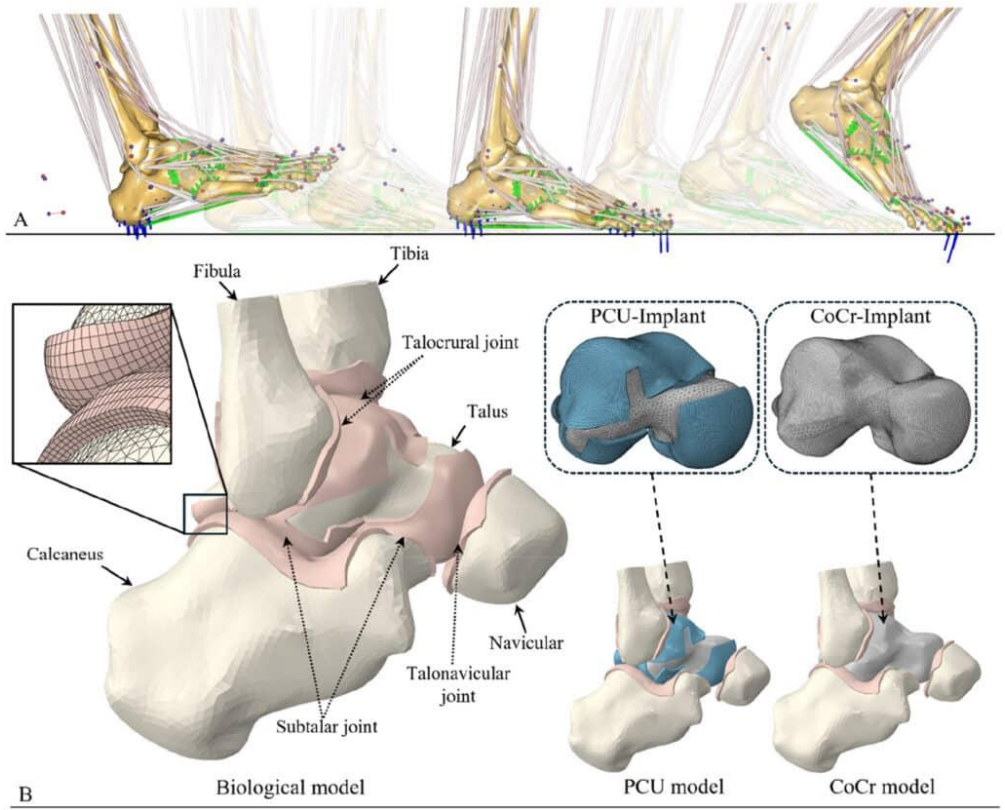
ANYBODY TECHNOLOGY

December 18, 2025

Evaluation of a universal talus implant during gait

A combined musculoskeletal and finite element modelling approach



The webcast will begin shortly...

Outline

- Introduction to the AnyBody Modeling System
- Presentation
- Foot model updates in AMMR4
- Question and answer session

Presenter and panelists

Sami Al Shweiki, MSc | ETH Zurich, Khalifa University

Institute for Biomechanics, ETH Zurich

Department of Mechanical and Nuclear Engineering, Khalifa University

Marwan El-Rich, PhD, Associate Professor | Khalifa University

Department of Mechanical and Nuclear Engineering, Khalifa University

Host

Divyaksh S. Chander

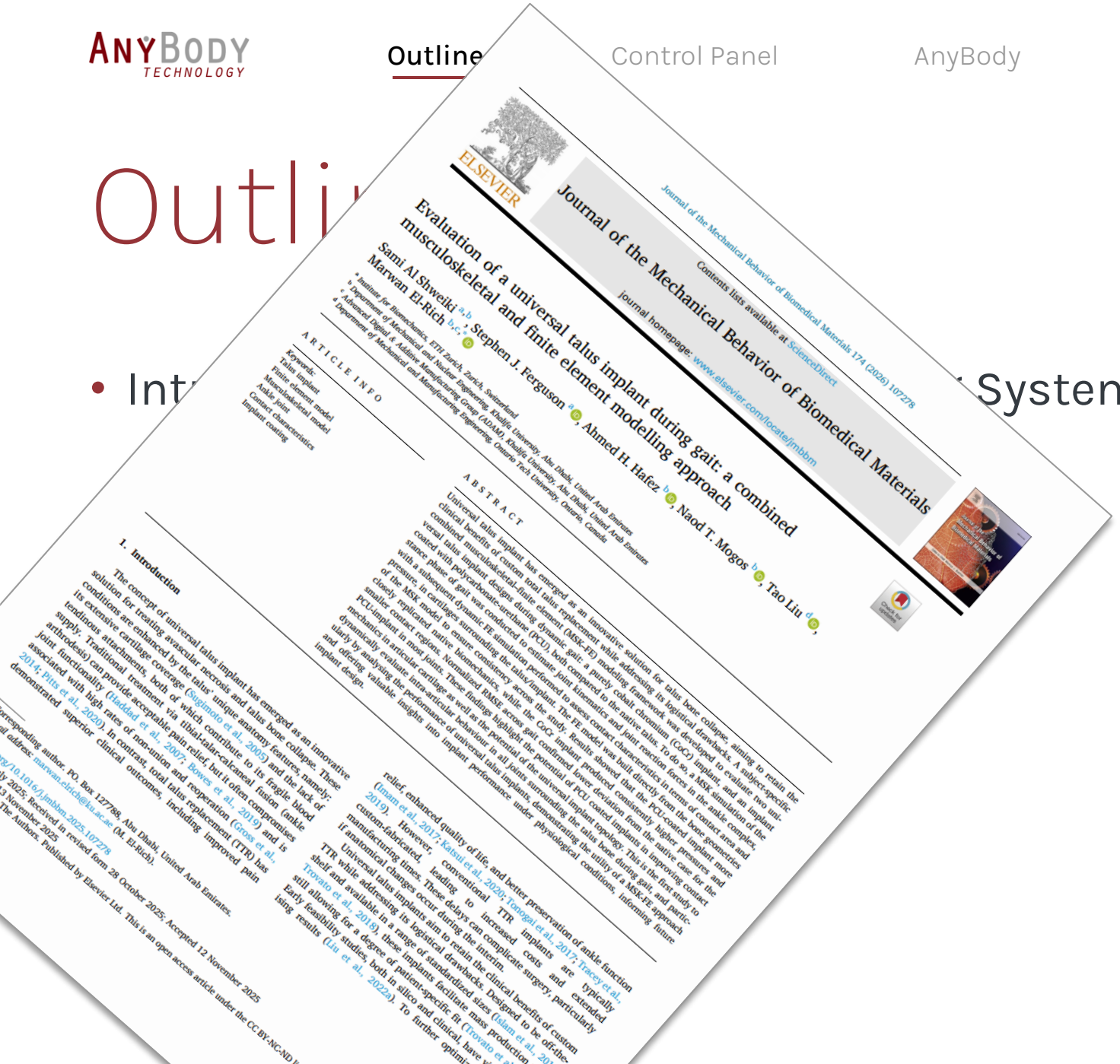
Biomechanical Specialist

AnyBody Technology

dsc@anybodytech.com

Outli

- Int System



Presenter and panelists

Sami Al Shweiki, MSc | ETH Zurich, Khalifa University

Institute for Biomechanics, ETH Zurich

Department of Mechanical and Nuclear Engineering, Khalifa University

Marwan El-Rich, PhD, Associate Professor | Khalifa University

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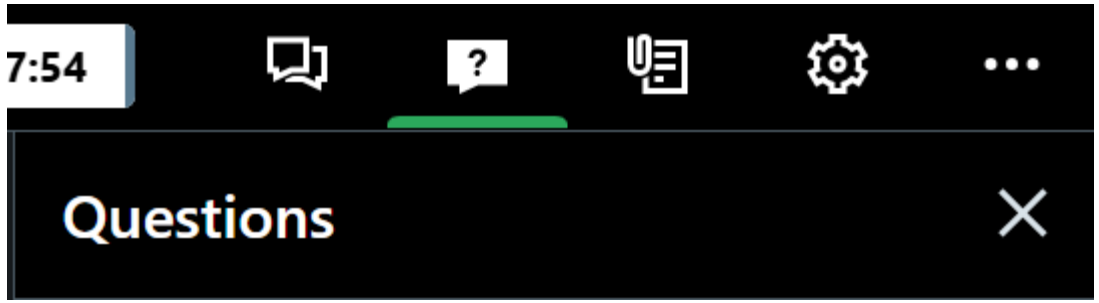
Control Panel

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

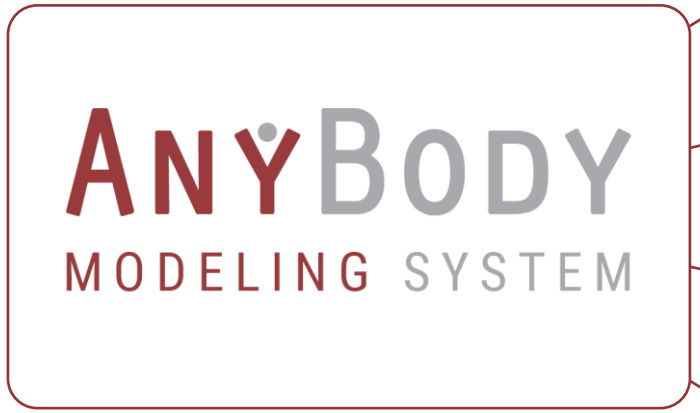


Submit questions and comments via the Questions panel.

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

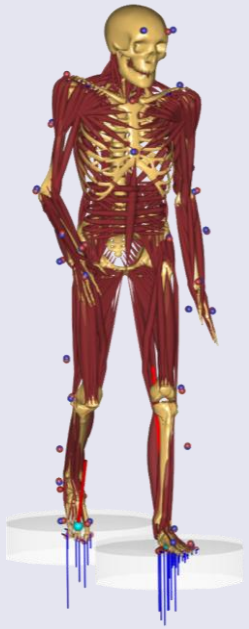
Musculoskeletal simulations

INPUT • Motion data



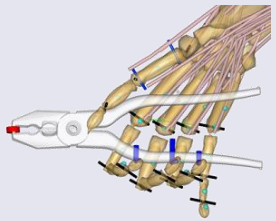
OUTPUT • Internal Body Loads

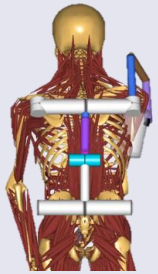
- Joint reaction forces
- Muscle forces
- Muscle activity
- Metabolic energy + fatigue



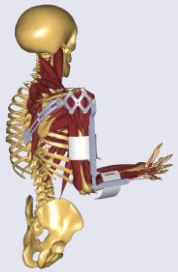
Motion analysis

Product design and optimization

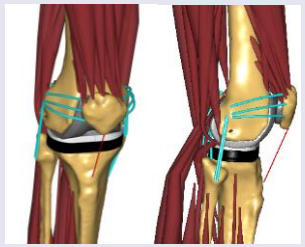




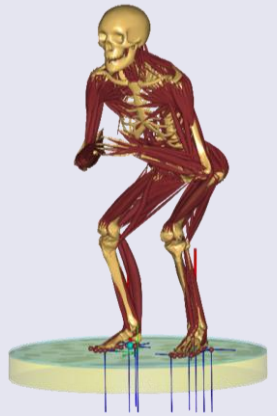
Ergonomics with/without exoskeletons



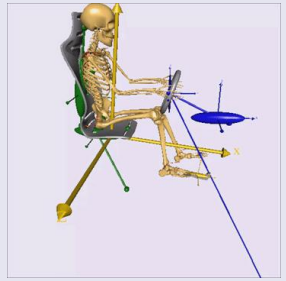
ANYBODY MODELING SYSTEM



Orthopedics and Rehabilitation



Sports

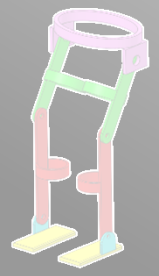


Automotive

Workflow

Motions and forces

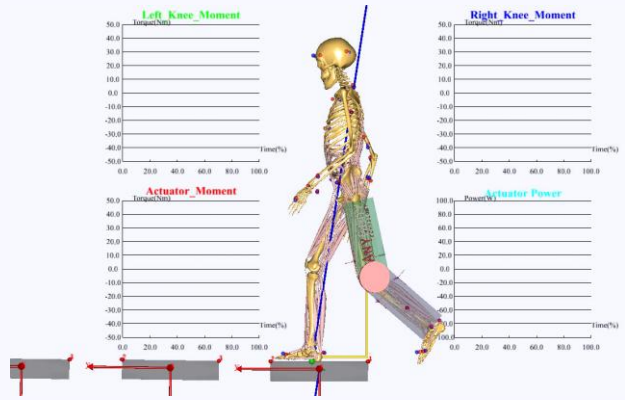
Body model



Environment model

Simulation

Inverse dynamics
Muscle recruitment



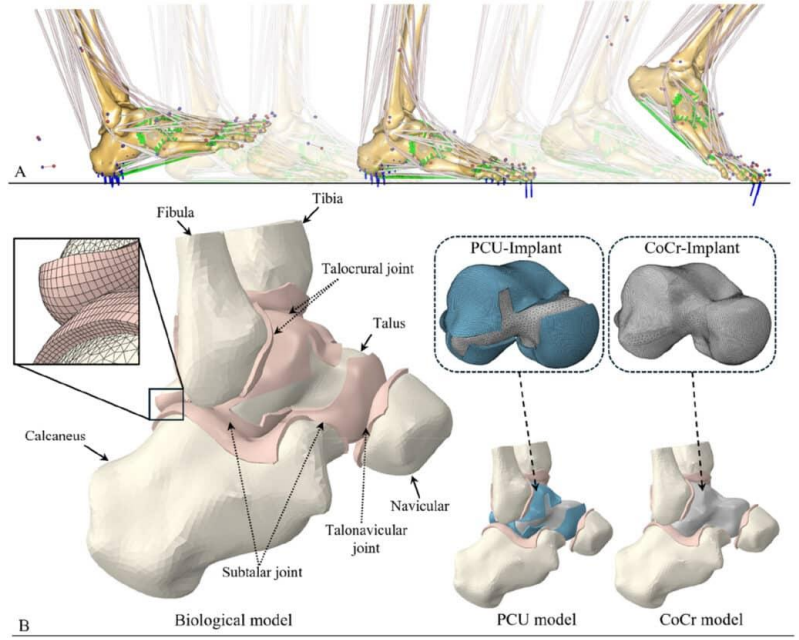
Internal body loads:
- Muscle forces
- Joint forces

Design Optimization

Post Processing
(e.g. Finite Element tools)

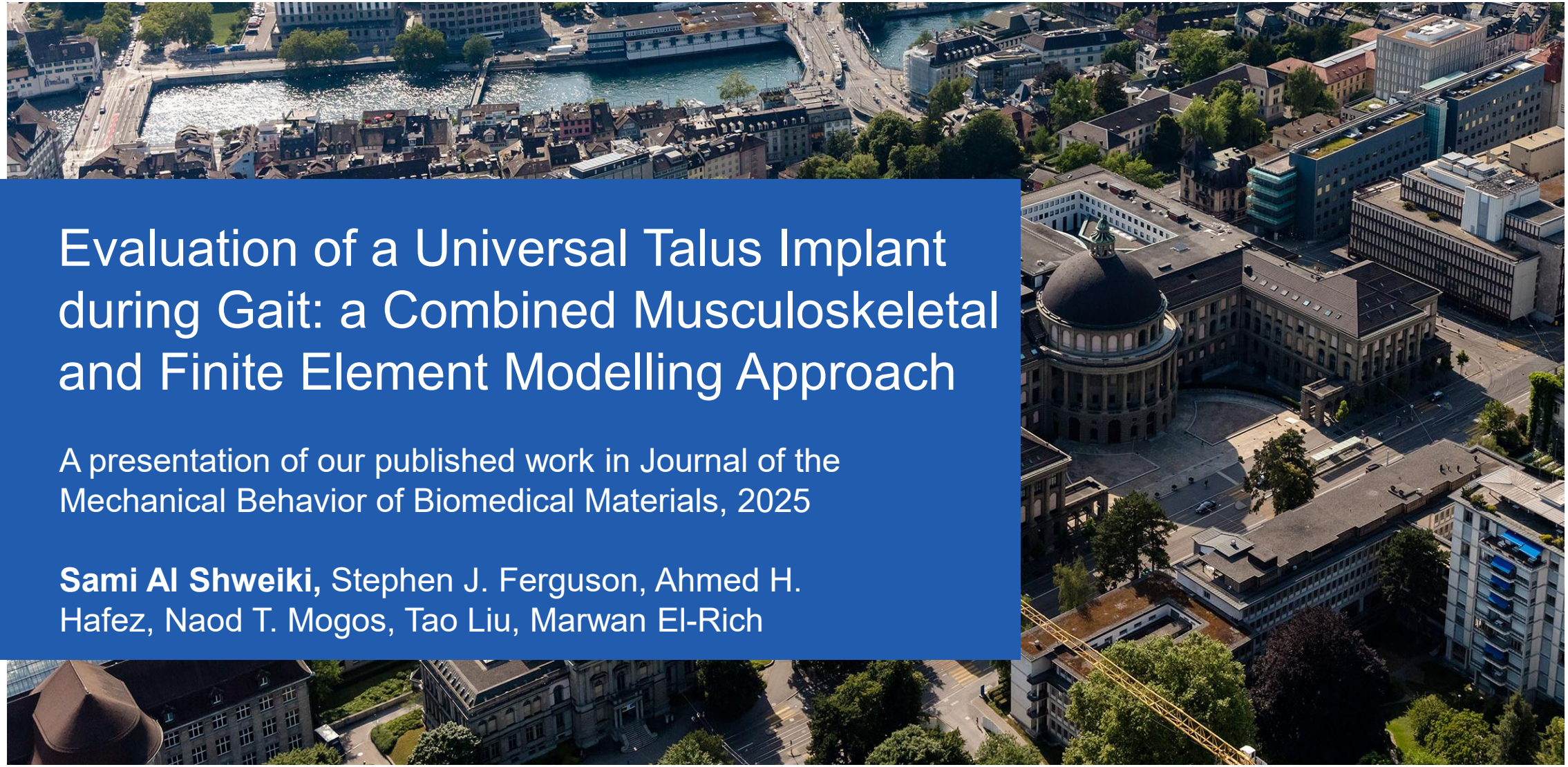
Evaluation of a universal talus implant during gait

A combined musculoskeletal and finite element modelling approach



ETH zürich

جامعة خليفة
Khalifa University

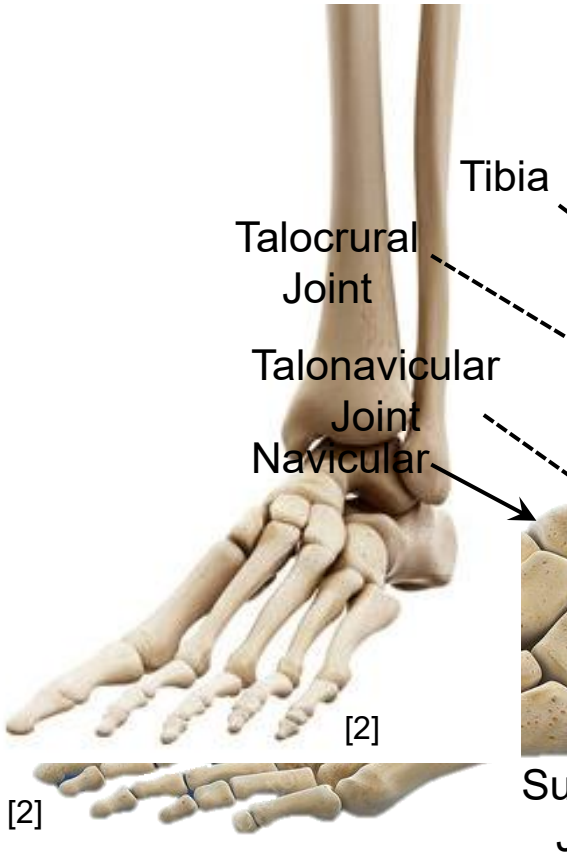


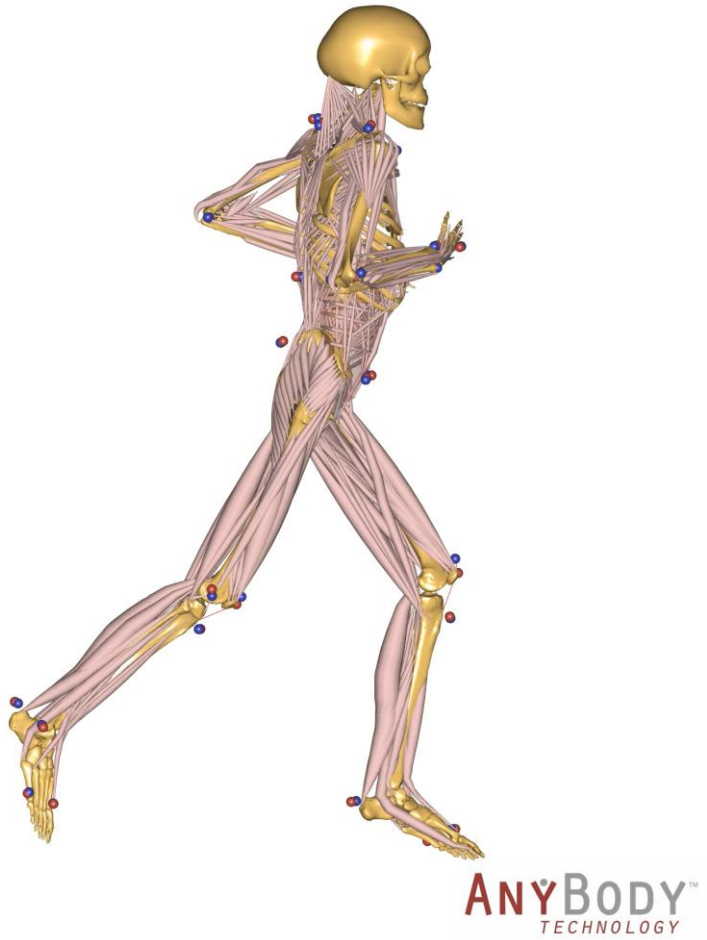
Evaluation of a Universal Talus Implant during Gait: a Combined Musculoskeletal and Finite Element Modelling Approach

A presentation of our published work in Journal of the Mechanical Behavior of Biomedical Materials, 2025

Sami Al Shweiki, Stephen J. Ferguson, Ahmed H. Hafez, Naod T. Mogos, Tao Liu, Marwan El-Rich

Introduction & Motivation – The Ankle Complex





[1]

Talus bone

[3]

1. AnyBody Technology
2. https://www.sciencephoto.com/media/581036/view/ankle-joint-anatomy-artwork
3. https://commons.wikimedia.org/wiki/File:Left_Talus_bone_-_animation03.gif

Introduction & Motivation – Talar AVN and Treatments

60% of talus surface covered by cartilage [1]

No tendinous attachment on talus

Avascular necrosis

death of a segment of bone due to limited blood supply

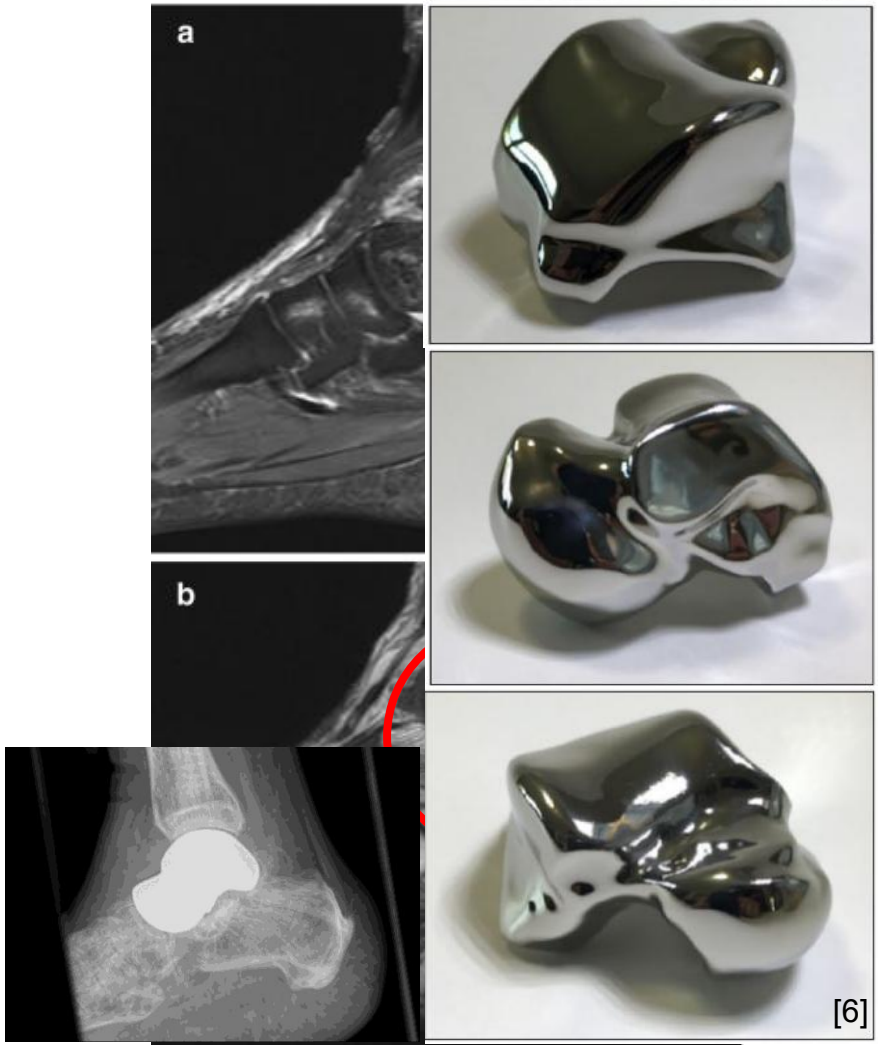
Ankle arthrodesis

- Decreased function [2]
- High rates of non-union [3]
- High rates of re-operation [3]

Total talus replacement (TTR)

- Long waiting time [4]
- High production costs [4]
- Need for contralateral talus

[5]



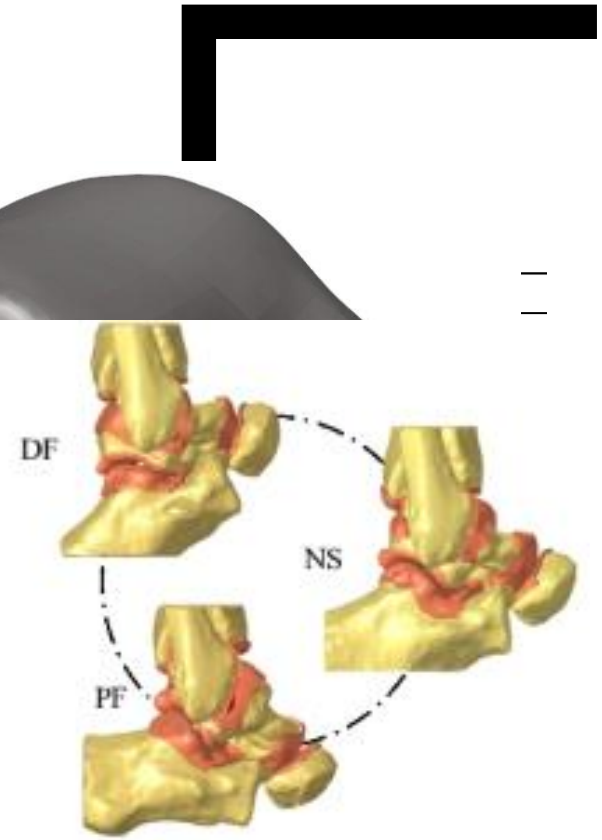
1. Sugimoto et al. (2005). Arthroscopy. 2005 Apr;21(4):401-4. doi: 10.1016/j.arthro.2004.12.005. PMID: 15800518.
2. Bowes et al. Front Surg. 2019 Nov 19;6:63. doi: 10.3389/fsurg.2019.00063. PMID: 31803752; PMCID: PMC6877655.
3. Gross et al. (2014). Foot Ankle Spec. 2014;7(5):387-397.
4. Trovato et al. (2017). Foot Ankle Surg. 2017 Jun;23(2):89-94.
5. Weber, J.S. (2019). Surgical Management of Talar Avascular Necrosis. Essential Foot and Ankle Surgical Techniques. Springer.
6. Tracey et al. (2018), "Custom 3D-Printed Total Talar Prostheses Restore Normal Joint Anatomy Throughout the Hindfoot".

Introduction & Motivation – Universal TTR

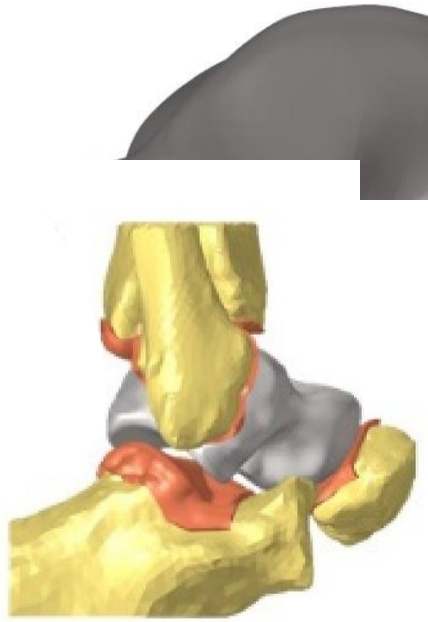
CoCr: Chobalt-chromium
PCU: Polycarbonate-urethane

[2]

CT scans

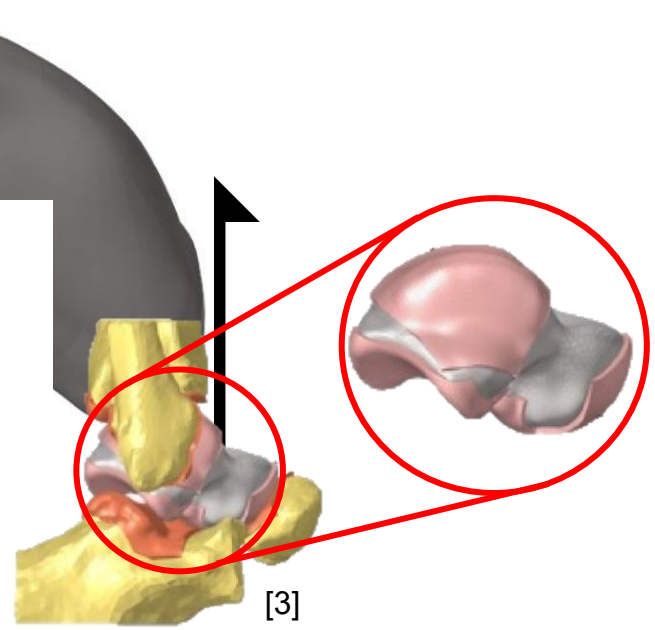


3 positions



CoCr Implant

[1]

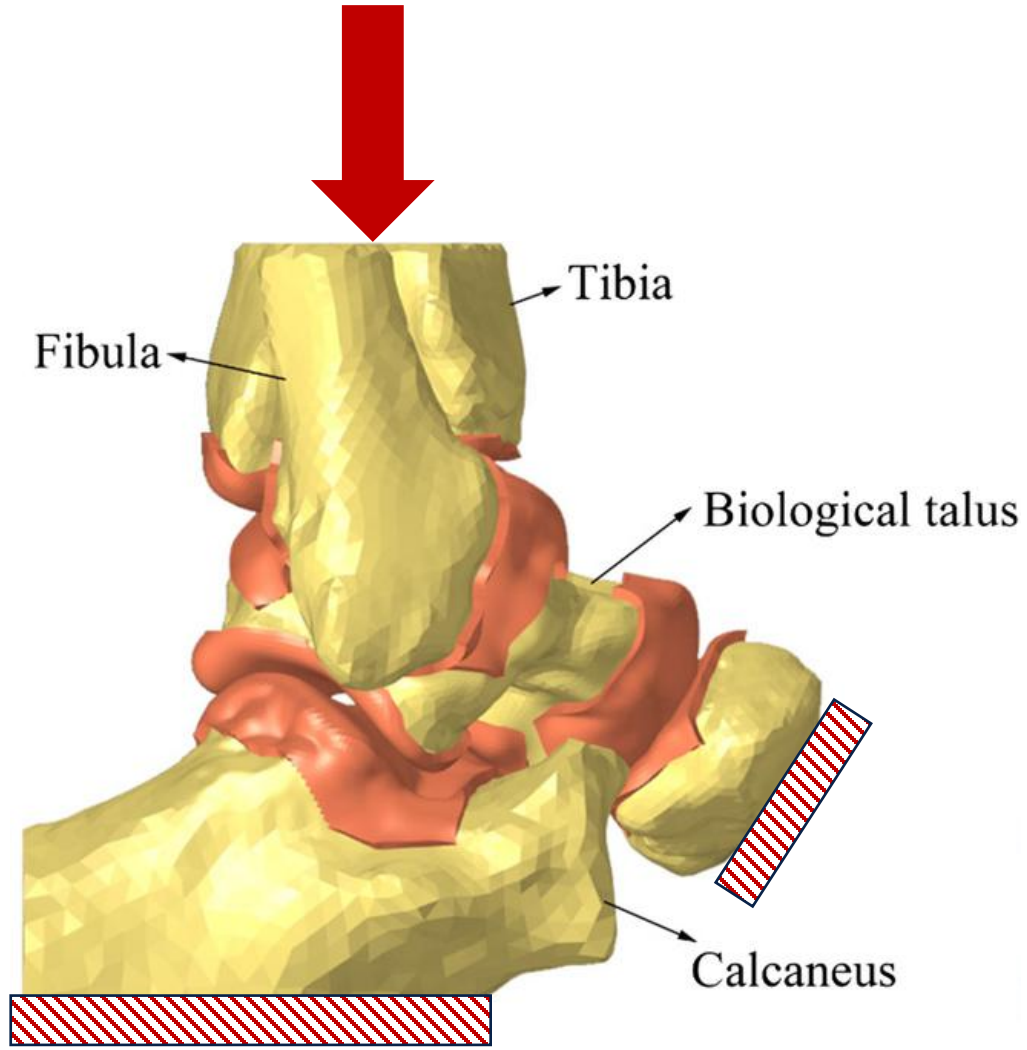


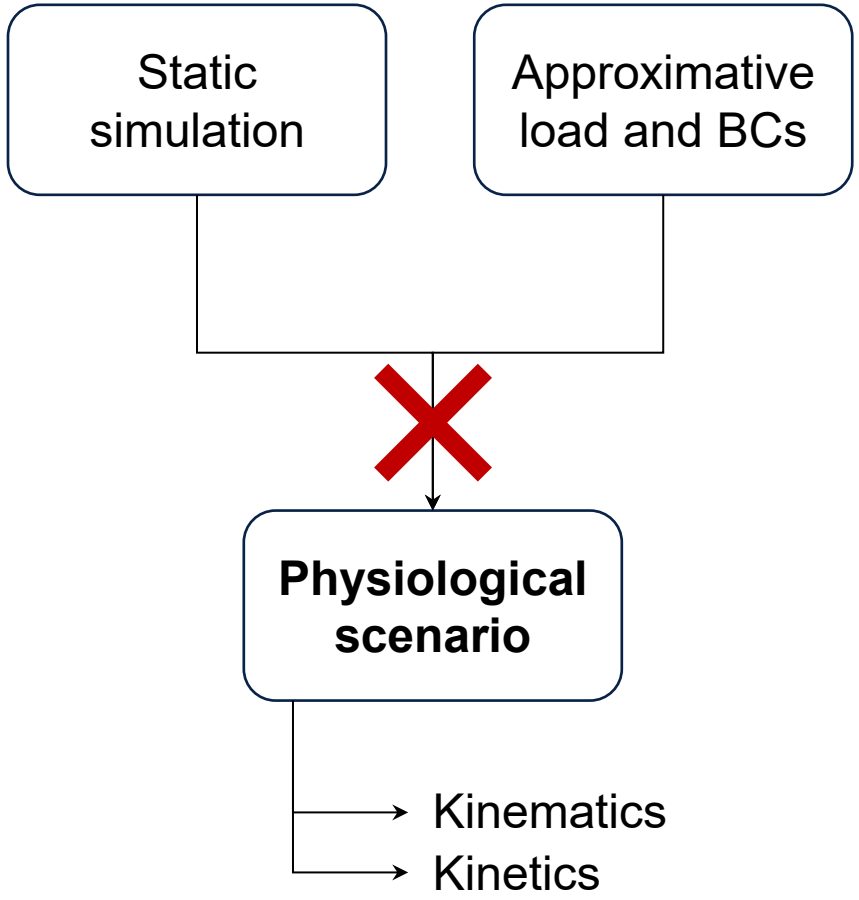
[3]

PCU-coated
CoCr Implant

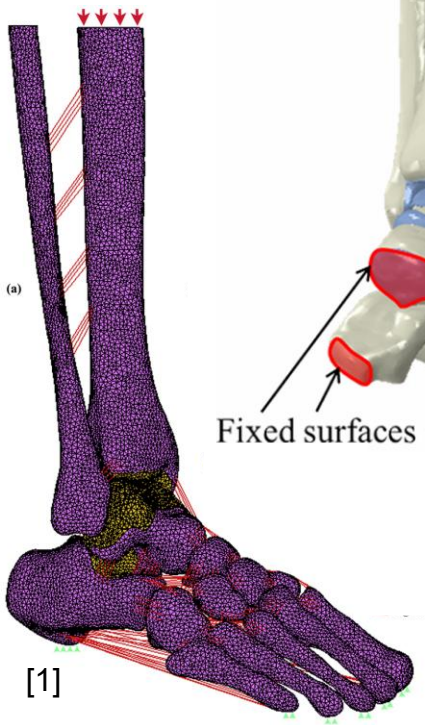
1. Trovato et al. (2017). Foot Ankle Surg. 2017 Jun;23(2):89-94.
2. Liu et al. (2022). Med Biol Eng Comput. 2022 Apr;60(4):1139-1158. Epub 2022 Mar 2.
3. Liu et al. (2023). J Mech Behav Biomed Mater. 2022 Jan;125:104936.. Epub 2021 Oct 28.

Introduction & Motivation – Simulation Scenario

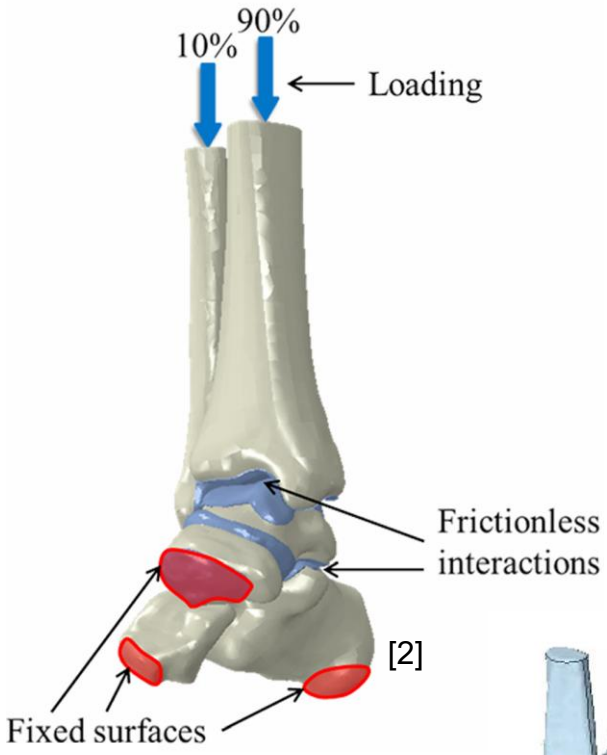




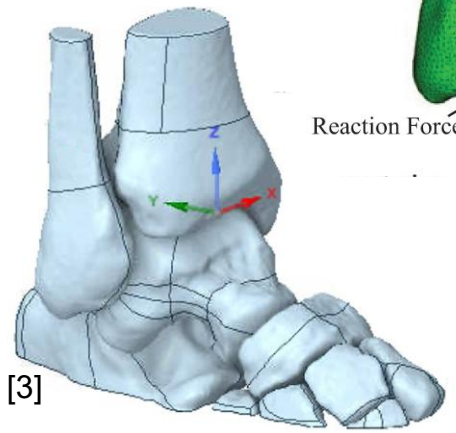
Introduction & Motivation – Literature, Static Models



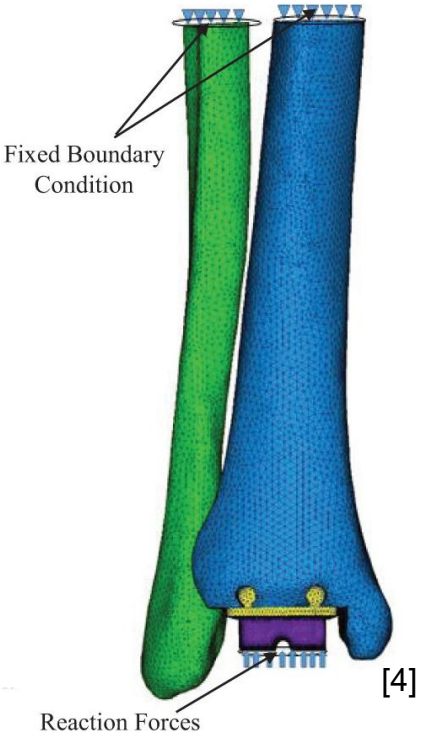
[1]



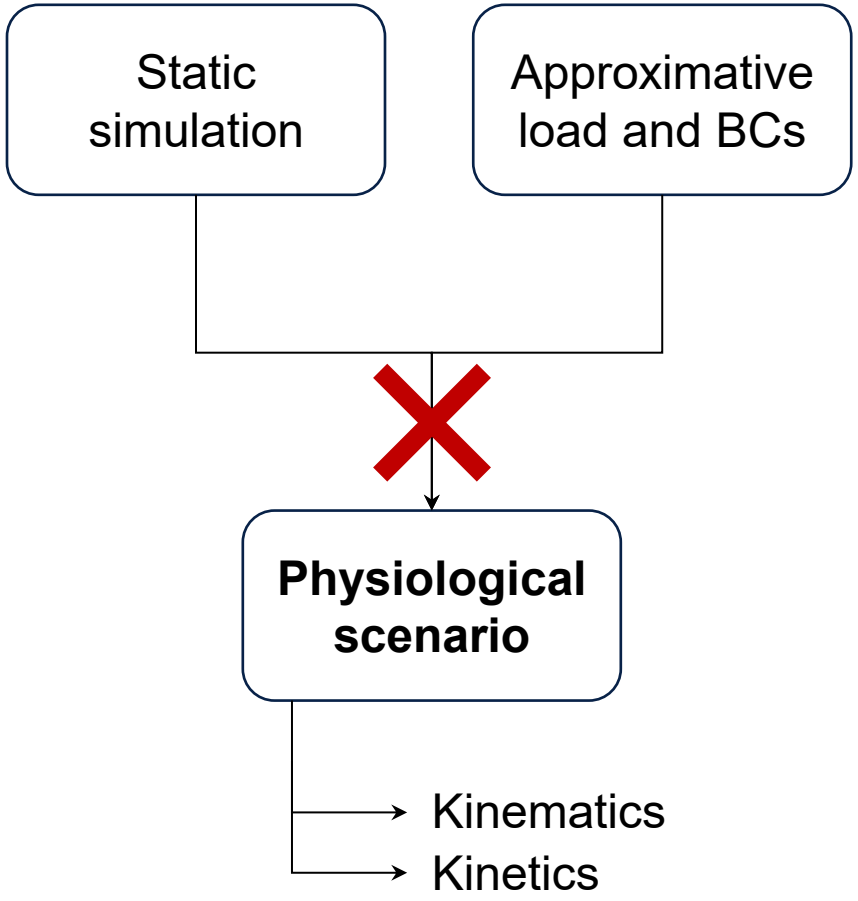
[2]



[3]

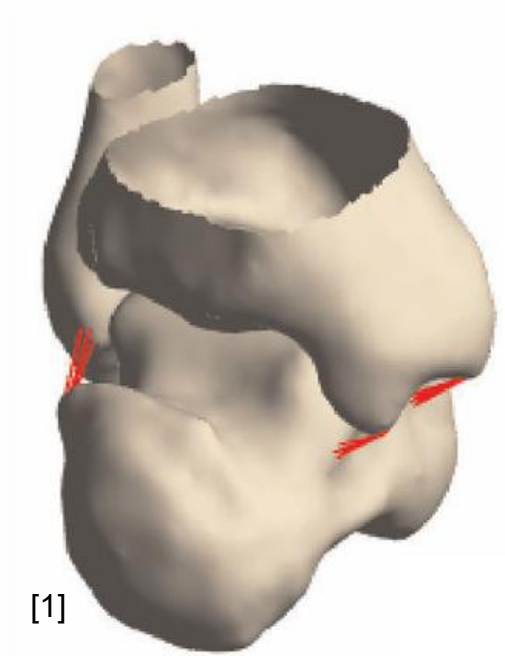


[4]



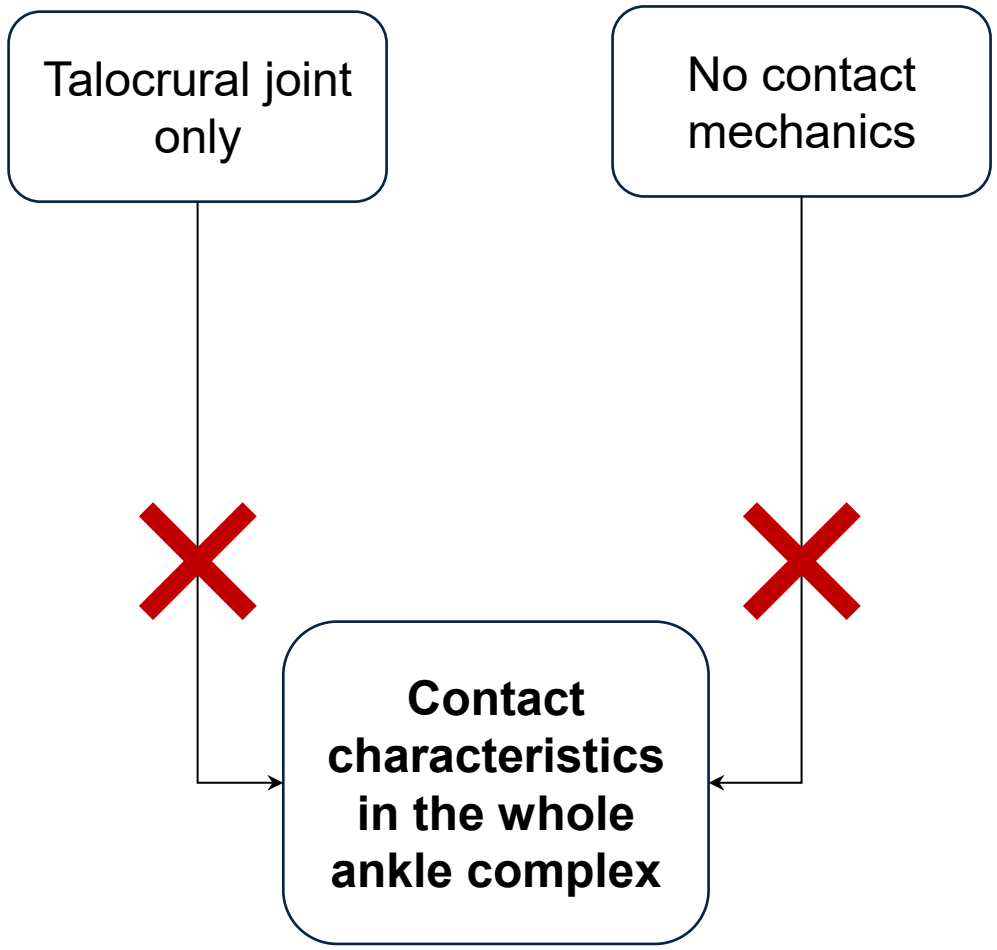
1. Alonso-Rasgado et al. Journal of Foot and Ankle Research (2017) 10:13 DOI 10.1186/s13047-017-0194-5
2. Ying et al. Journal of Orthopaedic Surgery and Research https://doi.org/10.1186/s13018-023-04432-x
3. Mondal S, Ghosh R. *Proceedings of the Institution of Mechanical Engineers, Part H*. 2019;233(3):318-331. doi:10.1177/0954411918823811
4. M.H. Ramlee et al. / Medical Engineering & Physics 36 (2014) 1358–1366. DOI: 10.1016/j.medengphy.2014.07.001

Introduction & Motivation – Literature, Dynamic Models



[1]

[2]



1. Benemerito et al. 2020, Proc IMechE Part H: J Engineering in Medicine 234(5)
2. T.L.-W. Chen et al./Journal of Biomechanics 83 (2019) 260–272

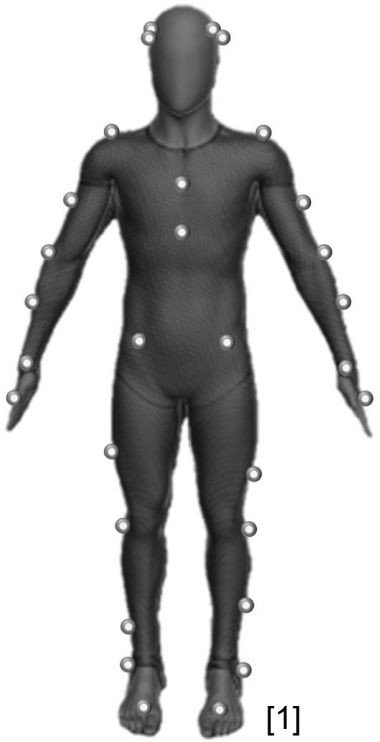
Aim of the Study & Research Question

1. Develop a high-fidelity dynamic **FE model** of the ankle complex

2. Simulate **contact characteristics** in the ankle joints during the **stance phase** of gait

3. Investigate the performance of the **universal talus implant**, with and without PCU coating

General Pipeline – Combined MSK-FE Approach

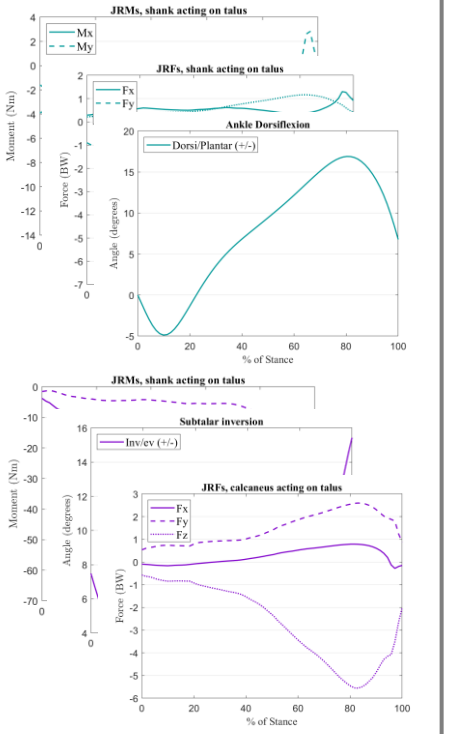


[1]

Motion Capture

MSK Simulation

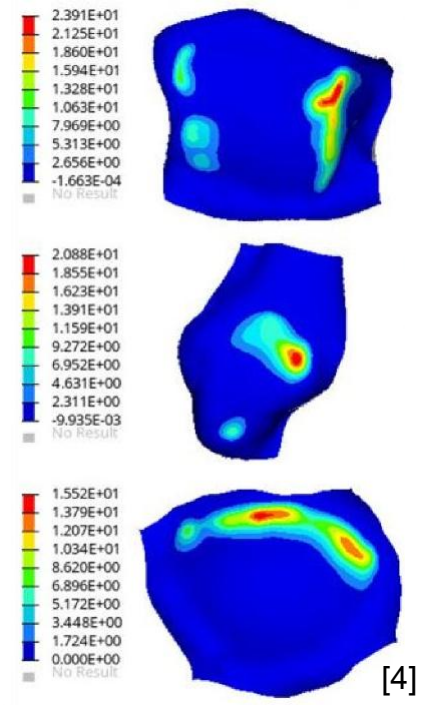
[3]



Kinematics & Kinetics

Load-BCs FE Simulation

[4]



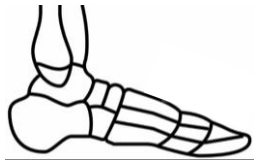
[4]

Articular Contact Analysis

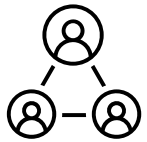
1. Kim et al. (2025) PLoS ONE 20(1): e0317933.
2. Liu et al (2024). Med Biol Eng Comput. 2024 May;62(5):1395-1407.
3. Yao et al. (2019). *BioMed Eng OnLine*,18, 89 (2019).
4. Hafez et al. (2023). Frontiers in Bioengineering and Biotechnology 11 (August 2023).

Requirements & Challenges

MSK Ankle Complex Precision → All joints surrounding the talus need to be modelled



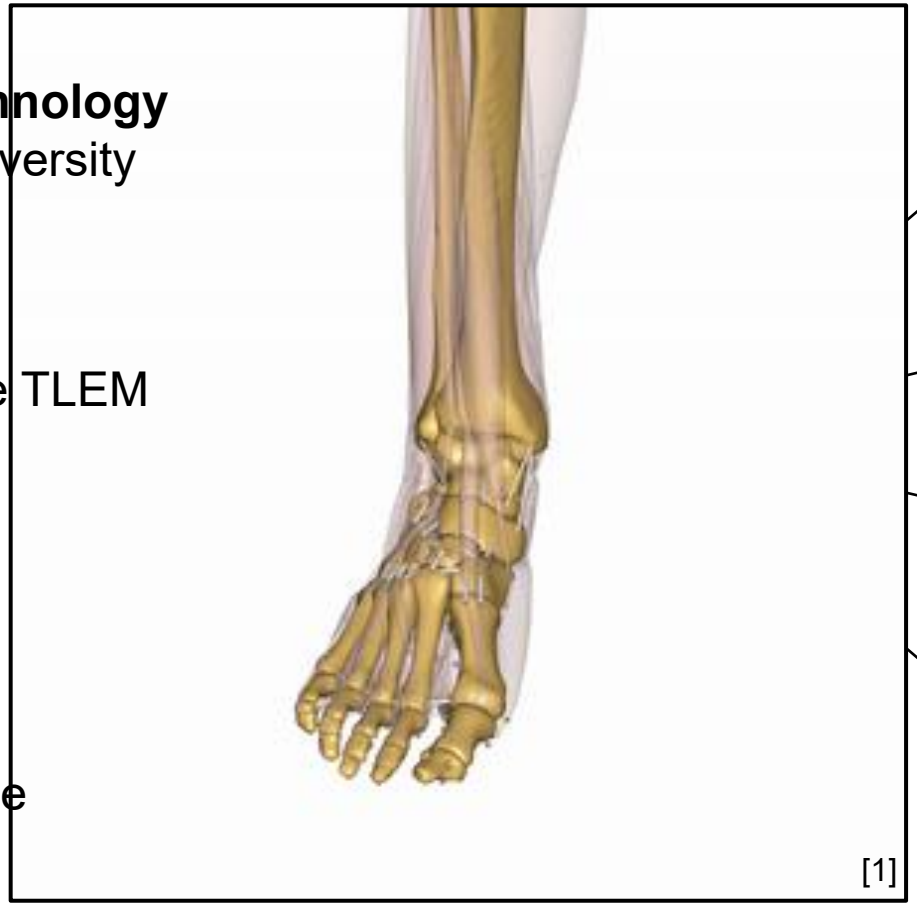
FE Model Bone Geometries → Where to obtain the bone geometries to build the FE model?



Consistency Across Domains → Motion capture data, MSK model and FE model should be based on the same subject

Methods – MSK Model

- Developed by **AnyBody Technology** with Glasgow Caledonian University and University of Maastricht
- Works in combination with the TLEM 2.1 lower extremity model.
- **Open source** in GitHub
- Example applications available



GM Foot Model

- 26 (all) foot bones
- Intrinsic and extrinsic muscles
- All joints modelled
- All ligaments

1. Oosterwaal M, Carbes S, Telfer S et al (2016) The Glasgow-Maastricht foot model, evaluation of a 26 segment kinematic model of the foot. J Foot Ankle Res 9:19

Methods – MSK Model & Input Data

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- Works in combination with the TLEM 2.1 lower extremity model.
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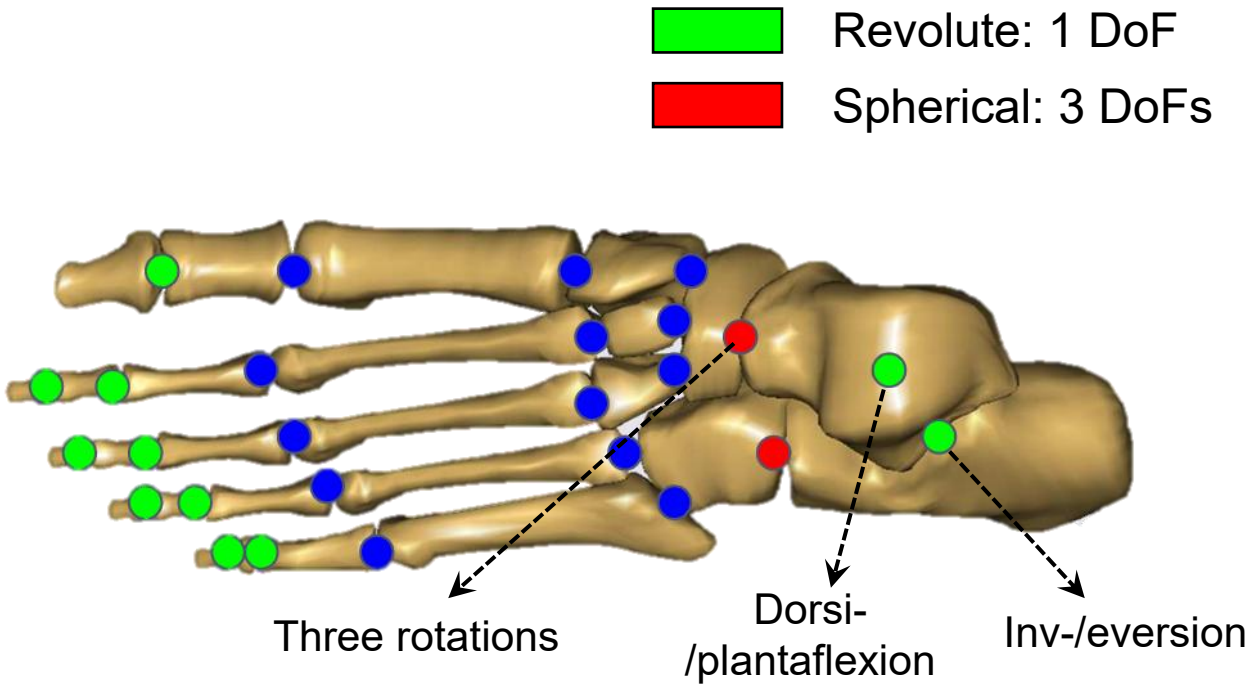
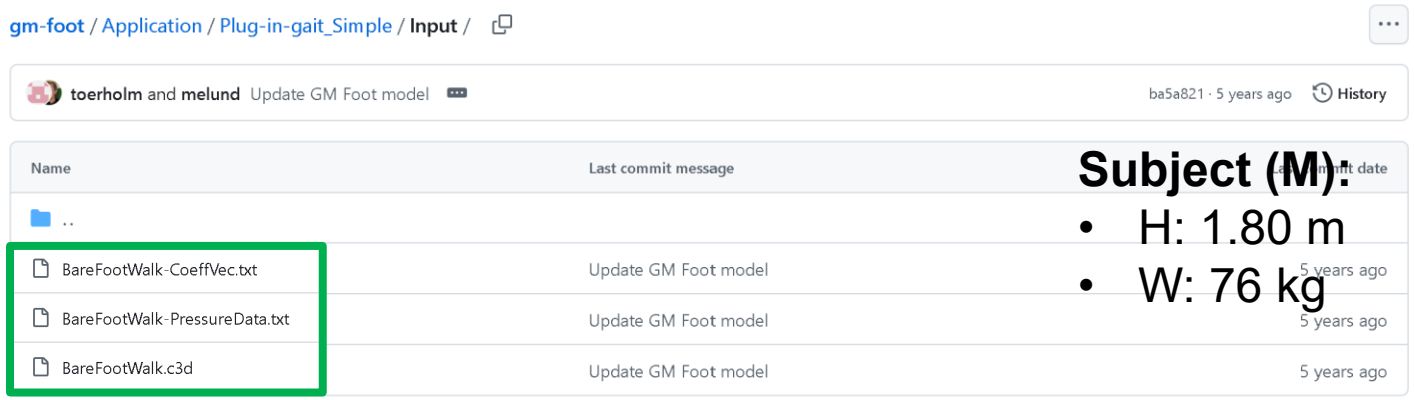




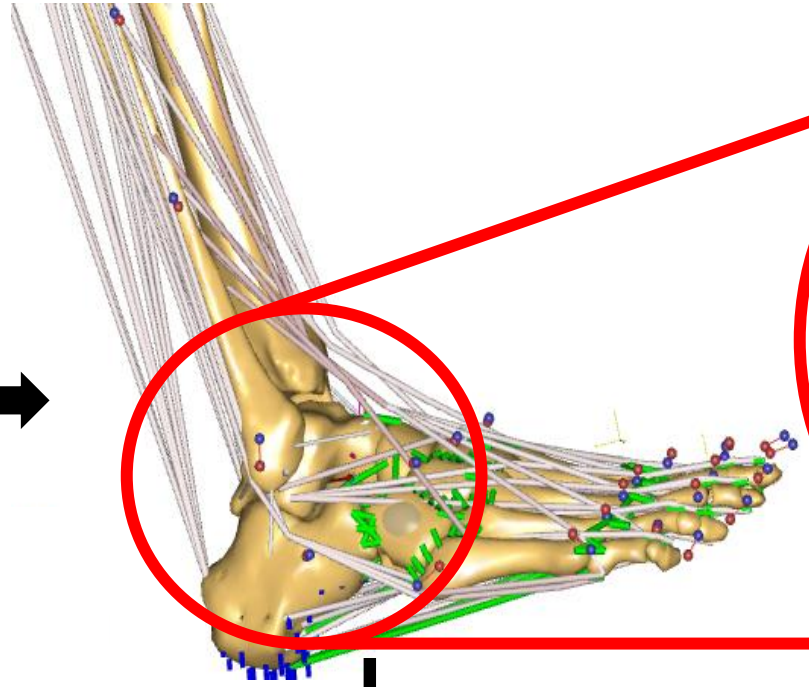
Subject (M):
- H: 1.80 m
- W: 76 kg

Specific Pipeline – Combined MSK-FE Approach

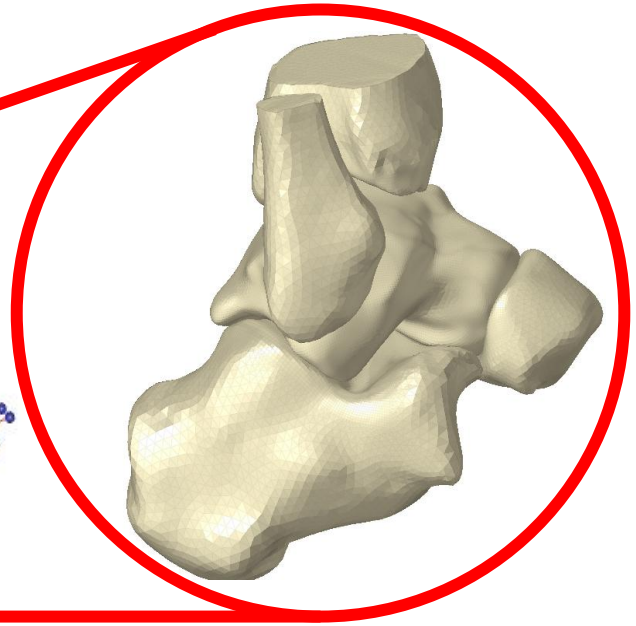
Gait Data

BareFootWalk-CoeffVec.txt
BareFootWalk-PressureData.txt
BareFootWalk.c3d

MSK Simulation



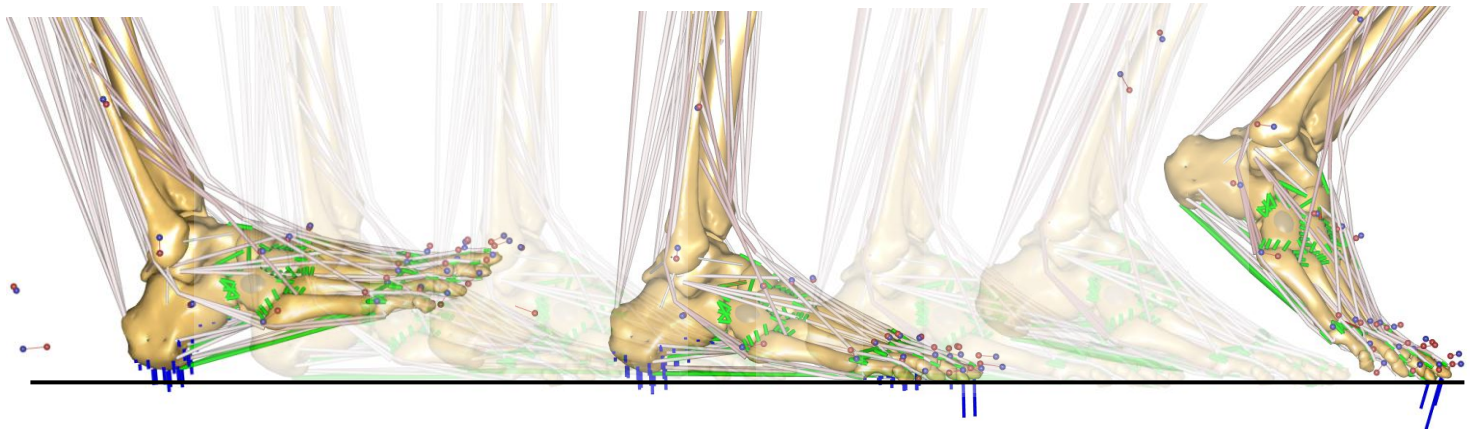
Bone Geometries



FE Model

Kinematics & Kinetics → BCs & Loads

Methods – MSK Simulation

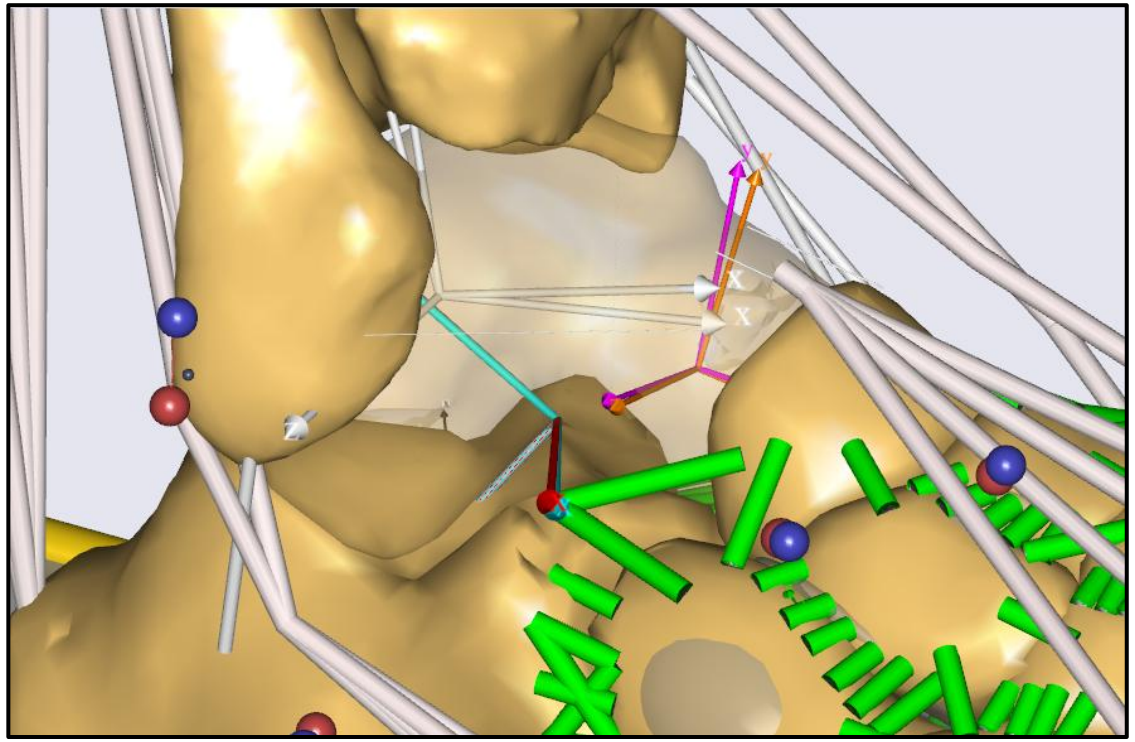


Simulation: t = 0.5948s (stance phase)

- Heel-strike to Toe-off

1. Parameters Optimization
2. Inverse Kinematics (Markers tracking)
3. Inverse Dynamics

Methods – MSK Simulation Outcome



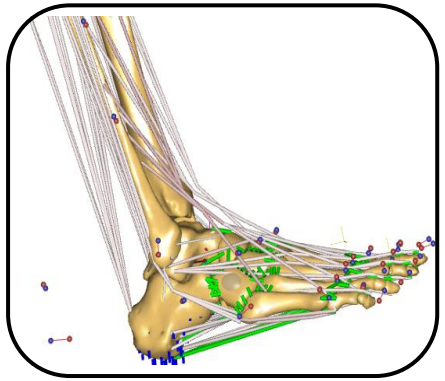
	X	Y	Z	Rx	Ry	Rz
Talocrural (Ti-Fi) Joint	⇓	⇓	⇓	⇓	⇓	↻
Sublatar joint	⇓	⇓	⇓	⇓	⇓	↻
Talonavicular joint	⇓	⇓	⇓	↻	↻	↻

⇓ **JRF**: Force/moment of one bone acting on the adjacent due to contact

↻ **Kinematic rotation**

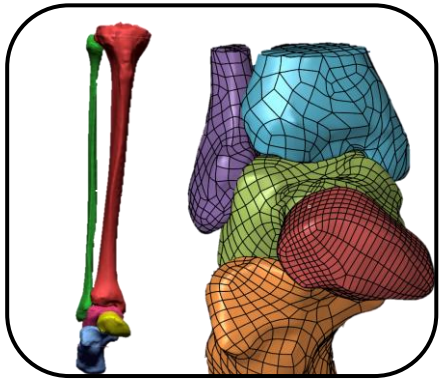
Methods – FE Model: Model Construction

AnyBody



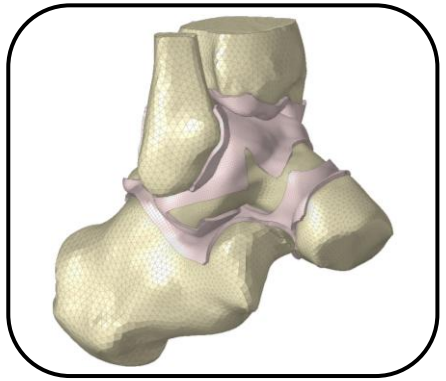
- **Bone geometries** at time step 0 (heel-strike) exported as **.stl**

Surfaces Edit



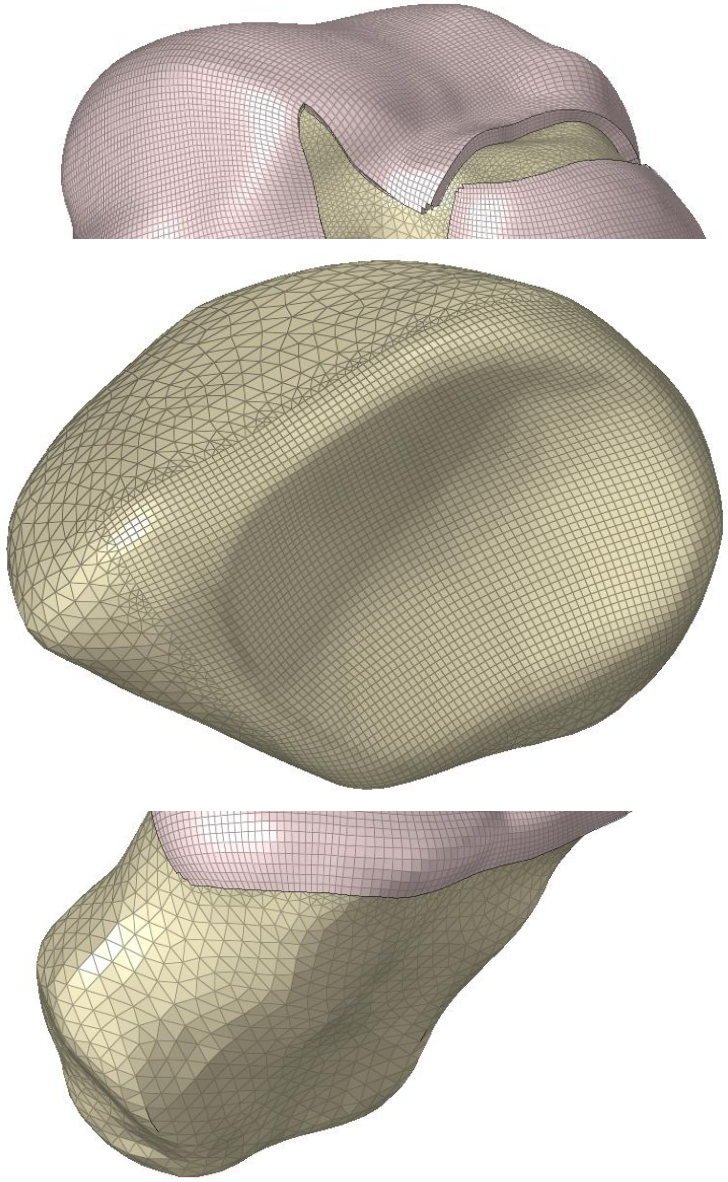
- Holes filling
- Smoothening
- Tibia & fibula **sectioned**
- Surface generation
- Exported as **.igs**

HyperMesh



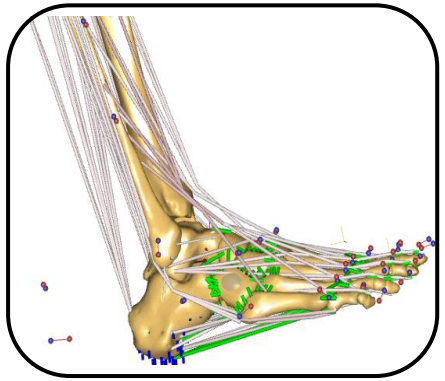
- «Split surf-node»
- Bone: **S3**
- Subchondral bone: **S4**
- «3D elem offset»
- Cartilage: **C3D8**
  - **4 layers**
  - **1.5 mm**
- S4 size: 0.4mm
- S3 size: up to 2mm
- Exported as **.inp**

[1]



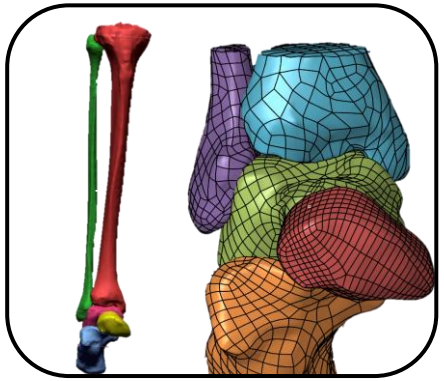
Methods – FE Model: Model Construction

AnyBody



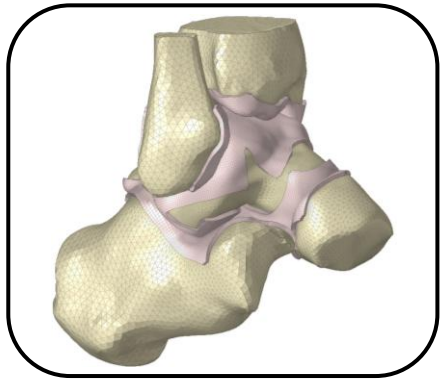
- **Bone geometries** at time step 0 (heel-strike) exported as **.stl**

Surfaces Edit



- Holes filling
- Smoothening
- Tibia & fibula **sectioned**
- Surface generation
- Exported as **.igs**

HyperMesh

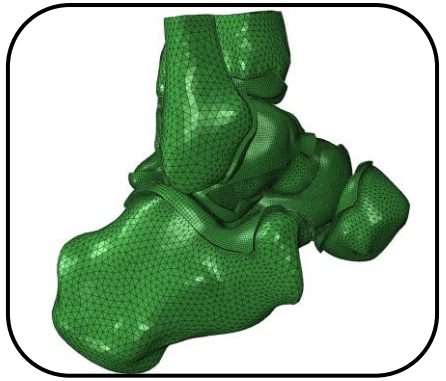


- «Split surf-node»
- Bone: **S3**
- Subchondral bone: **S4**
- «3D elem offset»
- Cartilage: **C3D8**
  - **4 layers**
  - **1.5 mm**

[1]

- S4 size: 0.4mm
- S3 size: up to 2mm
- Exported as **.inp**

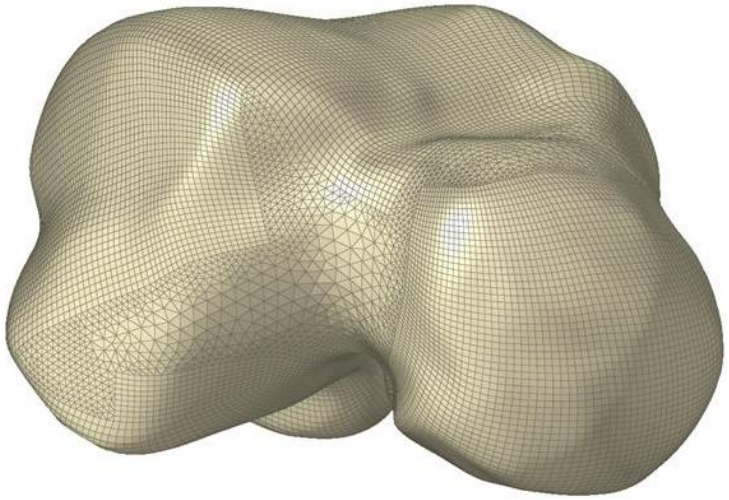
Abaqus

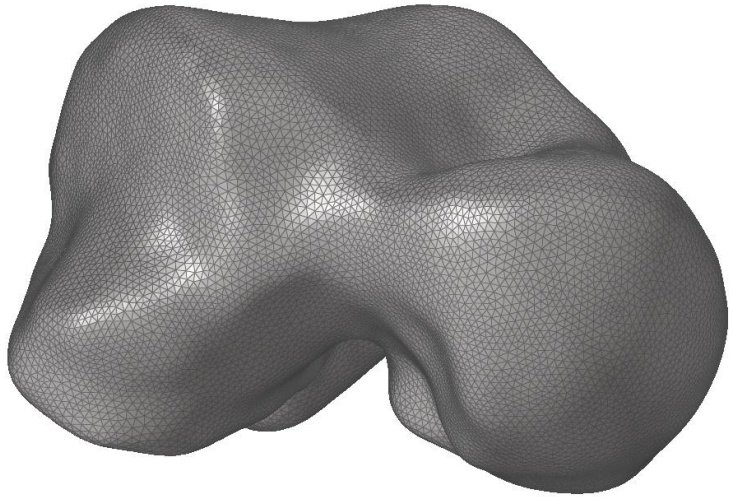


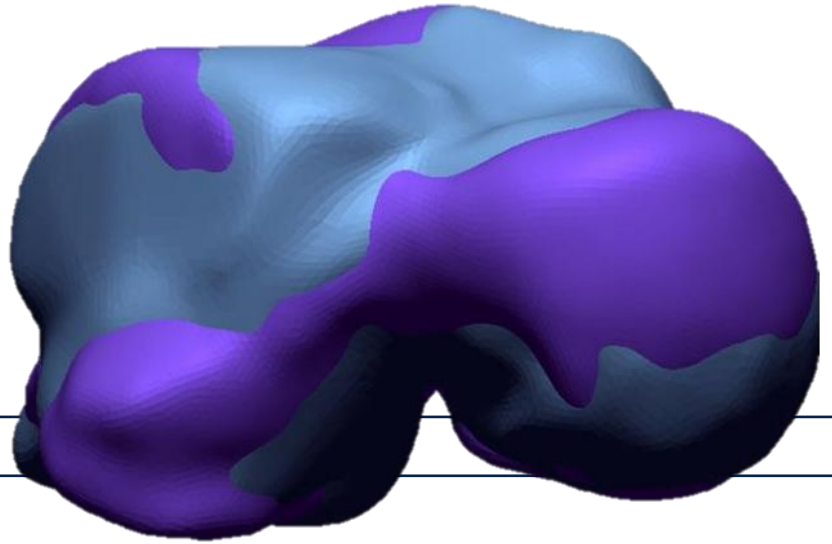
- Material properties
- Contact definition
- Shell thickness
- Interactions
- Constraints
- BCs
- Loads
- Steps

1. Liu et al. (2022). Med Biol Eng Comput. 2022 Apr;60(4):1139-1158. Epub 2022 Mar 2.
2. Liu et al. (2023). J Mech Behav Biomed Mater. 2022 Jan;125:104936.. Epub 2021 Oct 28.

Methods – FE Model: Talus Implant Size Selection







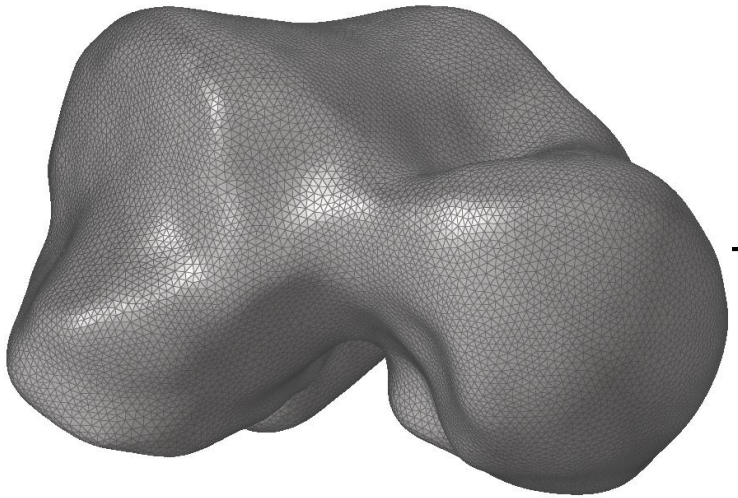
V=50,630 mm³

8

50,132

Talus models alignment

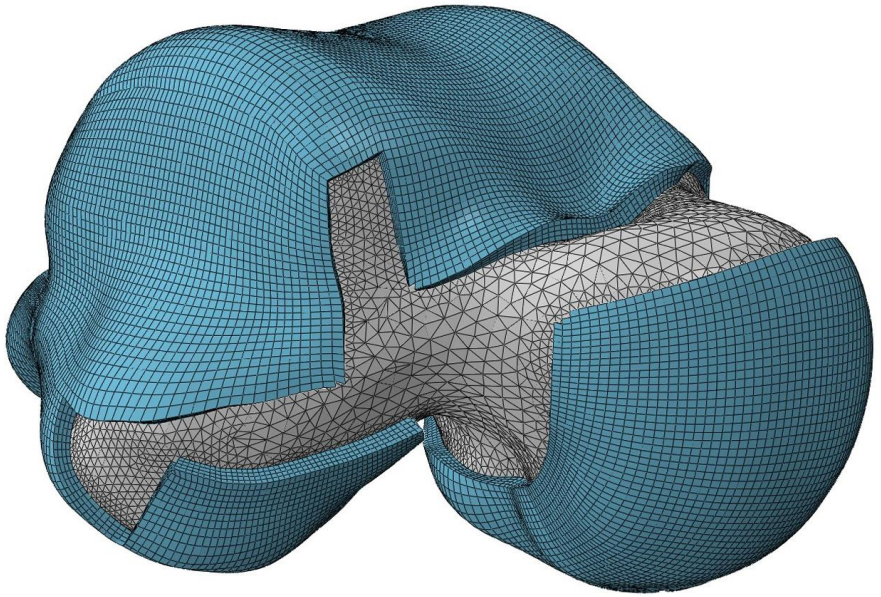
Methods – FE Model: Two Implant Models

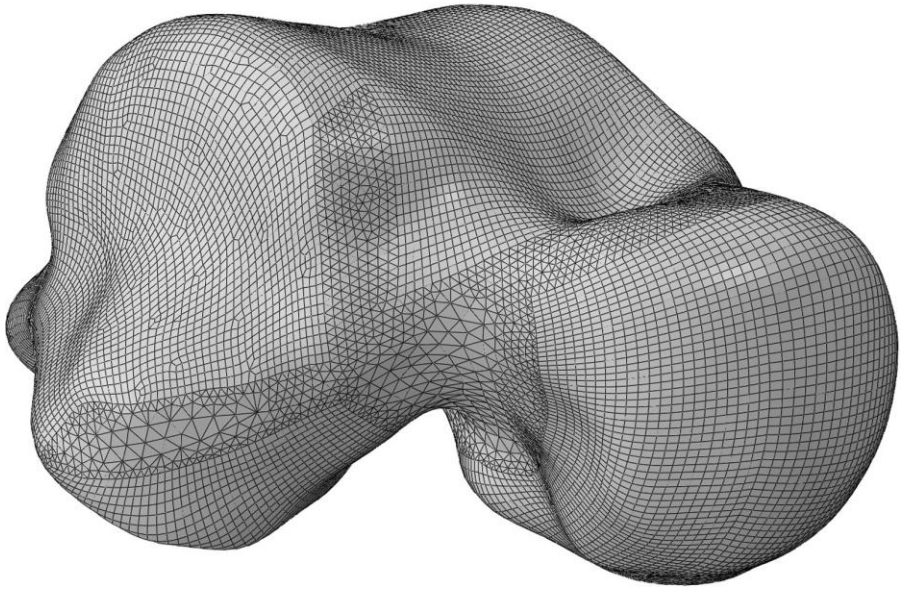


PCU-Implant

CoCr-Implant

Scale up:
+0.5mm[1]

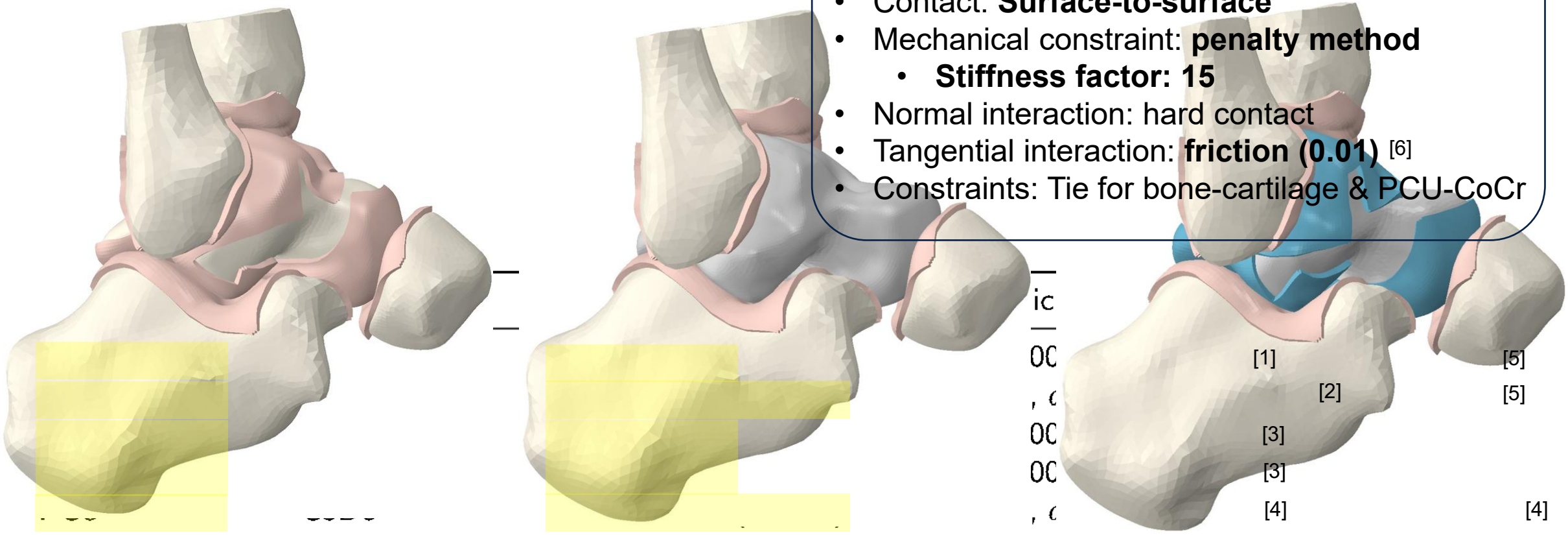




1. Liu et al. (2022). Med Biol Eng Comput. 2022 Apr;60(4):1139-1158. Epub 2022 Mar 2.
2. Liu et al. (2023). J Mech Behav Biomed Mater. 2022 Jan;125:104936.. Epub 2021 Oct 28.

Methods – FE Model: Material Properties & Model Set-up

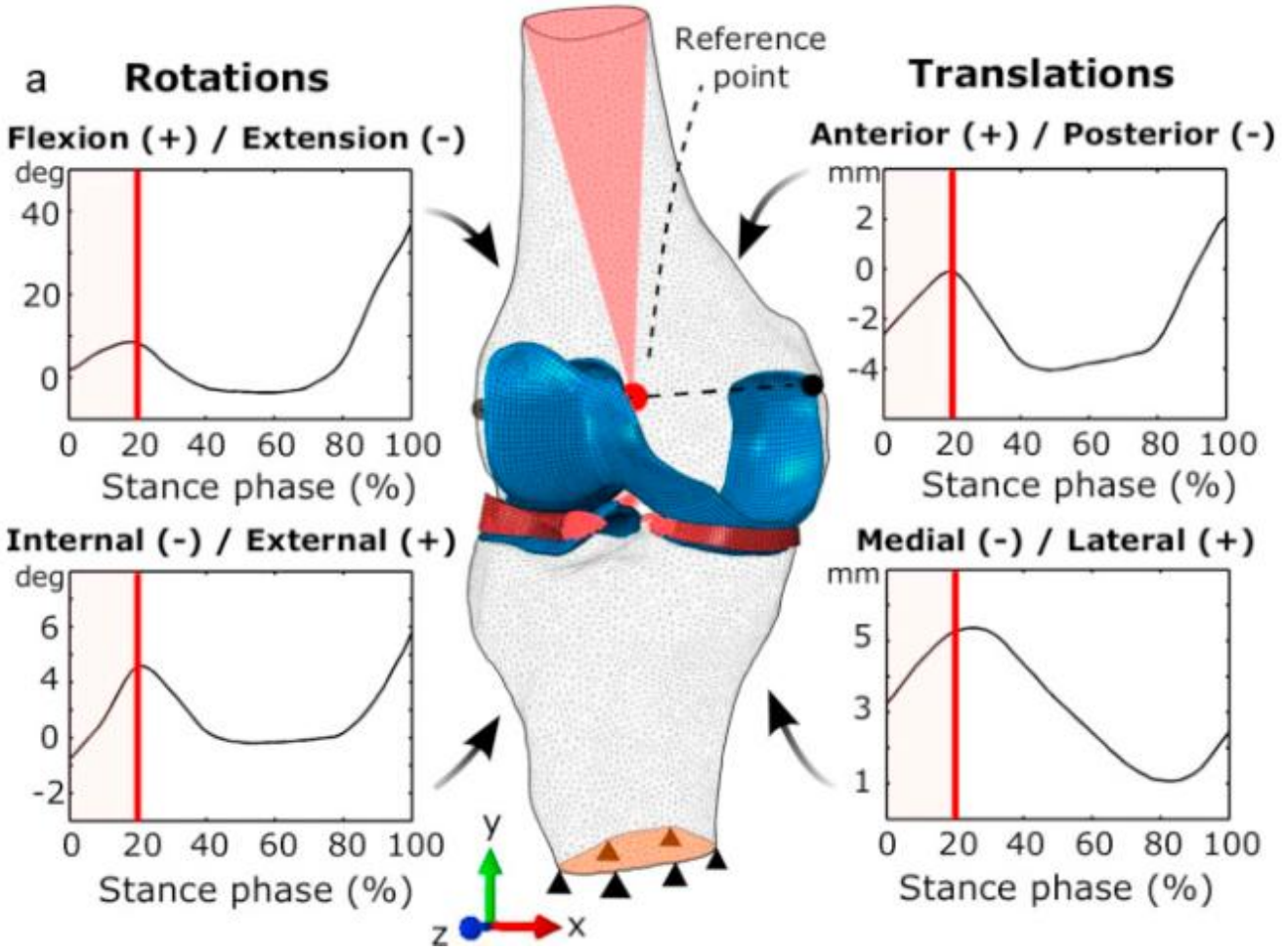
- Cortical Bone and CoCr **thickness: 1mm** [6]
- Contact: **Surface-to-surface**
- Mechanical constraint: **penalty method**
  - **Stiffness factor: 15**
- Normal interaction: hard contact
- Tangential interaction: **friction (0.01)** [6]
- Constraints: Tie for bone-cartilage & PCU-CoCr

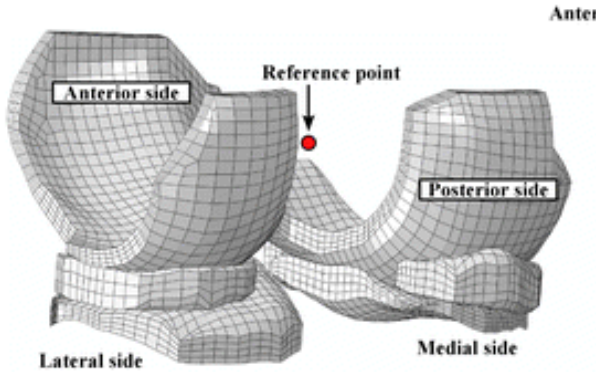


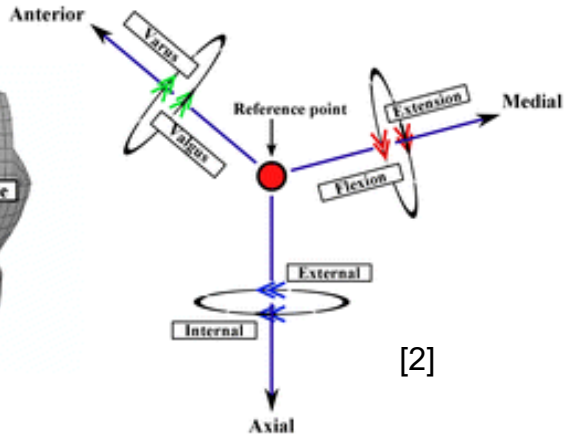
Biological Model | **CoCr Model** | **PCU Model**

1. Mondal and Ghosh (2019). *Proceedings of the Institution of Mechanical Engineers, Part H.* 2019;233(3):318-331.
2. Brown et al. (2009). Proc. Inst. Mech. Eng. H, 223 (2009), pp. 643-652.
3. Al Jabbari (2014). J. Adv. Prosthodont., 6 (2014), pp. 138-145.
4. DSM Corp (2021). https://www.dsm.com/corporate/home.html
5. Erbulut et al (2021). Journal of Biomechanical Engineering, Vol. 143 / 101006-1
6. Liu et al. (2023). J Mech Behav Biomed Mater. 2022 Jan;125:104936.. Epub 2021 Oct 28.

Methods – FE Simulation: BCs & Loads







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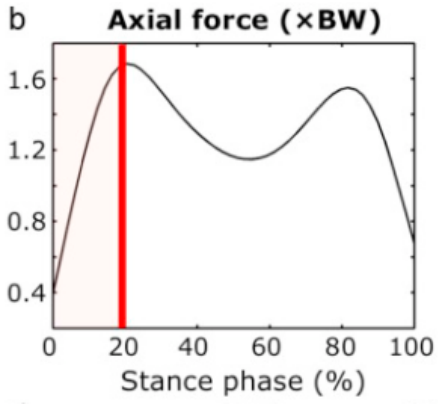
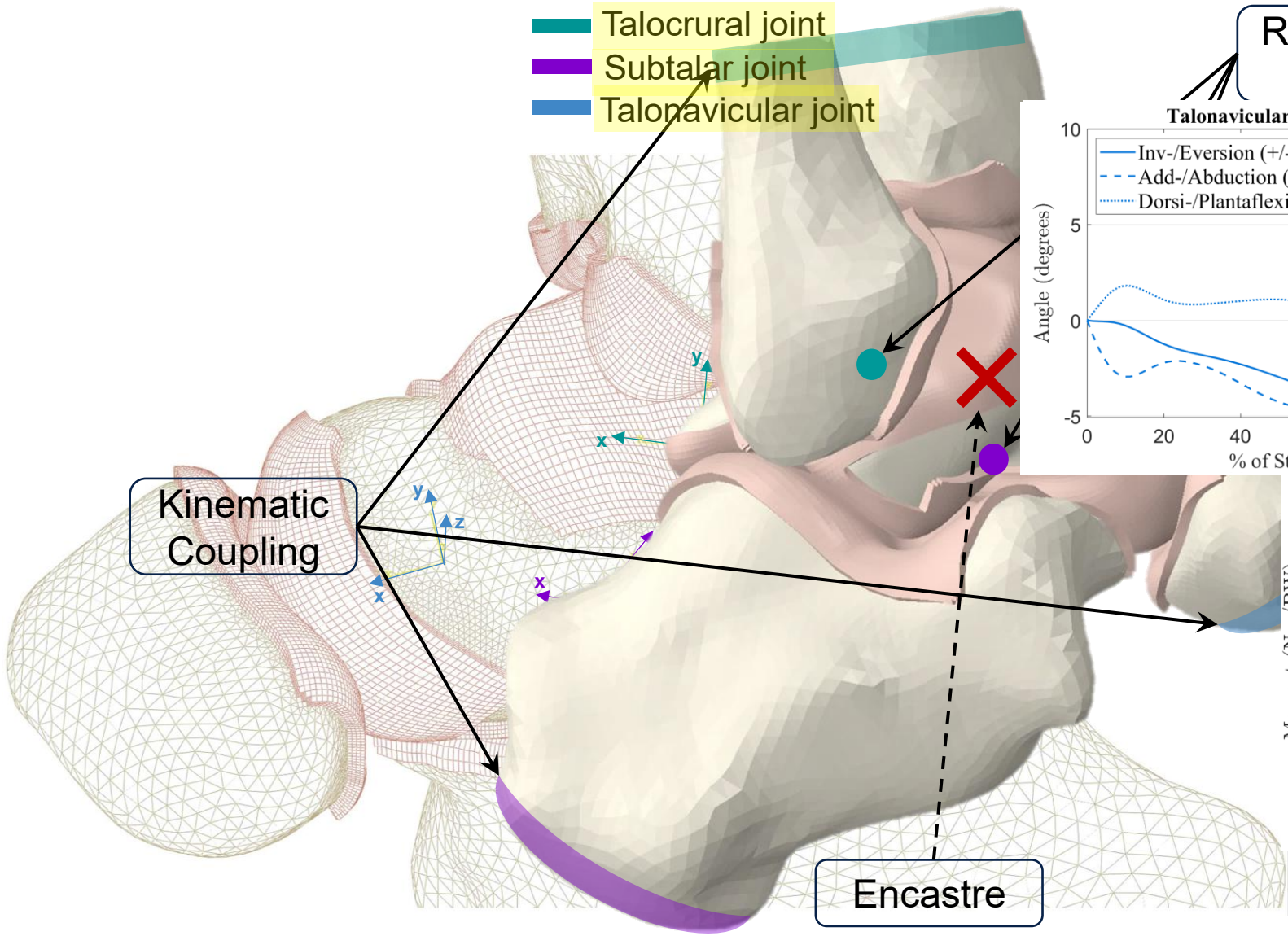
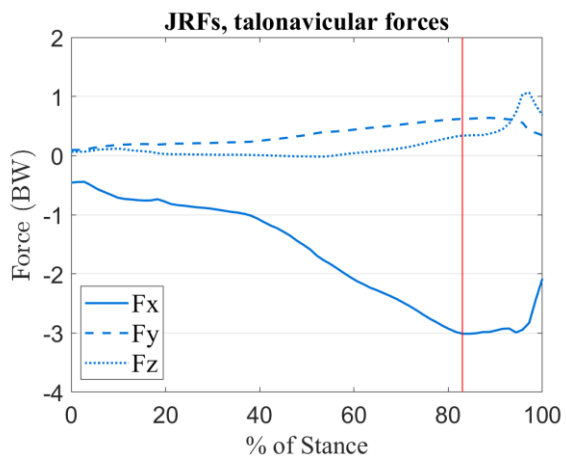
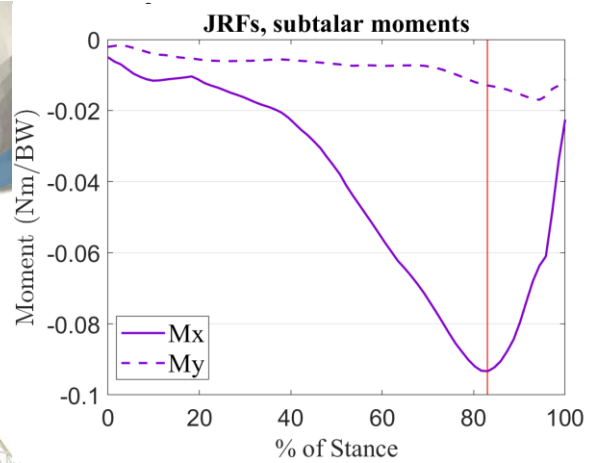


[1]

Methods – FE Simulation: BCs & Loads







Simulation: 0-83% stance phase

Methods – FE Model: Steps

Step 1
0.1 s

- **Initial loads applied** («smooth-step» from 0 to initial value) for all DoFs controlled by forces/moments.
- **Remaining DoFs constrained** to maintain predefined kinematic variables constant until the beginning of gait.

Step 2
0.1 s

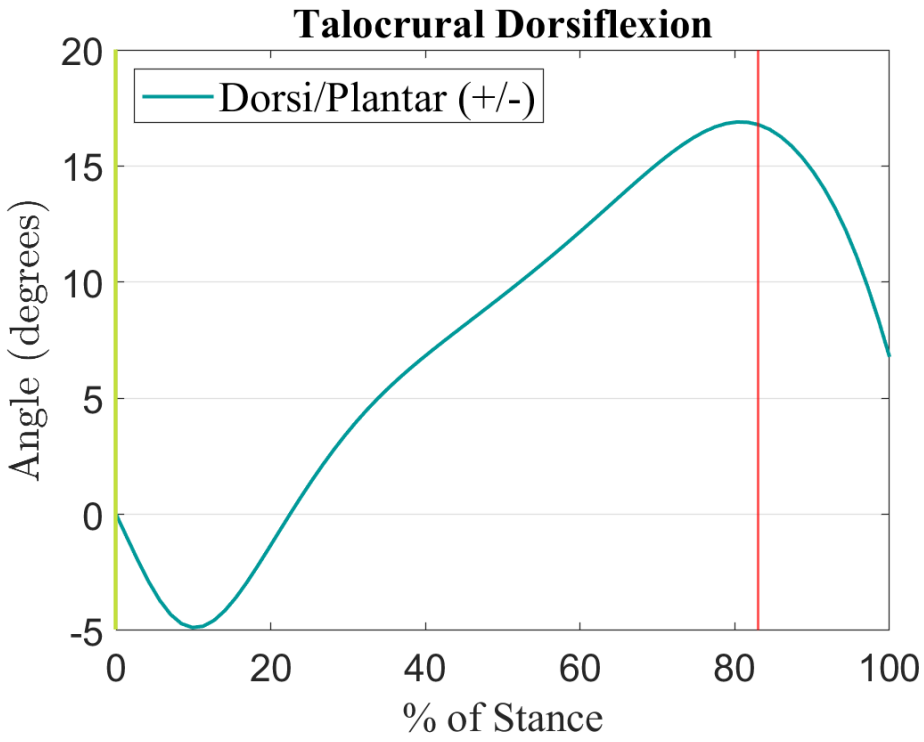
- All loads **maintained at initial condition** (values reached in step 1)
- Kinematics still constrained as in step 1

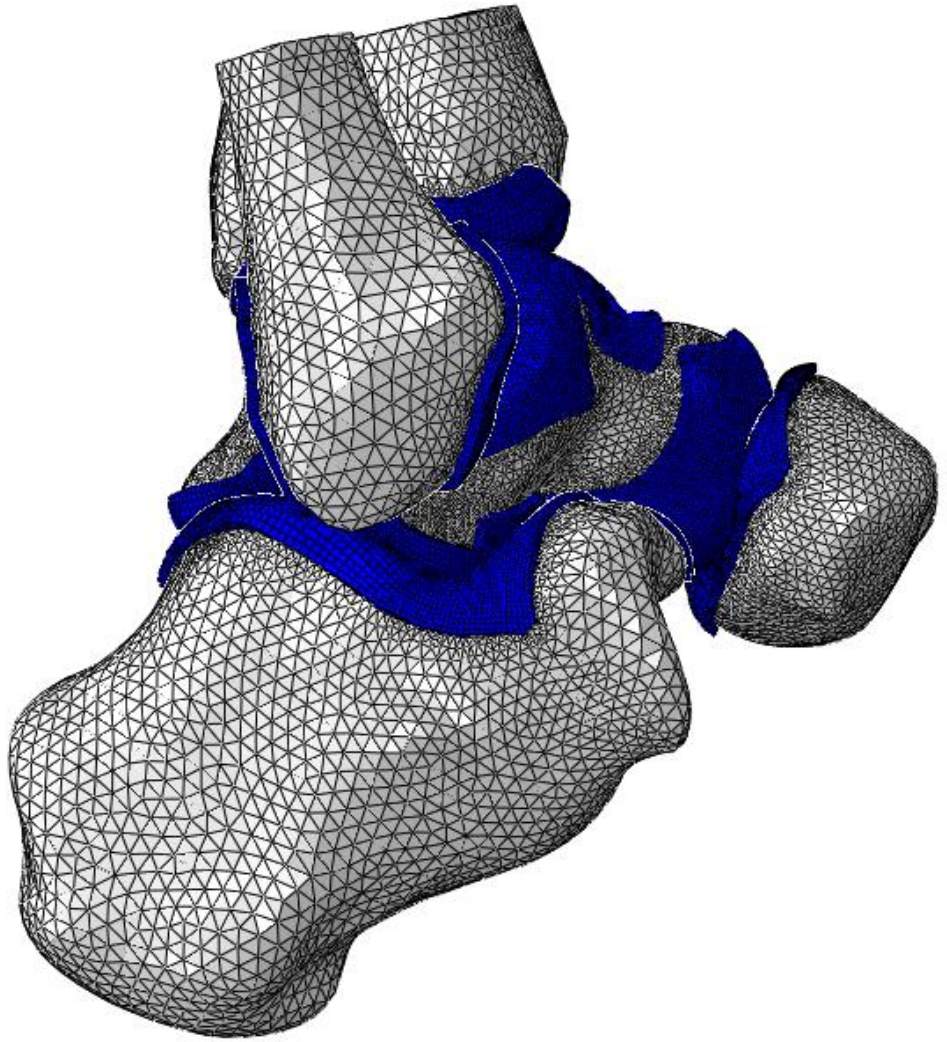
Step3
0.5948 s

- Joint **kinematics and JRFs applied** as time-dependent BCs and Loads
- «smooth-step» function between time steps

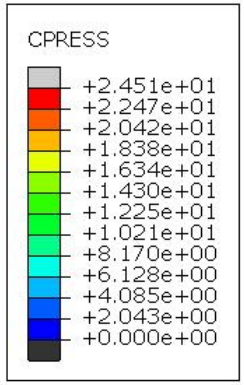
Solver: Dynamic Explicit

Results – Biological Model Simulation

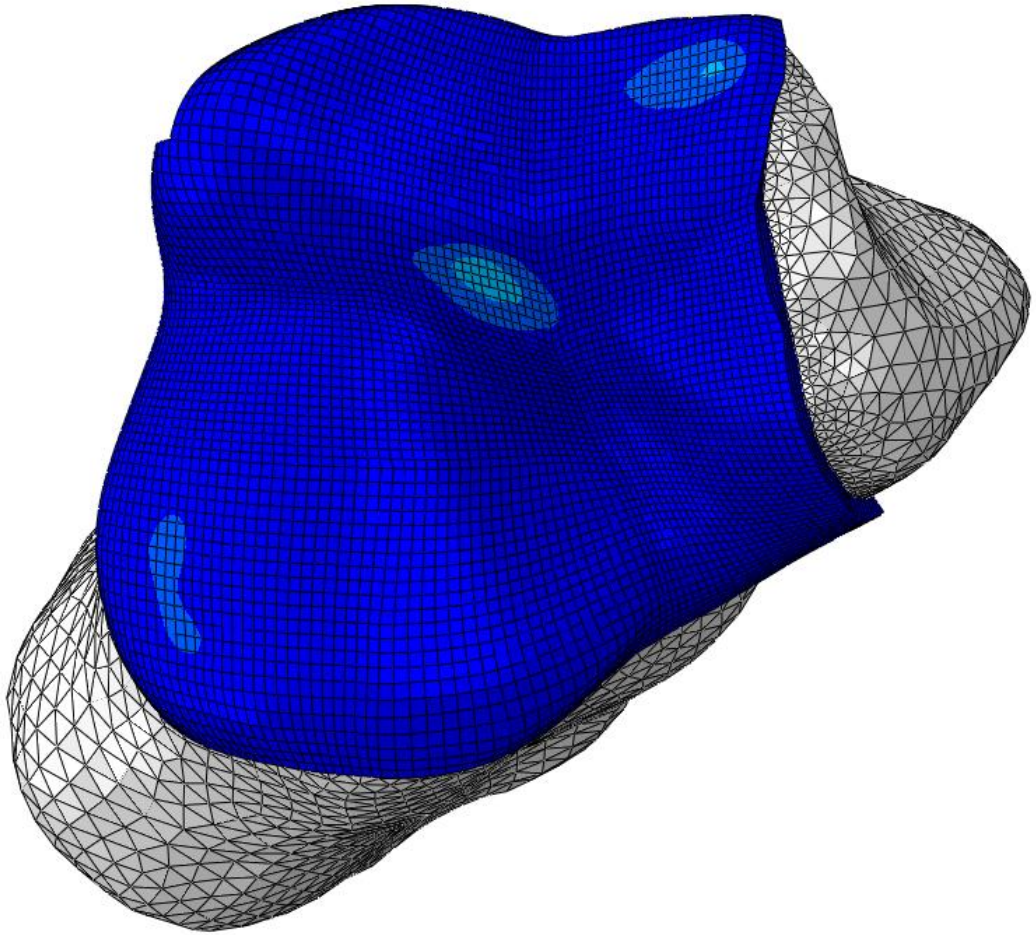


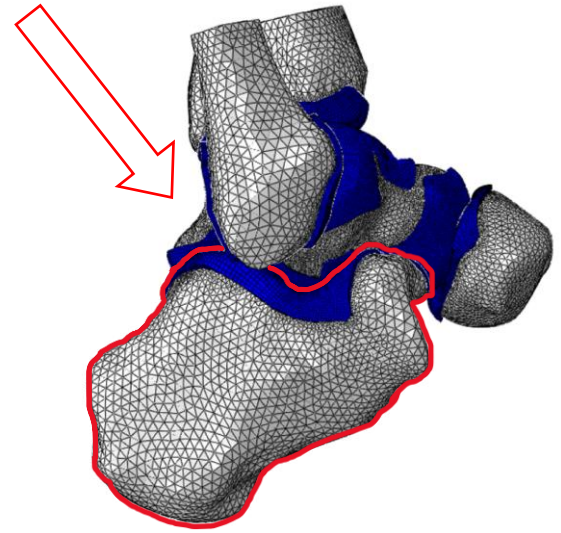


Results – Contact Patterns



Calcaneus

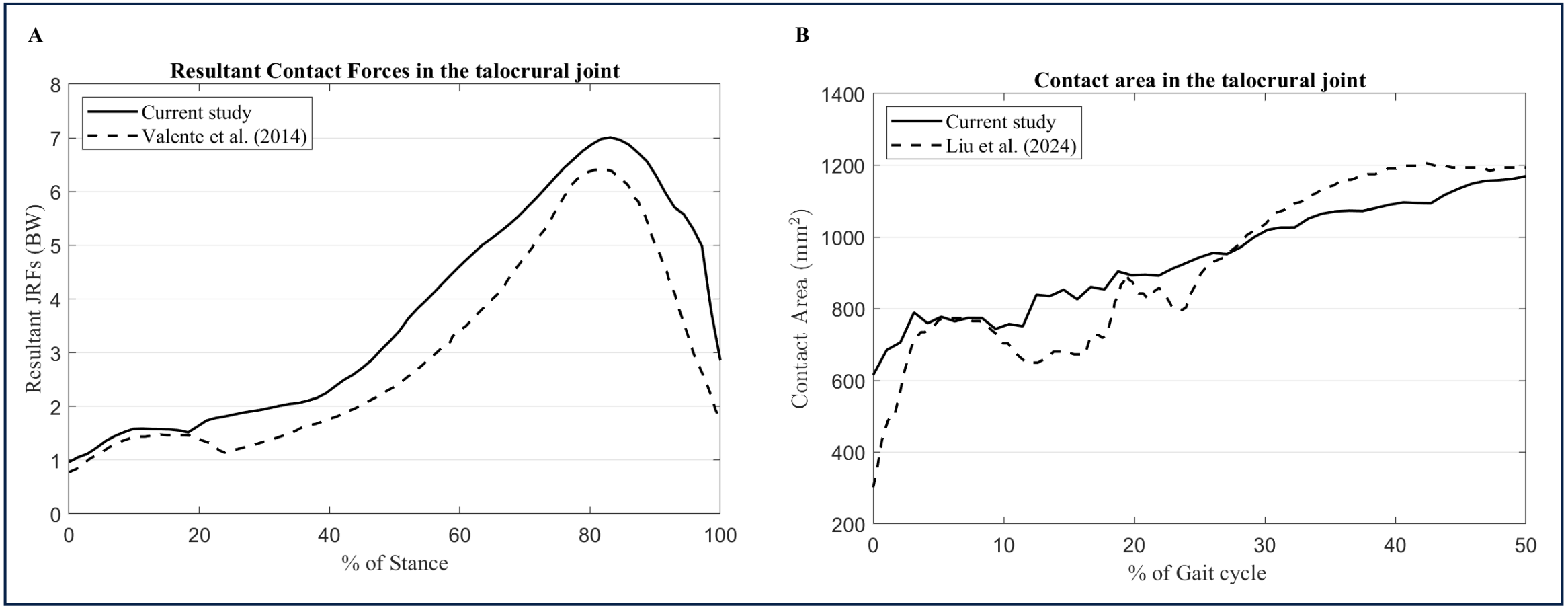




Results – Models Validation

MSK Model

FE Model



Results & Discussion – Contact Patterns

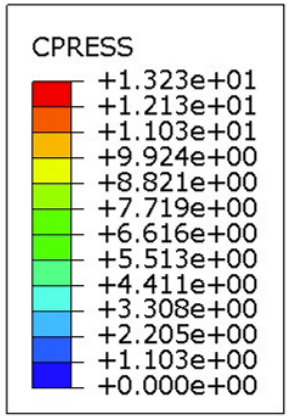
83% of stance

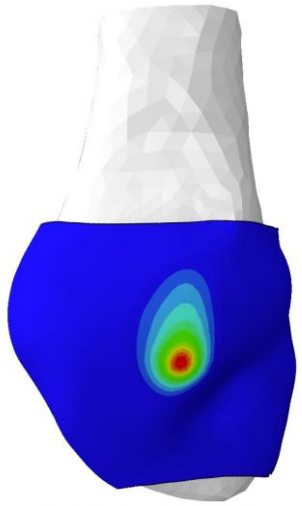
Biological talus model

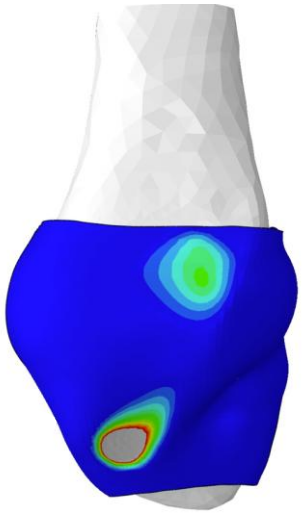
CoCr-Implant model

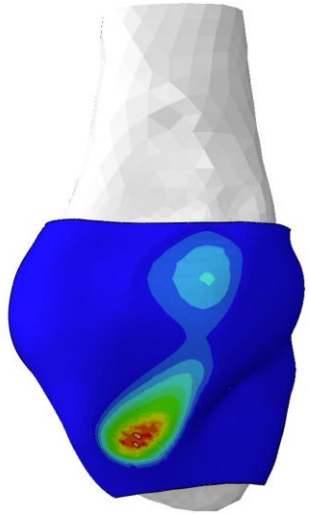
PCU-Implant model

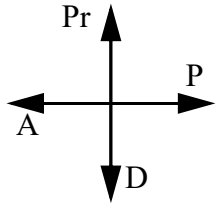
Fibula



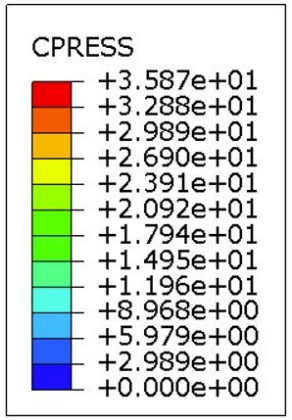


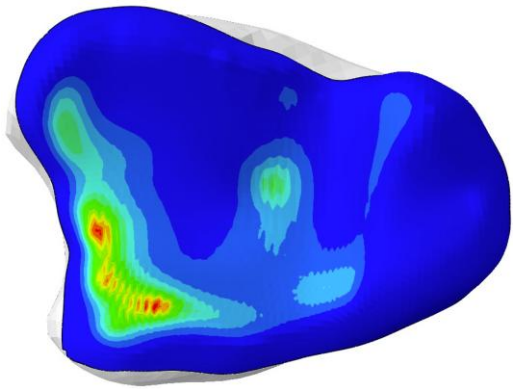


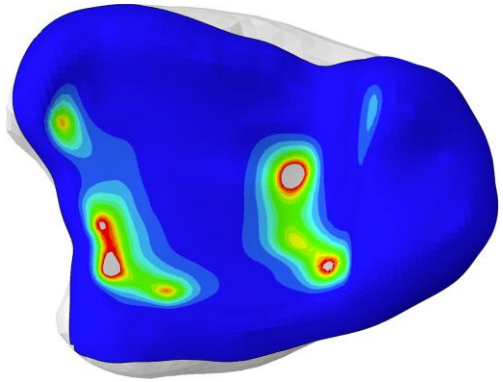


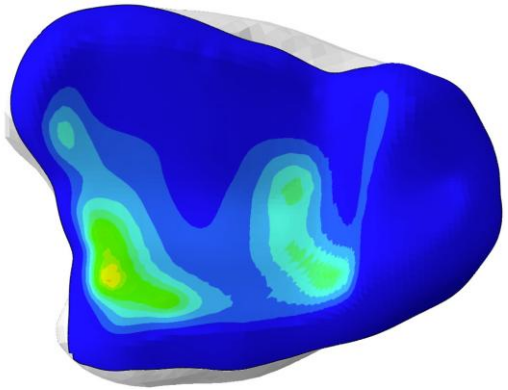


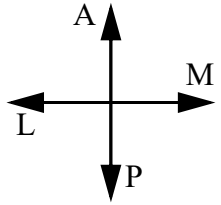
Tibia











Results & Discussion – Contact Patterns

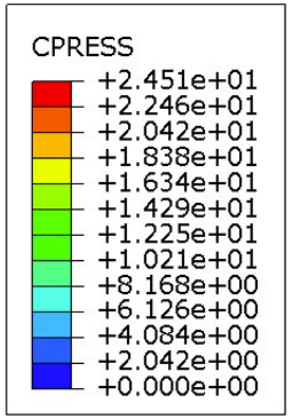
83% of stance

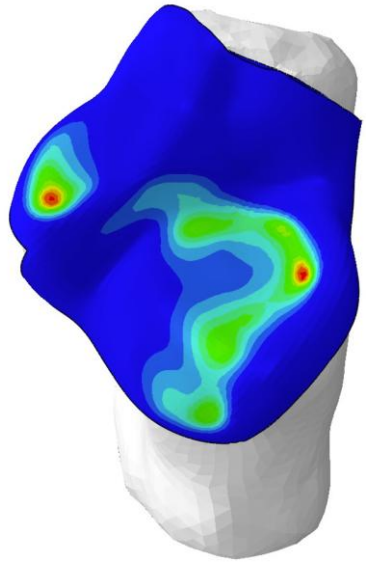
Biological talus model

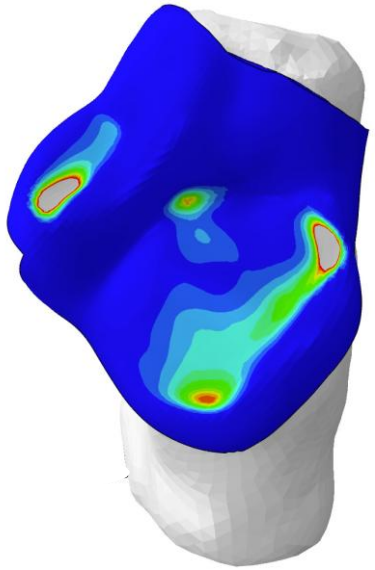
CoCr-Implant model

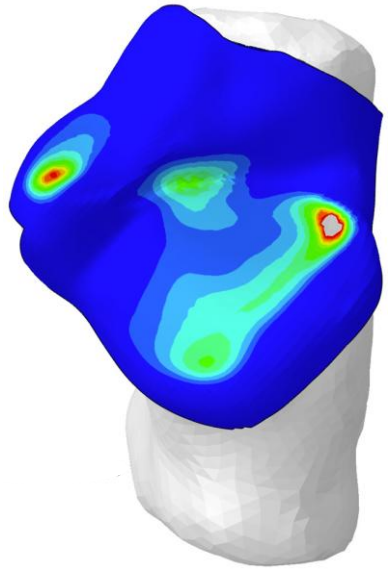
PCU-Implant model

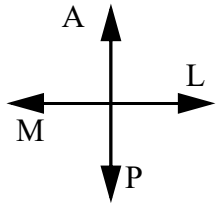
Calcaneus



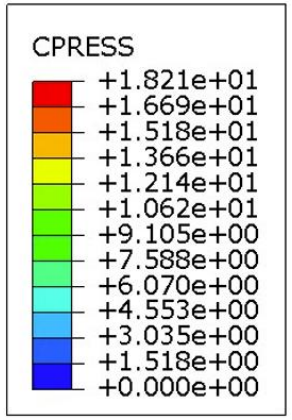


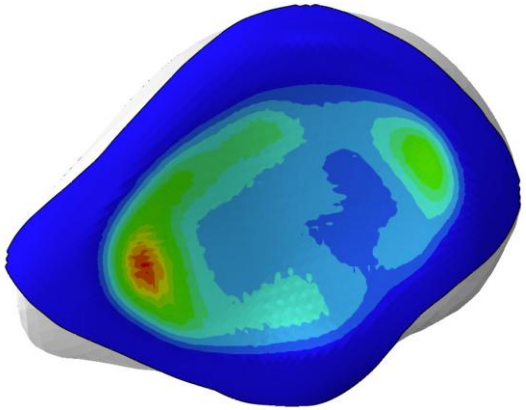


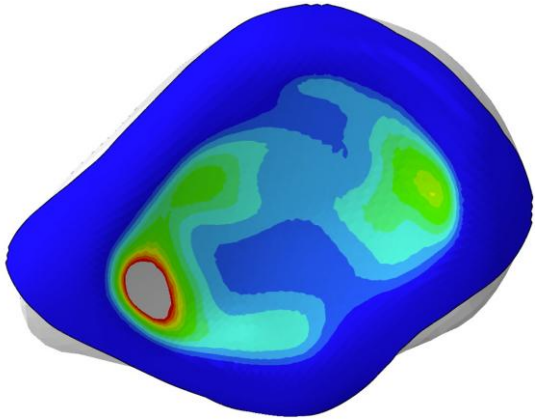


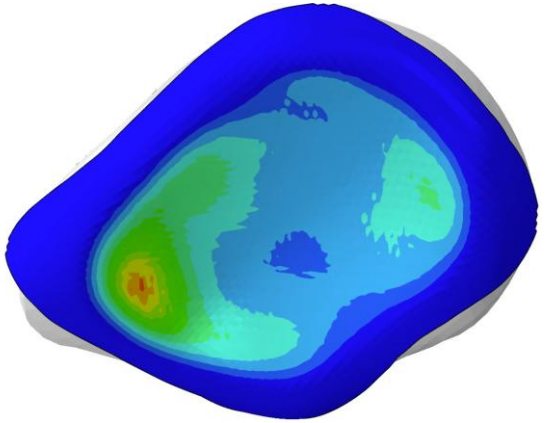


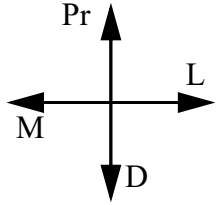
Navicular



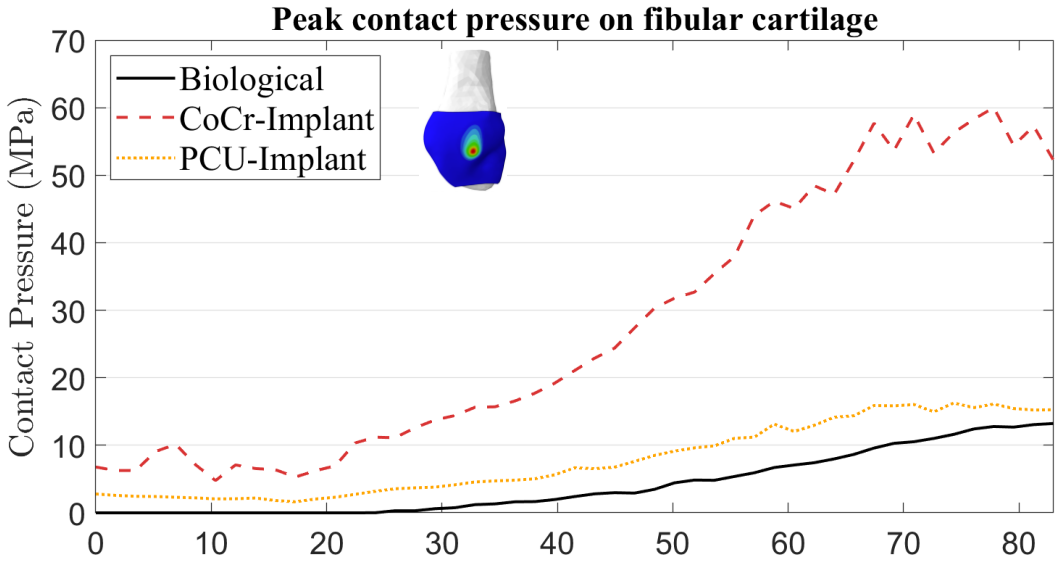


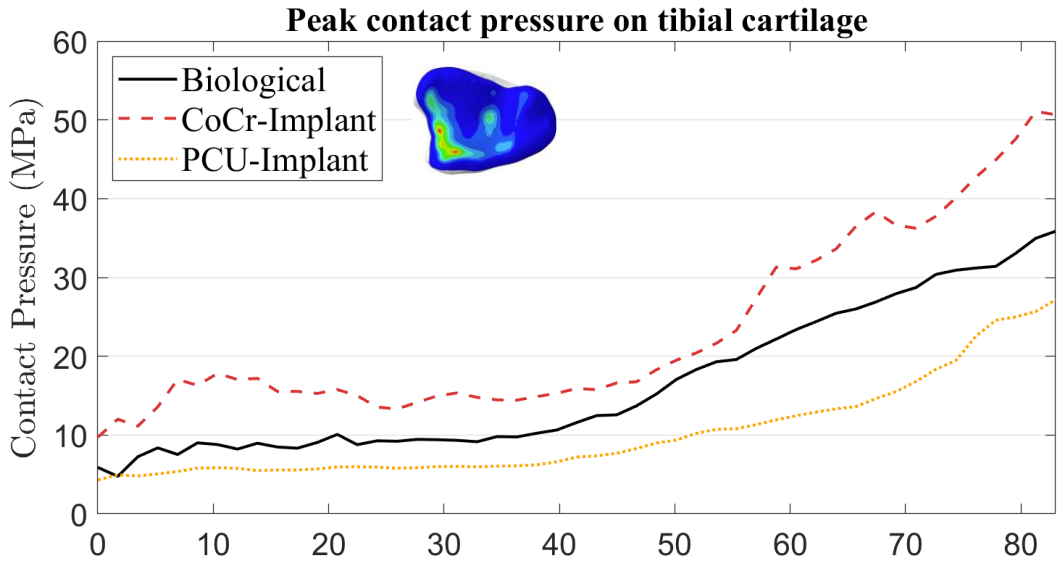


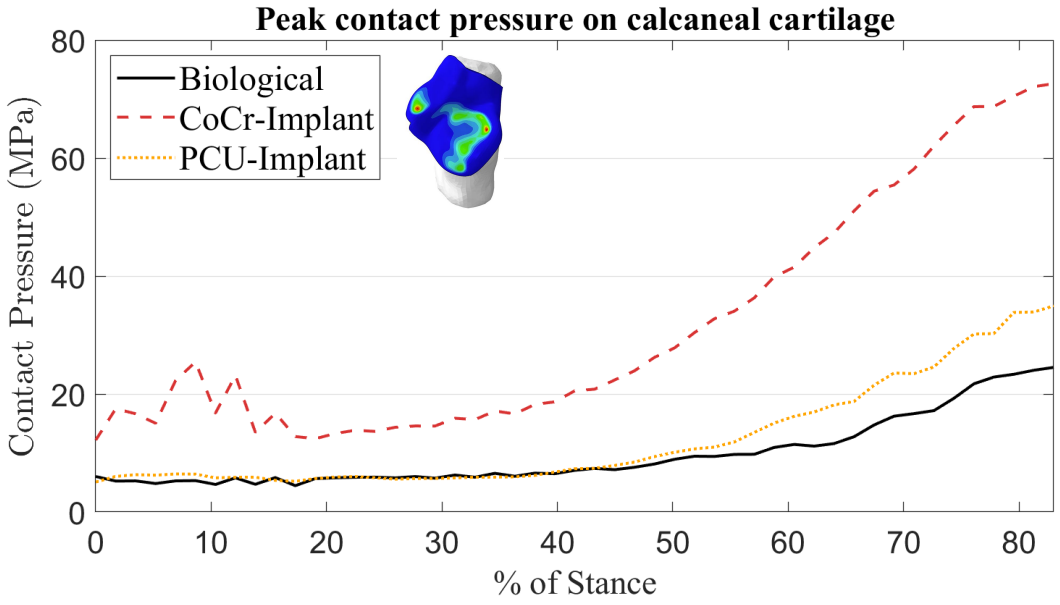


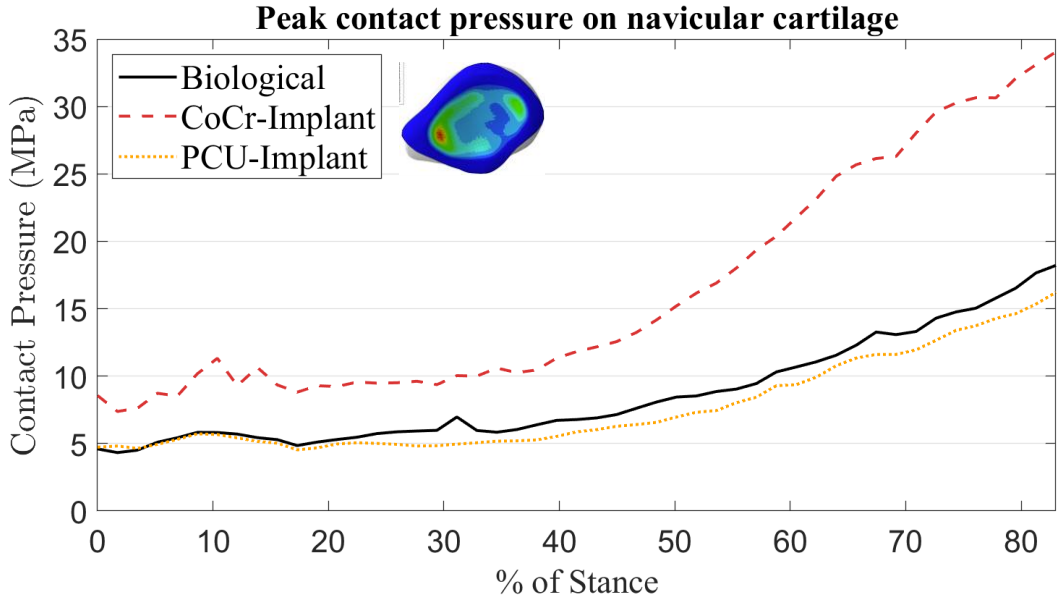


Results & Discussion – Peak Contact Pressure

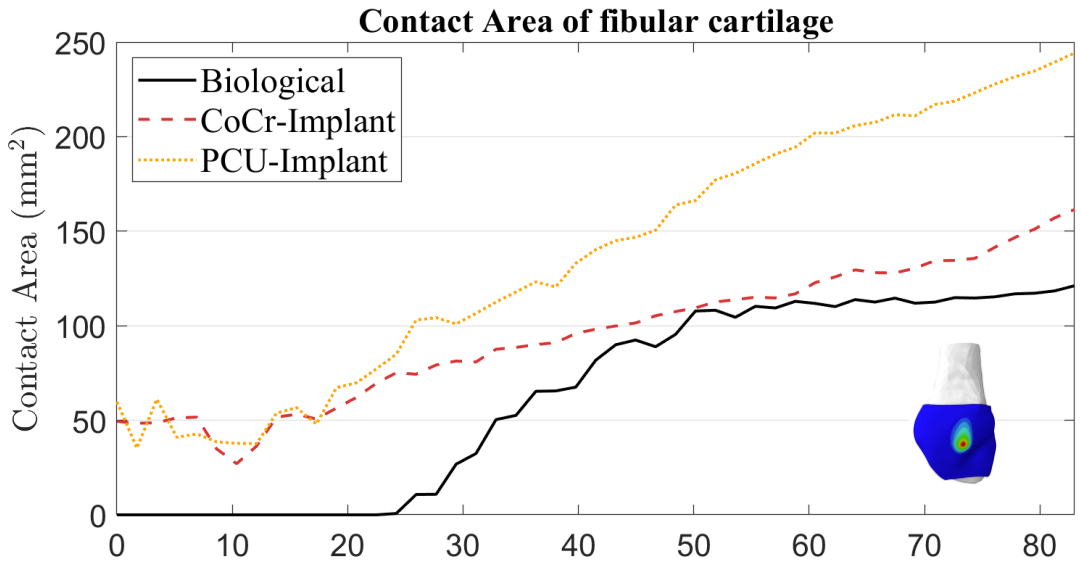


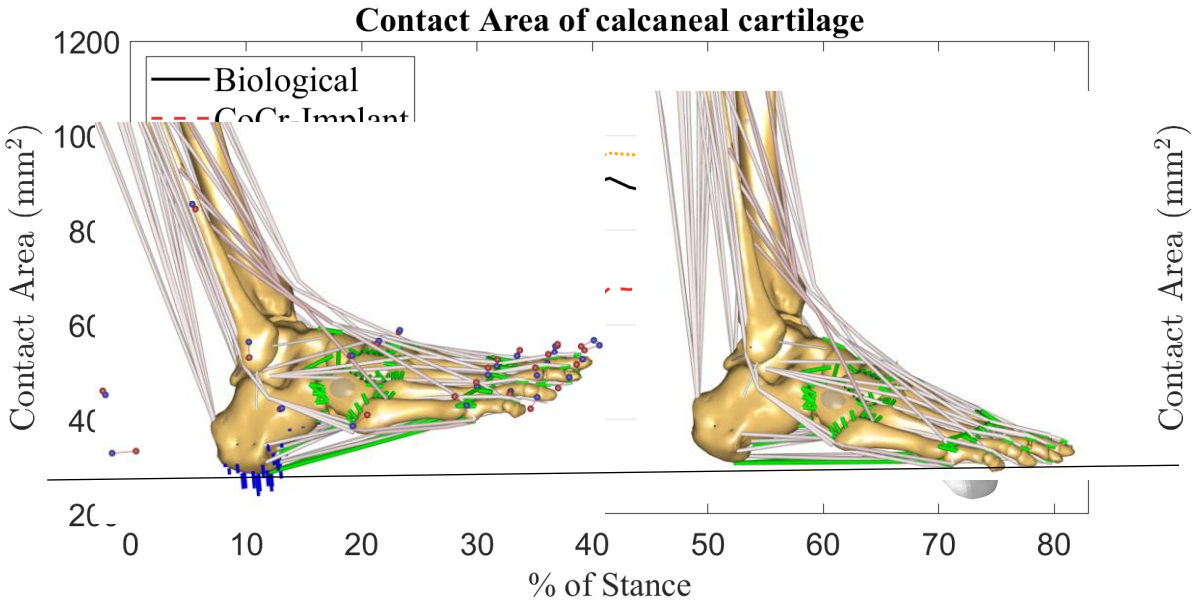


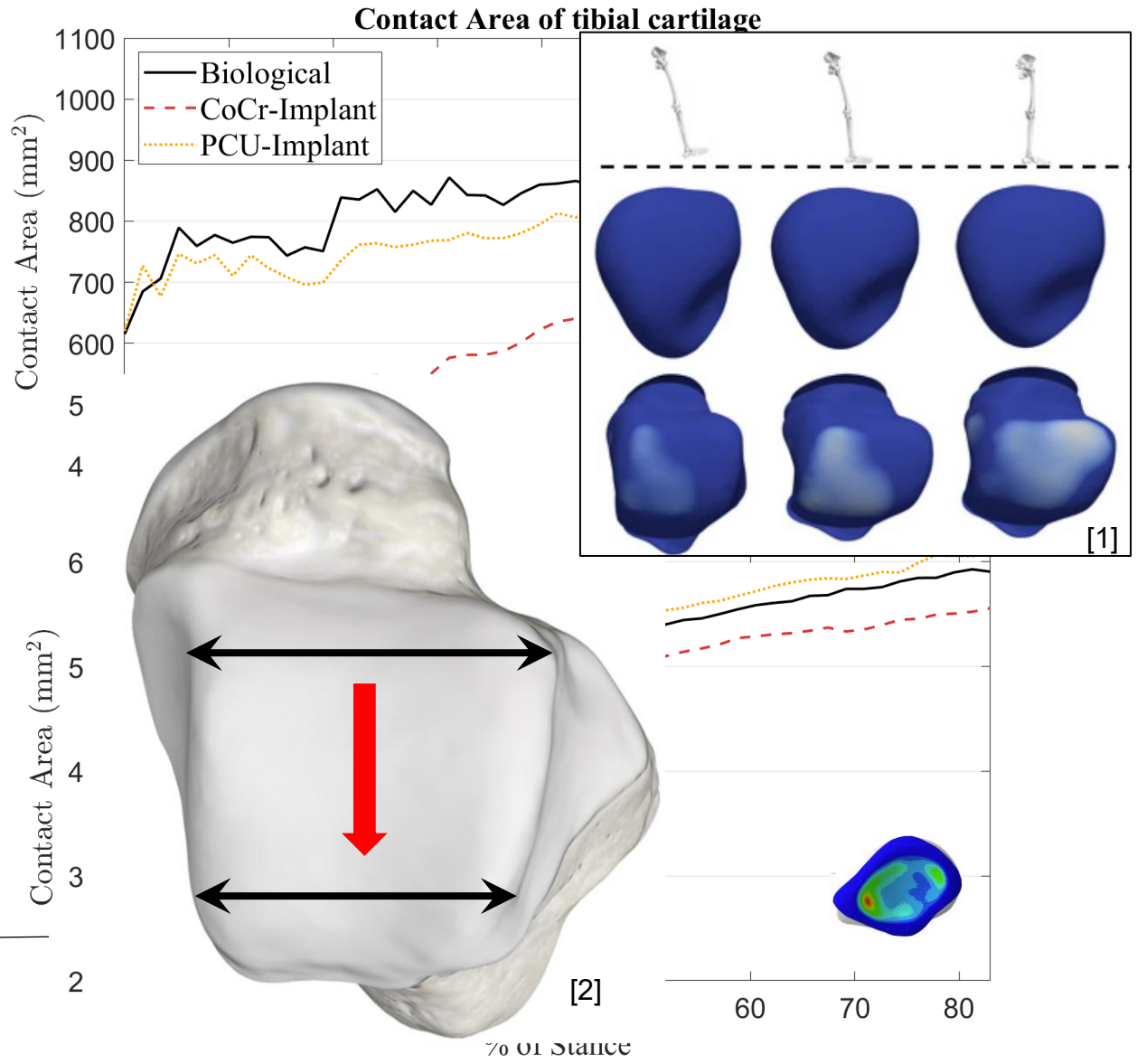




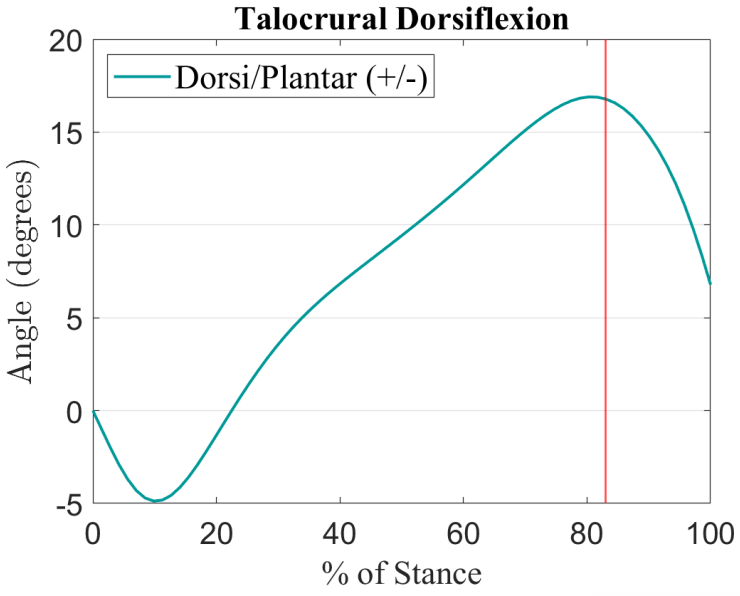
Results & Discussion – Contact Area

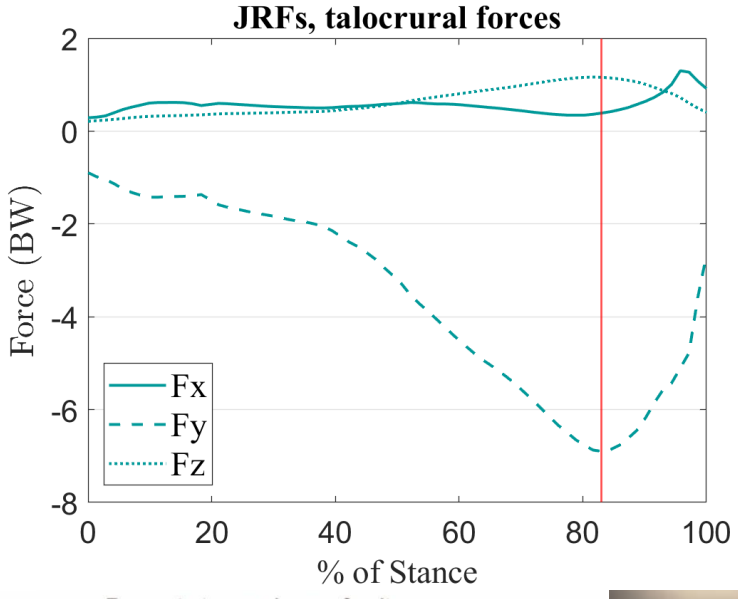


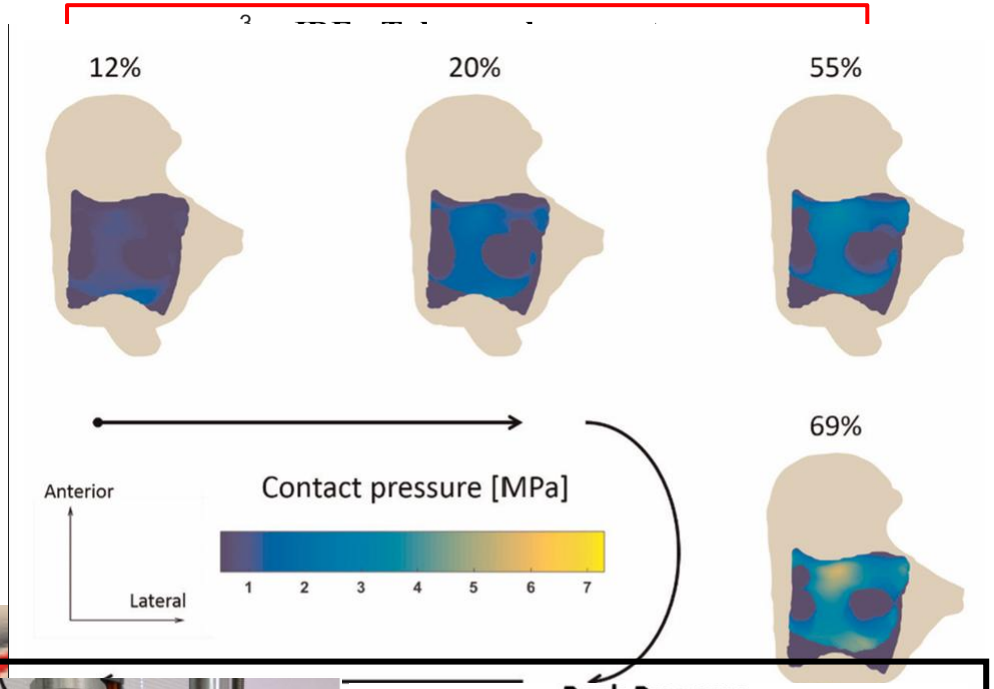




Results & Discussion – Comparison to Literature







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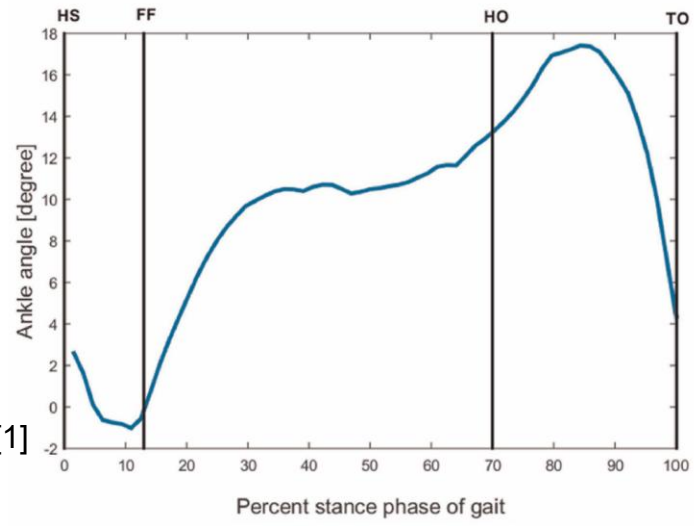
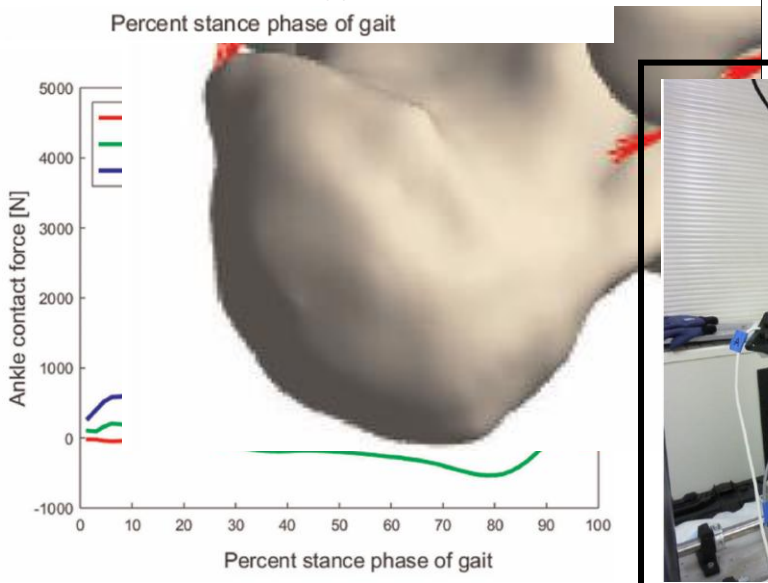
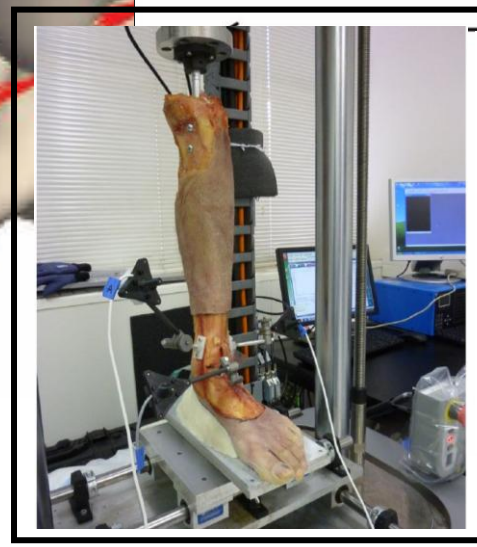
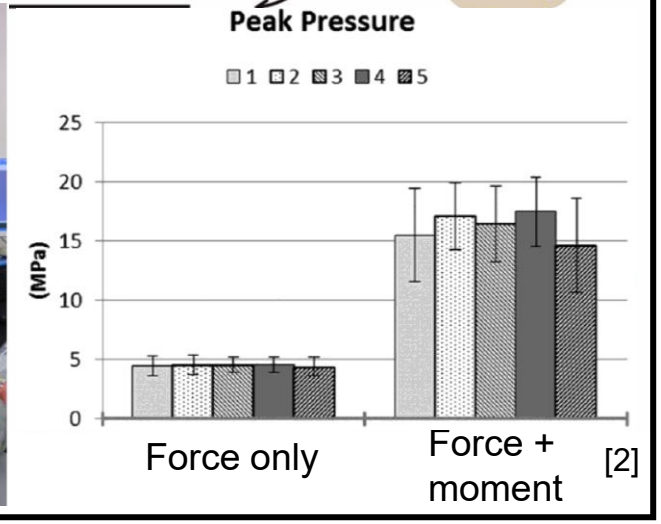






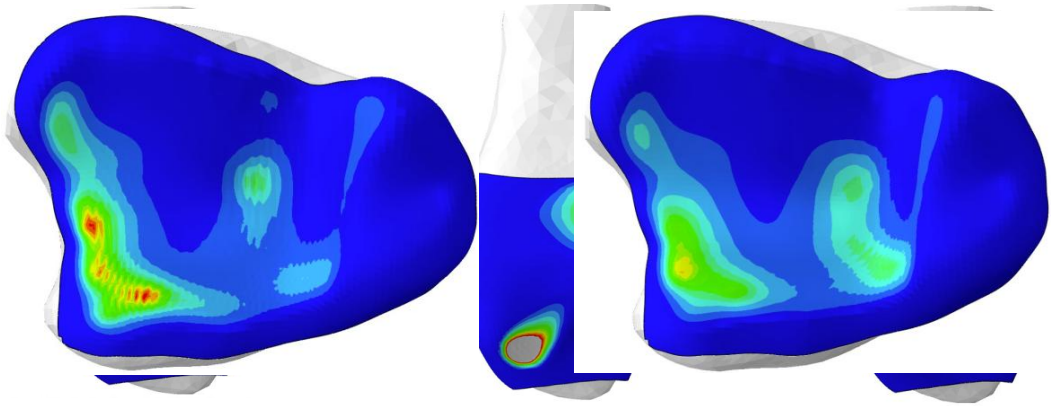


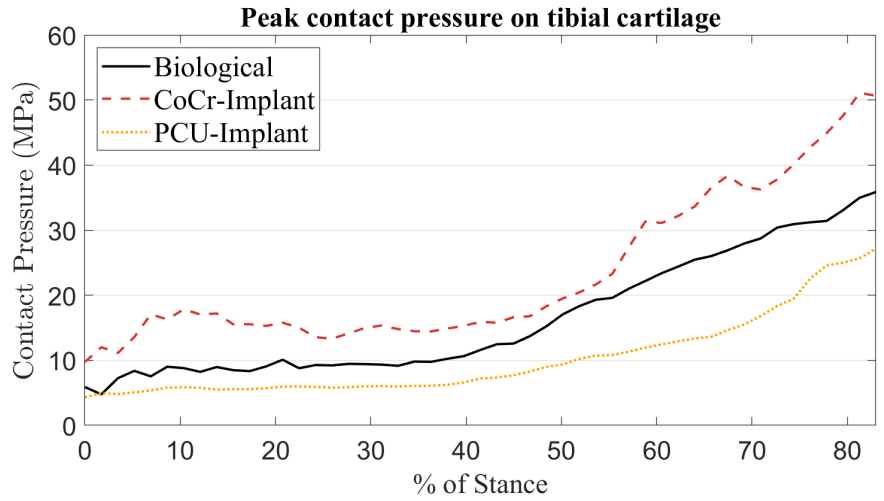
[2]

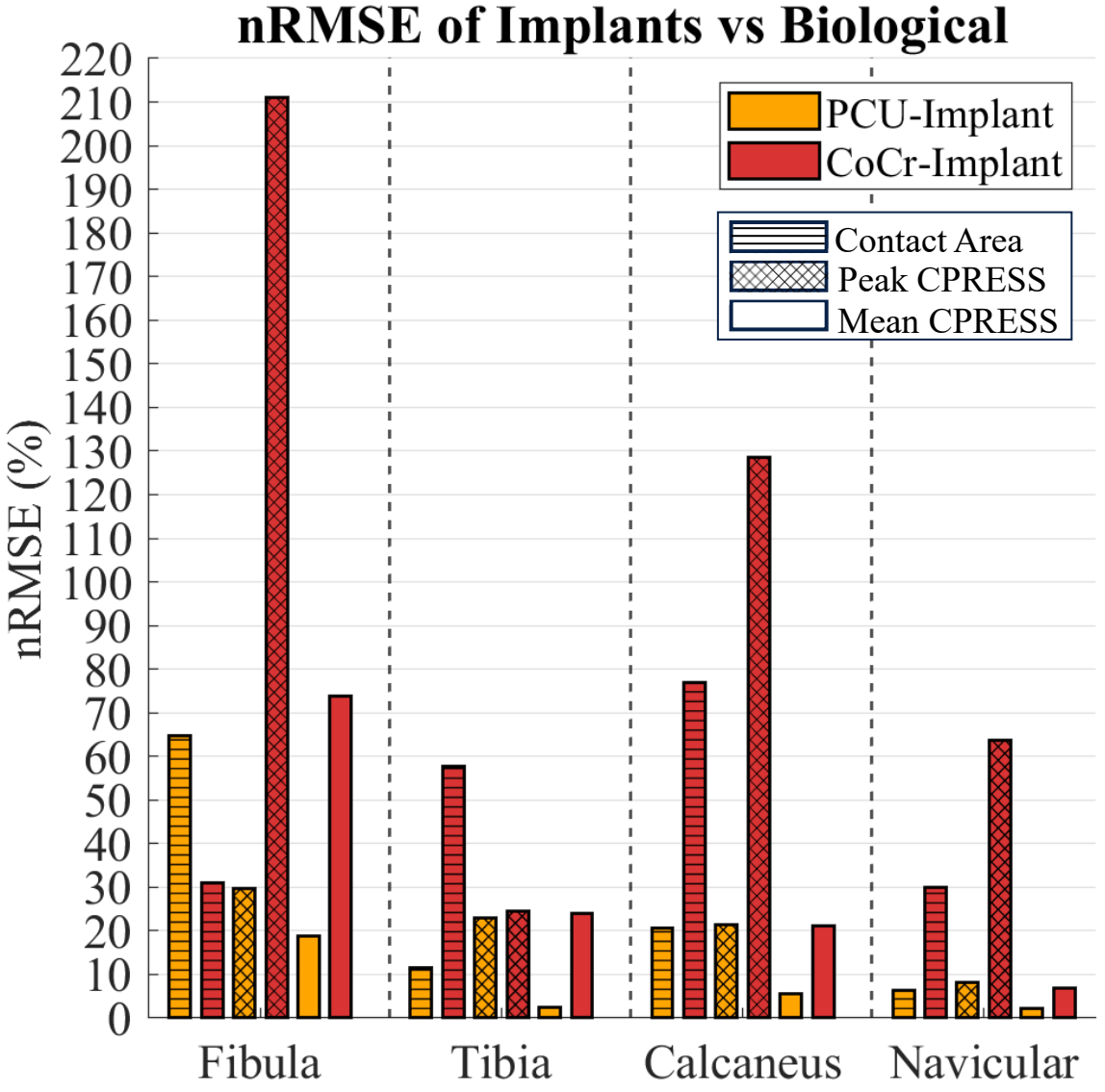
1. Benemerito et al. 2020, Proc IMechE Part H: J Engineering in Medicine 234(5)
2. Hunt et al. (2015), Foot Ankle Int. 2015 Sep;36(9):1095-103.

Results & Discussion – nRMSE Analysis

PCU generally decreases contact pressures and increases contact areas







Results & Discussion – Summary

Contact pressure and area increase from heel-strike to heel-rise

The **fibula plays little role** in the biological ankle **from heel-strike to flat-foot**

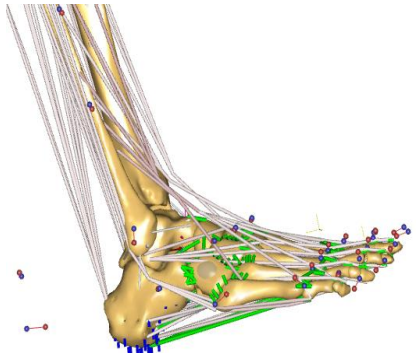
The **universal implant geometry partially replicates the contact pattern** on surrounding cartilages

In the talocrural joint, **for the implant models, the fibula transfer more load** compared to the biological

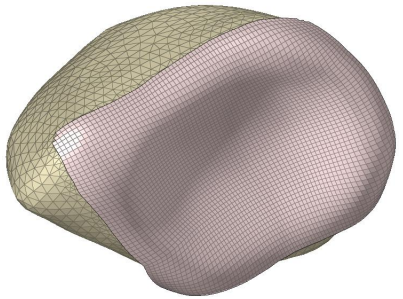
CoCr-Implant resulted in the highest peak pressures and smallest contact areas

The addition of a compliant **PCU layer mitigates the difference**

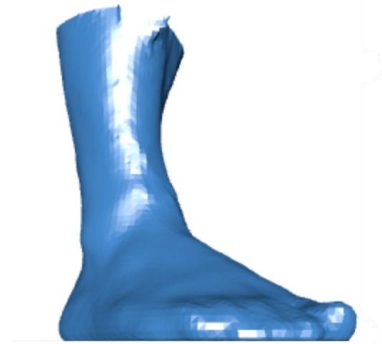
Limitations & Outlook



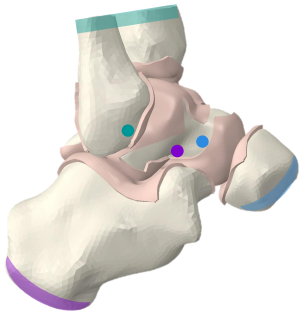
1. Sample Size



2. Cartilage definition

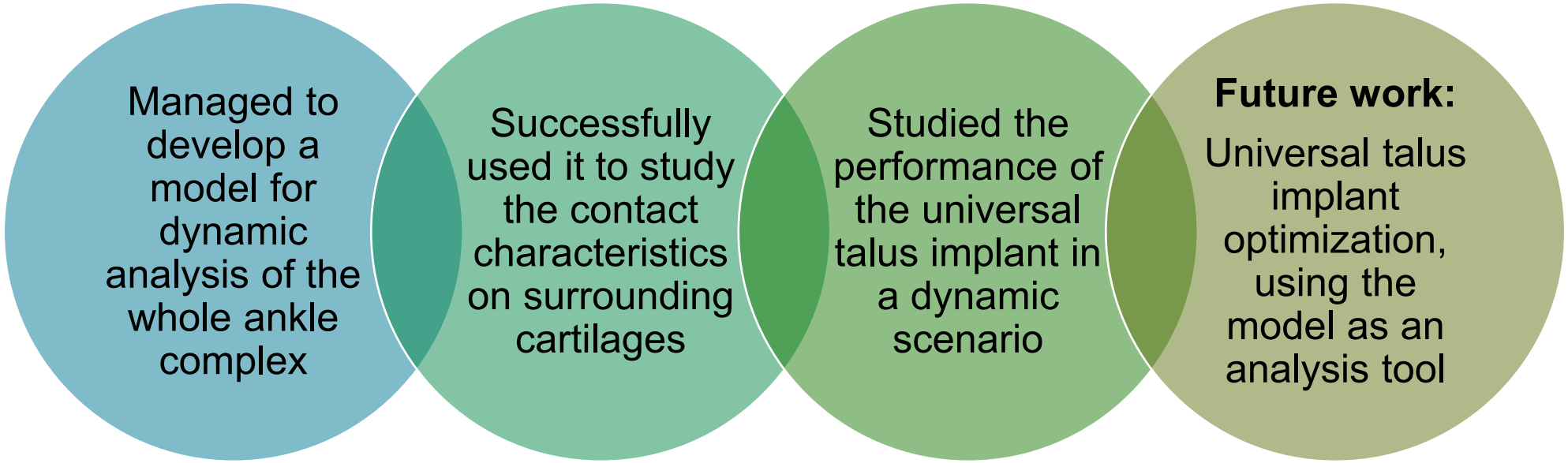


3. Soft tissues



4. DoFs control

Conclusion & Take-home Message



Thank You:

- **Co-authors: Stephen J. Ferguson, Ahmed H. Hafez, Naod T. Mogos, Tao Liu, Marwan El-Rich**
- **ETH Zurich & Khalifa University**
- **AnyBody Technology**

Foot Model Updates

Upcoming updates to AMMR4

Highlights

- Integration of Glasgow-Maastricht (GM) Foot model in AMMR4
  - Rigid foot
  - Toe flexion model
  - Full-blown detailed foot model
- GM Rigid foot becomes the new default foot for Twente Lower Extremity Model (TLEM) leg model
  - Option to go back to TLEM foot
- New class template to drive toe flexion model

Merge of GM and TLEM foot

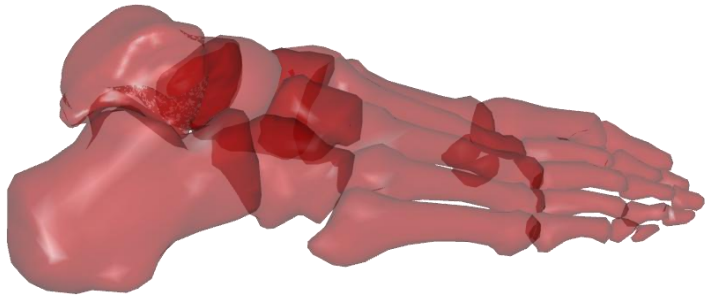
TLEM

- Complete leg model
- Joint parameters
- Extrinsic muscles

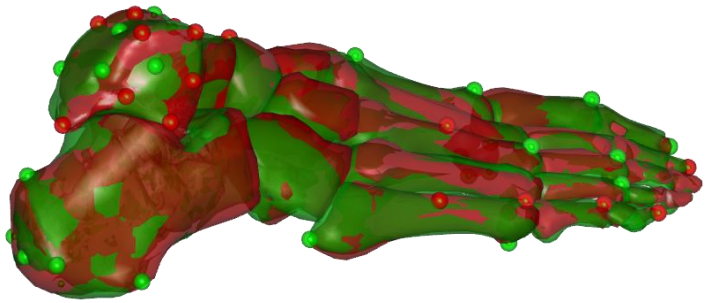
GM

- Detailed geometry of foot
- Muscle parameters
- Intrinsic foot muscles

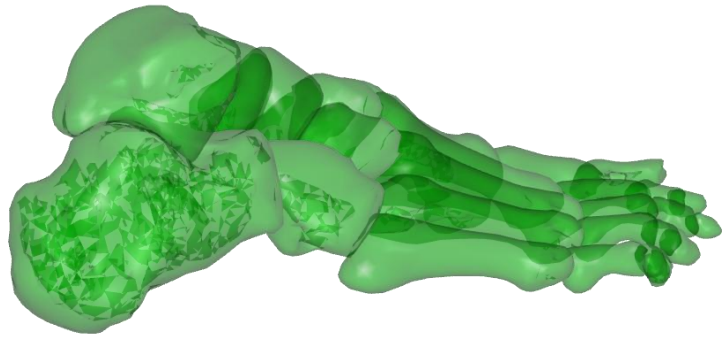
Morphed to TLEM



TLEM



GM morphed to TLEM

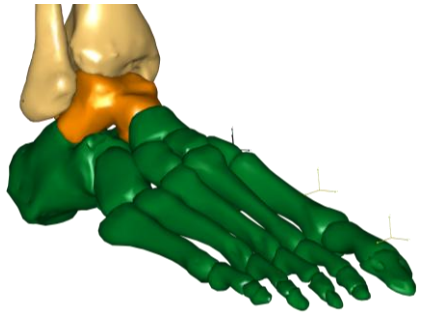


GM

Variants of GM Foot model

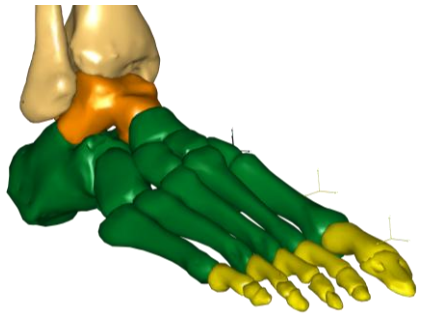
Rigid foot model (default):

- 2 segments
- Talus + rigid part



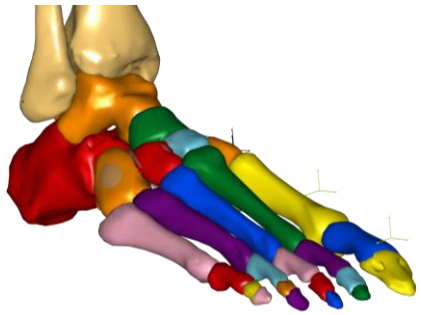
Rigid foot with toe flexion:

- 3 segments (technically 7!)
- Talus + rigid part + linked toe flexion
- Improved fidelity of foot motion in mocap trials – even without toe tip marker!



Detailed foot model:

- 26 segments
- Full blown model for research



Rigid Foot

Toe Flexion

How to work with GM Foot

- Early access to AMMR 4 – Beta on GitHub
  - Migration guide
- Foot model documentation page
- Foot model configuration switches.
- Application examples:
  - BVH toe flexion
  - C3D toe flexion
  - Full-blown detailed GM foot mocap example
- Class template for driving toe flexion without toe tip marker.

Questions

Meet us

- Send email to sales@anybodytech.com

Trial version

- Send email to sales@anybodytech.com

Presentation questions

- Send email to dsc@anybodytech.com

Thank you for your attention!