Open Knee

A Pathway to Community Driven Modeling and Simulation in Joint Biomechanics

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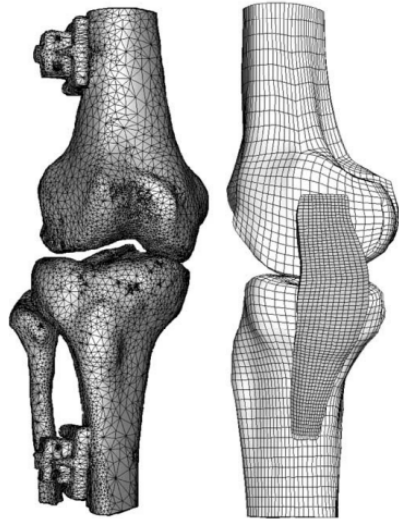Lerner Research Institute
Cleveland Clinic

PURPOSES OF KNEE MODELING

Joint and tissue functions

MCL function
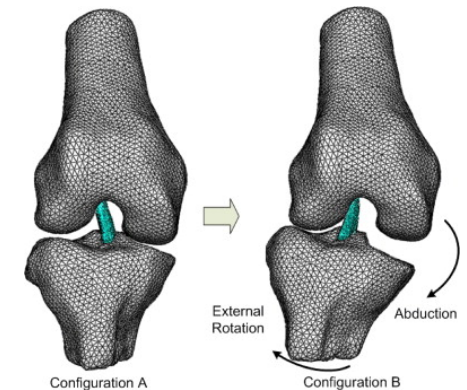
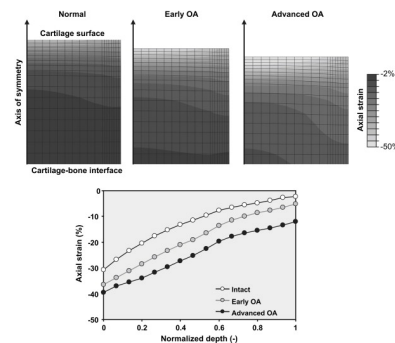*Gardiner and Weiss, J Orthop Res, 21: 1098-106, 2003.*

Injury mechanisms

*Park et al., J Biomech, 43: 2039-42, 2010.*

ACL impingement

External Rotation · Abduction

Configuration A · Configuration B

Pathological impacts

Normal · Early OA · Advanced OA

Cartilage surface

Axis of symmetry

Axial strain

-2%

-50%

Cartilage-bone interface

Axial strain (%)

Normalized depth (-)

Intact
Early OA
Advanced OA

Osteoarthritis

Saarakkala et al., Osteoarthritis and Cartilage, 18: 73-81, 2010.

Surgical interventions

With healthy meniscus time=60 s
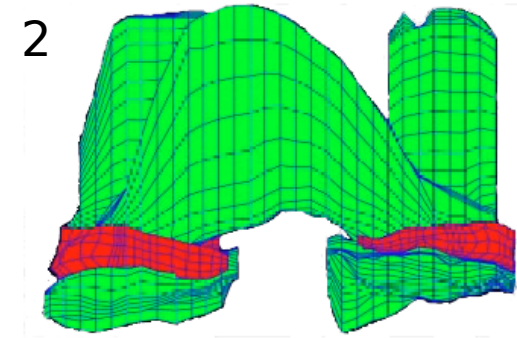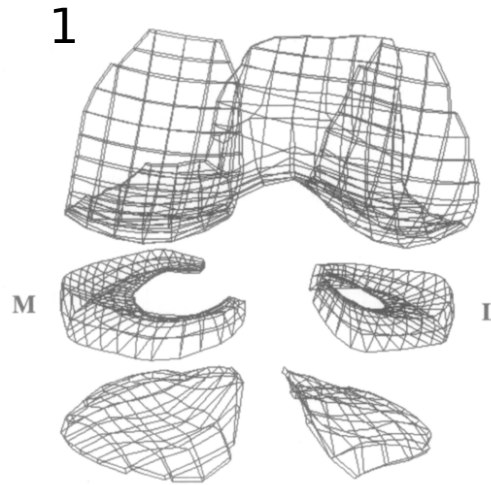
After meniscectomy time=60 s
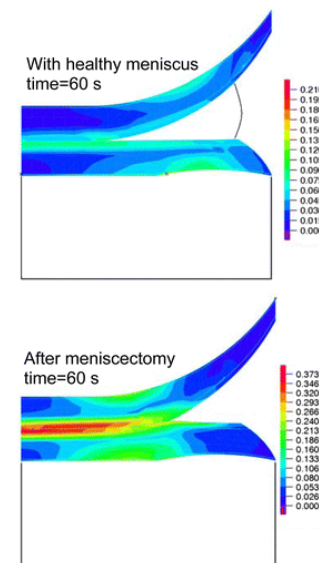
Menisectomy

Vaziri et al., Annals of Biomed Eng, 36: 1335-44, 2008.

EXAMPLES OF KNEE MODELING

586 (as of Sep 10, 2013)
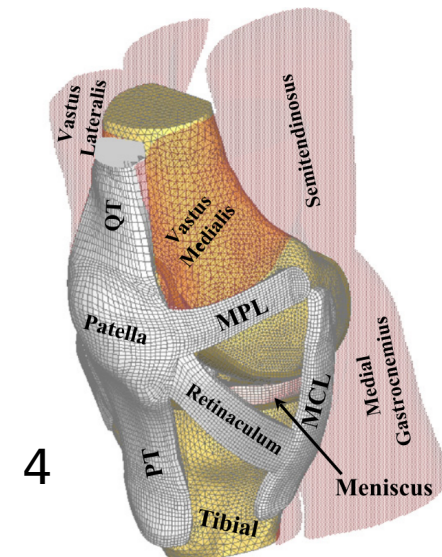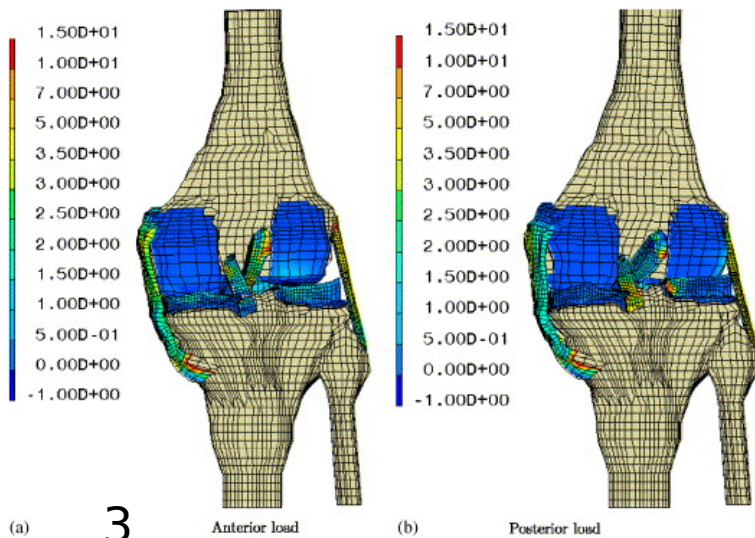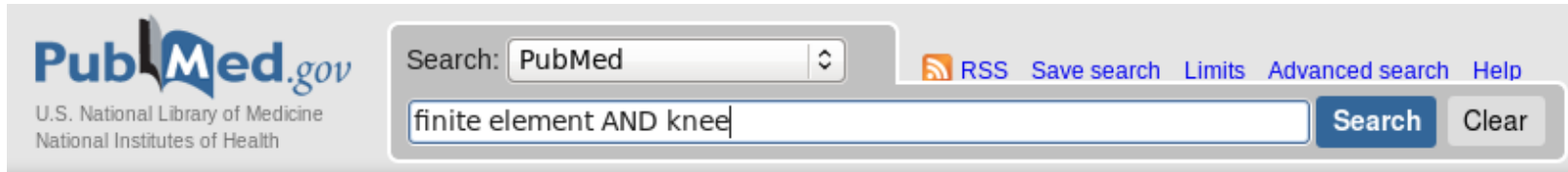
[1] Bendjaballah et al., Clin Biomech, 12: 139-48, 1997.
[2] Donahue et al., J Biomech Eng, 124: 273-80, 2002.
[3] Peña et al., J Biomech, 39: 1686-701, 2006.
[4] Dhaher et al., J Biomech, , 43: 3118-25, 2010.

GOALS OF OPEN KNEE

Open development and **dissemination** of a general purpose **knee joint model**

Opportunity for **crowd-sourced review**, **modification**, and **validation** to address clinical and research problems in knee biomechanics

DATA

Cadaver Specimen

Right knee (70 years old female)

Magnetic Resonance Imaging

Multi-plane scans
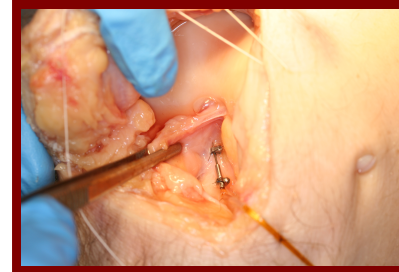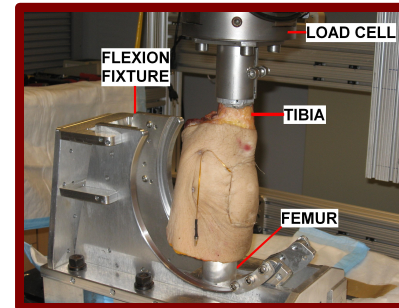   1.5 Tesla MRI (Orthone, ONI, Inc.)

Robotics Testing

Measurements joint kinematics/kinetics
    Rotopod 2000 (PRC Corp.)

Measurements of ACL length
    DVRT (MicroStrain, Inc.)

Degree of freedom	Ranges of Motion	Ranges of Load
Flexion/extension	0.0 – 45.0°	-10.1 – 4.3 Nm
Internal/external rotation	-24.7 – 32.5°	-5.0 – 5.0 Nm
Varus/valgus	-7.9 – 12.9°	-9.9 – 9.9 Nm
Anterior/posterior translation	-10.4 – 24.5 mm	-99.9 – 104.1 N
Medial/lateral translation	-8.7 – 6.0 mm	-6.4 – 7.1 N
Compression/distraction	-9.9 – 3.1 mm	-73.8 – 394.4N

Borotikar BS, Doctoral Dissertation, Cleveland State University, 2009.

MODEL

Legend:
- bones (grey)
- cartilage (blue)
- menisci (orange)
- ligaments (red)

Labels: ACL, ligament ligament contact, ligament bone contact, cartilage cartilage contact, cartilage meniscus contact, ligament meniscus contact, LCL, MCL, PCL, springs (meniscal horn)
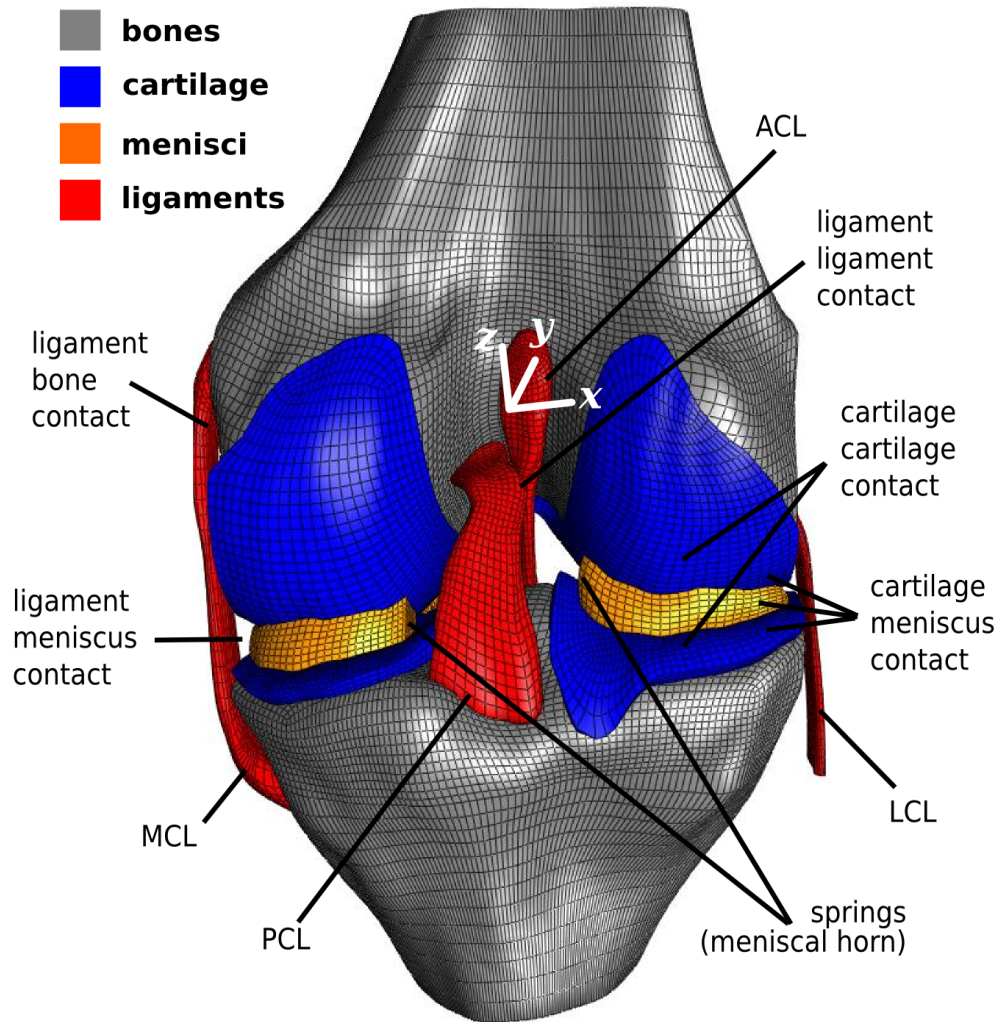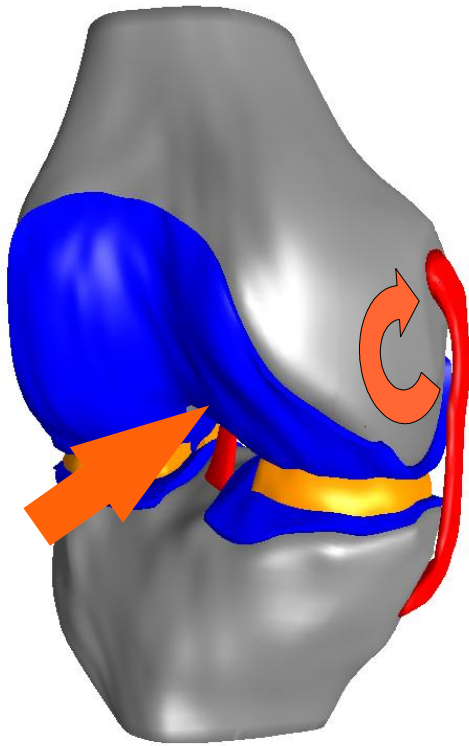
Bones
rigid body

Cartilage
nearly incompressible Neo-Hookean

Menisci
Fung orthotropic hyperelastic horn attachments as springs

Ligaments
transversely isotropic hyperelastic

Erdemir and Sibole, Open Knee User's Guide, Version 1.0.0, 2010.

SIMULATIONS

Simulation Type

Dynamic; implicit time integration

Tibia BCs
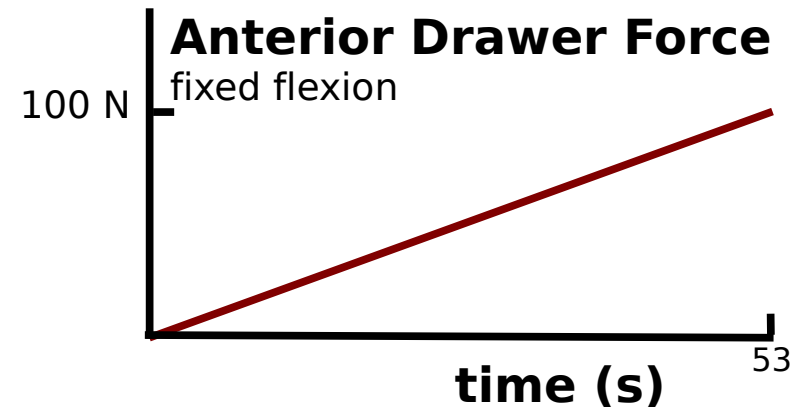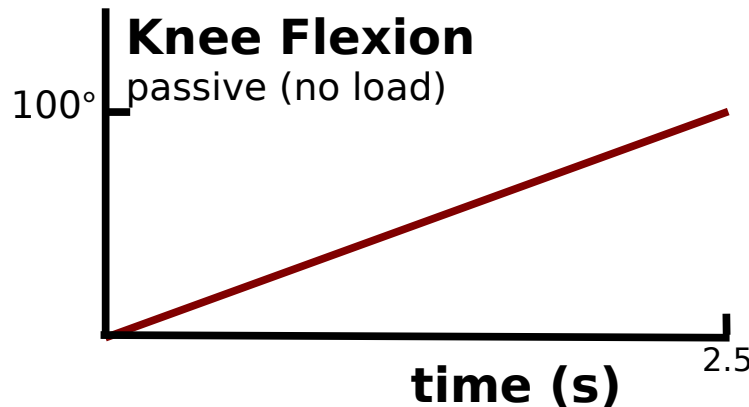
Fixed in space

Femur BCs

Prescribed flexion (or fixed)
Other dofs free (or under load control)

Typical Scenarios

Knee Flexion
passive (no load)

100°

time (s)   2.5

Anterior Drawer Force
fixed flexion

100 N

time (s)   53

DISSEMINATION

Open Knee

http://simtk.org/home/openknee

Wiki
Subversion repository
Release package
Creative Commons Attribute Share-Alike Licensing

Software

Finite element analysis (free and open for academia)
http://mrl.sci.utah.edu/software

Scripting (free and open for all)
http://www.python.org

Mesh generation (proprietary)
http://www.truegrid.com

SITE STATISTICS

Open Knee Statistics (January 30, 2012)	
Project site	https://simtk.org/home/openknee
Project launch date	February 18, 2010
Page hits	19525 (past 180 days)
Unique visitors	902 (past 180 days)
Team members	8 total 3 active 2 original, 1 from community
Documentation	1 user's guide 3 conference abstracts
Development	248 repository commits
Releases	v.1.0.0.199 (major) December 17, 2010 v.1.0.1.202 (minor)
Release downloads	207 total 162 unique
Expected use of downloads (feedback provided by users)	56 research 54 training 24 reference for other models 14 evaluation 9 anterior cruciate ligament 9 instrumentation/implants/ orthotics/prosthetics 6 cartilage/osteoarthritis 5 potential contributions 4 impact biomechanics 4 knee loads 2 knee movements 2 knee geometry 1 meniscal injury 1 femur biomechanics Rest unspecified/unsure

as of Sep 10, 2013

442,993 page hits past 180 days

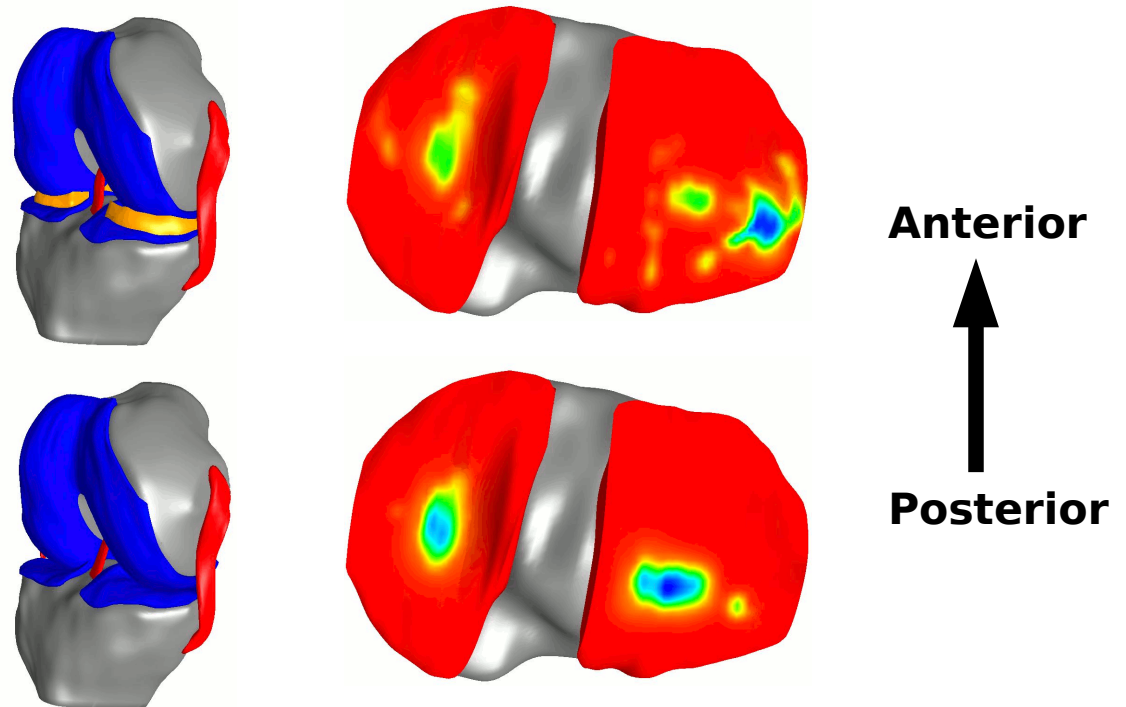**17,872** unique visitors past 180 days

286 repository commits

402 total downloads
303 unique downloads

OPEN KNEE STUDIES

*Sibole, S., Bennetts, C., Borotikar, B., Maas, S., van den Bogert, A. J., Weiss, J. A. and Erdemir, A. **Open knee: a 3D finite element representation of the knee joint**, 34th Annual Meeting of the American Society of Biomechanics, August 18-21, 2010, Providence, RI.*

- A **tibiofemoral joint model** was developed with potential for problem specific **customization**.

- A transparent development platform was established.

- Dissemination pathway was constructed.

- Simulation capacity was illustrated through simulations of passive flexion under compressive loading.

- Customization potential was illustrated by simulations of menisectomy.

Anterior

Posterior

*Erdemir, A., and Sibole, S. **Open knee: capacity to reproduce passive joint kinematics**, 23rd Congress of the International Society of Biomechanics, July 3-7, 2011, Brussels, Belgium.*

- Complete **passive kinematics** response (translation + rotation) was compared against **population data**.

- Passive kinematics was coupled to flexion.

- Proximal-distal translation predictions were not in agreement.

- Open Knee exhibited deviations from experimental data in high flexion angles.
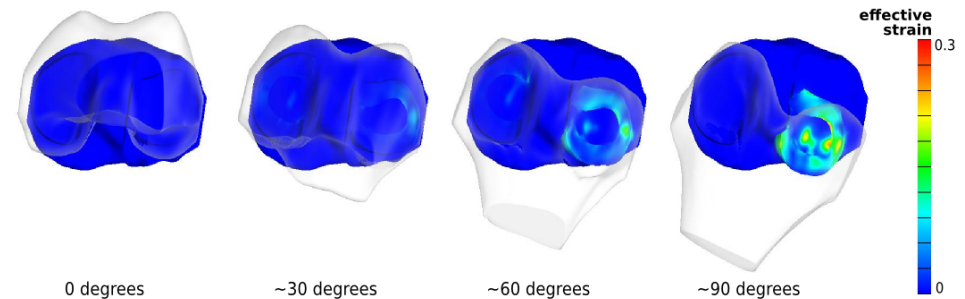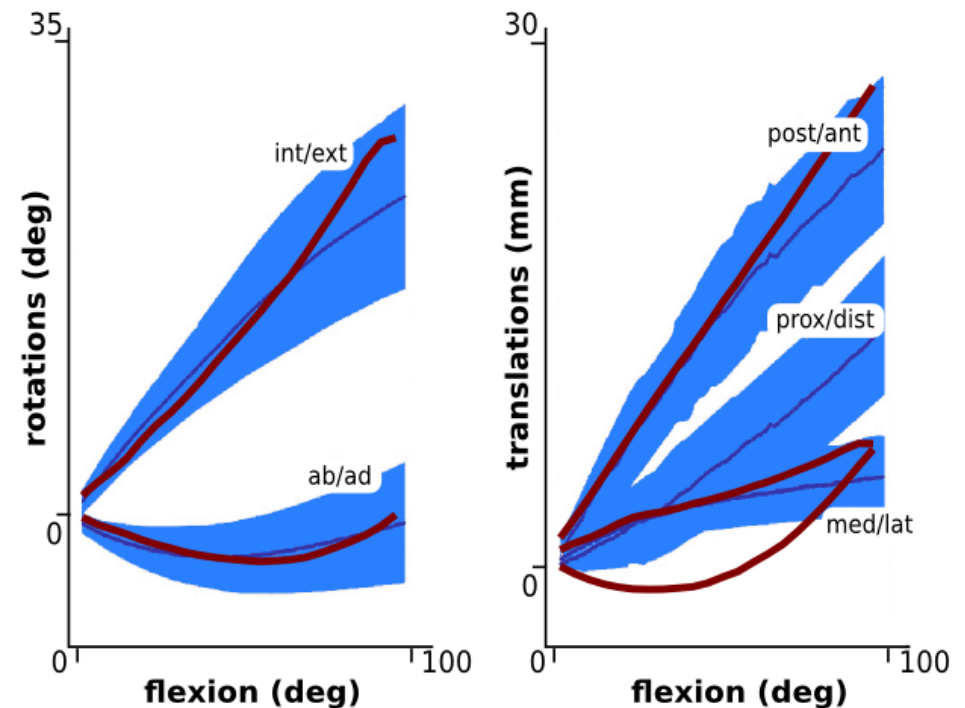
OPEN KNEE STUDIES

Erdemir, A. and Sibole, S. **Open knee: capacity to reproduce anterior cruciate ligament deformations**, *10th International Symposium, Computer Methods in Biomechanics and Biomedical Engineering, April 11-14, 2012, Berlin, Germany.*

- **Anterior drawer test kinematics** (translation + rotation) and **ACL deformations** were compared against **specimen-specific data**.

- Model predicted anterior displacements were lower.

- Model predicted ACL deformations were higher.

- Large discrepancies in off-axis kinematics (internal tibial rotation, lateral translation) were observed.
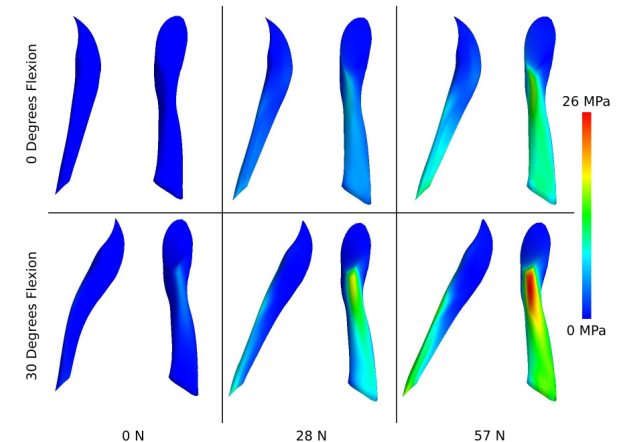
Anterior Translation
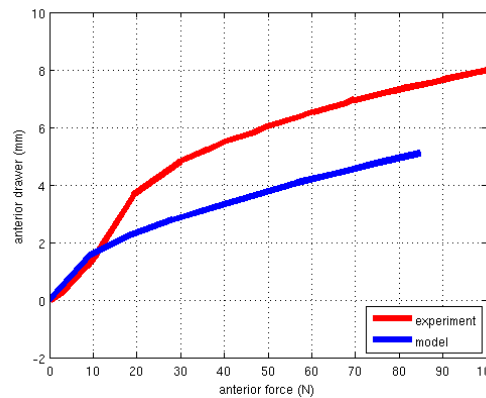
ACL Deformation
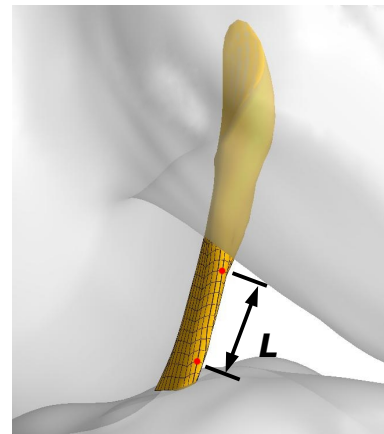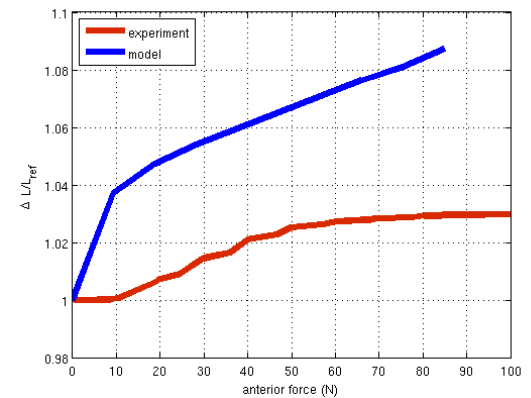
ACL 1st Principal Stress vs Anterior Tibial Load

ENABLED STUDIES

Peer-Reviewed Articles

Sibole, S. C. and Erdemir, A. (2012) Chondrocyte deformations as a function of tibiofemoral joint loading predicted by a generalized high-throughput pipeline of multi-scale simulations, PLoS ONE, 7, e37538.

Guo, H. and Spilker, R. L. (in press) An augmented Lagrangian finite element formulation for 3D contact of biphasic tissues, Computer Methods in Biomechanics and Biomedical Engineering.

Thesis

Heydon, R. (2011) Finite element analysis of knee articular cartilage, M.A.Sc. Thesis, Ryerson University, Toronto, Ontario, Canada.

Tichon, D. J. (2011) Finite element analysis of the effect of low-speed rear end collisions on the medial meniscus, M.Sc. Thesis, University of Connecticut, Storrs, Connecticut, USA.

Conference Abstracts

Erdemir, A. and Sibole, S. Chondrocyte deformations as a function of tibiofemoral joint loading, Multiscale Modeling Consortium Meeting, October 5-6, 2011, Bethesda, MD.

Sibole, S. and Erdemir, A. A pipeline for high throughput post-processing of joint and tissue simulations for estimation of cell level deformations, ASME Summer Bioengineering Conference, June 22-25, 2011, Farmington, PA.

Tichon, D. J. and Peterson, D. R. Effect of rear end low-speed collisions on the meniscus, IEEE 37th Annual Northeast Bioengineering Conference, April 1-3, 2011, Troy, NY.

Valkeapää, A., Kłodowski, A., Rantalainen T. and Mikkola A. Knee cartilage surface loading during stationary bicycling, Computer Methods in Mechanics, May 9-12, 2011, Warsaw, Poland.

LIMITATIONS & DIRECTIONS

Model Modifications

Prescription of *in situ* strain
Improvements in geometry & material properties
Simplification of ligament modeling
Addition of patellofemoral joint

Experimentation

Elaborate specimen-specific data
    accurate registration
    high-resolution imaging
    joint & tissue characterization

Model Validation

Sensitivity analysis
Population-based & specimen-specific
Passive flexion & joint envelope
Tissue response

Multiphysics Simulations

Biphasic analysis

LONG-TERM FUTURE

Open Knee(s): Virtual Biomechanical Representations of the Knee Joint
Open Platforms for Modeling & Simulation of Healthy, Aged and Osteoarthritic Knees
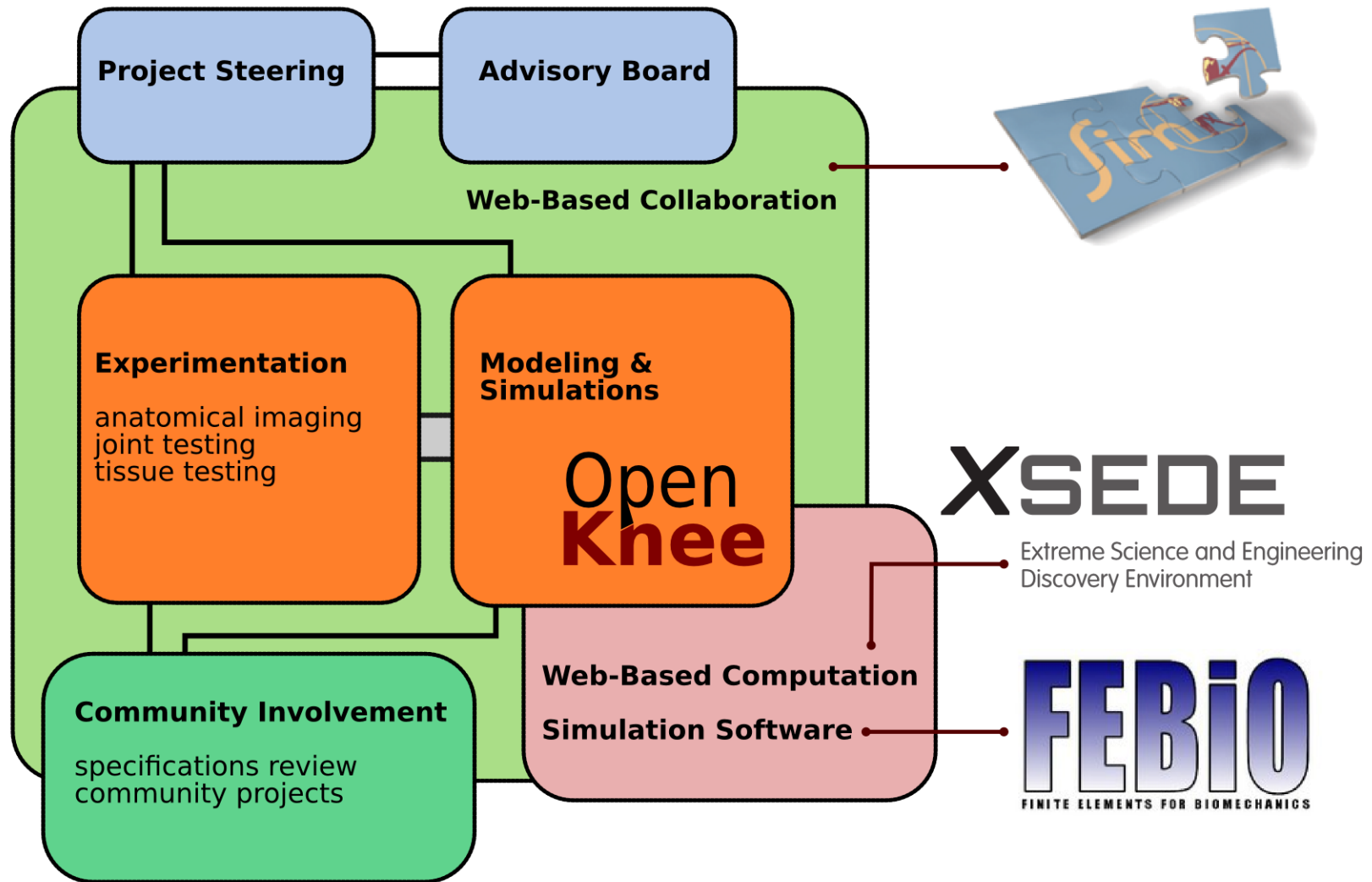
CREDITS

Open Knee

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LICENSING

TRADEMARKS & OWNERSHIPS