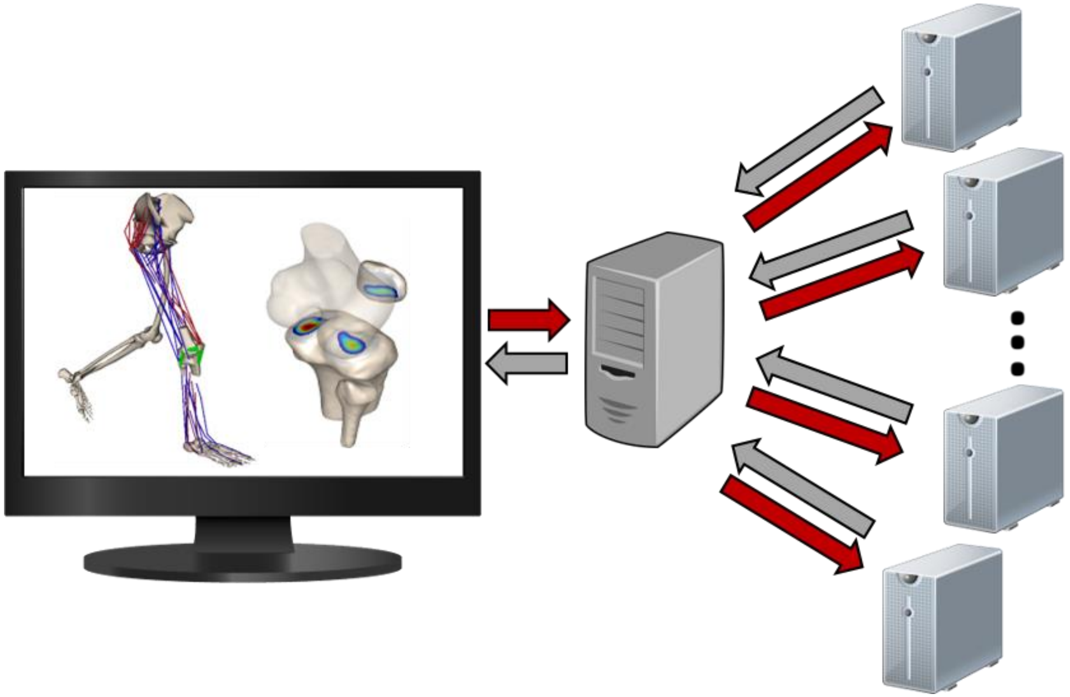


Probabilistic Simulation of Knee Loading using HTCondor

Colin R Smith, Darryl G Thelen

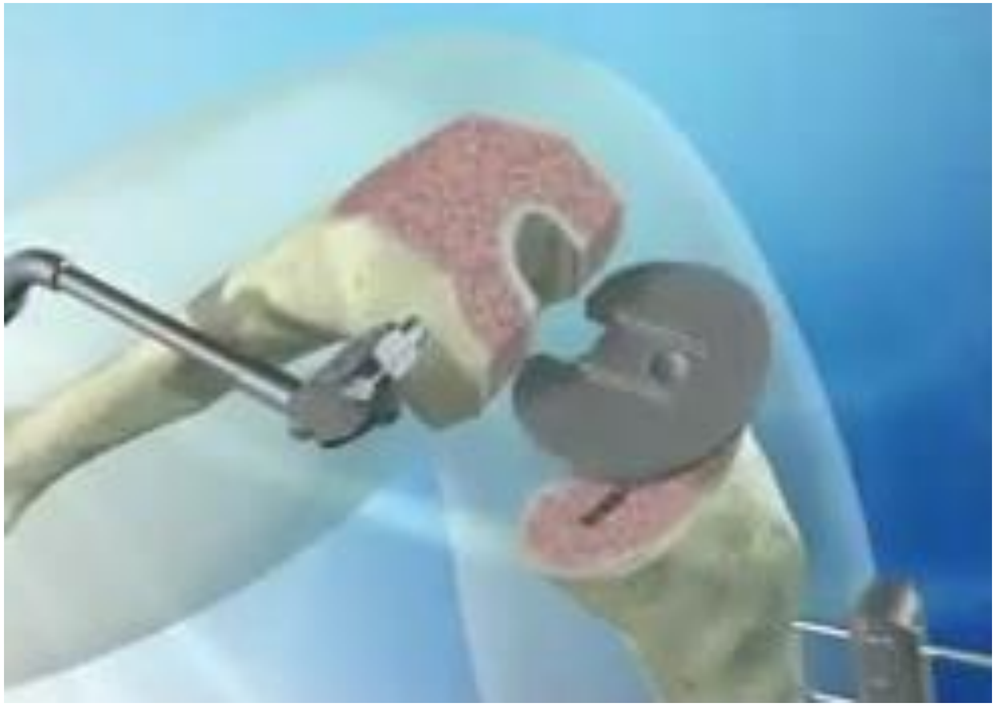
UW Neuromuscular Biomechanics Lab

Department of Mechanical Engineering, UW-Madison

HTCondor Week 2017

Robotic Knee Surgery

Robotic assistance enables precise surgeries

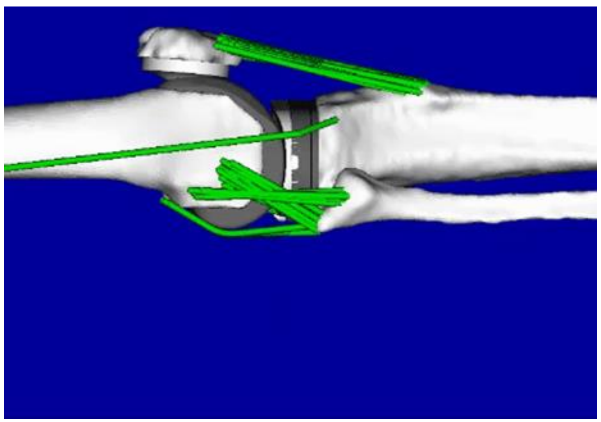


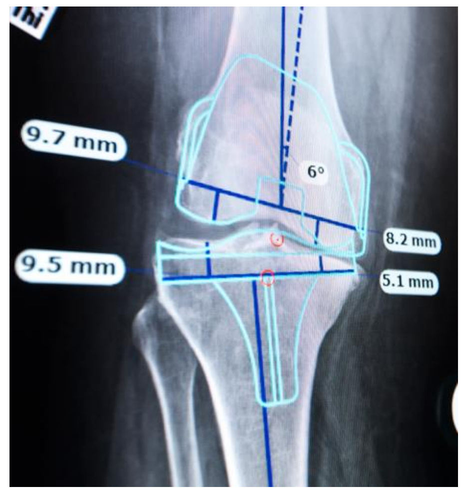
How do you determine the optimal cuts?

https://www.youtube.com/watch?v=QfmLdCHtqWA

Computer Simulation for Surgical Planning

How do surgical factors affect knee function during daily activities?



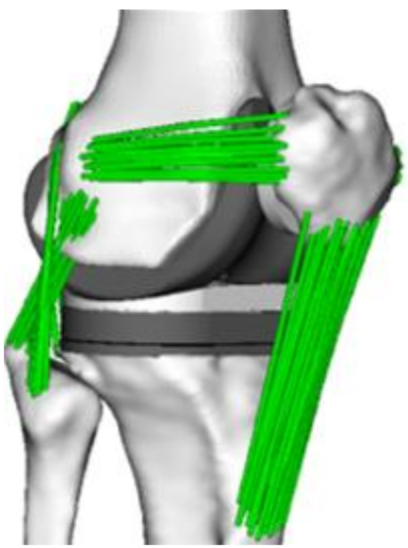


Present: Inform surgical planning

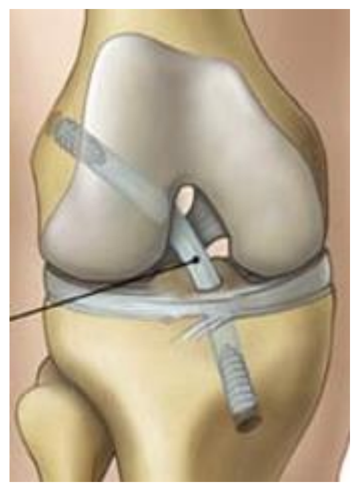
Future: Optimize patient-specific treatments

Orthopedic Applications

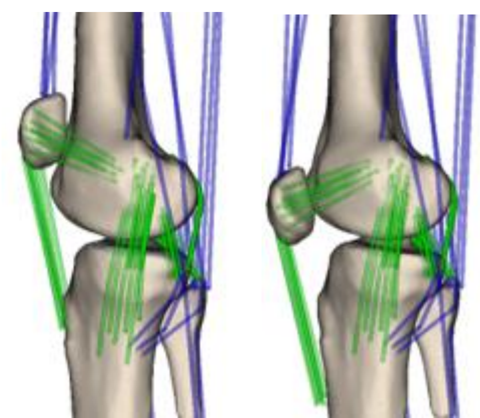
Total Knee Replacement



Ligament Reconstruction

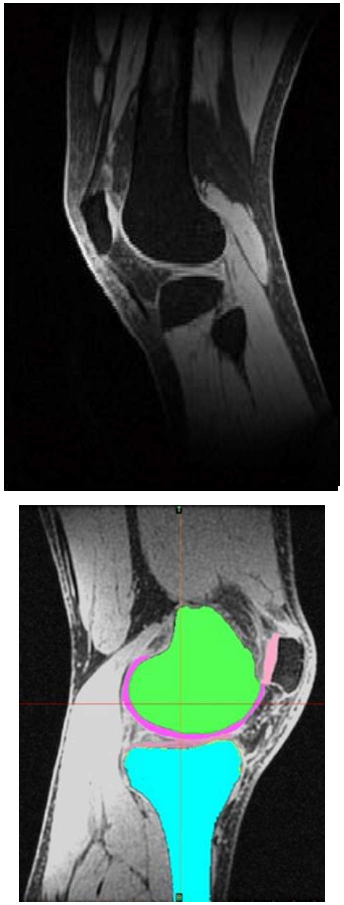


Pediatric Orthopedics

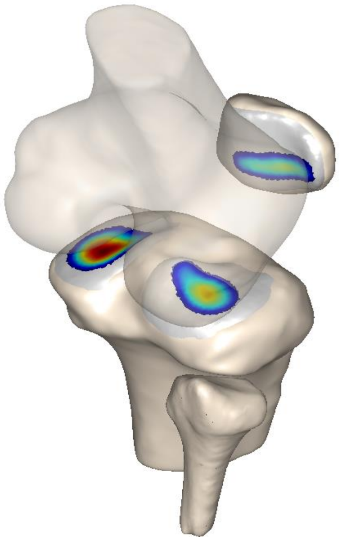


Uncertainty in Computational Knee Models

Knee Geometries

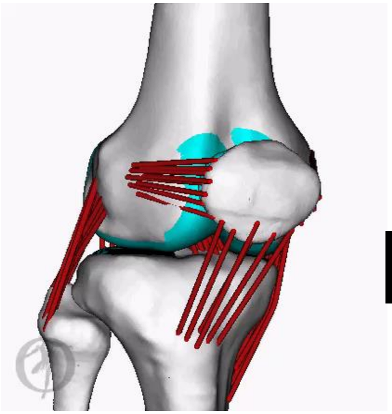


Cartilage Contact Model



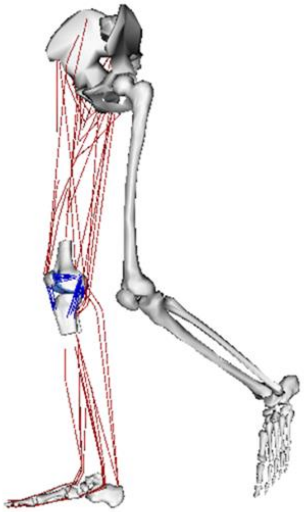
Cartilage Material Properties?

Ligament Model



Ligament Stiffness?

Musculoskeletal Model

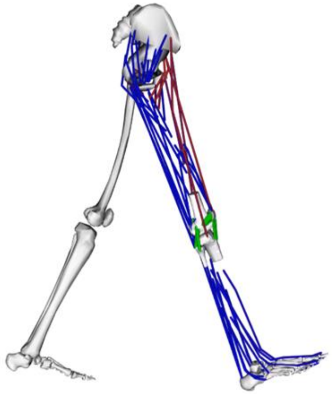


Neuromuscular Coordination?

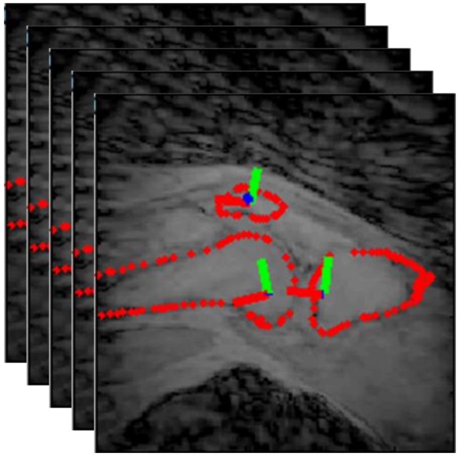
Lenhart et al, *Ann Biomed Eng*, 2015

Agenda

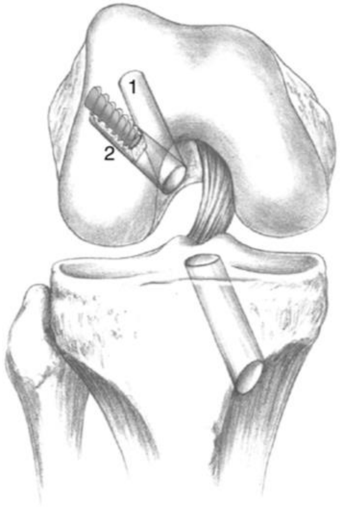
Simulation Framework



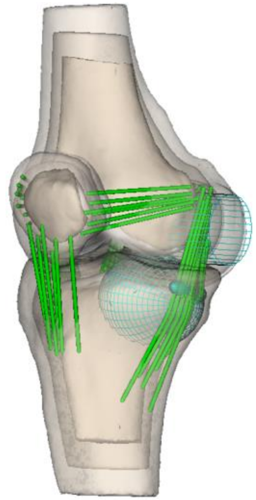
Validation in Presence of Uncertainty



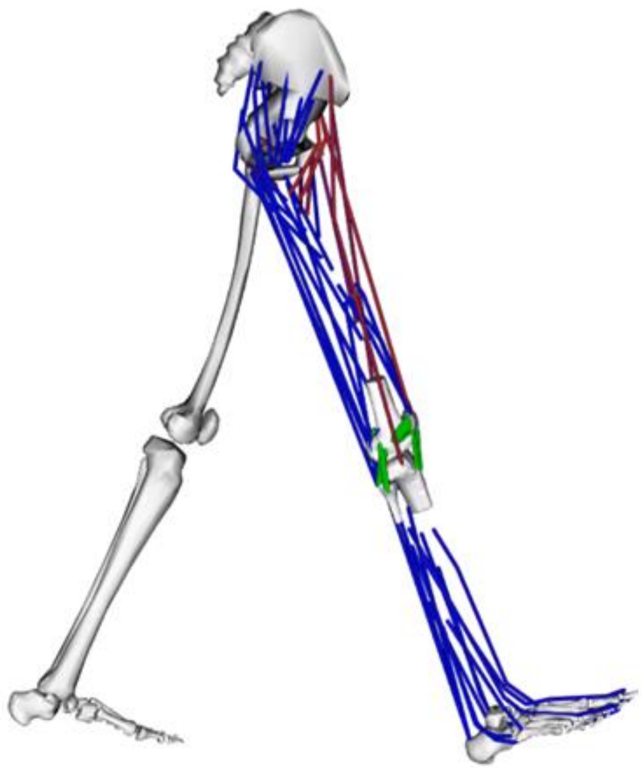
Surgical Simulation



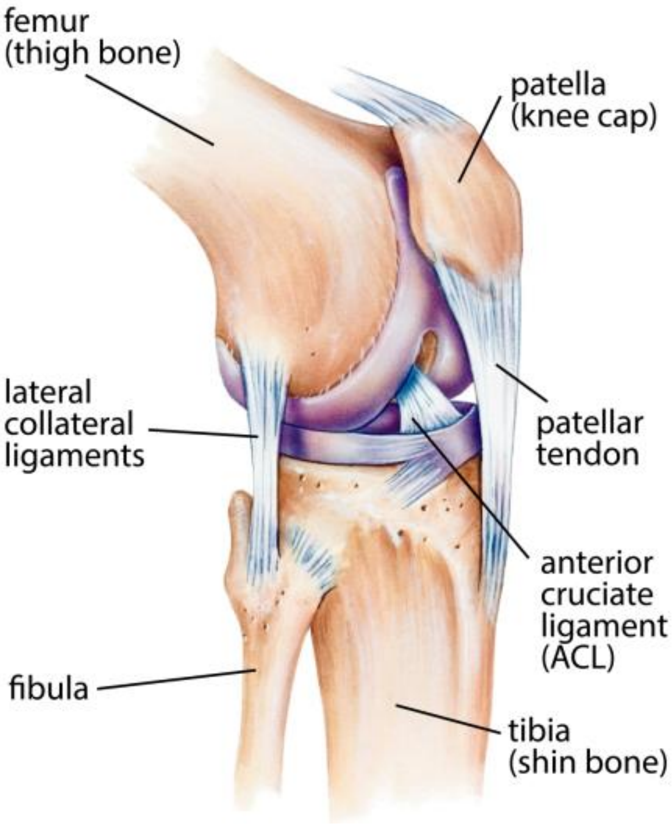
Future Directions



Knee Model and Movement Simulation Framework

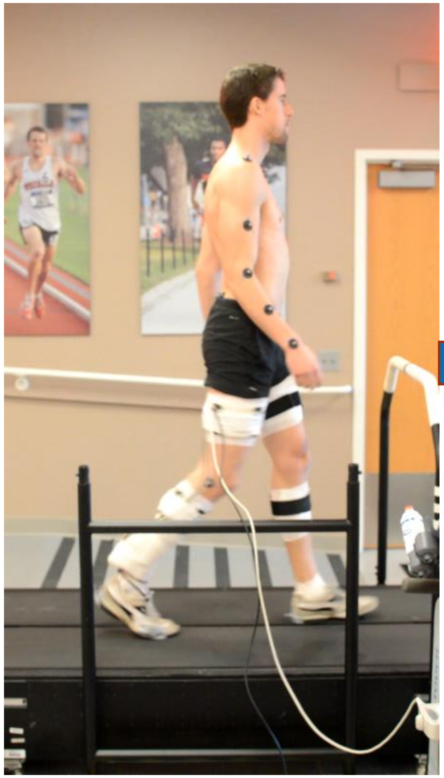


Knee Anatomy and Model

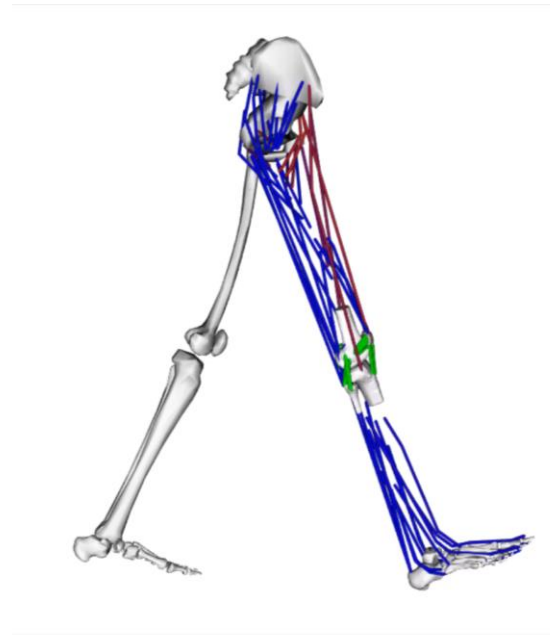


Physics-Based Simulation of Movement

Gait Analysis



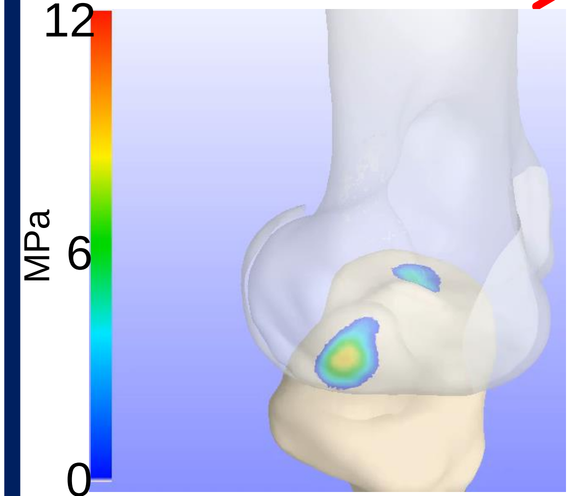
Musculoskeletal Simulation



Muscle Forces

Knee Movement

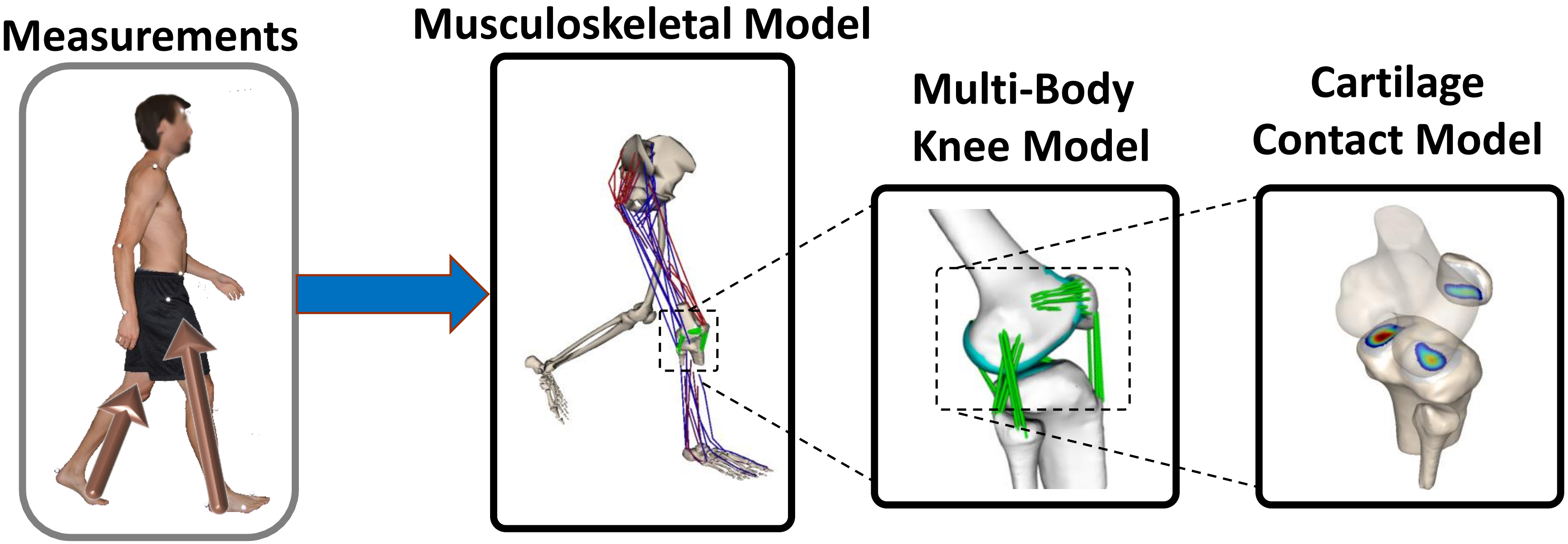
Ligament Forces



Cartilage Pressures

Smith et al, *J Knee Surg*, 2016

Simulation of Knee Mechanics during Movement



gait simulation takes ~0.5 hours

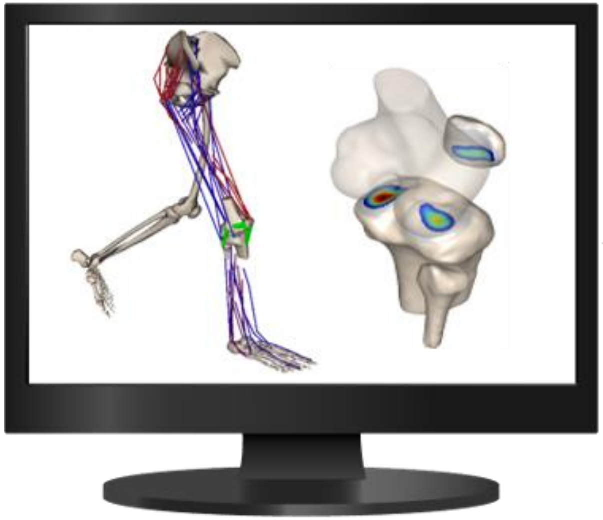
3000 simulations done in series in ~1500 hours

OpenSim

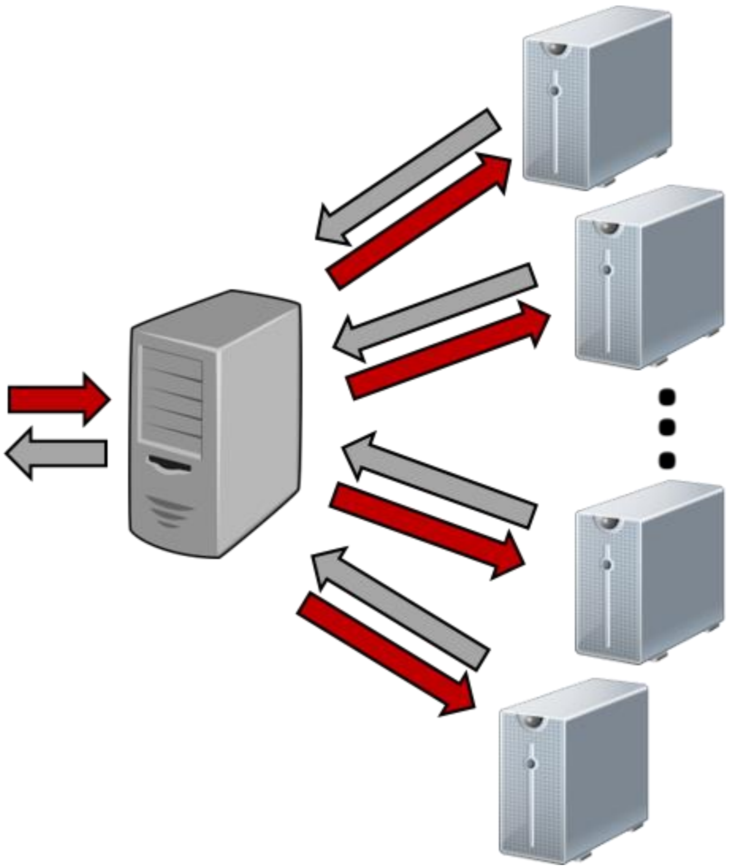
MATLAB

python™

HTC Enables Monte Carlo Analyses

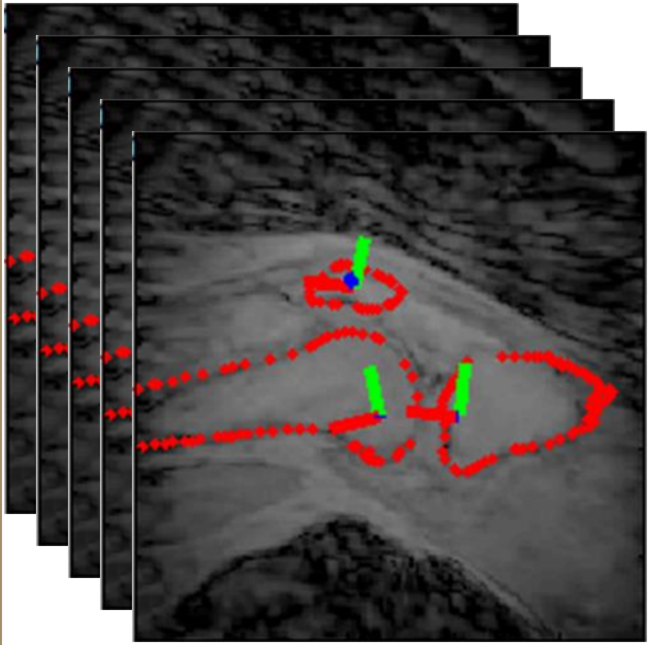


1 simulation in ~0.5 hours

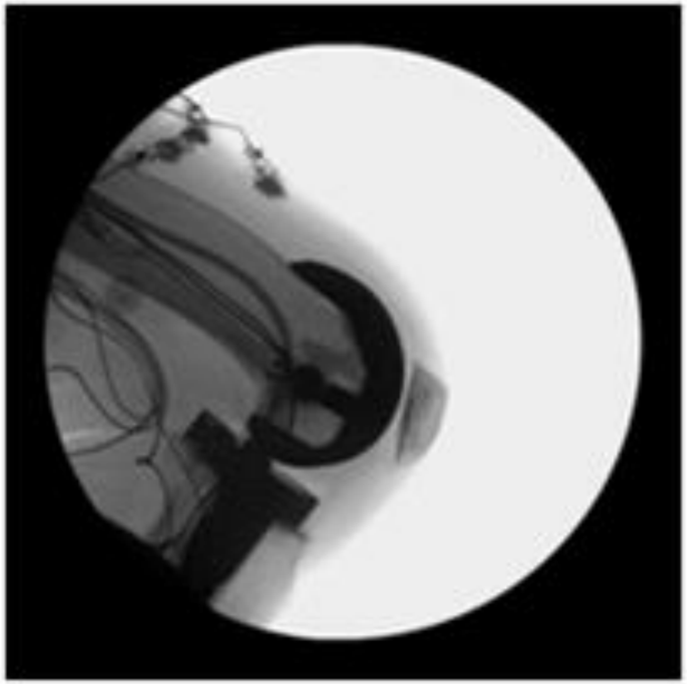


3000 simulations in ~2 hours

Extending Model Validation: Uncertainty and Sensitivity Analysis



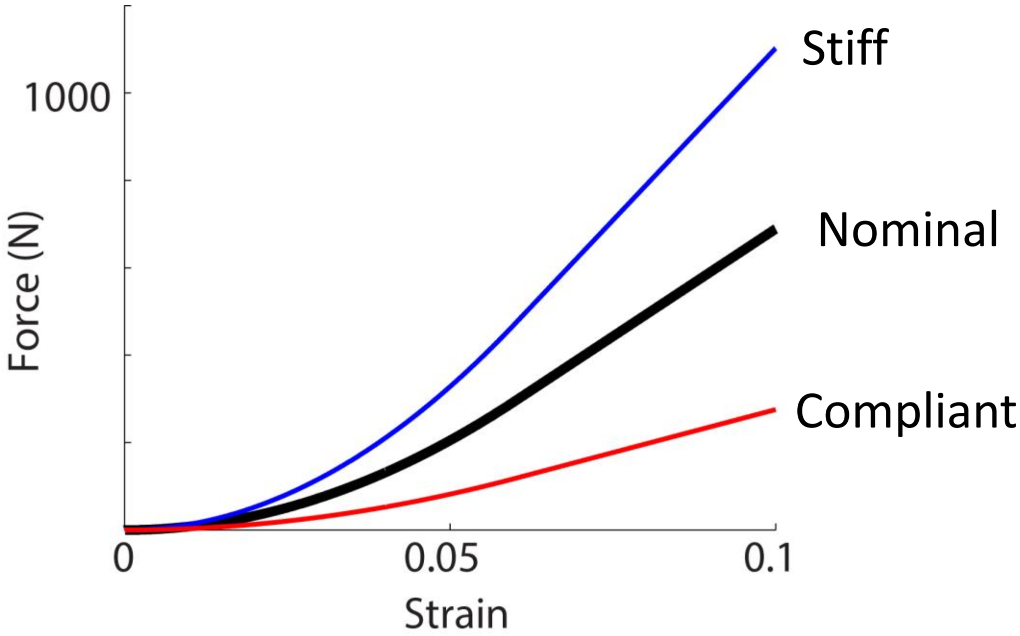
Dynamic MRI

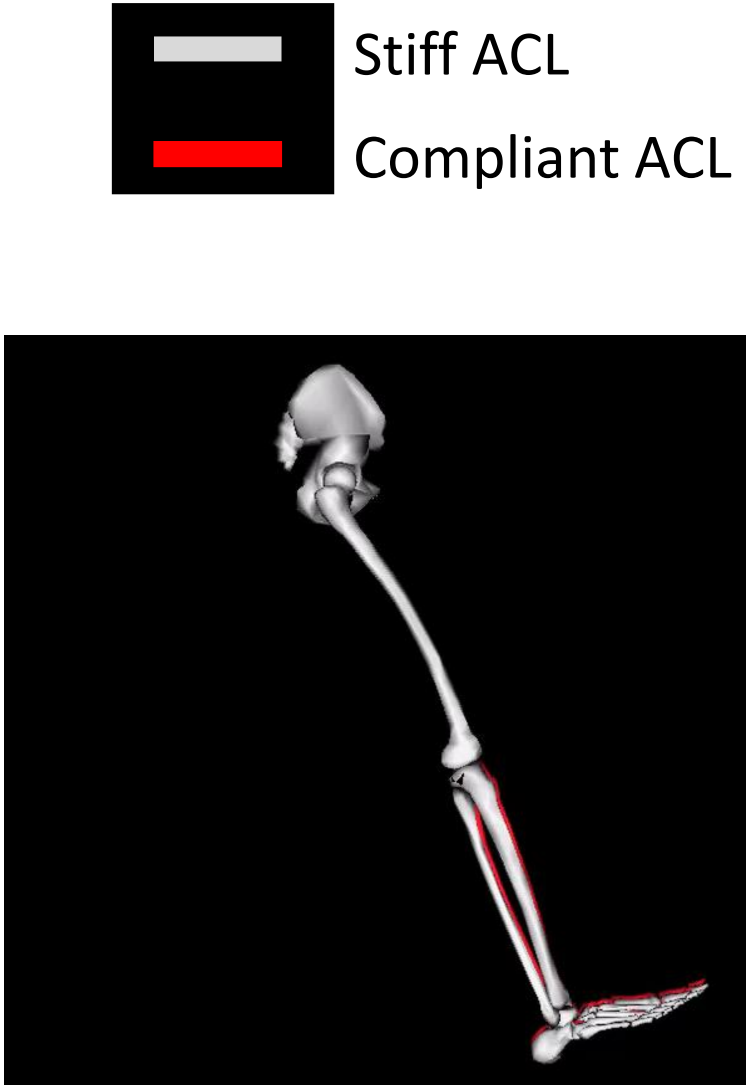


Instrumented Knee Replacement

Ligament Parameter Uncertainty

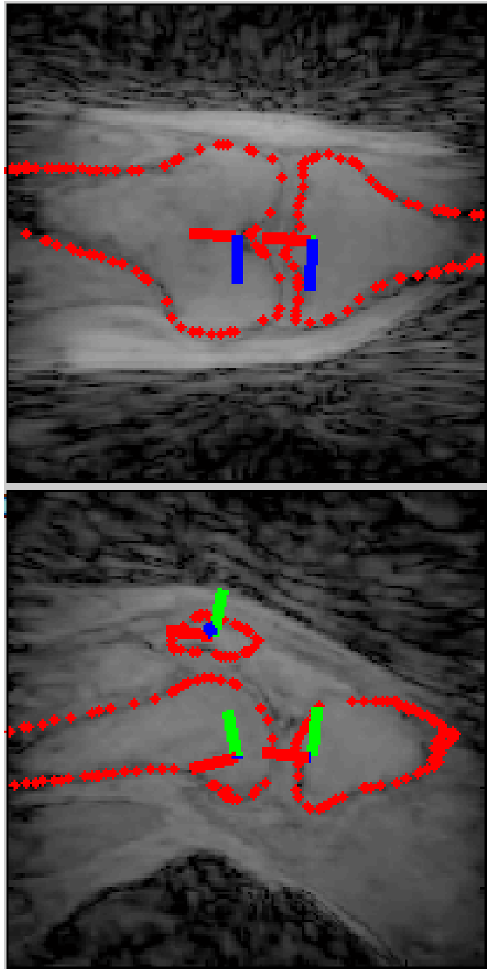
ACL Stiffness



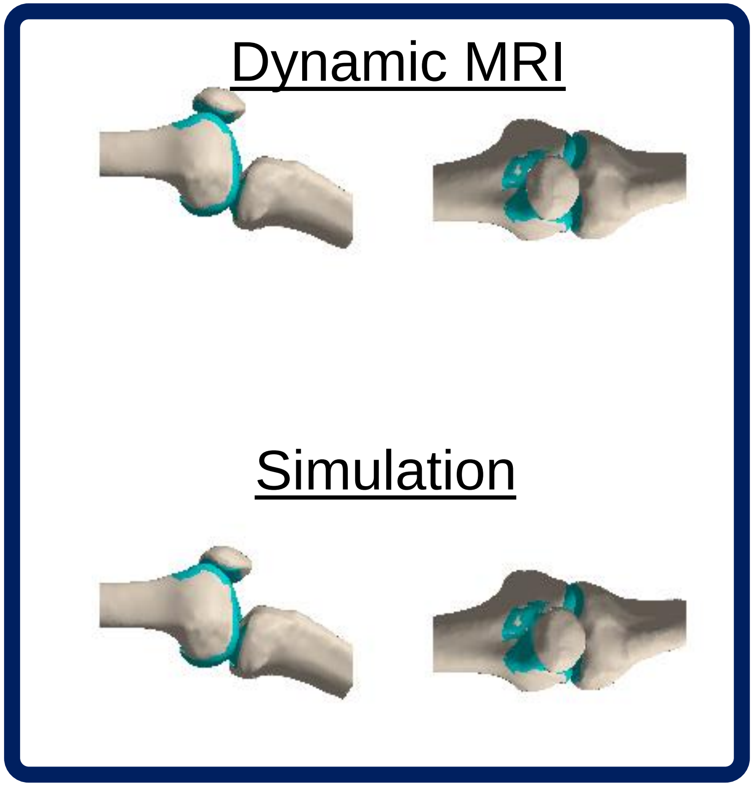


Dynamic MRI Validation of Simulated Kinematics

Dynamic MRI



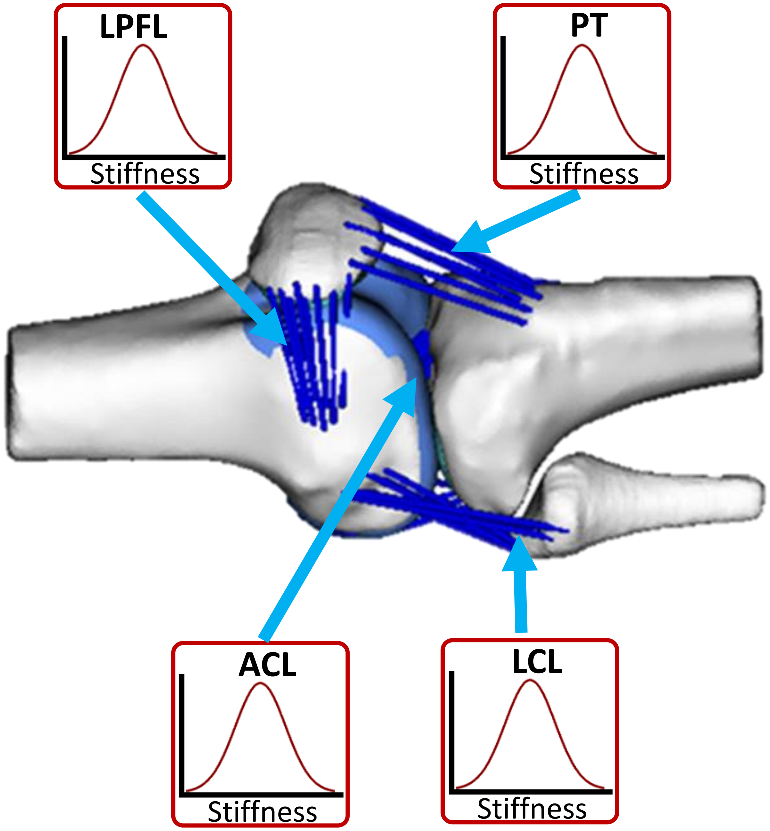
Kaiser et al, *Magn Reson Med* 2013

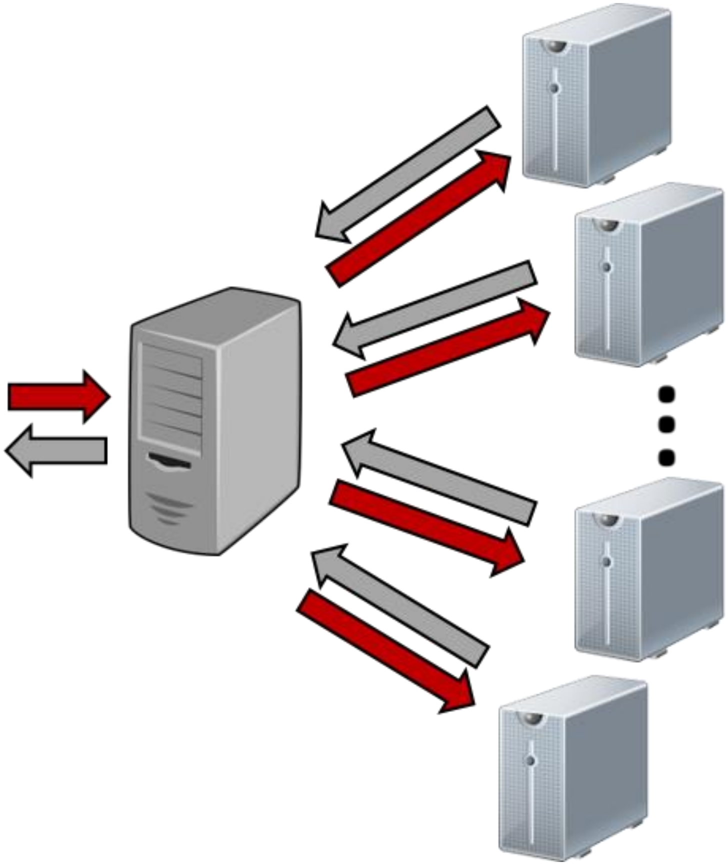


Lenhart et al, *Ann Biomed Eng*, 2015

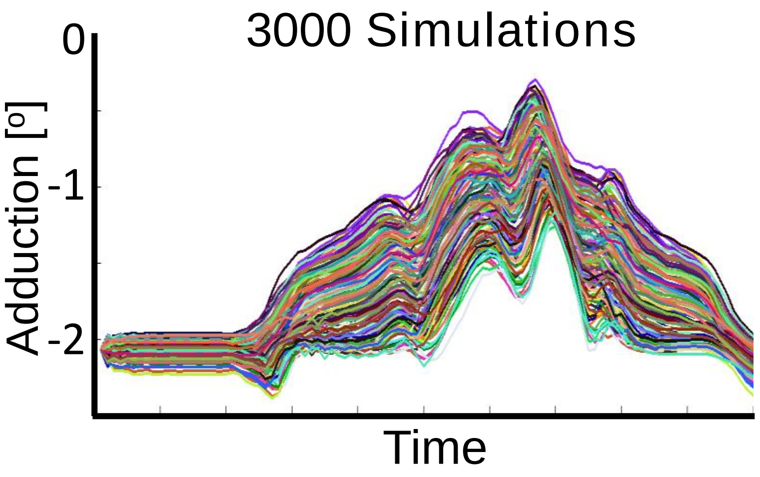
Monte Carlo Simulation

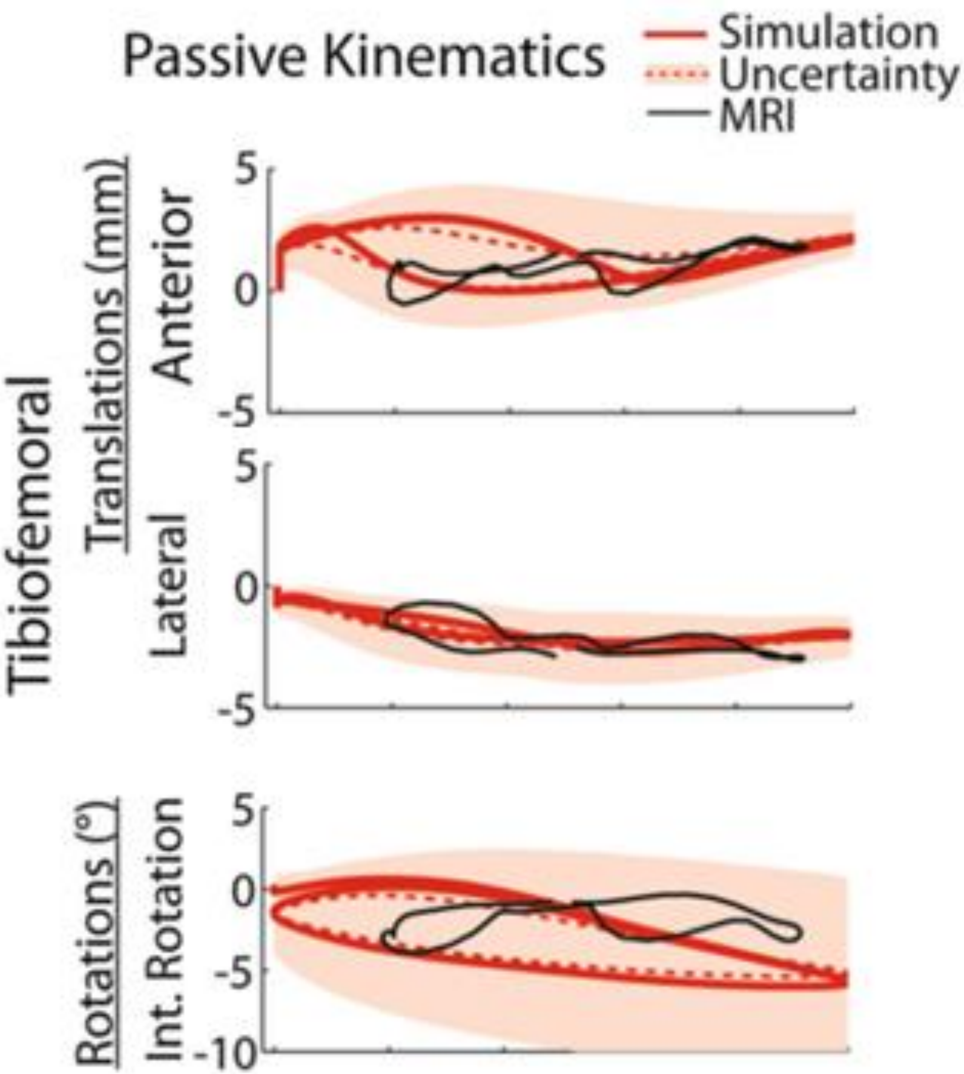
Probabilistic Ligament Stiffness





Accounting for Ligament Property Uncertainty



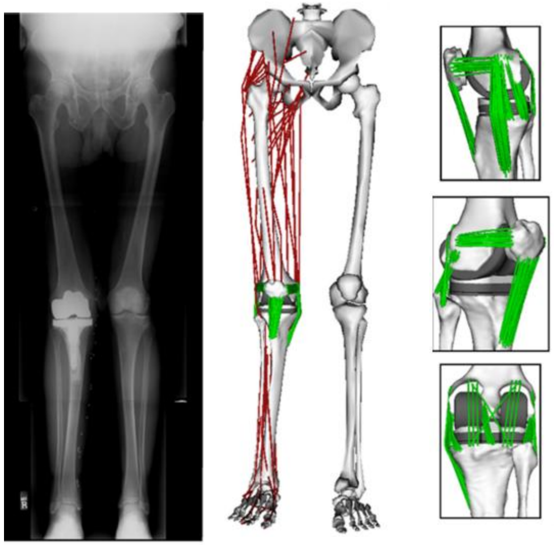


Lenhart et al, *Ann Biomed Eng*, 2015

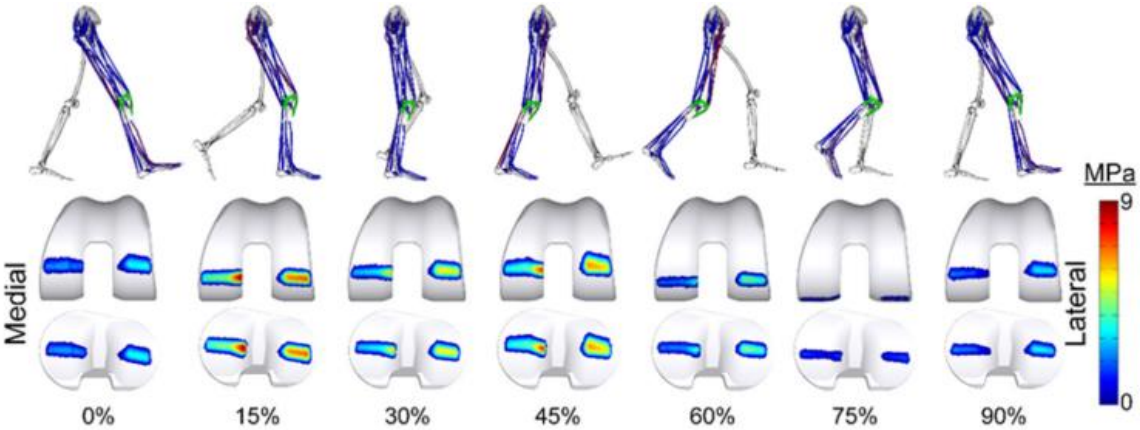
Knee Contact Force Validation

Instrumented Knee Replacement

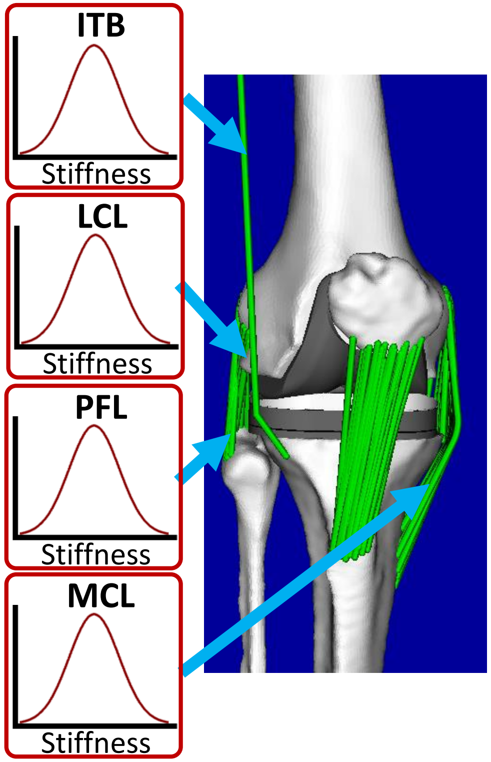
Subject-Specific Model

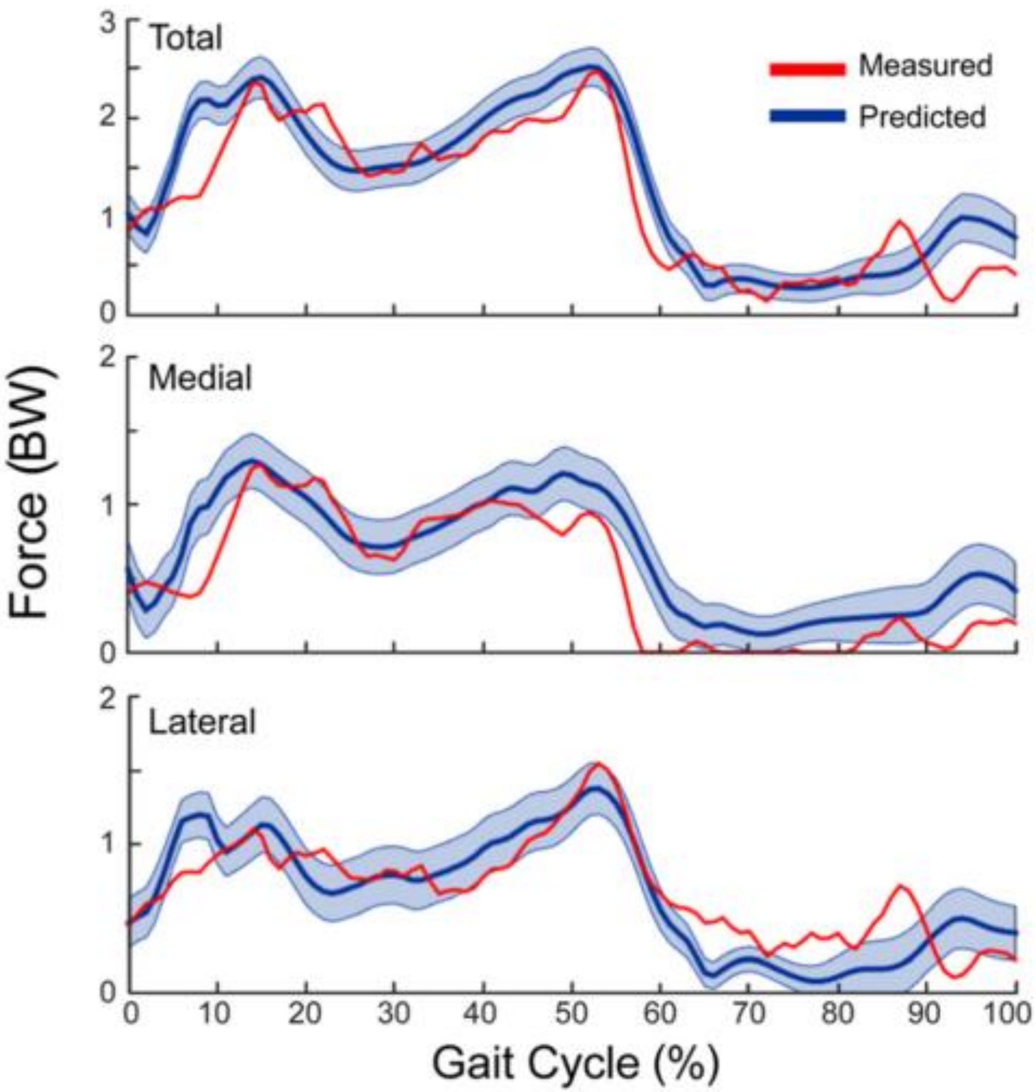


Walking Simulation

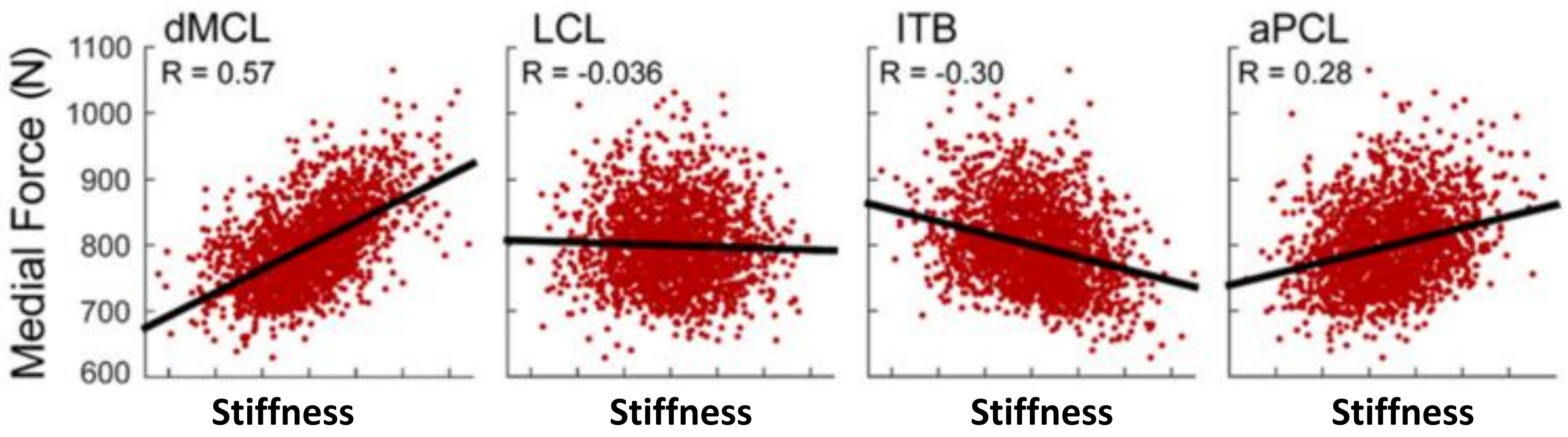


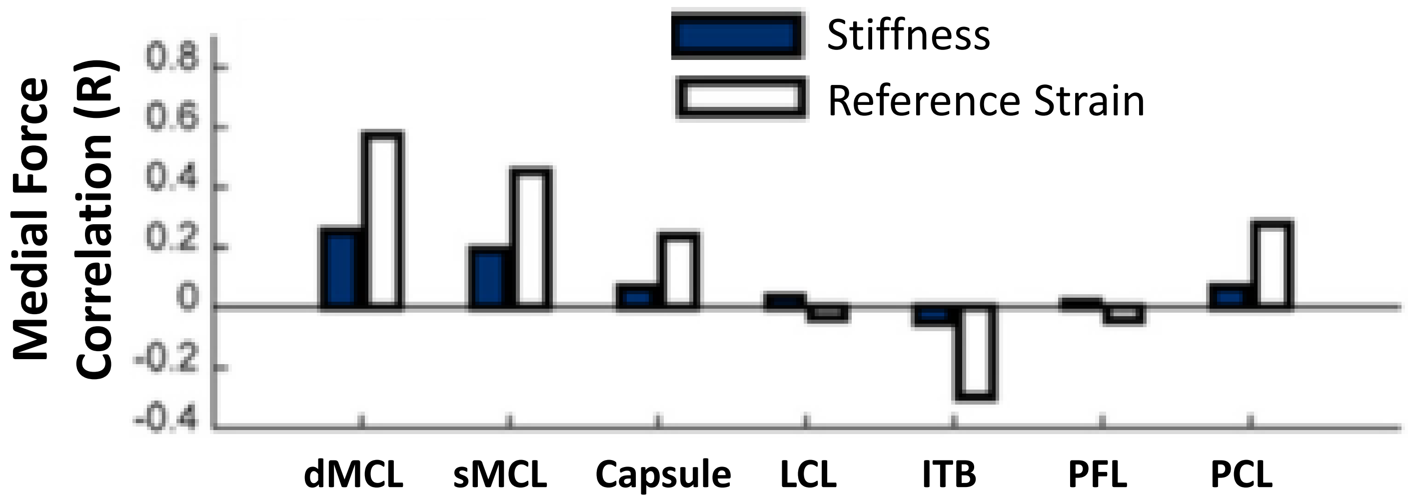
Ligament Uncertainty Propagation





Ligament Influence on Contact Force



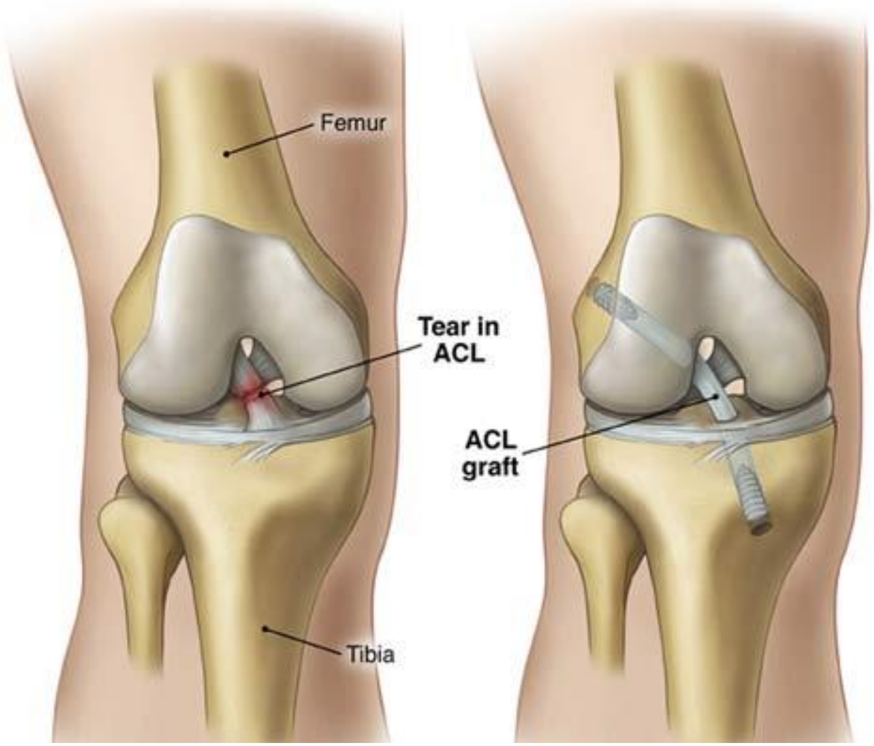


Surgical Simulation:

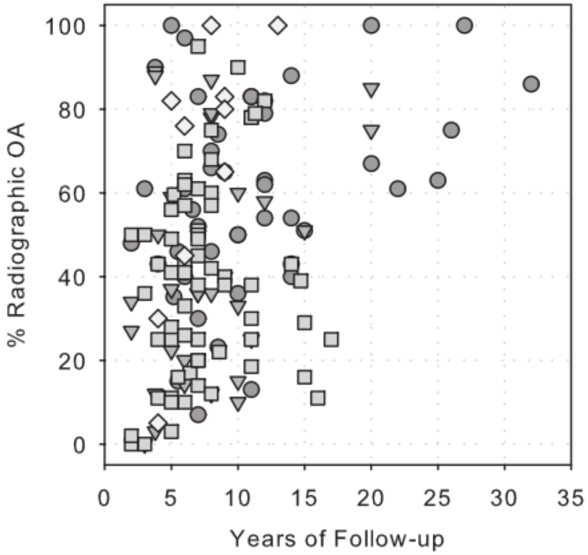
Anterior Cruciate Ligament Reconstruction

Clinical Application: ACL Reconstruction

Anterior Cruciate Ligament (ACL)



ACL injury and Osteoarthritis

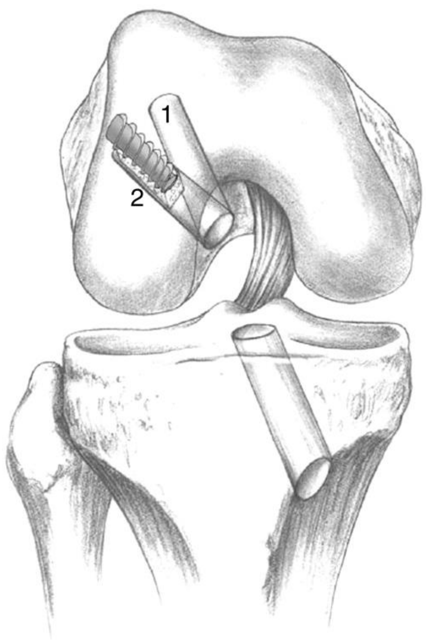


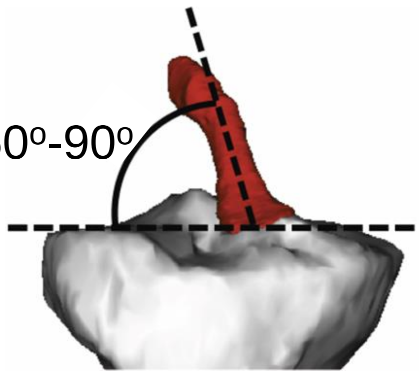
Lohmander et al, *Am J Sports Med*, 2007

Monte Carlo Analysis of ACL Femoral Attachment

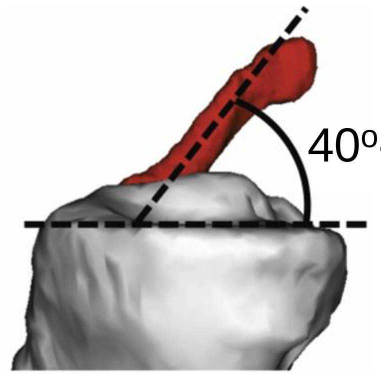
Tunnel Position

(Attachment Location)





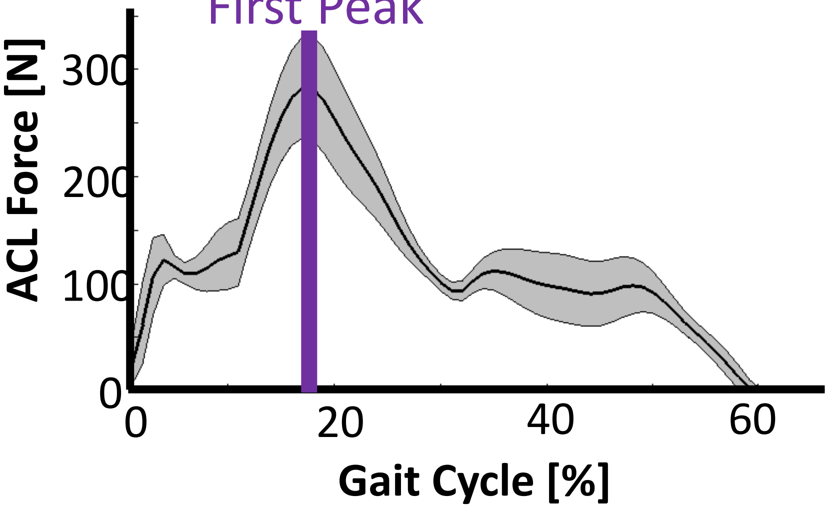
Coronal Angle

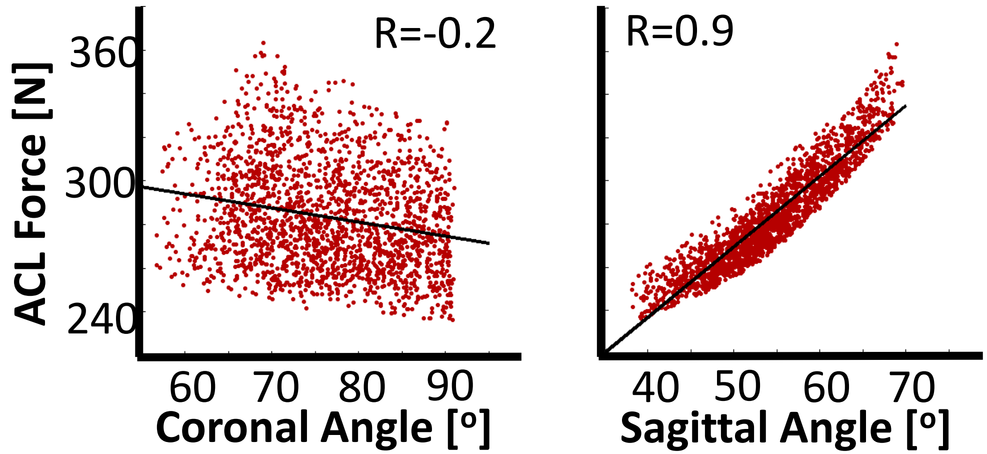


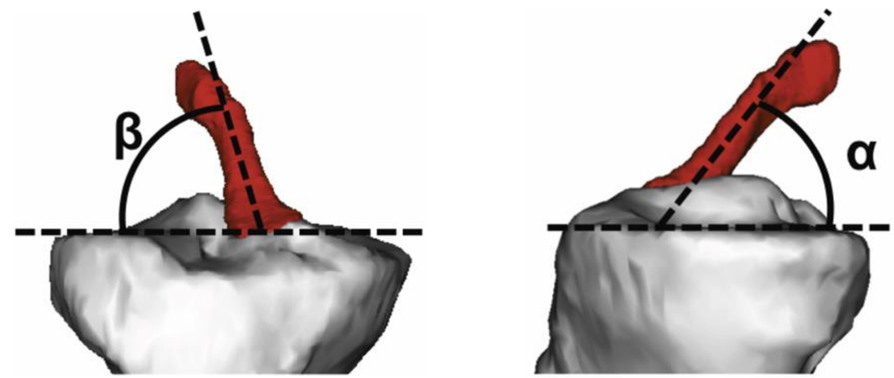
Sagittal Angle

2000 Simulations

ACL Forces during Walking





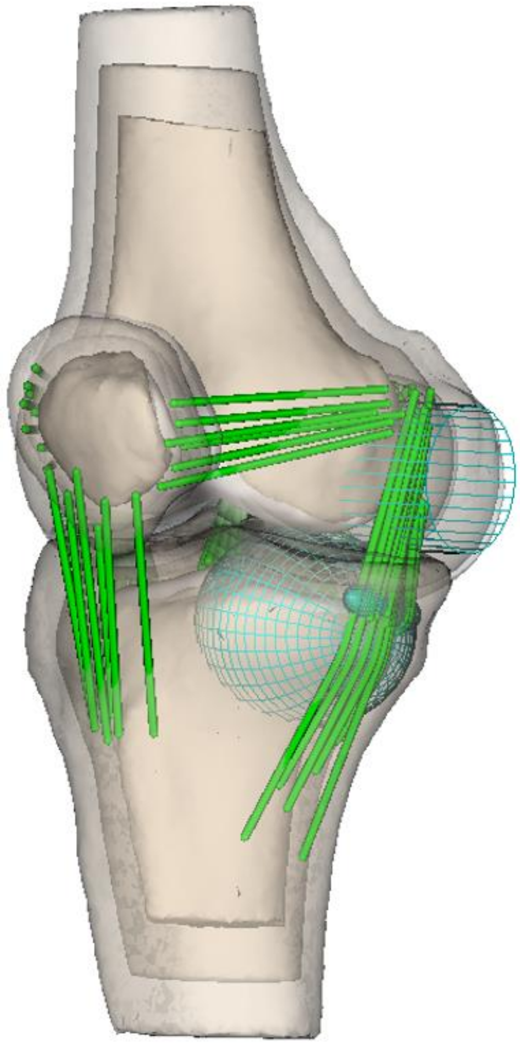


Graft Failure in Intra-Articular Anterior Cruciate Ligament
Reconstructions: A Review of the Literature

Anil Vergis, M.B.B.S., M.S., and Jan Gillquist, M.D., Ph.D.

Smith et al, ORS, 2015

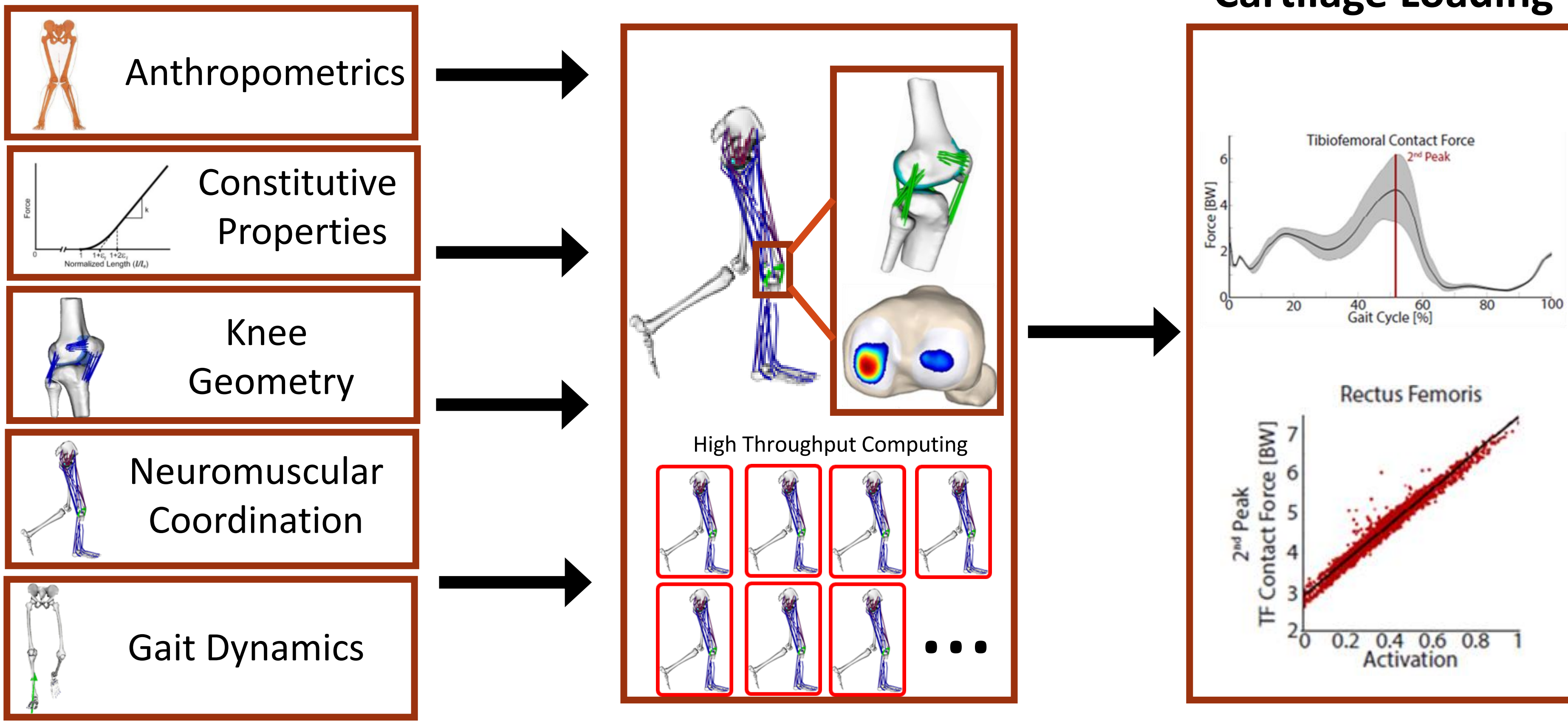
Future Direction:



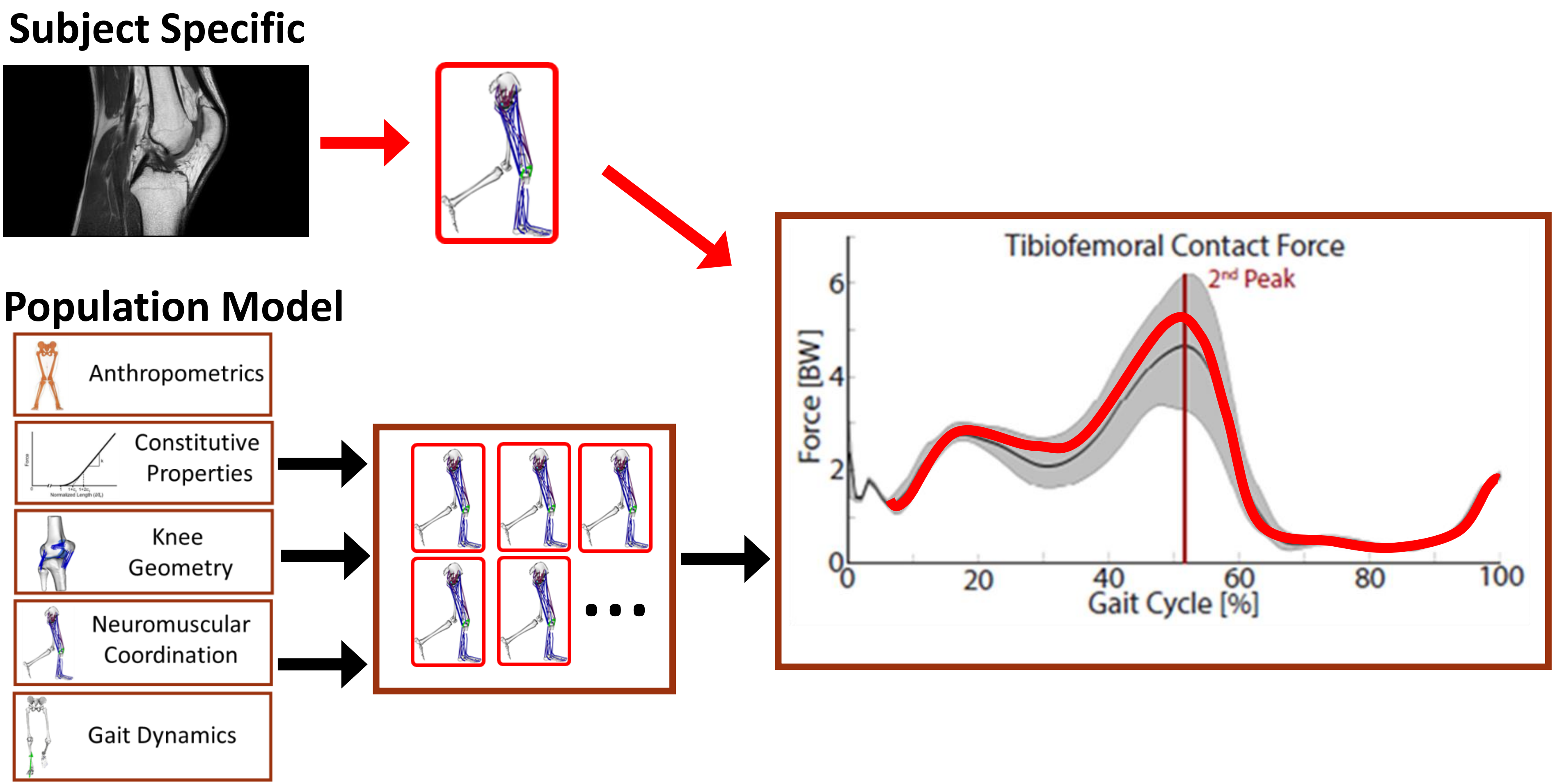
Parametric Knee Model

Stochastic Simulation Framework

Parameterized Inputs | **Stochastic Simulation** | **Probabilistic Cartilage Loading**



Subject Specific Modeling



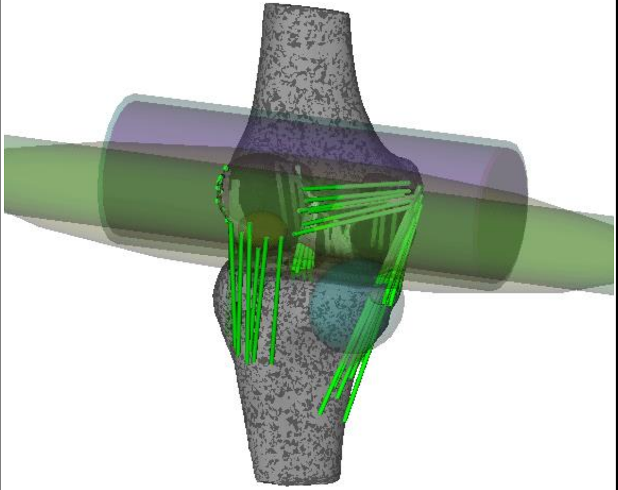
Statistical Shape Modeling

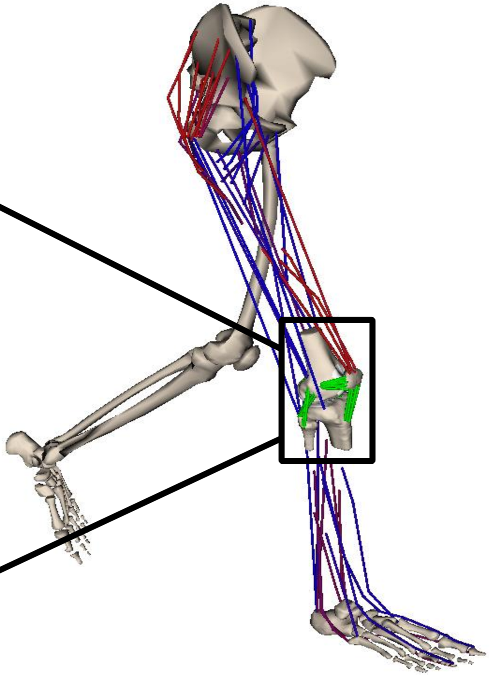
Parameterized Geometries

Segmented MRI

20 Healthy Subjects

Statistical Shape Model

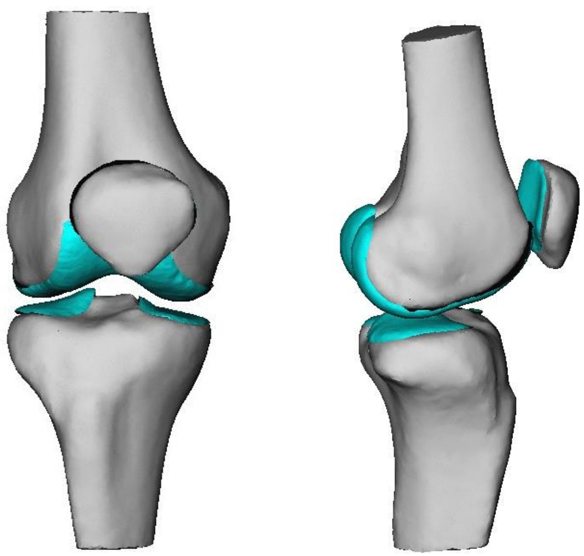




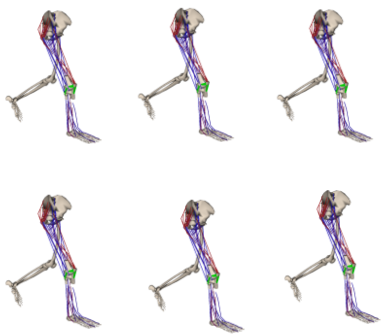
HTC and Stochastic Knee Geometry

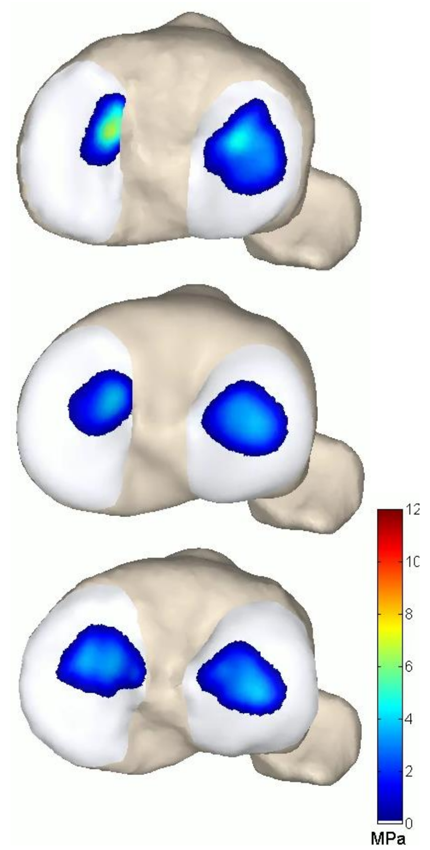
How does knee geometry influence cartilage loading?

Sample SSM



HTC



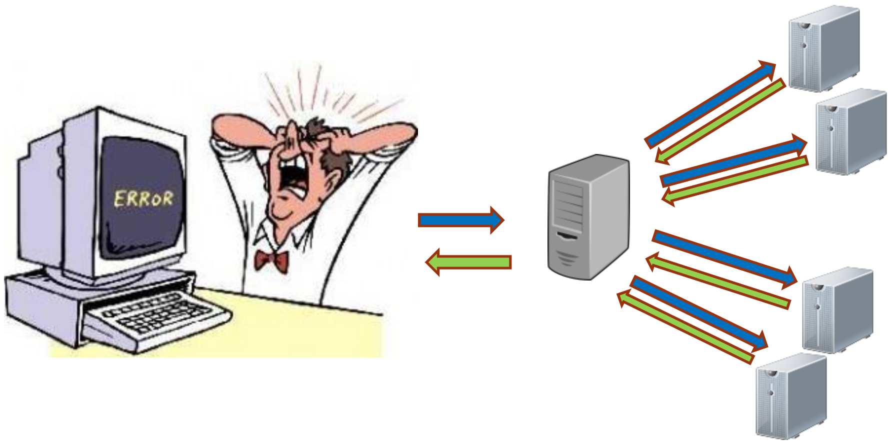


Clouthier et al, ORS, 2017

Closing Remarks

Challenges with HTC

- Programming Difficulties
  - Linux Compatibility
  - C/C++ Memory Errors
- Security
  - Medical Imaging Data
  - HIPAA
- Big Data Management
  - 1000 input files = 0.4 GB
  - 1000 results files = 2.6 GB



- Failed Simulations

Introducing HTC to the Biomechanics Community

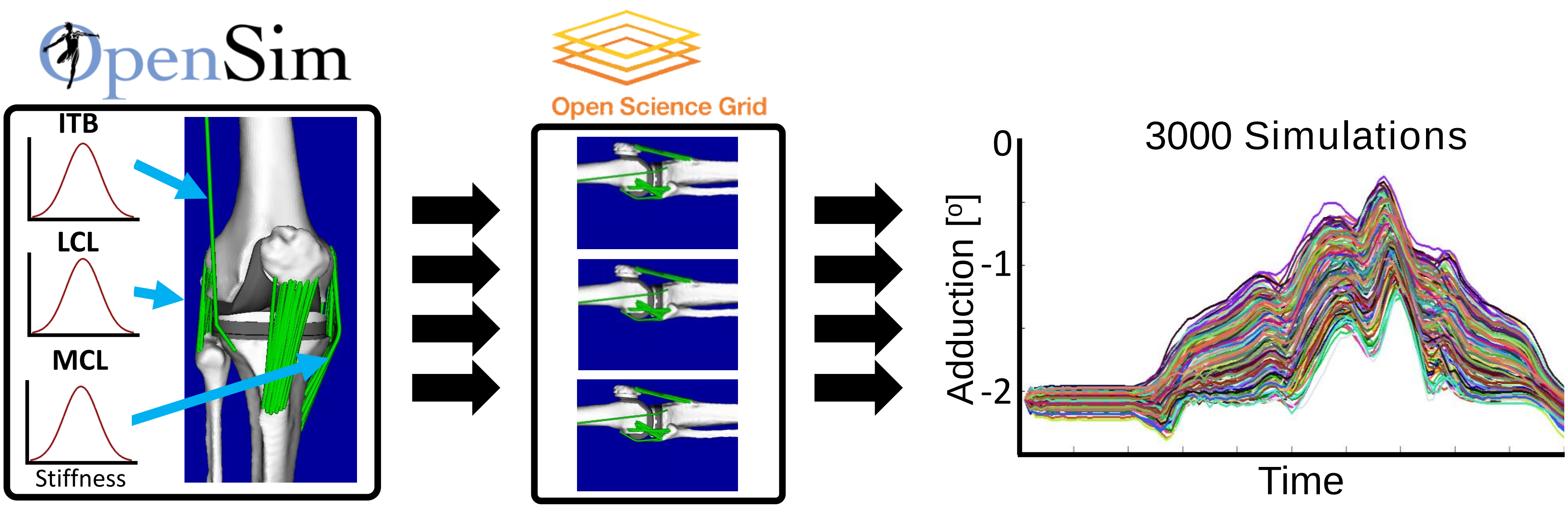
International Society of Biomechanics:

BRISBANE 2017

Stochastic Simulation of Knee Mechanics Enabled via Novel Solution Techniques and High Throughput Computing

OpenSim Webinar:

http://opensim.stanford.edu/support/event_details.html?id=169



Acknowledgements

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

UW Neuromuscular Biomechanics Lab
http://uwnmbl.engr.wisc.edu/

Christina Koch

CENTER FOR HIGH THROUGHPUT COMPUTING

OpenSim

Open Science Grid

Funding

NIH National Institutes of Health

NIH EB015410, HD084213, AR062733, HD065690