

The Development and Implementation of a Computational Framework to Simulate Patellofemoral Joint Mechanics

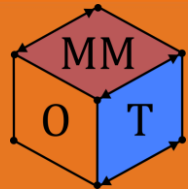
Direct Comparisons Between Musculoskeletal Modeling and Finite Element Analysis

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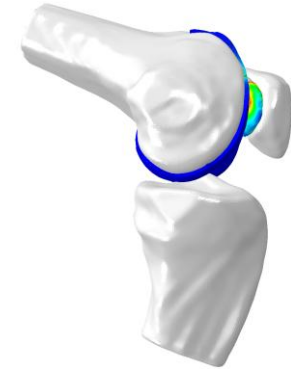
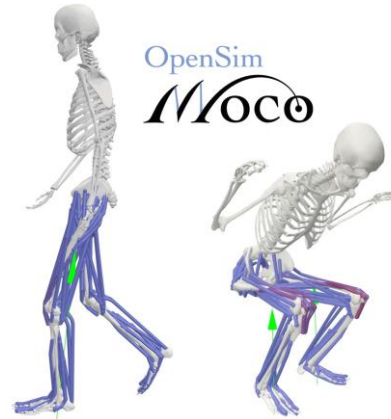
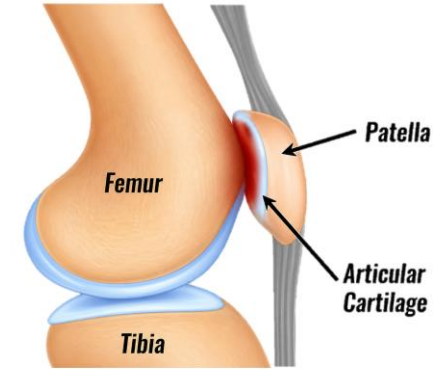
Mechanics and Modeling of
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Project Motivation and Scope

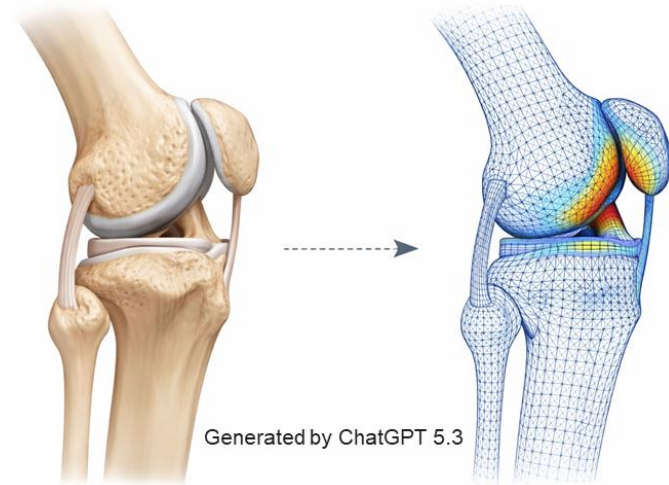
- AKP is highly prevalent (25-50% of population) [1-2]
- Altered mechanics associated with pain and disease [3]
- Computational modeling:
 - I. Musculoskeletal modeling (rapid, less precise)
 - II. Finite element analysis (time-intensive, more precise)



Project Motivation and Scope

- Prior modeling:
 - I. Either MSK or FEA modeling
 - II. MSK used for inputs to FEA
- *Link between two model outputs is unclear*

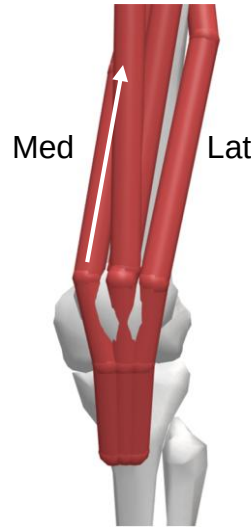
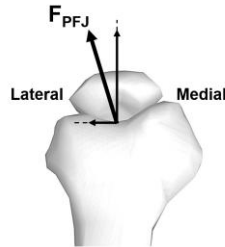
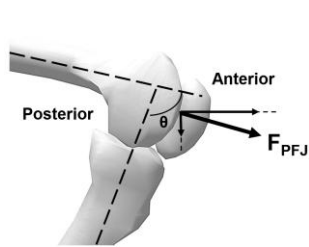
could we skip FEA and just use MSK?



Project Goal: Establish a validated workflow that enables direct comparison between musculoskeletal and finite element modeling of the patellofemoral joint.

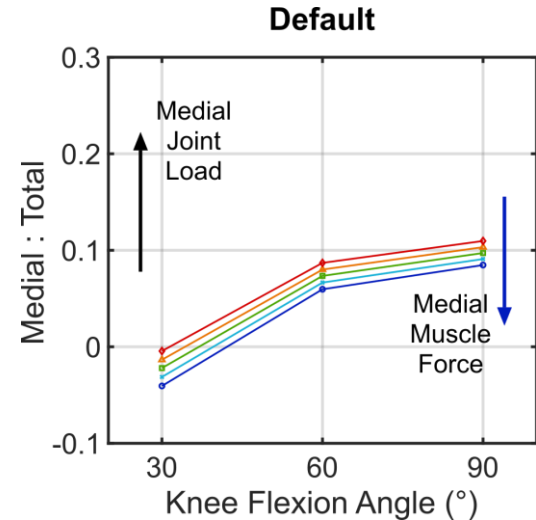
Musculoskeletal Modeling

- Rajagopal MSK model with Lai Uhlich updates [1,2]
- Patellofemoral joint not calibrated to medial/lateral load alignment
- Literature: increasing vas med force $\rightarrow$ PFJ contact/pressure on femur shifts medially [3]
- Default model: increasing vas med force $\rightarrow$ PFRF shifts *laterally*

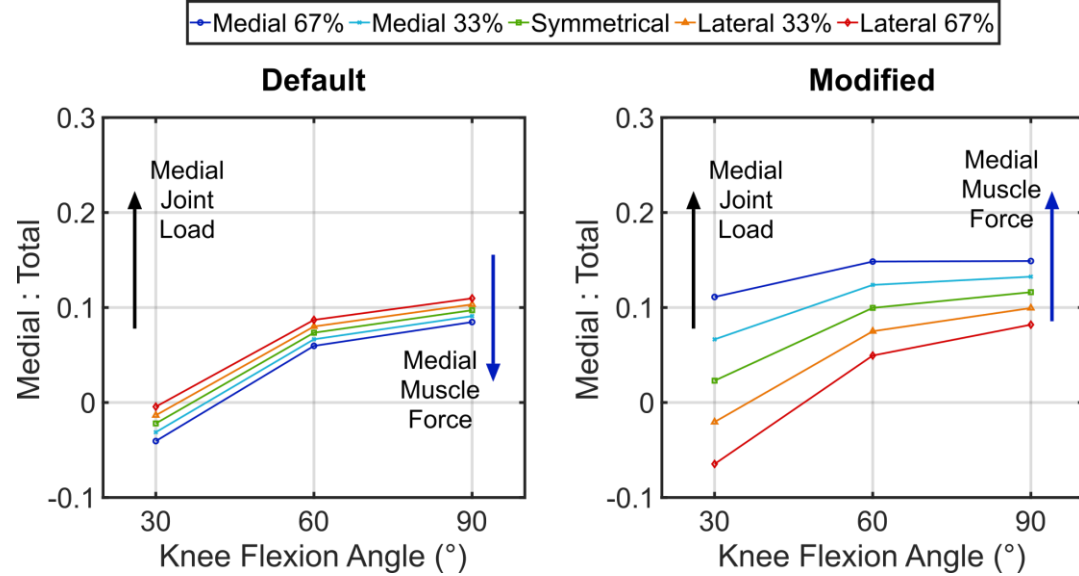
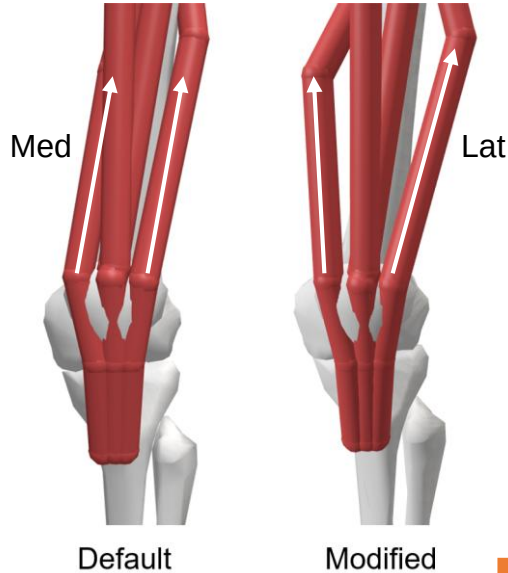


Default

—●— Medial 67%
 —●— Medial 33%
 —●— Symmetrical
 —●— Lateral 33%
 —●— Lateral 67%



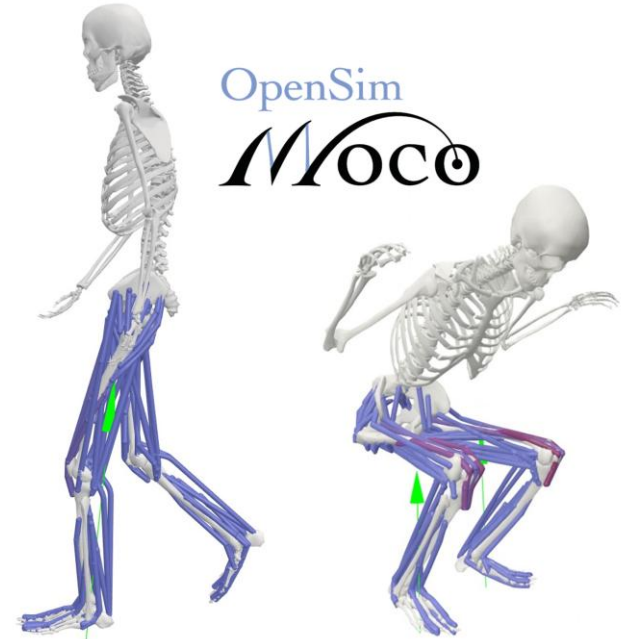
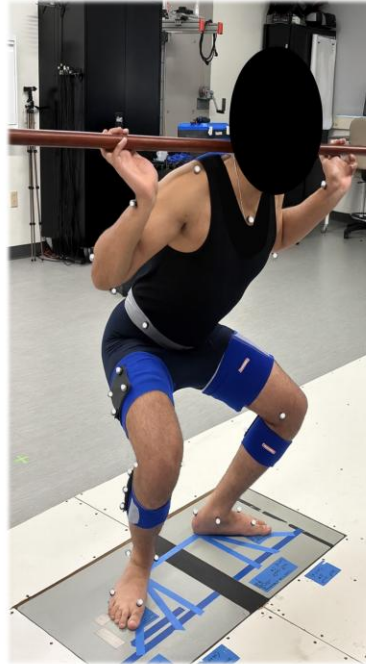
Musculoskeletal Modeling



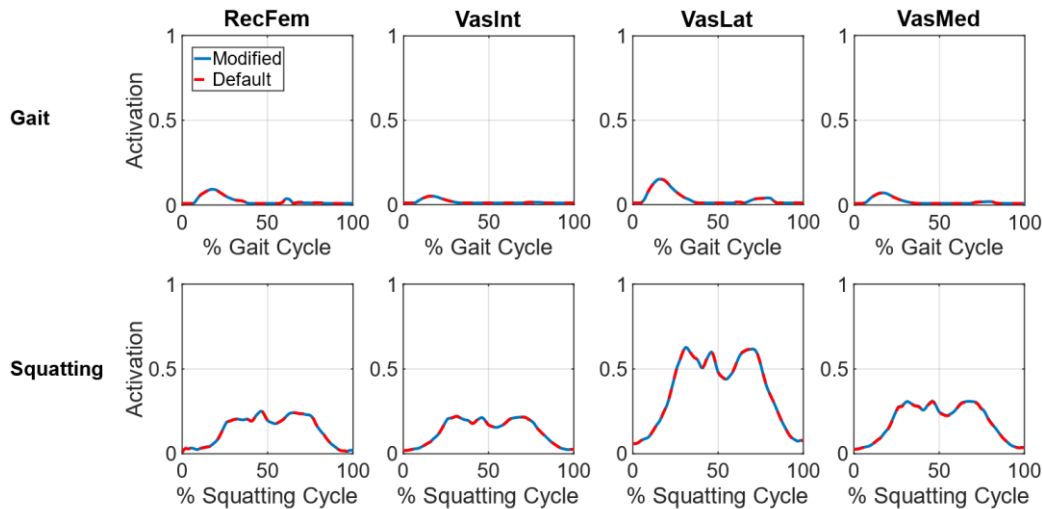
Muscle	Default	Modified	Literature [1]
Vastus Lateralis	5° lateral	10° lateral	12–16° lateral
Vastus Medialis	3° <u>lateral</u>	9° medial	15–18° medial

Musculoskeletal Modeling

- One adult male subject (35 years, 180 cm, 82 kg)
- 12-camera VICON + two AMTI force plates, 52 reflective markers
- Walking and bodyweight squatting
- OpenSim Moco [1,2] to for kinematic, dynamic, and muscle-driven analyses

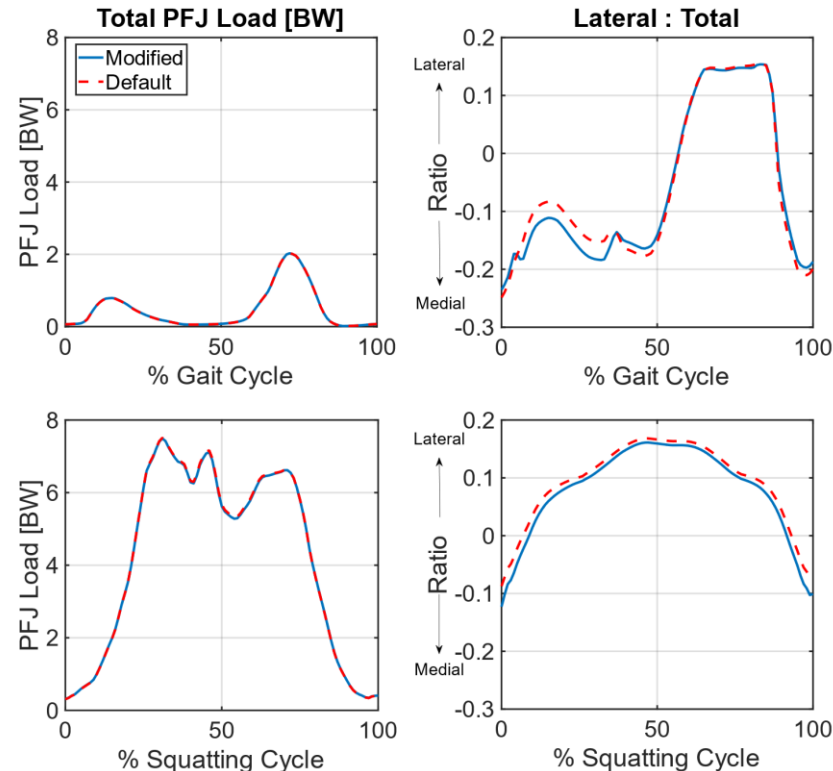


Musculoskeletal Modeling



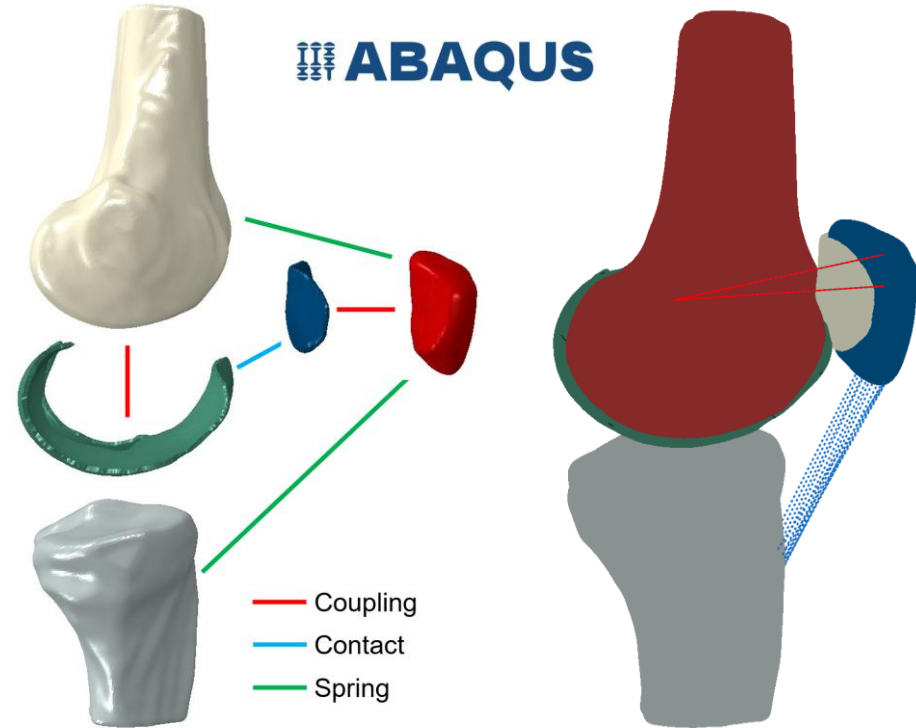
- Muscle activations and baseline joint loads largely unchanged

MSK Model: Improved physiological accuracy of PFJ modeling, key model validation metrics unaffected.



Finite Element Modeling

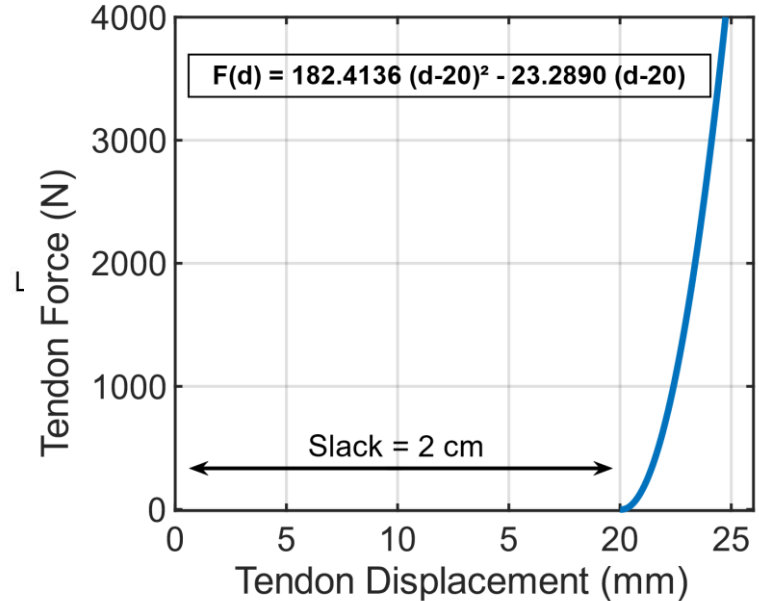
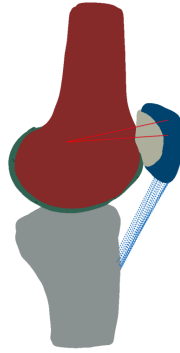
- OpenKnee [1] geometries (OKS009)
- Cartilage: neo-Hookean ($E=6.5$ MPa, $\nu=0.475$) [2]
- LPFL & MPFL as linear springs [1]



Finite Element Modeling

- Boundary conditions → cylindrical joints [1]
- Quadriceps muscle forces [2]
- Nonlinear patellar tendon + slack [3]

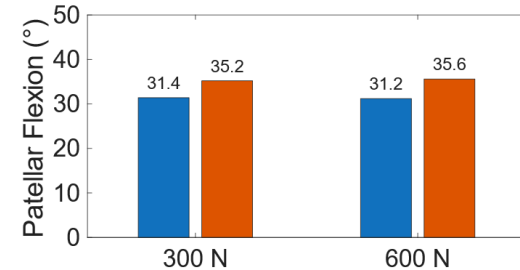
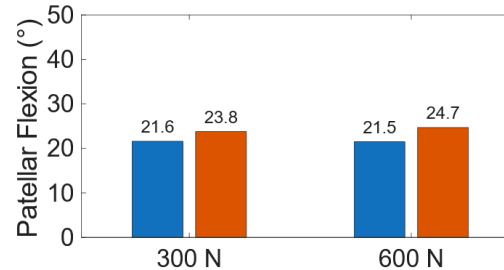
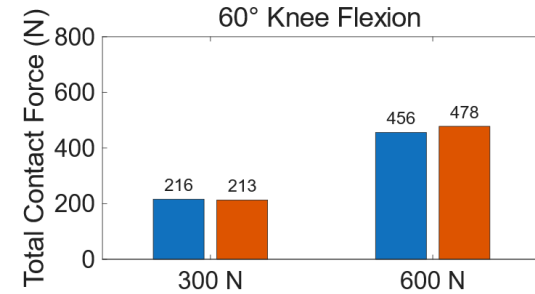
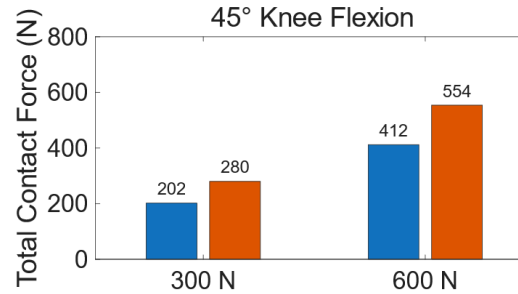
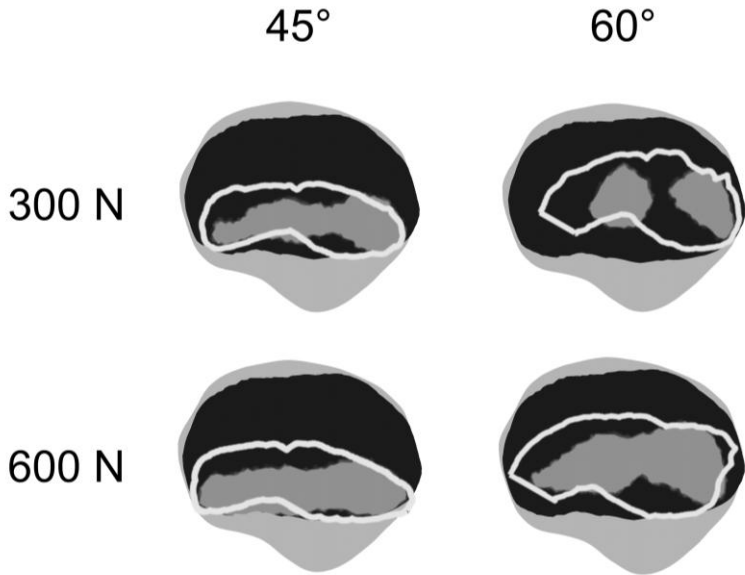
slack: key model calibration parameter



Finite Element Modeling

- Model validation to OpenKnee data (OKS009)

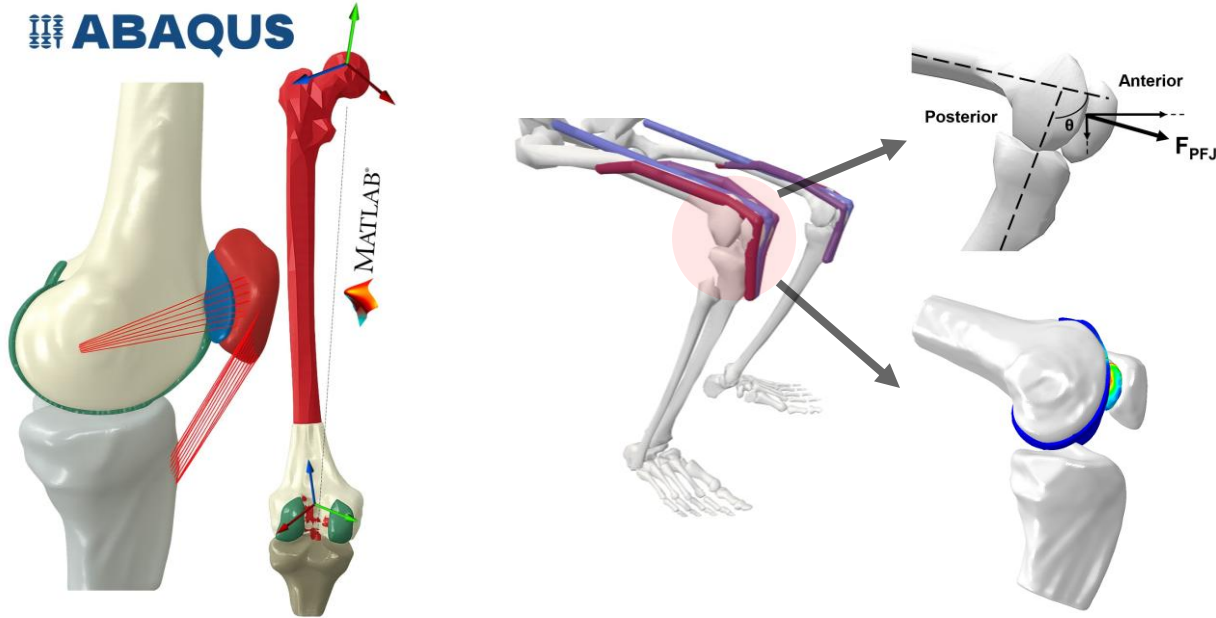
Experimental Model



FEA Model: Subject-specific validation to OpenKnee data using *tendon slack* as a calibration parameter.

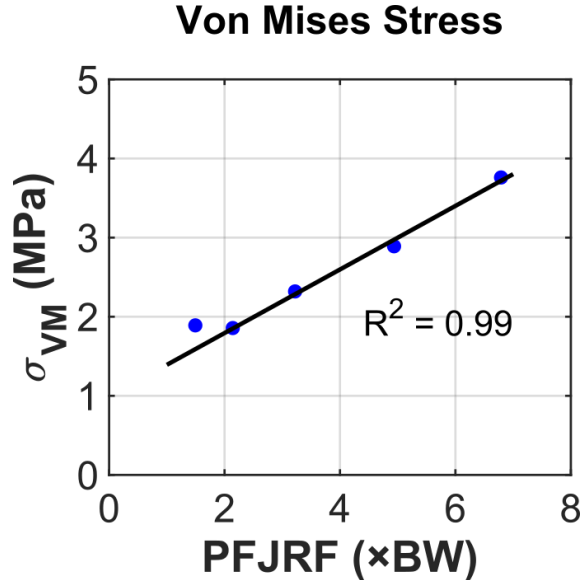
Model Integration

- Alignment of musculoskeletal and finite element model coordinate systems
- Synchronized joint loads (MSK) and cartilage mechanics (FEA)

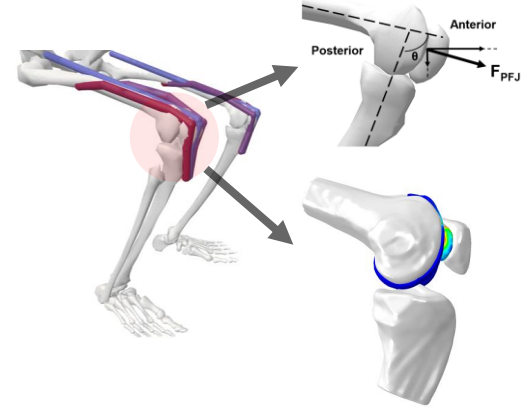


Model Integration

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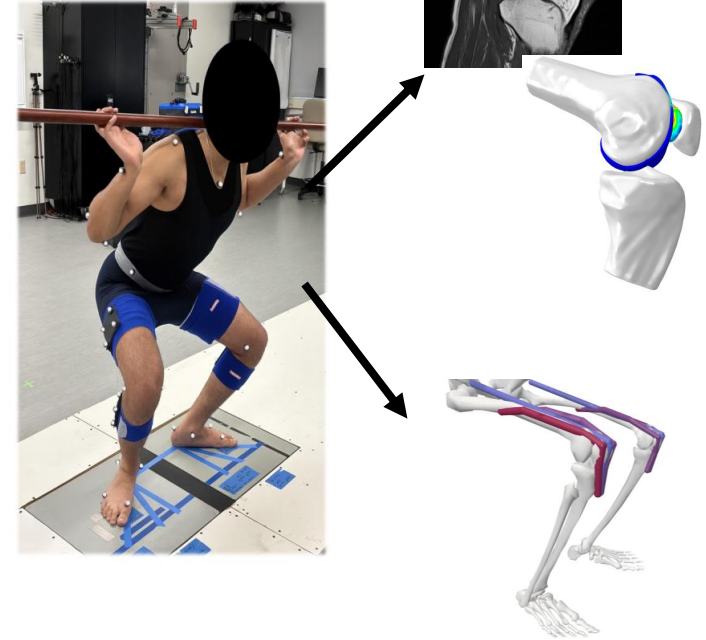
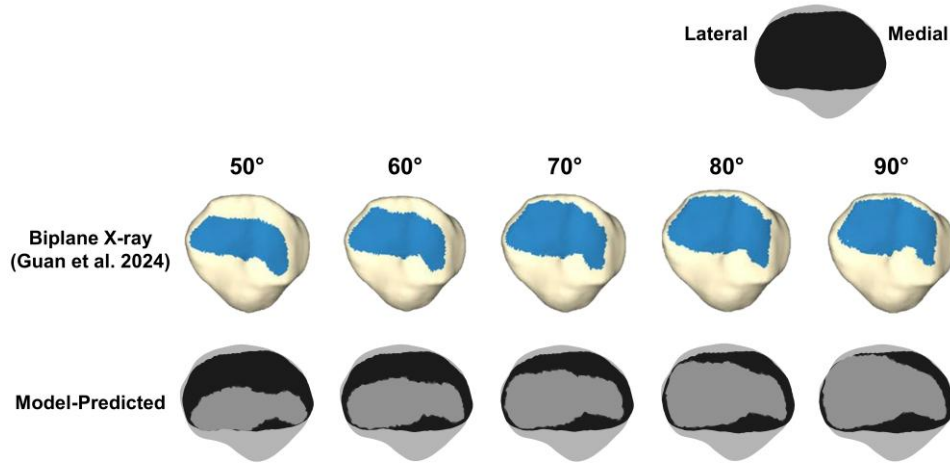


Direct comparisons
between MSK & FEA
patellofemoral joint
mechanics.



Limitations & Future Work

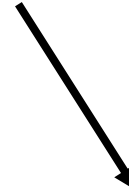
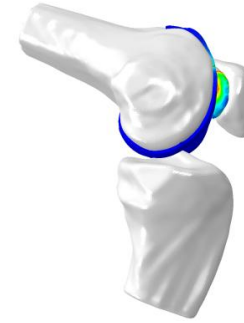
- *In vivo* finite element model validation
- Dataset expansion & subject consistency



Limitations & Future Work

- Long-term: multi-modal machine learning
 - Low-cost, rapid motion analysis
 - Clinical data
 - FEA databases

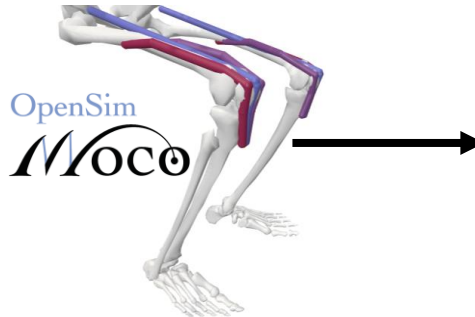
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**Interventions
that address anterior
knee pain and disease**



OpenCap



Acknowledgements & Questions



Mahmood Rashedi
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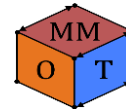


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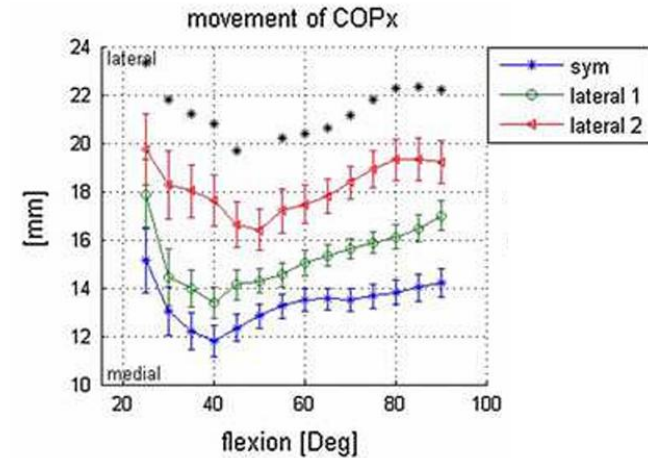
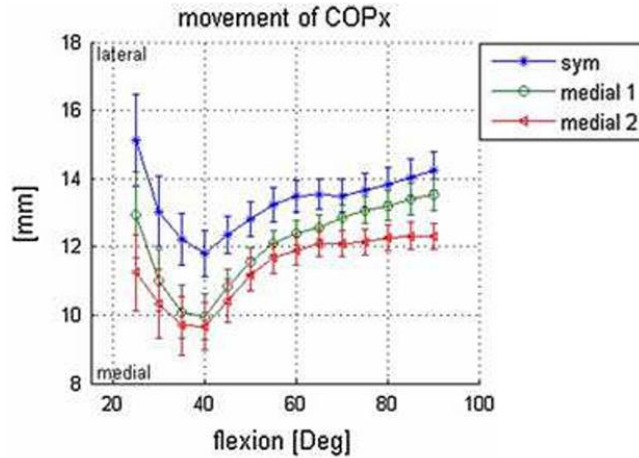
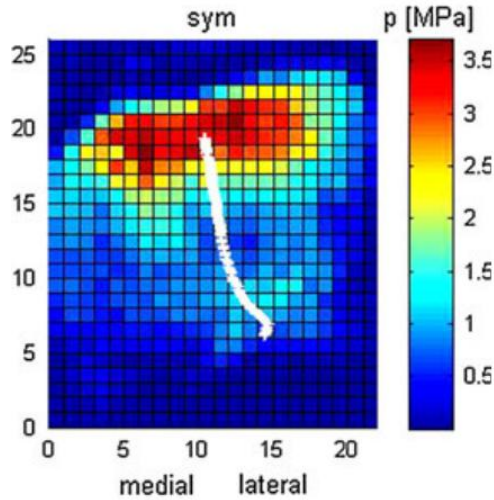
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Bucknell-Geisinger Research Initiative



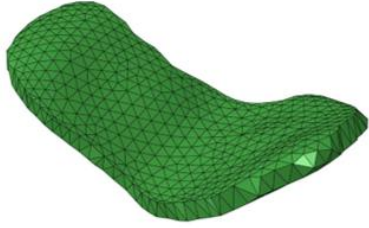
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Medial-Lateral PFJ Loading

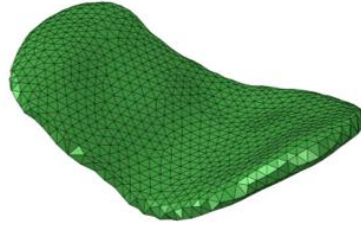


M. Wünschel, U. Leichtle, C. Obloh, N. Wülker, and O. Müller, "The effect of different quadriceps loading patterns on tibiofemoral joint kinematics and patellofemoral contact pressure during simulated partial weight-bearing knee flexion," *Knee Surg. Sports Traumatol. Arthrosc.*, vol. 19, no. 7, pp. 1099–1106, Jul. 2011, doi: 10.1007/s00167-010-1359-y.

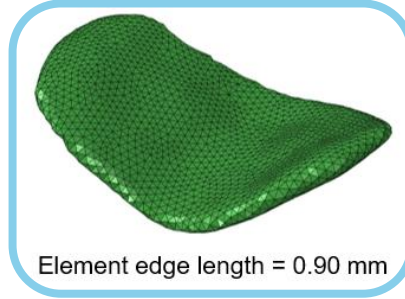
Finite Element Mesh Convergence



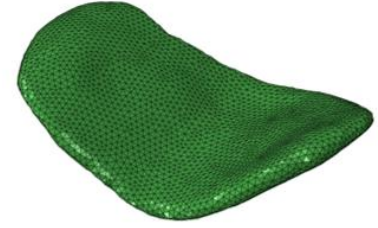
Element edge length = 1.5 mm



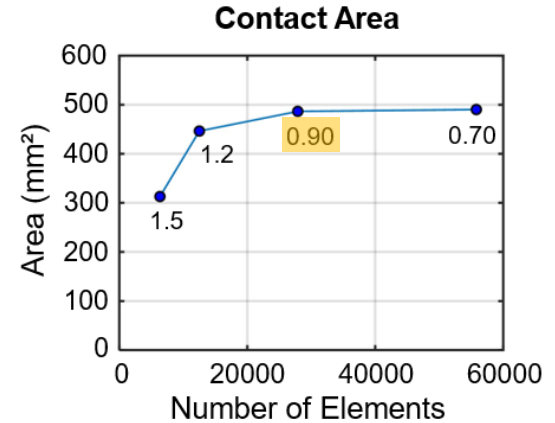
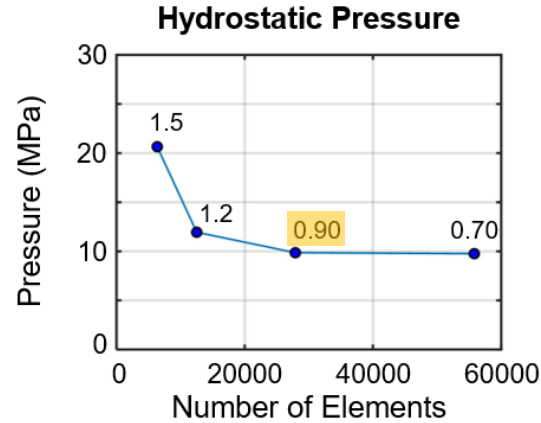
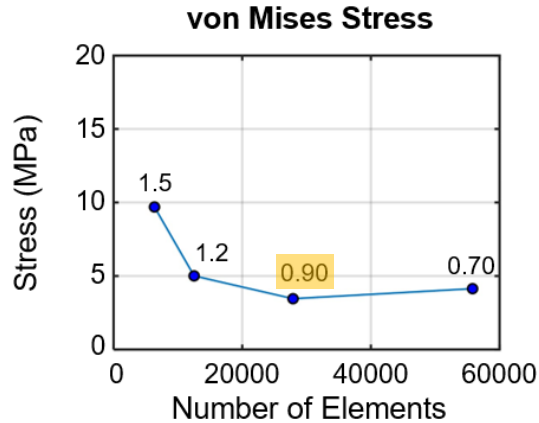
Element edge length = 1.2 mm



Element edge length = 0.90 mm



Element edge length = 0.70 mm



FE Model Calibration

