response [2]

OA



Thorough knowledge of knee joint mechanobiological environment is essential to studying progression of knee osteoarthritis -> modeling

[1] Ebrahimi et al., Ann. Biom. Eng., 2019
[2] Loeser RF., Matrix Biol., 2014
[3] Haapala et al., Int J. Sports Med., 2000
[4] Hosseini et al., OA and Cart., 2013
[5] Leong et al., FASEB Journal, 2011

Intro: Modeling at different spatial scales

Higher spatial scale

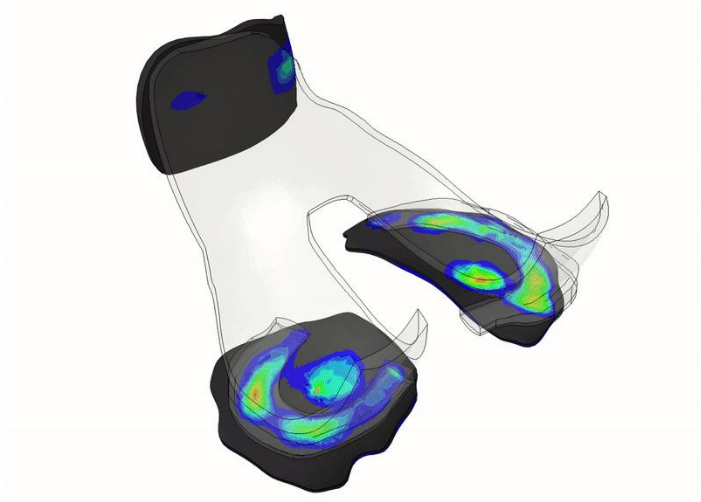
Musculoskeletal modeling

- ✓ Kinematics (joint angle, etc.)
- ✓ Kinetics (joint moments, muscle forces, joint contact forces)
  - ▪ Joint-level mechanics [1]

Multiscale modeling [1] →

Lower spatial scale

Continuum mechanics (e.g., finite element modeling)



- ✓ Kinematics and kinetics
- ✓ Tissue or cell level mechanics [1,2]
  - Govern tissue degradation
- ▪ Time consuming modeling and analysis [3]
- ▪ Joint-level mechanics are needed as inputs

[1] Esrafilian et al., IEEE TNSRE, 2021
[3] Bolcos et al., Scientific Reports, 2018
[2] Tanska et al., J. Biomech., 2015

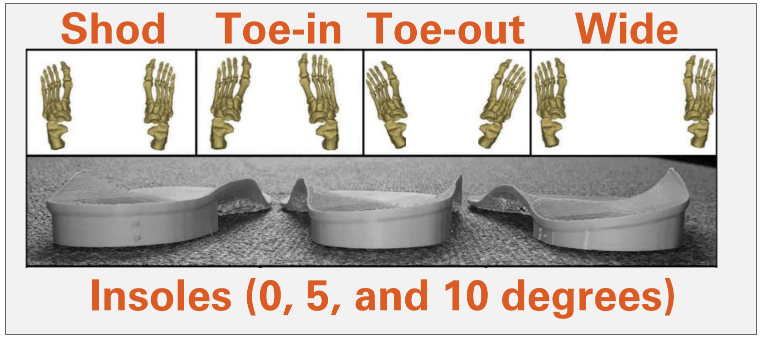
Aim: Gait modifications

- **Gait modification** is a common nonsurgical approach to **alter the load distribution** at the knee, intending to **decelerate the progression** of mechanically induced knee osteoarthritis.

- **Nevertheless:**
  The **success rate** of these approaches is **controversial,**
  and alterations in tissue-level knee mechanics governing cartilage degradation are unexplored.

➢ **Here, we used personalized musculoskeletal finite element models to:**
1) **Investigate** the effect of different **gait modifications** on **tissue-level** knee mechanics.
2) Demonstrate if the computational models could **assist in tailoring** gait modifications.

Gait modifications



Dzialo et al., International Biomechanics, vol 6(1), 2019

Methods: Dataset of the study

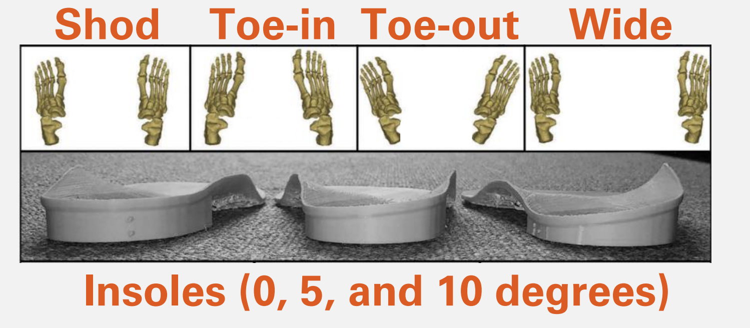
5 participants with medial tibiofemoral osteoarthritis

KL = 4,
Age (years): 56 – 74 (mean: 62.4)
Mass (kg): 74 – 112 (mean: 84.2)
Height (m): 1.56 – 1.84 (mean: 1.67)
Test leg: 3 Right & 2 Left

- 5 walking trails per gait modification were selected for analysis

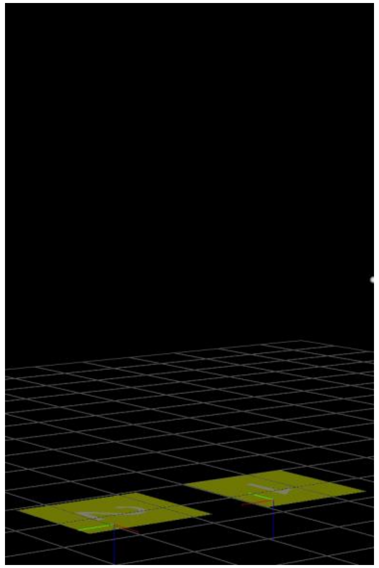
3D marker trajectories
Ground reaction forces

Gait modifications

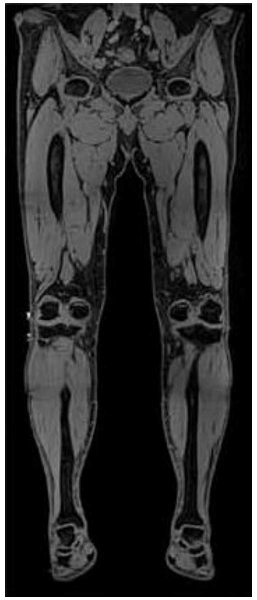


Dzialo et al., International Biomechanics, vol 6(1), 2019

Motion data

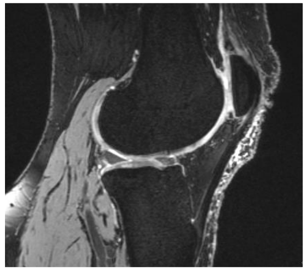


Lower limb MRI



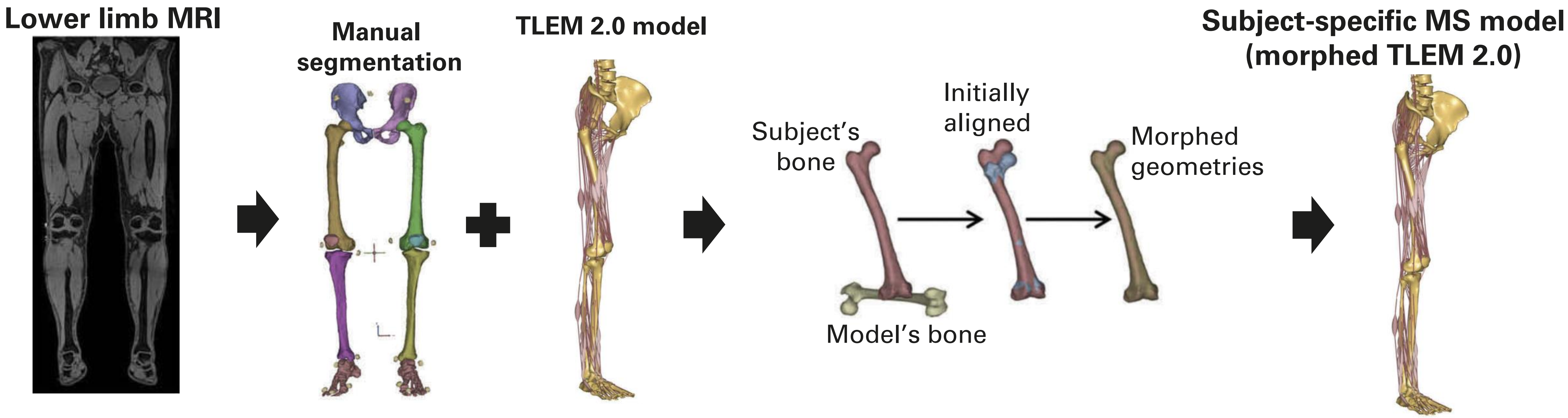
- Peripheral Angio 36 coil
- T1W-Vibe-Dixon sequence
  - In-plane resolution: 1.4mm
  - Slice thickness: 1.4mm

Detailed knee MRI



- Quad knee coil
- Sagittal 3D-DESS-WE sequence
  - In-plane resolution: 0.6mm
  - Slice thickness: 0.7mm

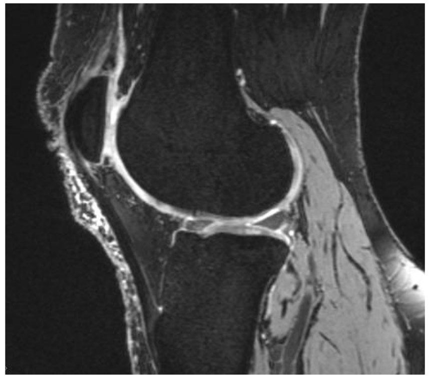
Methods: Creating the musculoskeletal models [1]



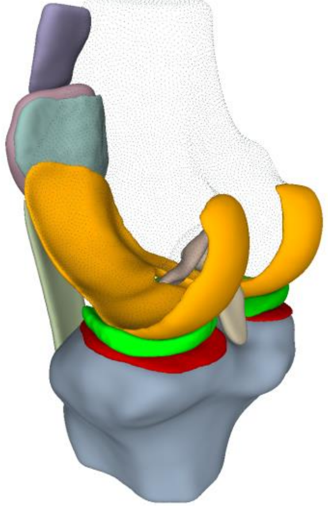
[1] Dzialo et al., International Biomechanics, vol 6(1), 2019

Methods: Creating the finite element models [1]

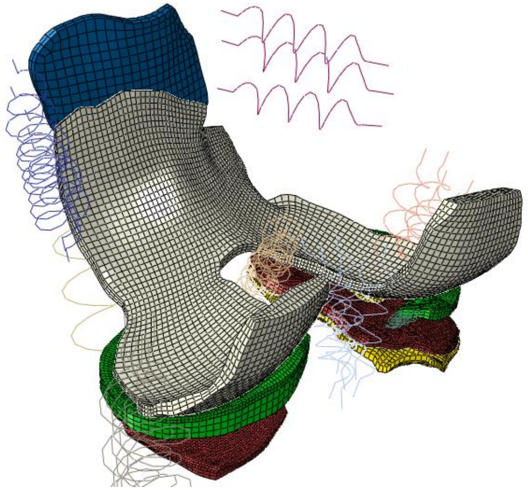
Detailed knee MRI



Manually segmented geometries



Finite element mesh with hexahedral elements (C3D8P)



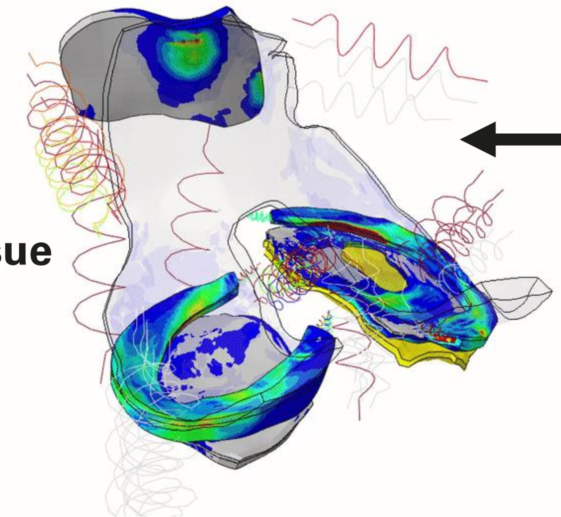
Bones:
Linear elastic

Cartilage and menisci:
Fibril-reinforced biphasic

Ligaments:
nonlinear elastic (springs)

Musculoskeletal modeling output

Estimated tissue mechanics



[1] Esrafilian et al., Journal of Orthopaedic Research, 2023; 1–13

Methods: Material model of cartilage and meniscus

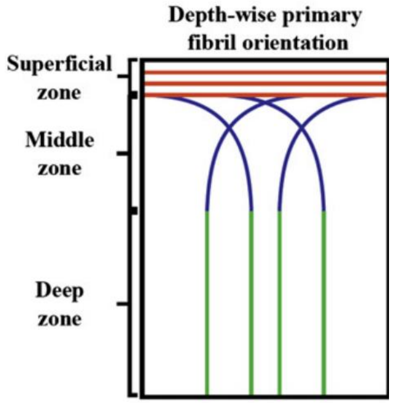
Fibril-reinforced poroviscoelastic material model

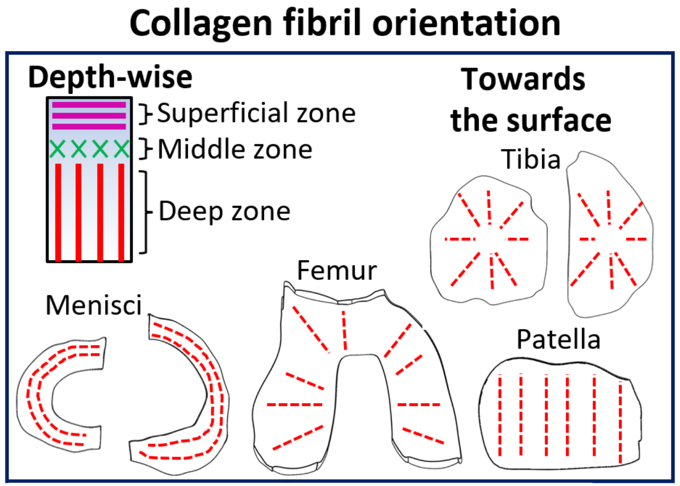
$$\sigma_{total} = \boxed{\sigma_{non-fib}} + \boxed{\sigma_{fibrilar}} - \boxed{pI}$$

Non-fibrillar solid matrix → **Hyperelastic Neo-Hookean**

Collagen network → **- Strain-dependent viscoelastic**

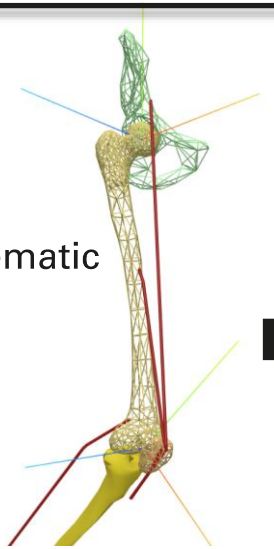
Depth and strain dependent permeability and fluid content



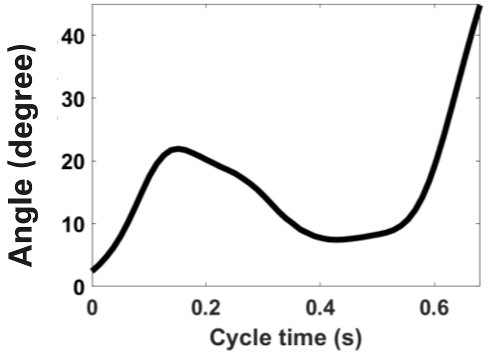


Methods: Inputs to the finite element models

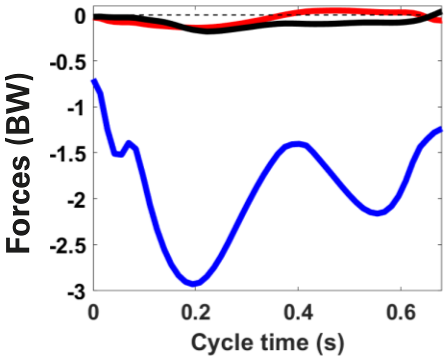
Schematic

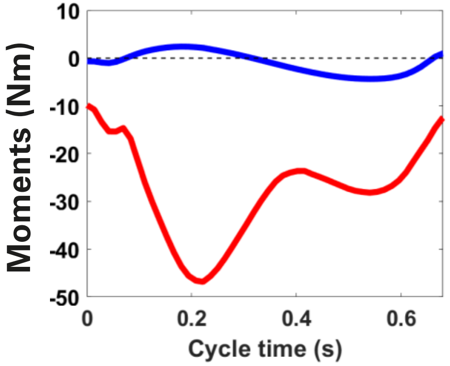


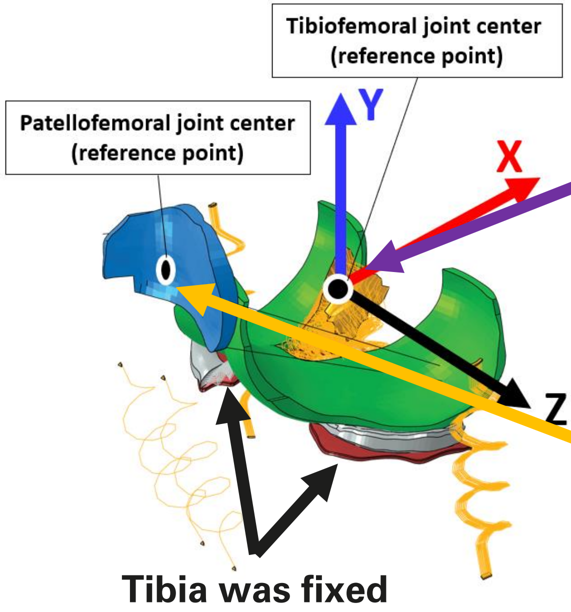
Knee flexion angle



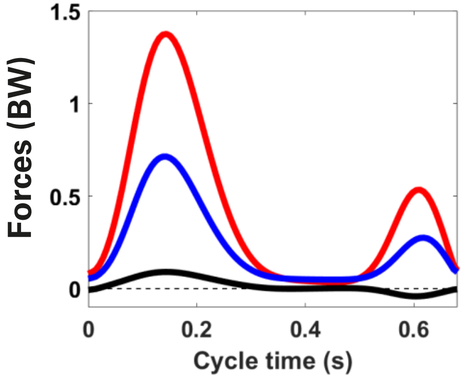
Net forces and moments on the **femur** from the gravity, inertia, muscles, and hip joint reaction forces

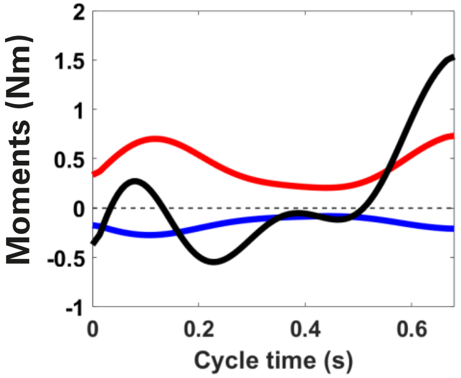






Net forces and moments applied on the **patella** from the gravity, inertia, and the quadriceps muscles.



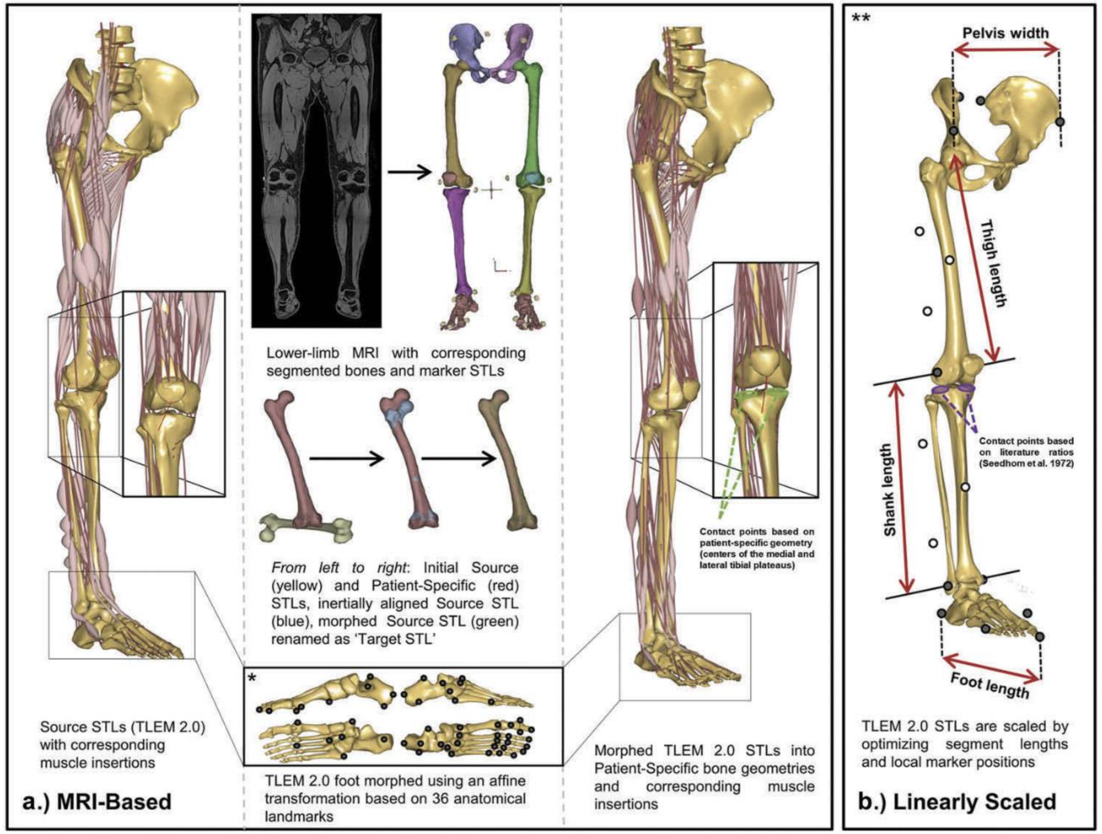


Results: Detailed results on the musculoskeletal results

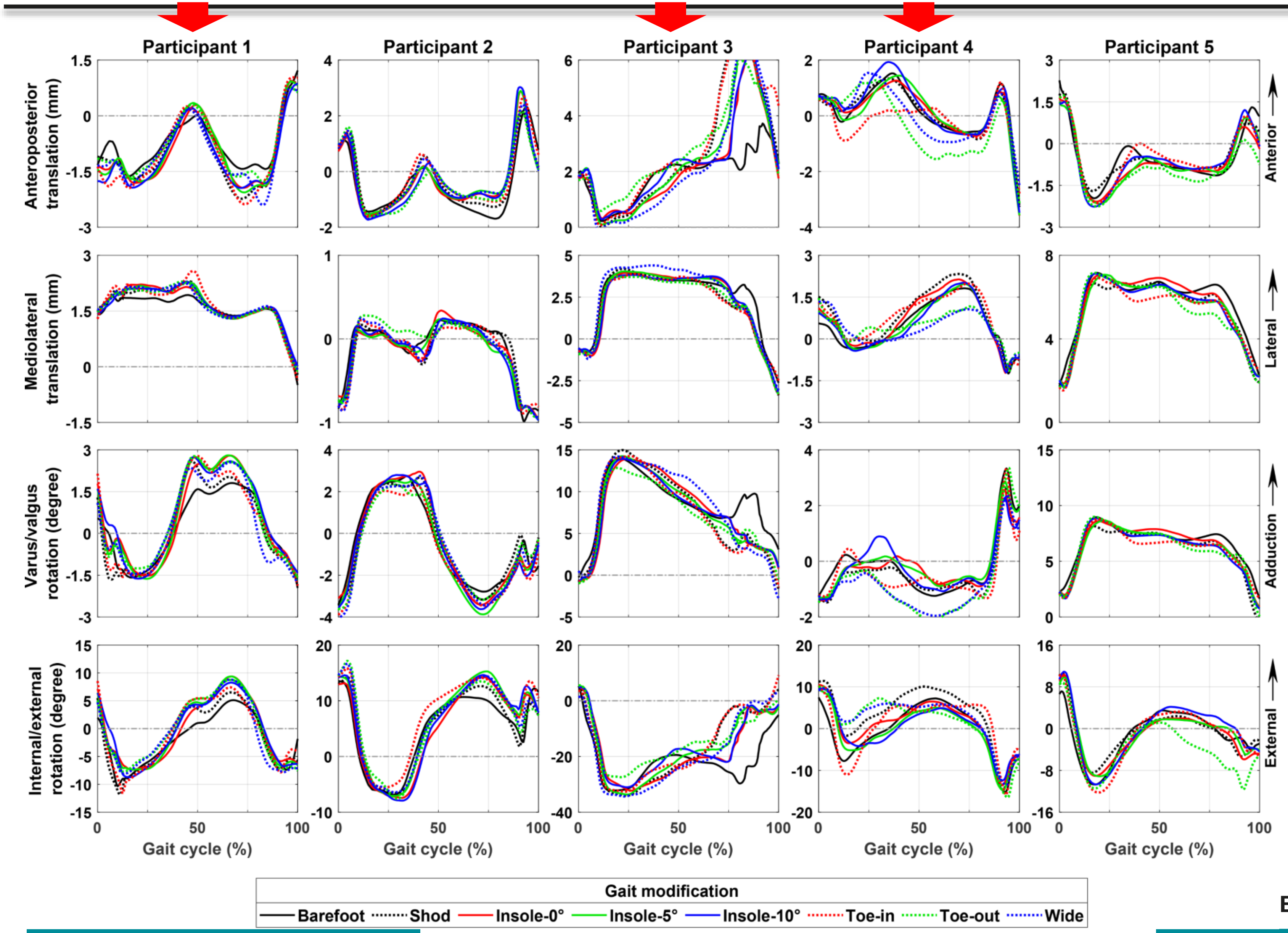
A comparison of joint loading via generic and patient-specific musculoskeletal model scaling techniques

Dzialo et al., International Biomechanics, vol 6(1), 2019

https://doi.org/10.1080/23335432.2019.1629839



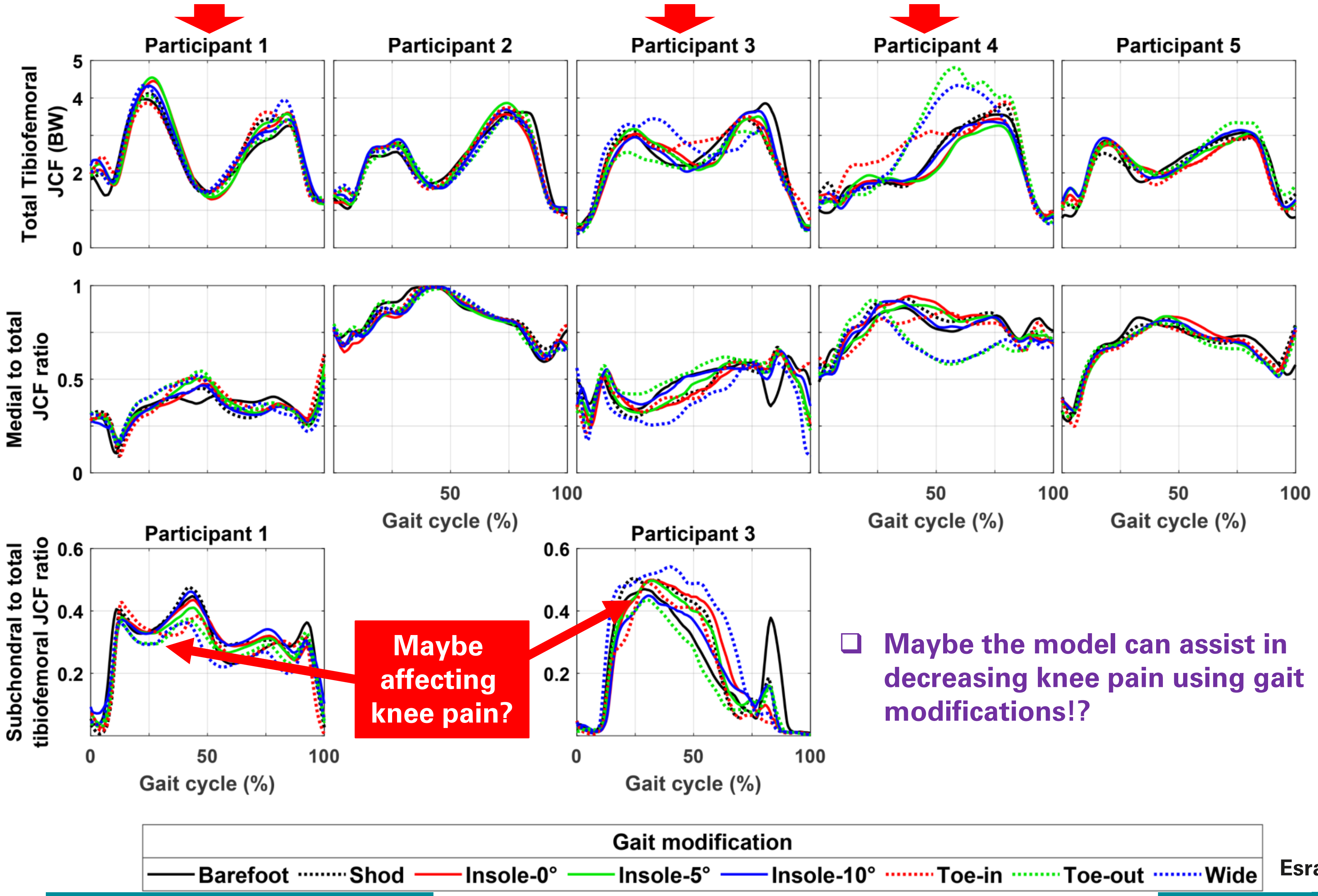
Results: Knee kinematics (FE estimates)



- Effect of gait modification on knee kinematics varied across participants
- Lateral wedge insoles caused minimal alterations in knee kinematics
- Gait modifications showed the potential to alter knee kinematics.

Esrafilian et al., J. of Orthopaedic Research, 2023; 1–13

Results: Knee contact force (FE estimates)

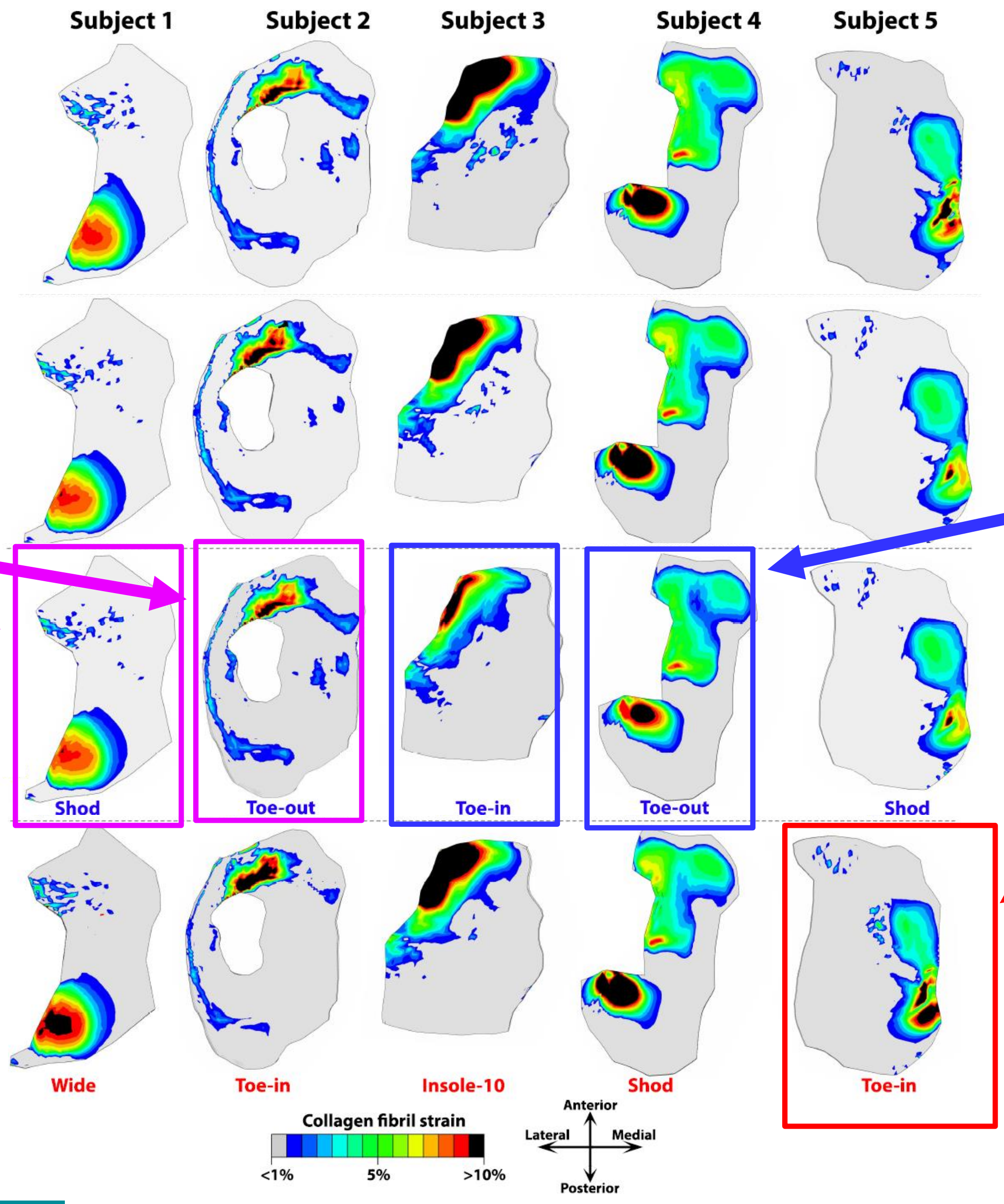


- ❑ Maybe the model can assist in decreasing knee pain using gait modifications!?

- ➢ Effect of gait modification on knee kinetics also varies across participants
- ➢ Lateral wedge insoles caused minimal alterations in knee kinetics
- ➢ Forces through the subchondral bone was also altered
- ❖ Potential of gait modifications to alter knee kinematics and kinetics

Esrafilian et al., J. of Orthopaedic Research, 2023; 1–13

Results: Collagen fibril strain within the medial tibial cartilage



Barefoot

Shod

Minor changes

Considerable changes

Best case

Recommended to minimize JCF using joint-level modeling

Potentially negative effects

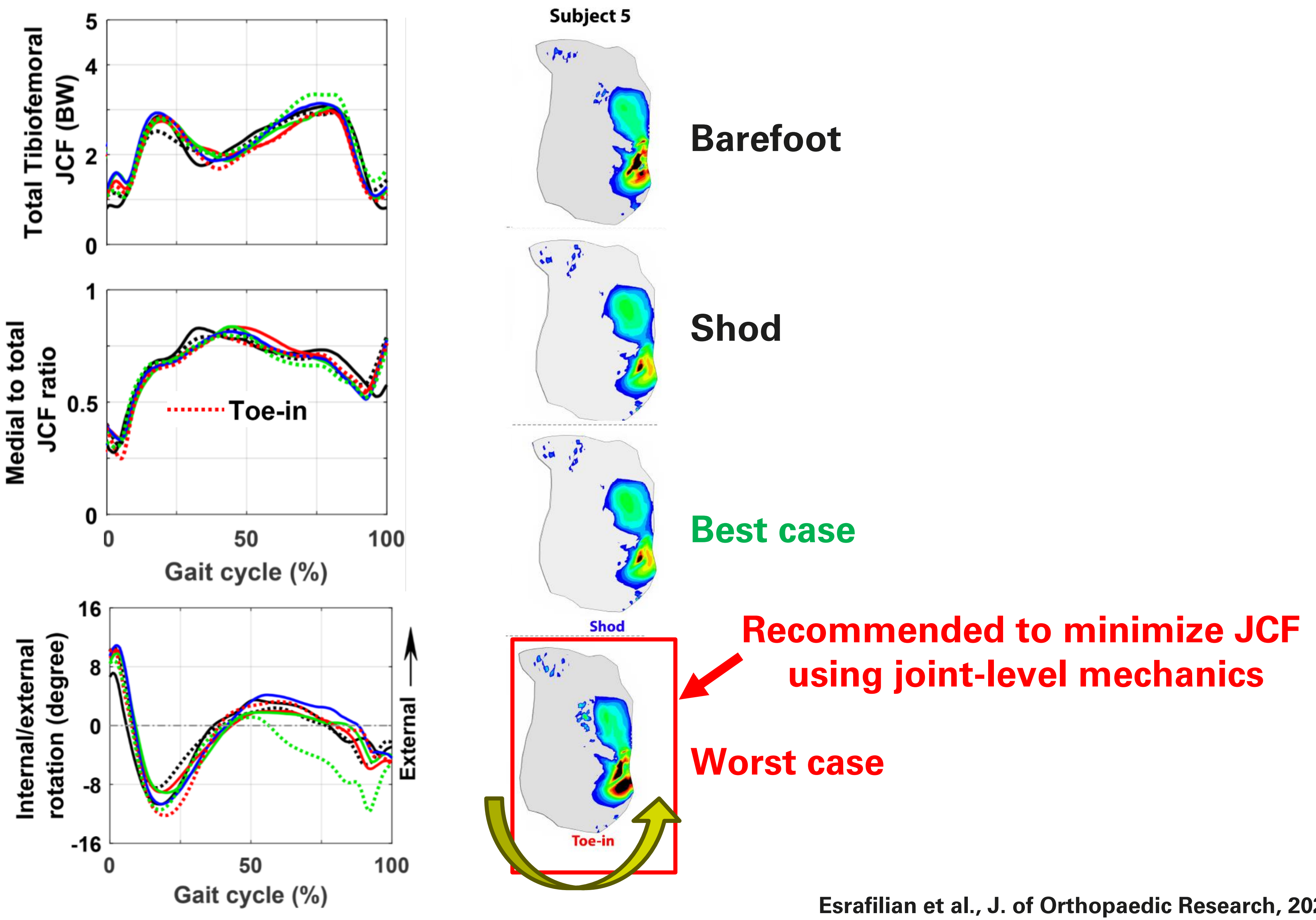
Worst case

Esrafilian et al., J. of Orthopaedic Research, 2023; 1–13

Results: Collagen fibril strain within the medial tibial cartilage

Reduced medial JCF

More Internal rotation at max JCF



Esrafilian et al., J. of Orthopaedic Research, 2023; 1–13

Conclusion

- The optimum gait modification (e.g., to minimize knee tissue mechanics) could vary among the subjects

  This optimum gait modification could differ depending on whether joint- or tissue-level mechanics are considered.

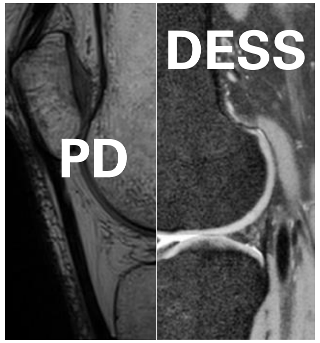
- The computational modeling showed the potential to assist in choosing the optimal gait modification, which may decelerate or postpone knee osteoarthritis progression.

- Altered subchondral loads suggest that personalized gait modifications might reduce mechanically induced knee pain, as well.

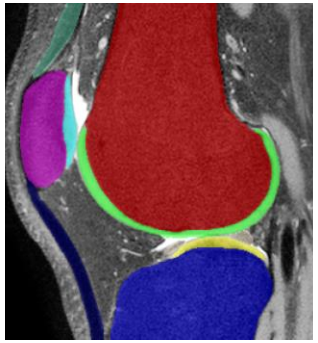
Next step: Automated knee modeling [1]

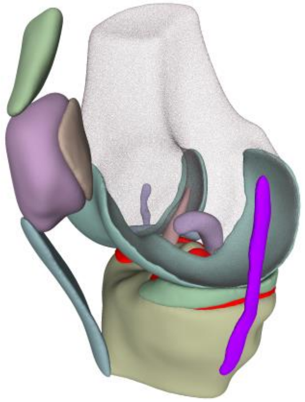
preprint:

Knee MRI



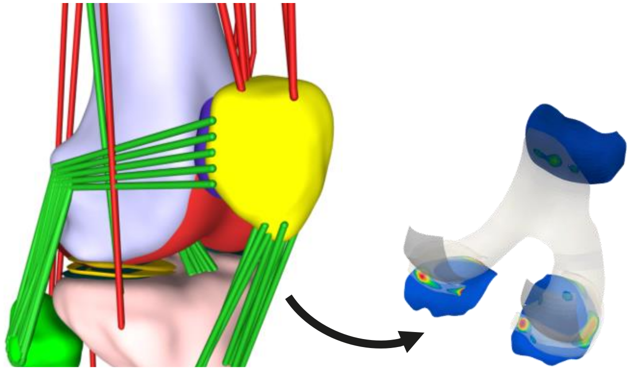
Auto-segmentation (2D & 3D U-Net)





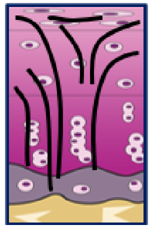
- Bones (femur, tibia, patella, fibula)
- Cartilages (femur, tibia, patella)
- Menisci
- Ligaments:
  ACL, PCL, LCL, MCL
  Patella tendon and ligament

Musculoskeletal model with **elastic foundation** contact [2]

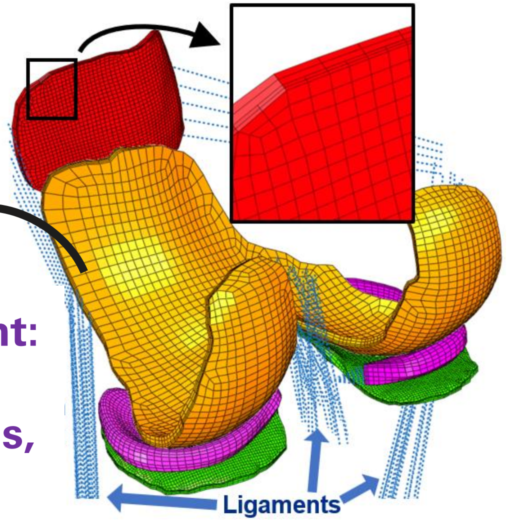


+

Fibril-reinforced finite element model [3]



Depth-dependent:
-Water,
-Proteoglycans,
-Collagen, …

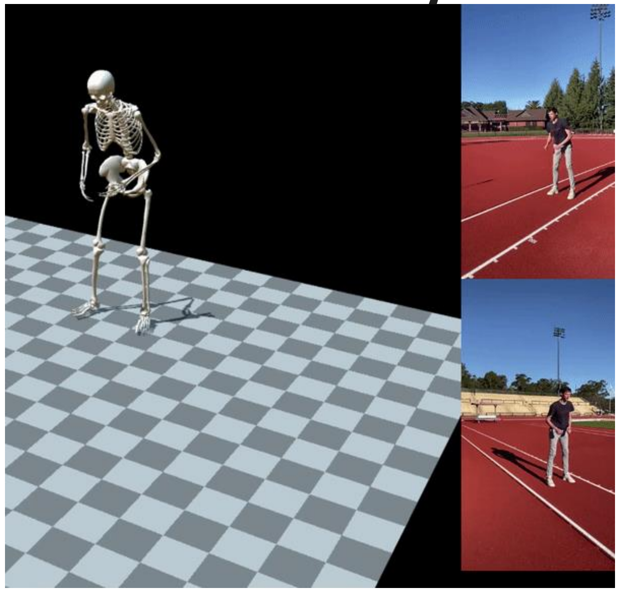


- Template-based model
- Auto meshing model
- Ligaments' insertion

[1] Esrafilian et al., bioRxiv, 2023, doi: 10.1101/2023.10.14.562320
[2] Smith et al., J Biomech, 2019 [3] Wilson et al., J Biomech, 2005

Next step: Clinically viable modeling and analysis tool (MathKOA)

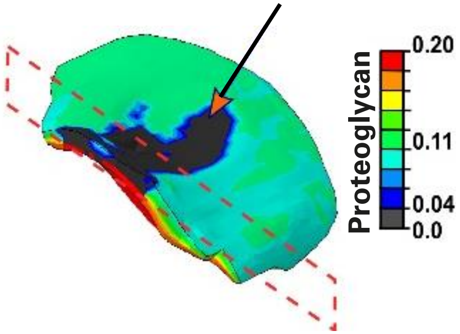
Out-of-lab (2D video) motion analysis



To estimate kinematics and kinetics

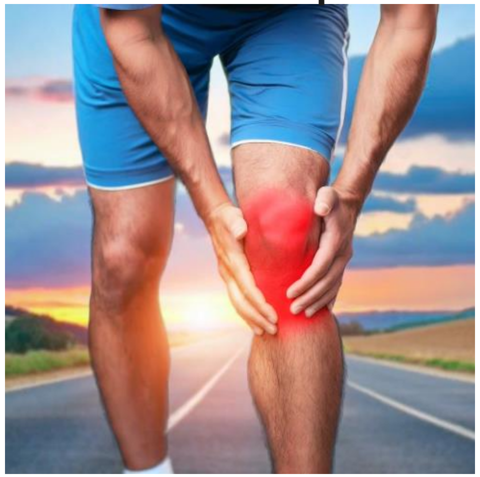
Surrogate/AI models to rapidly

estimate tissue degradation

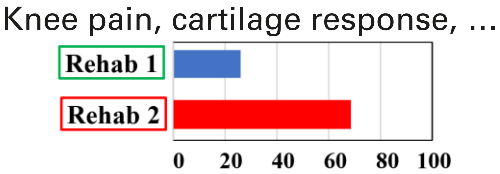


collagen degradation, cell death, proteoglycan loss,...

Predict knee pain



Clinically viable in silico tool for personalized rehab and gait modification



Thanks for your attention!

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- 15th Annual Meeting of the Danish Society of Biomechanics
  - 24 November 2023 in Aalborg, Denmark

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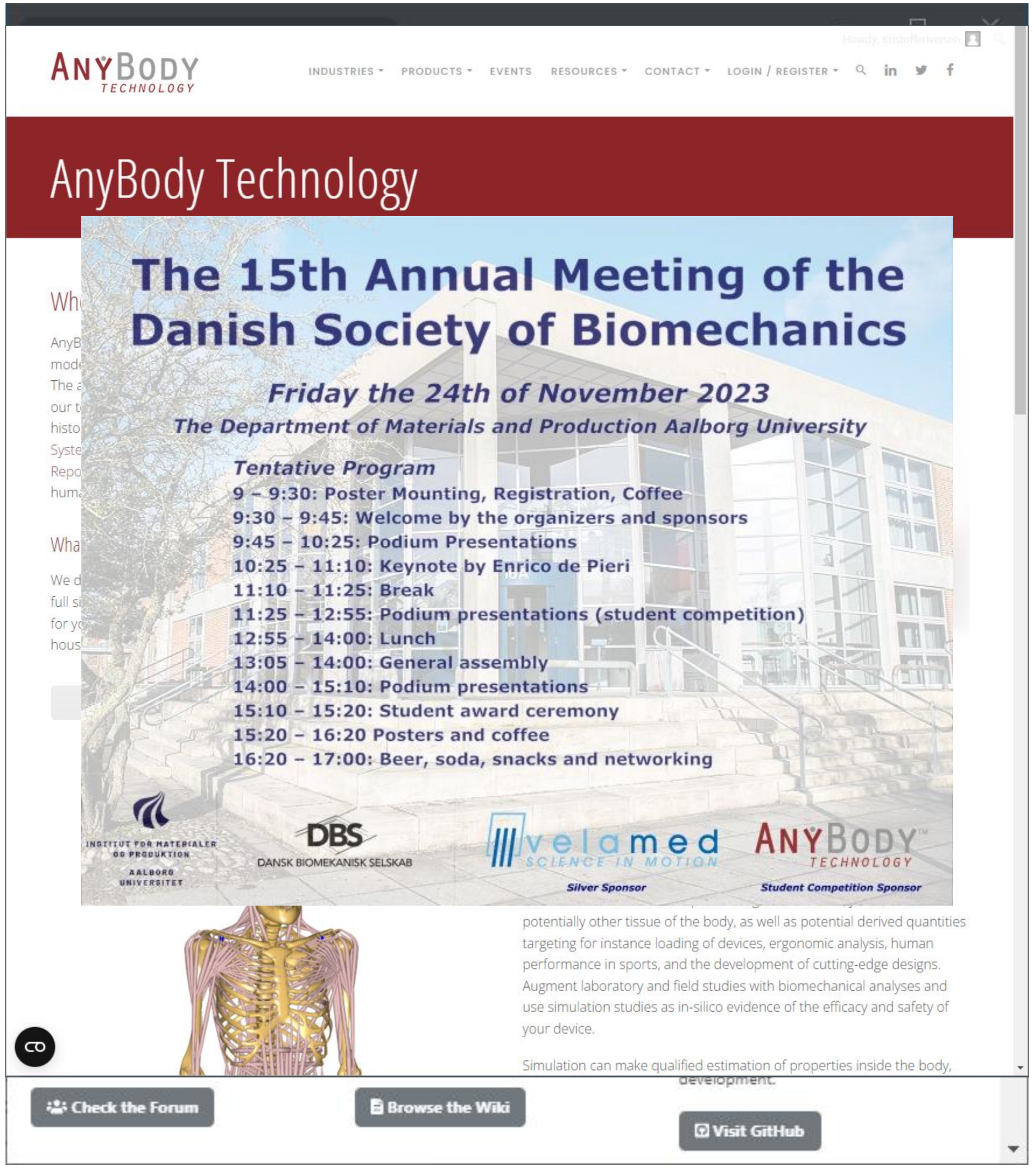

Thank you for your attention
- Time for questions