Stochastic Simulation of Functional Knee Mechanics Enabled via Statistical Shape Modeling and High Throughput Computing

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Introduction

Articular cartilage mechanics are determined by complex interactions across multiple scales involving movement dynamics, neuromuscular coordination, ligament mechanics, and cartilage morphology and internal microstructure.

Simulating the contributions of these factors to knee behavior can enhance our understanding of knee pathologies, e.g. osteoarthritis, and enable improvements in clinical treatments.

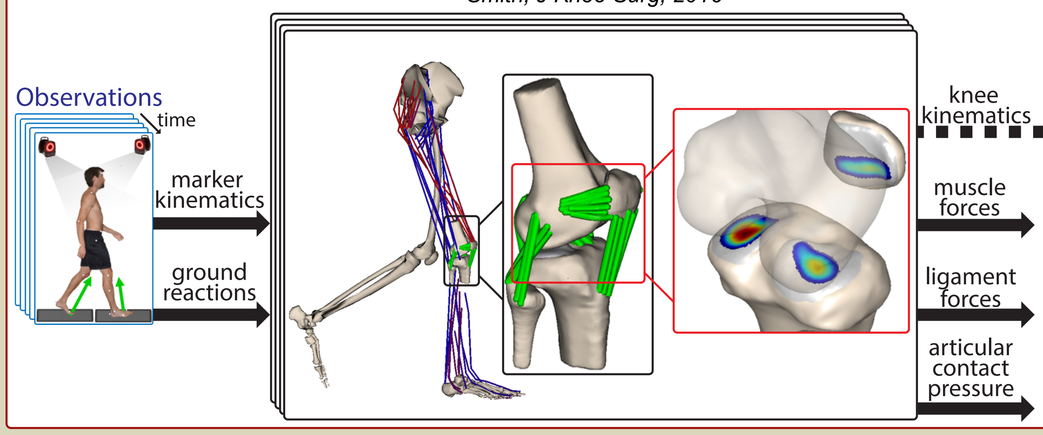
We developed a multiscale knee model and simulation framework that leverage recent advancements in musculoskeletal simulation, statistical shape modeling, and high throughput computing (HTC) [1].

The framework is used to stochastically simulate muscle, ligament and cartilage mechanics during complex movements such as gait.

Multiscale Simulation of Knee Joint Mechanics during Walking

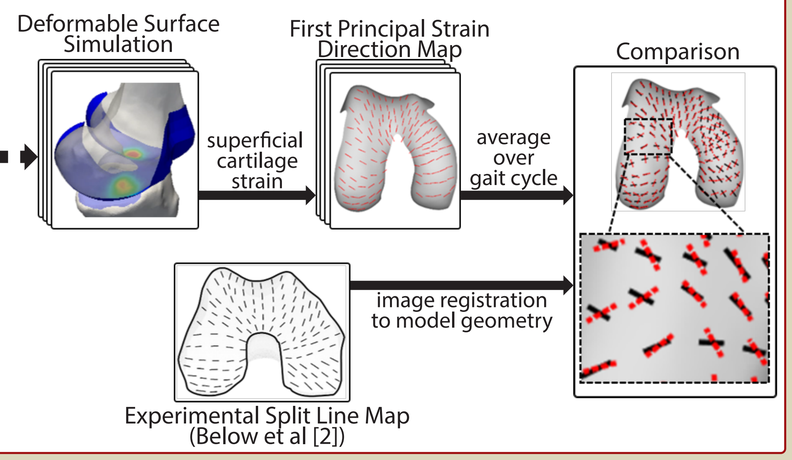
Concurrent Optimization of Muscle Activations and Kinematics (COMAK)

Smith, J Knee Surg, 2016



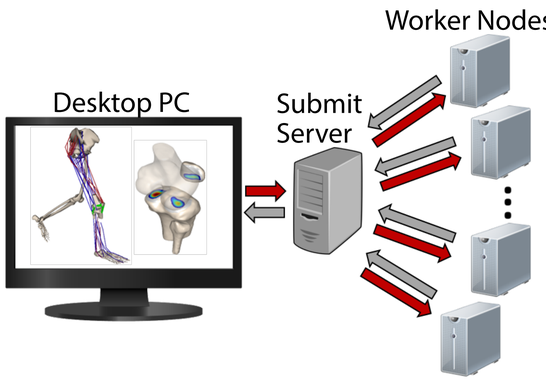
Prediction of Cartilage Mechanobiologic Adaptation

Rakhsha, CMBBE I&V, in review



Stochastic Simulation Framework

High Throughput Computing (HTC)



0.5 hours: 1 simulation on desktop PC

vs

2 hours: 2000 simulations on HTC grid

Open Science Grid

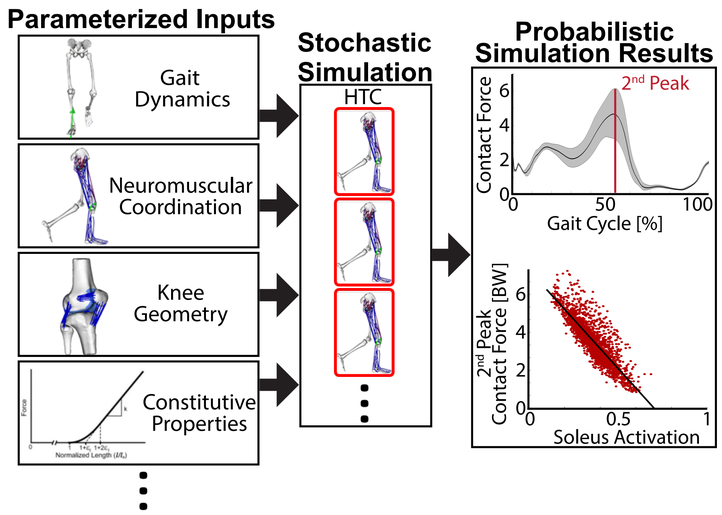
www.opensciencegrid.org

1.2 Billion CPU hours in 2016

Freely available for all US based researchers [3]

Monte Carlo Type Analyses

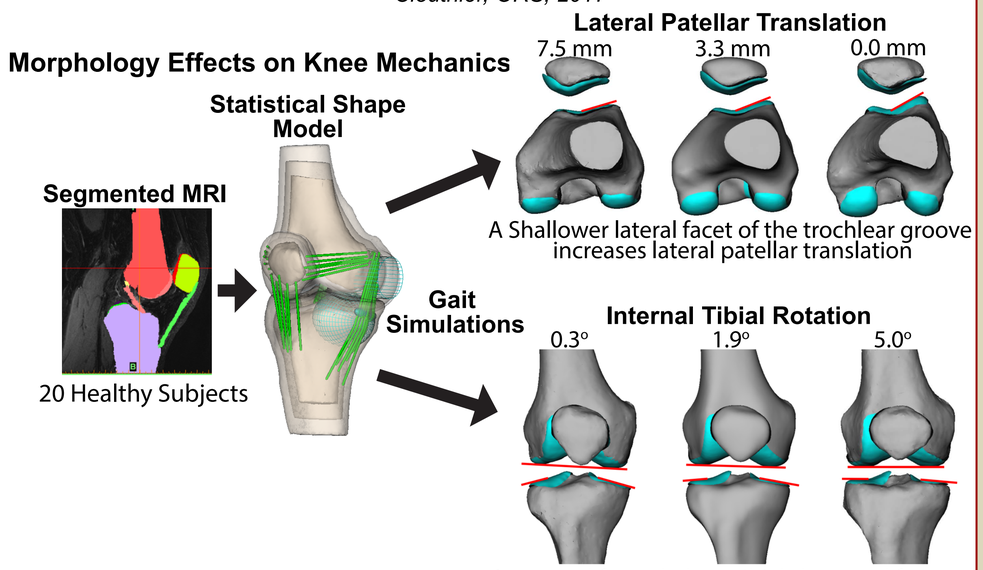
IMAG/OpenSim Webinar, 2016 [3]



By representing simulation inputs as distributions and leveraging HTC to perform probabilistic analysis we are able to quantify uncertainty and sensitivities in subject-specific simulations or model populations

Statistical Shape Modeling

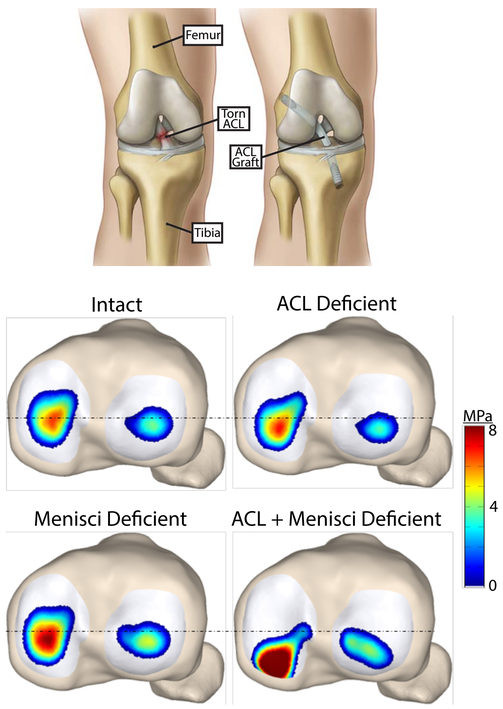
Clouthier, ORS, 2017



Clinical Applications

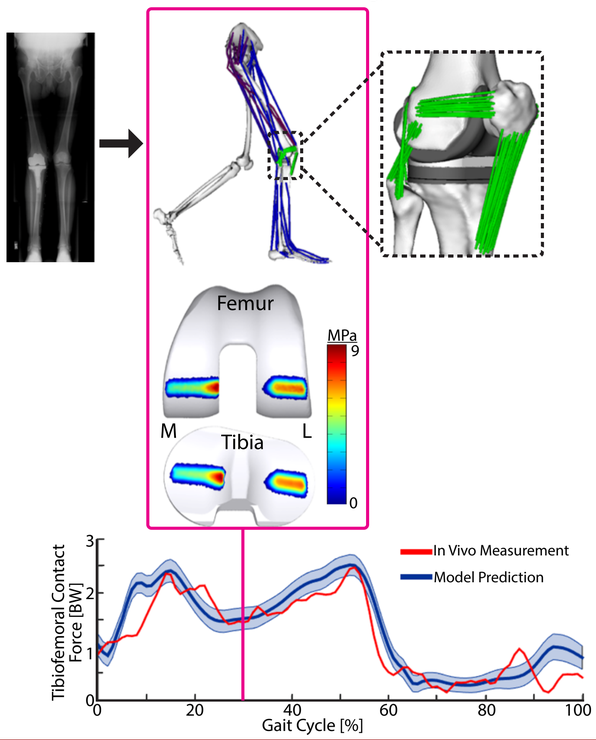
Knee Ligament Injury and Repair

Smith, J Knee Surg, 2016



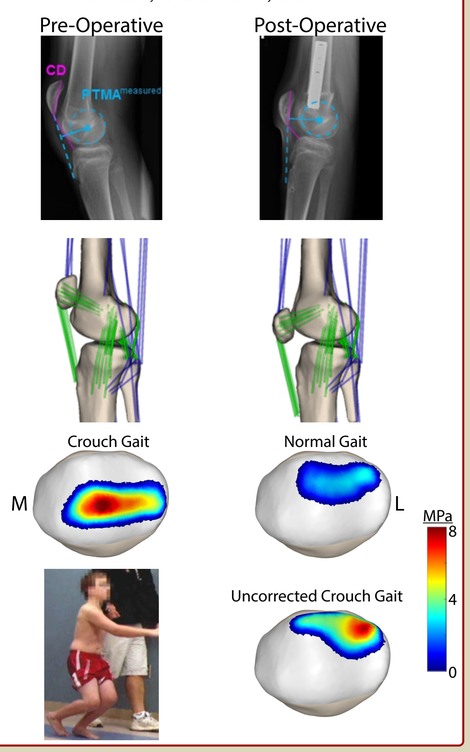
Total Knee Arthroplasty

Smith, J Biomech Eng, 2016



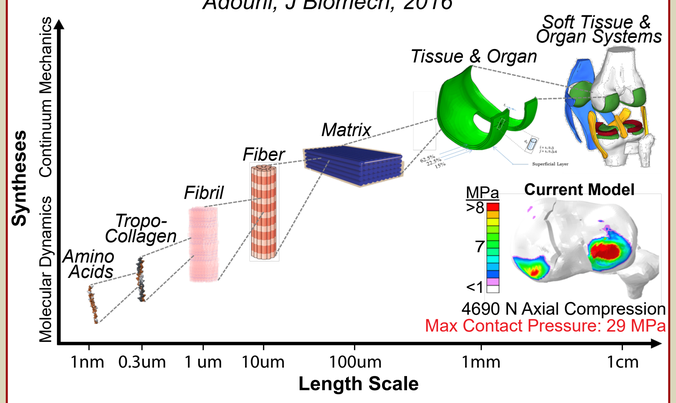
Pediatric Orthopedics

Lenhart, J Biomech, 2017



Future Directions

Adouni, J Biomech, 2016



We developed a finite element model of the knee that incorporates the structural hierarchies of the cartilage tissue enabling detailed investigation of the microstructure mechanics. In the future, we intend to apply the COMAK predicted joint mechanics as boundary conditions to this finite element model to investigate the influence of macroscale interventions such as gait retraining and orthopedic surgeries on the loading of the cartilage microstructure.

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References

[1] Smith CR, J Knee Surg 29(2):99-106, 2016.

[2] Below S, Arthroscopy 18(6):613-17, 2002.

[3] Smith CR, https://web.stanford.edu/group/opensim/support/event_details.html?id=169