Open Knee(s)
Founding Data for Next Generation Knee Models

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DISCLOSURES

UNLABELED USE

INVESTIGATIONAL PRODUCTS

AFFILIATIONS WITH COMMERCIAL FIRMS

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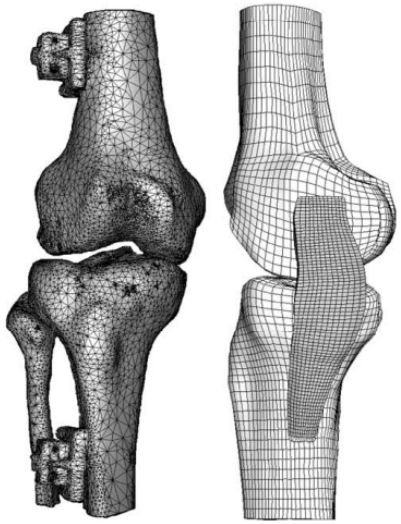
National Institute of Biomedical Imaging and Bioengineering (partially)
National Inst. of Arthritis and Musculoskeletal and Skin Diseases (partially)
National Institutes of Health

WHY KNEE MODELING?

Joint and tissue functions



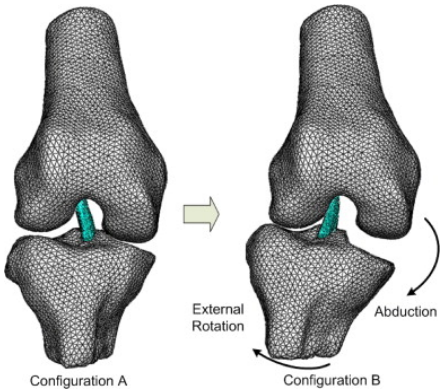
MCL function

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

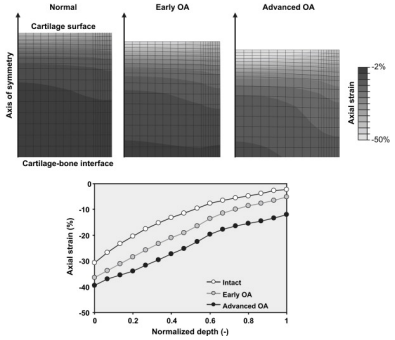
Injury mechanisms

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

ACL impingement



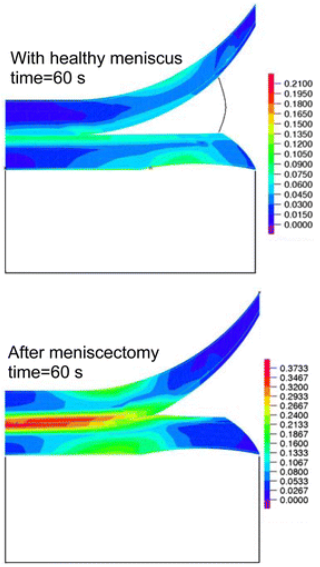
Pathological impacts



Osteoarthritis

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

Surgical interventions



Menisectomy

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

STATE OF KNEE MODELS

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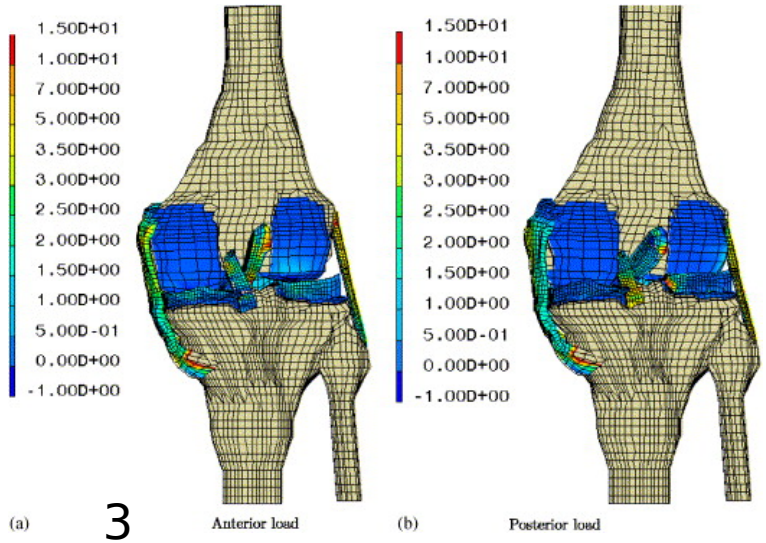
Search: PubMed | RSS | Save search | Limits | Advanced search | Help

finite element AND knee | Search | Clear

Display Settings: Summary, 20 per page, Sorted by Recently Added

Results: 1 to 20 of ~~412~~

699 (as of Mar 15, 2015)



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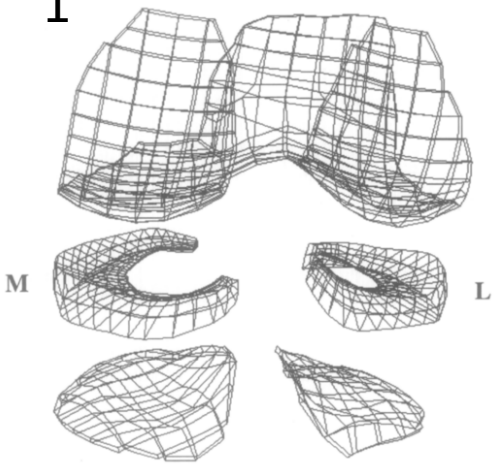

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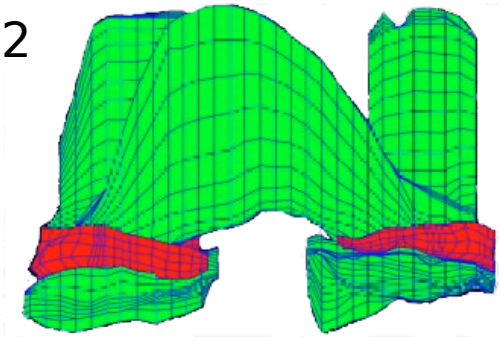

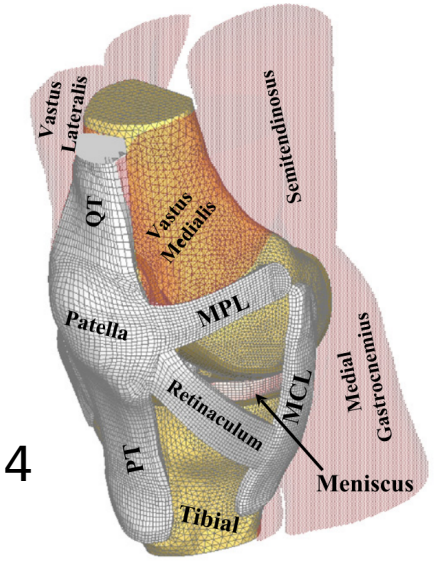

4

[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.*

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finite element AND knee | Search | Clear

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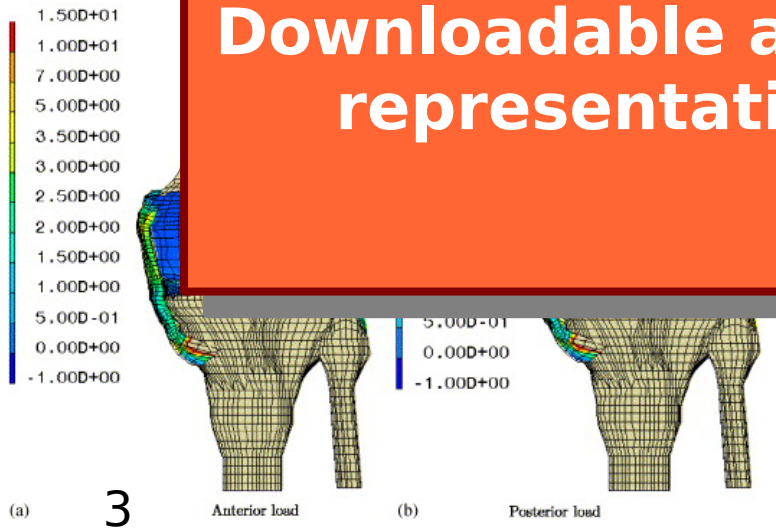
Downloadable and resuable finite element representations of knee models are scarce.

2



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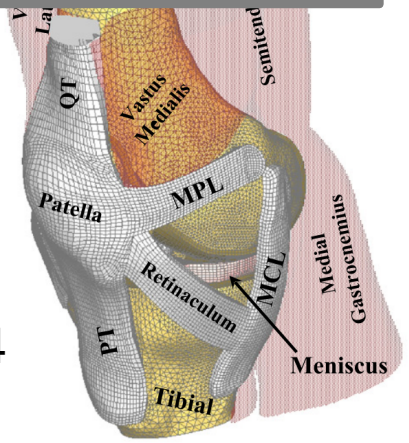

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[1] *Bendjaballah et al., Clin Biomech, 12: 139-48, 1997.*
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[3] *Peña et al., J Biomech, 39: 1686-701, 2006.*
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finite element AND knee | Search | Clear

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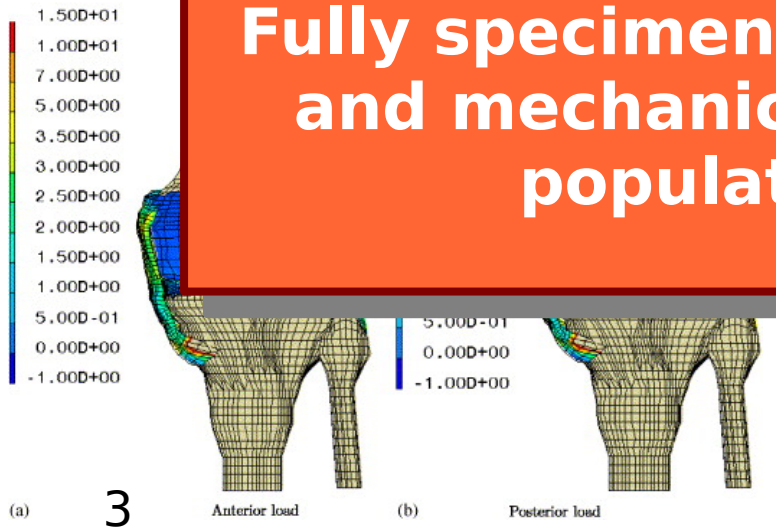
699 (as of Mar 15, 2015)

Fully specimen-specific models (anatomy and mechanical properties) of diverse populations do not exist.

2



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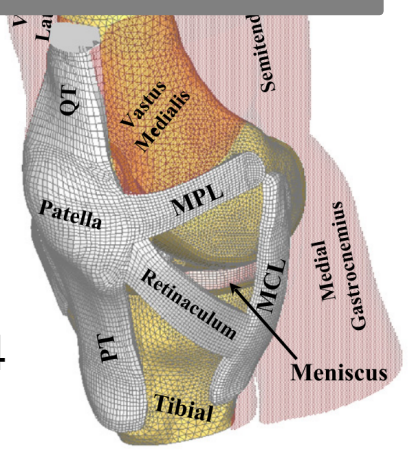

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[1] *Bendjaballah et al., Clin Biomech, 12: 139-48, 1997.*
[2] *Donahue et al., J Biomech Eng, 124: 273-80, 2002.*
[3] *Peña et al., J Biomech, 39: 1686-701, 2006.*
[4] *Dhaher et al., J Biomech, , 43: 3118-25, 2010.*

OPEN KNEE(S) GOALS

- To provide an open, freely available, and collaborative development, testing, simulation and dissemination platform for in silico exploration of the biomechanics of healthy and diseased knees.

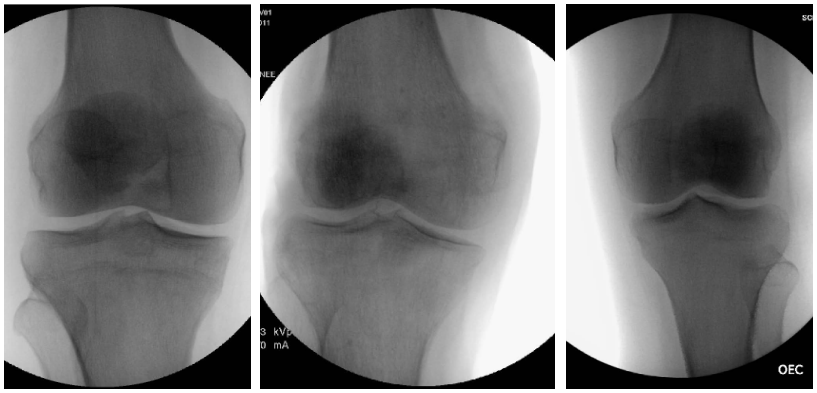
→ Platform for community driven modeling & simulation

- To develop in silico biomechanical models of healthy and diseased knee joints of different genders and ages, supported by specimen-specific joint and tissue level experimental mechanics.

→ General purpose models of healthy and diseased knees

OPEN KNEE(S) GOALS

- Full knee models
  - *tibiofemoral joint*
  - *patellofemoral joint*
- Complete specimen-specificity
  - *geometry*
  - *material*
- Comprehensive data
  - *magnetic resonance imaging*
  - *joint kinematics/kinetics*
  - *tissue stress/strain*
- Multiple knees
  - *young/elderly*
  - *male/female*
  - *healthy/osteoarthritic*



STUDY GOALS

- to establish a *workflow* to collect **heterogeneous data** on cadaver knee specimens for **development & evaluation** of specimen-specific **knee joint models**

- to summarize progress on the collection of *specimen-specific* **anatomical imaging** and **mechanics** data from varying populations, aka Open Knee(s)

SPECIMENS





oks001

Right knee

Gender: Male
Age: 71 years
Race: White
Height: 1.83 m
Weight: 77.1 kg
BMI: 23.1

oks002

Right knee

Gender: Female
Age: 67 years
Race: White
Height: 1.55 m
Weight: 45.3 kg
BMI: 18.9

oks003

Left knee

Gender: Female
Age: 25 years
Race: White
Height: 1.73 m
Weight: 68 kg
BMI: 22.8

oks004

Right knee

Gender: Female
Age: 46 years
Race: White
Height: 1.58 m
Weight: 54.4 kg
BMI: 21.9

oks006

Right knee

Gender: Female
Age: 71 years
Race: White
Height: 1.52 m
Weight: 49.4 kg
BMI: 21.3

oks007

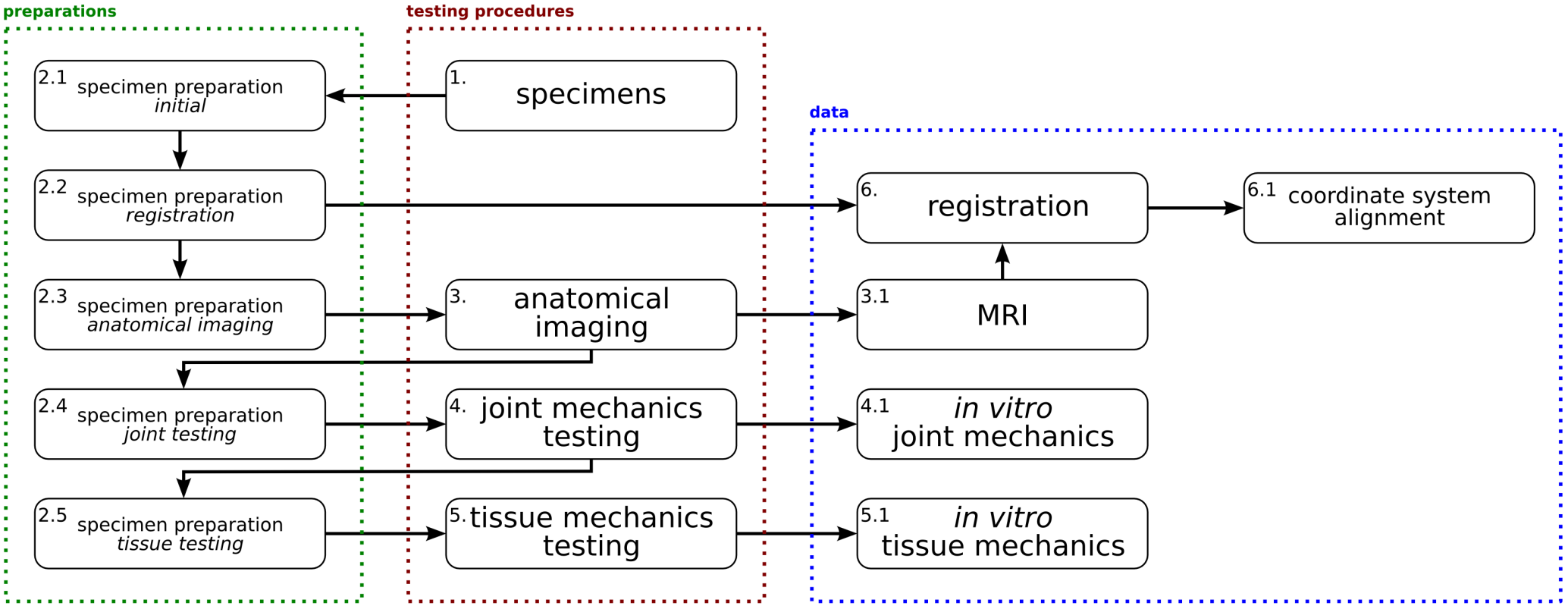
Right knee

Gender: Male
Age: 71 years
Race: White
Height: 1.7 m
Weight: 65.8 kg
BMI: 22.7

4 more on the way...

EXPERIMENTATION

Workflow



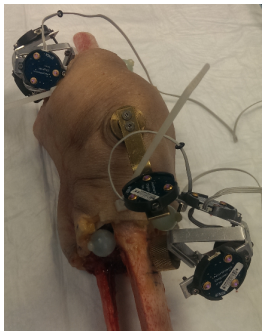
For mature and developing standard operating procedures, refer to ***http://wiki.simtk.org/openknee/Specifications*****.**

PREPARATION

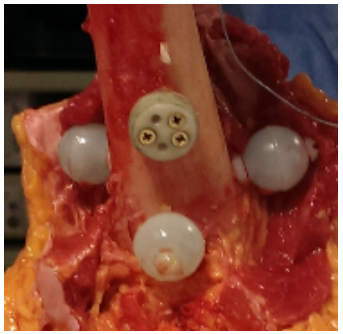
Preparation

dissection

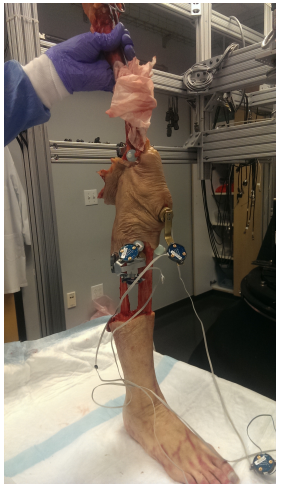
bone plugs



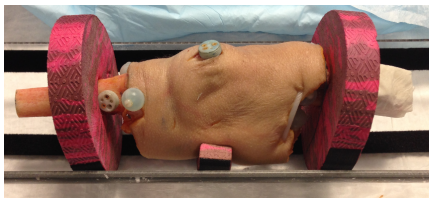
motion capture markers



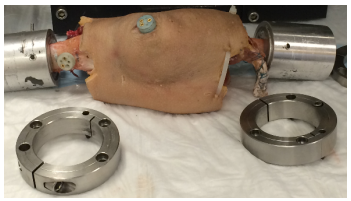
registration markers



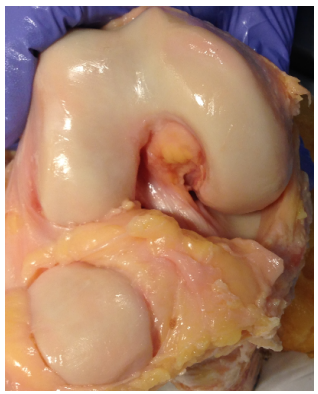
anatomical landmarks



preparation for imaging



preparation for joint testing



preparation for tissue testing

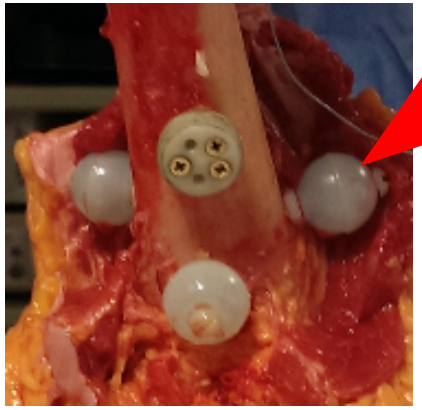
to anatomical imaging

to joint testing

to tissue testing

REGISTRATION

Registration



coordinate system transformations
femur – tibia – patella

association of reference states
pose & orientation

joint experimentation

anatomical imaging

ANATOMICAL IMAGING

General Purpose

3D T1-weighted
w/o fat suppression
0.5 x 0.5 x 0.5 mm
TE = 6.01 ms
TR = 20 ms

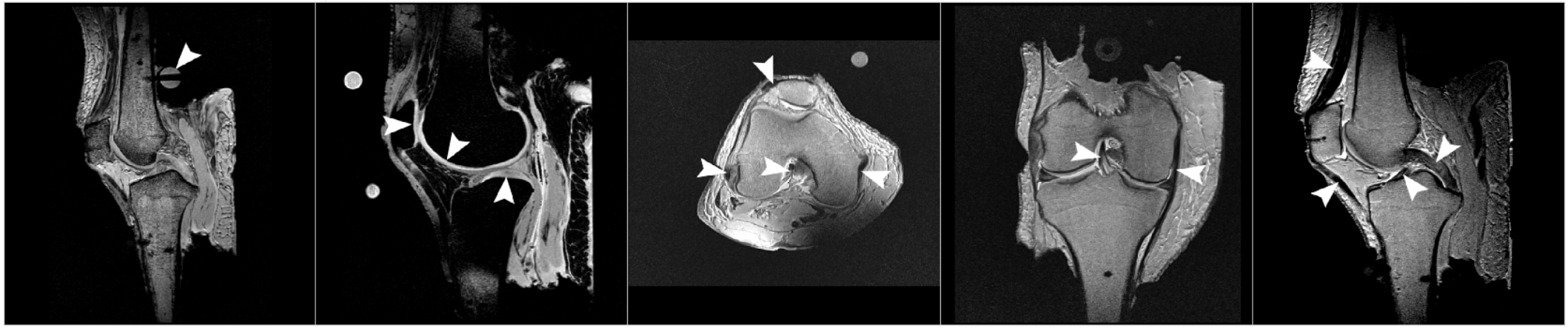
Cartilage

3D T1-weighted
w/ fat suppression
0.35 x 0.35 x 0.7 mm
TE = 5.34 ms
TR = 29 ms

Ligaments

Proton density
Turbo spin echo
0.35 x 0.35 x 2.8 mm
TE = 9.7 ms
TR = 10,000 ms

Anatomical Imaging



JOINT MECHANICS

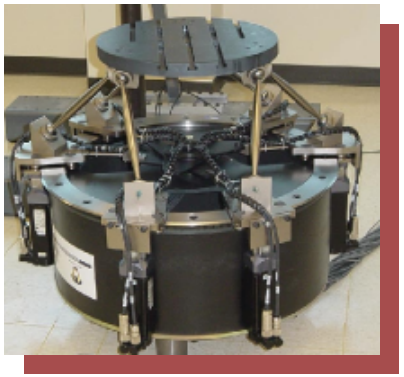
Tibiofemoral Joint Mechanics

Laxity Testing

Internal/external rotation
- 0 to ±5 Nm
- w/ 1 Nm increment

Varus/valgus
- 0 to ±10 Nm
- w/ 2.5 Nm increment

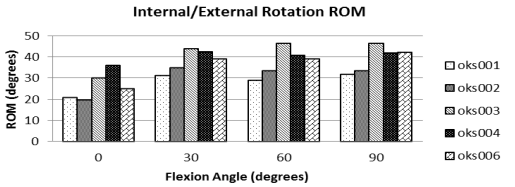
Anterior/posterior translation
- 0 to ±100 N
- w/ 10 N increment

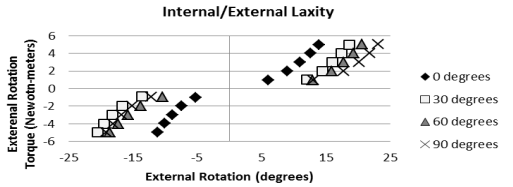


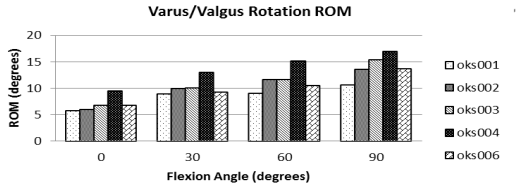
Combined Loading

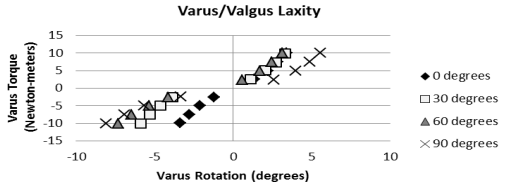
Permutations of
- Internal/External rotation – -5, 0, 5 Nm
- Varus/valgus – -10, 0, 10 Nm
- Anterior/posterior translation – -100, 0, 100 N

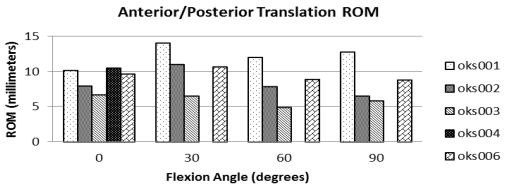
@ 0°,30°,60°,90° flexion
w/ 20 N compression force
measurement of kinematics-kinetics

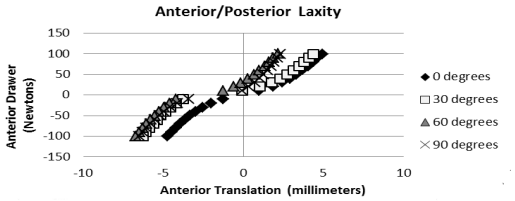


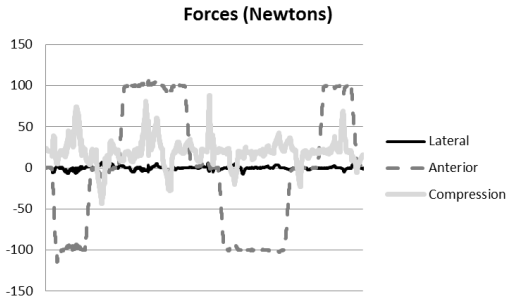


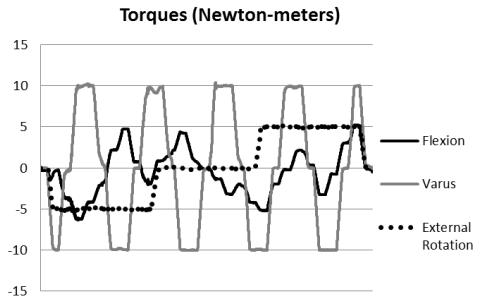


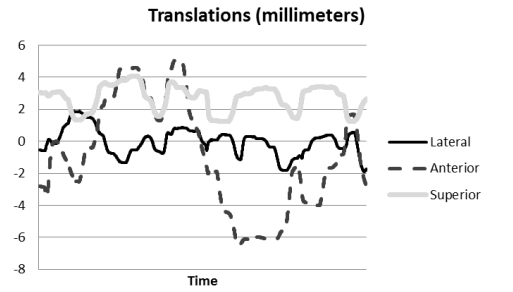


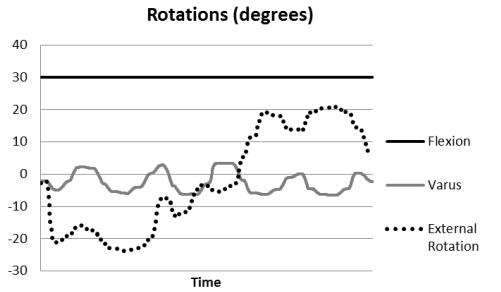








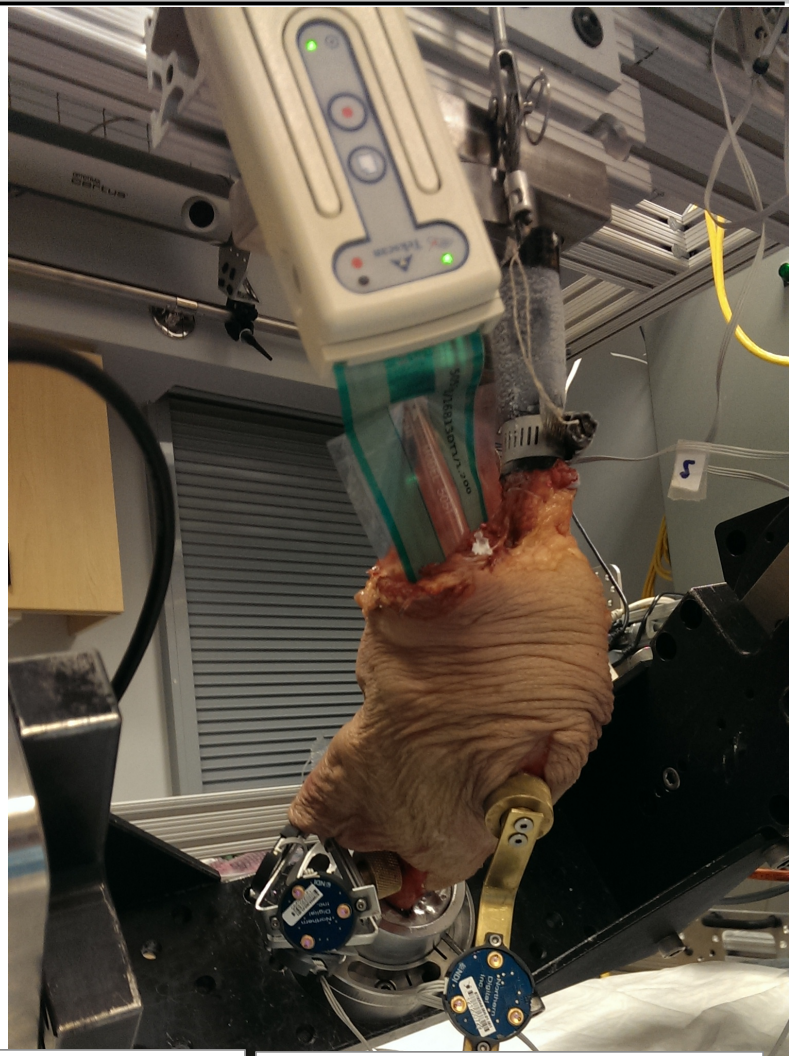


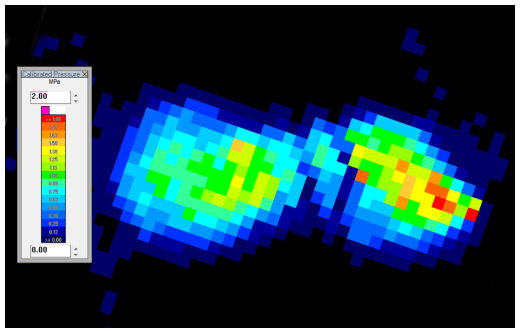


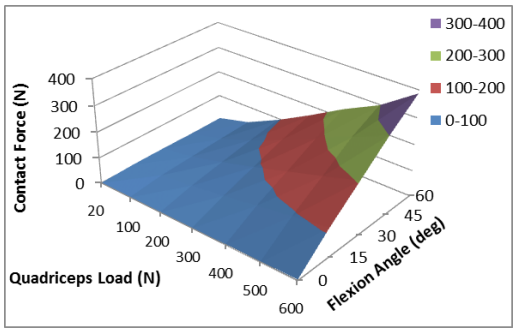
JOINT MECHANICS

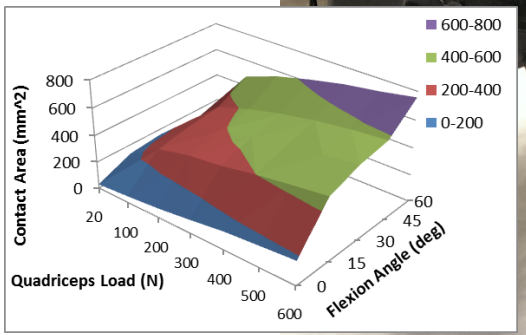
Patellofemoral Joint Mechanics

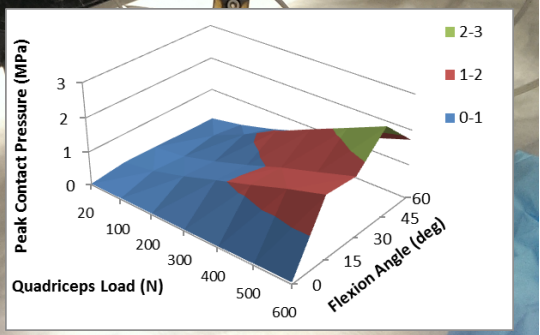
@ 0°,15°,30°,45°,90° flexion
20 N, 100 – 600 N quadriceps force
w/ 100 N increments
measurement of kinematics-kinetics
measurement of contact pressures











TISSUE MECHANICS

Tissue Mechanics

Cartilage

unconfined compression
confined compression
tension

medial – lateral femoral condyle
medial – lateral tibial plateau
femoral groove - patella

Meniscus

unconfined compression
confined compression
tension

medial – lateral

Ligament

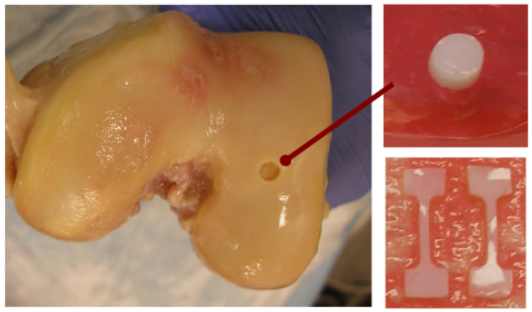
tension

anterior – posterior cruciate
medial – lateral collateral
patellar
transverse

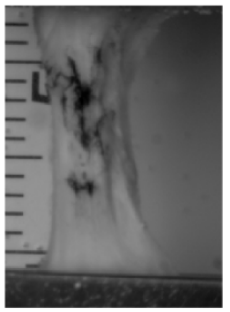
Tendon

quadriceps

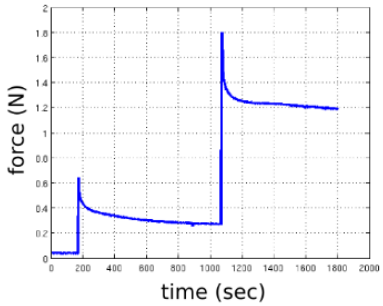
Tissue Sampling



Uniaxial Testing



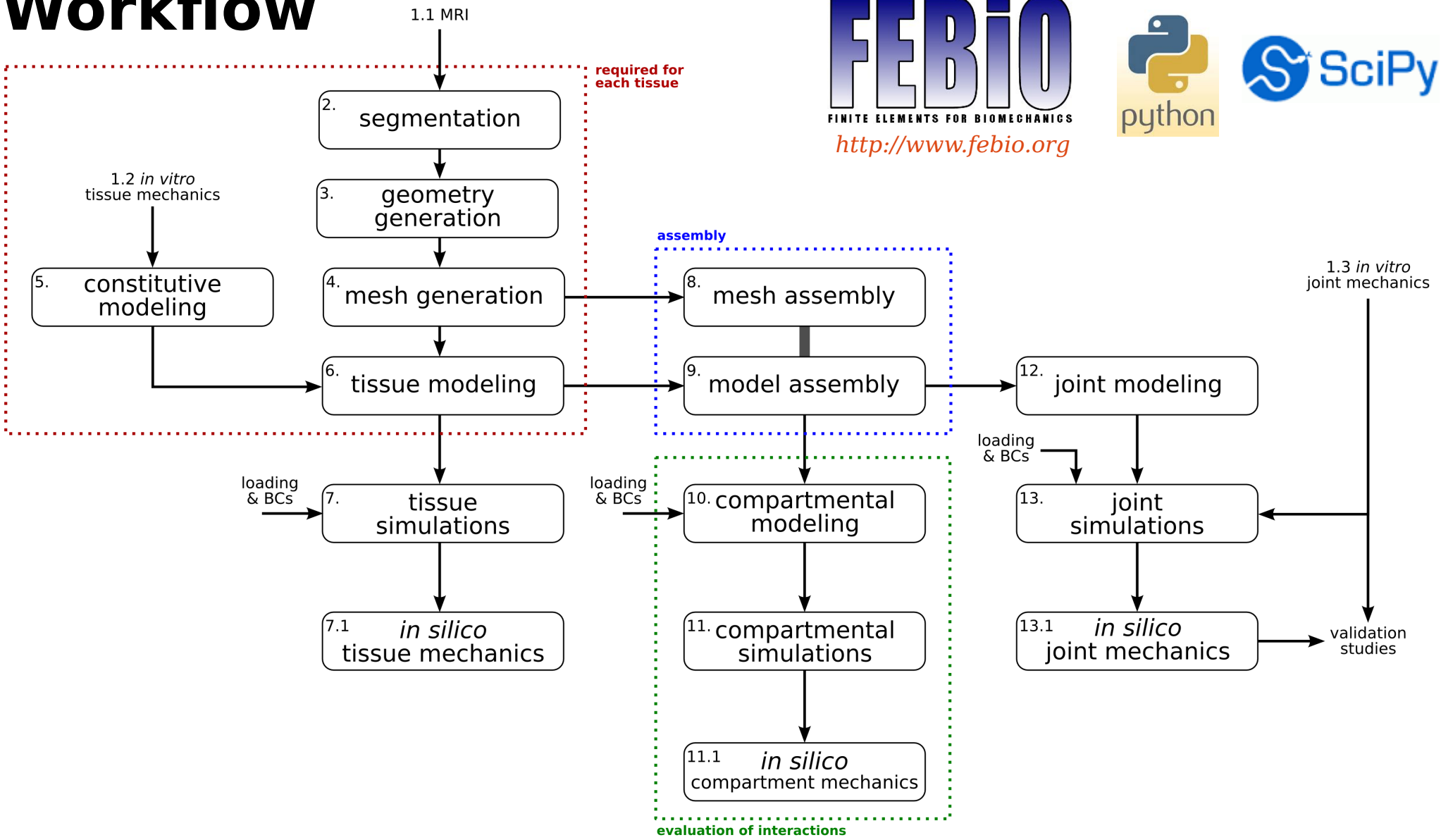
Stress Relaxation



multi-step stress relaxation tests
measurement of displacement – force
measurement of sample size
image capture (tension samples)

UTILITY FOR MODELING

Workflow



FEBiO FINITE ELEMENTS FOR BIOMECHANICS
http://www.febio.org

python

SciPy

For mature and developing standard operating procedures, refer to ***http://wiki.simtk.org/openknee/Specifications*****.**

CONCLUDING REMARKS

- A comprehensive **data collection scheme** specifically targeted for the development of **high fidelity models** of the knee

- In-depth **heterogeneous data** as the foundation for authentic virtual knees

different knees

→ *variability within population*

anatomical imaging

→ *specimen-specific geometry*

tissue mechanics

→ *specimen-specific tissue material properties*

joint kinematics-kinetics

→ *specimen-specific evaluation of joint mechanics*

CONCLUDING REMARKS

- A comprehensive **data collection scheme** specifically targeted for the development of **high fidelity models** of the knee

open & freely available virtual knee population for design, evaluation & regulation of interventions

anatomical imaging

→ *specimen-specific geometry*

tissue mechanics

→ *specimen-specific tissue material properties*

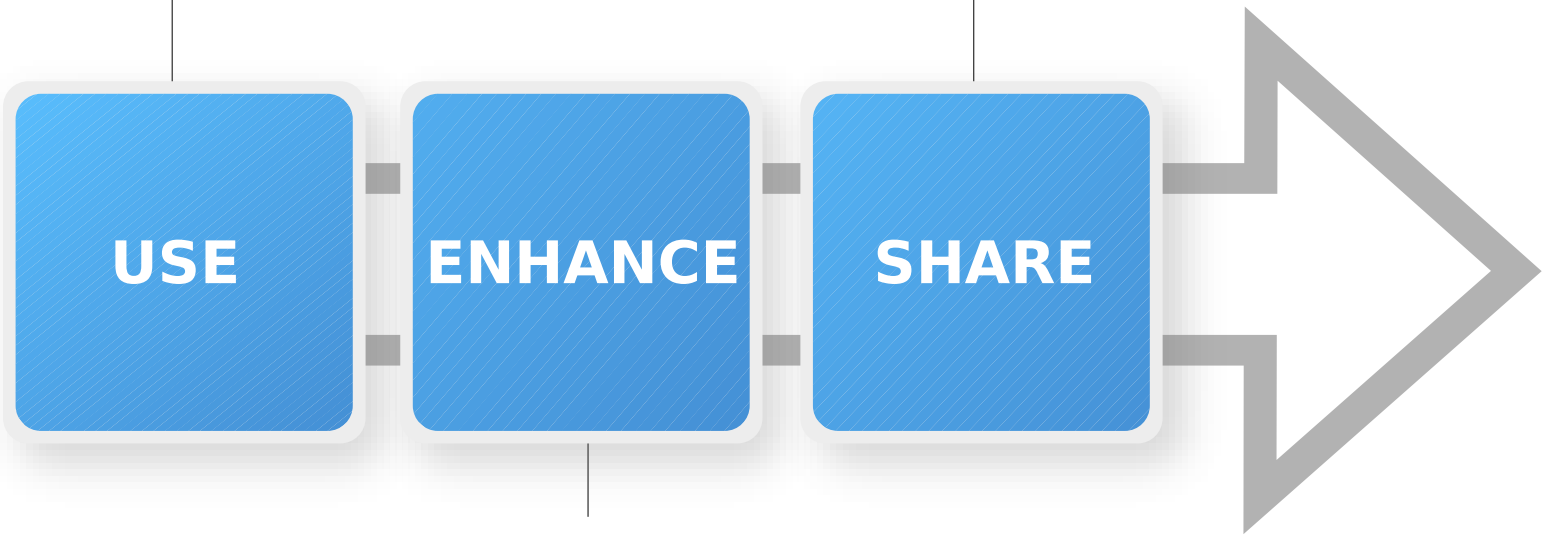
joint kinematics-kinetics

→ *specimen-specific evaluation of joint mechanics*

HOW CAN YOU CONTRIBUTE?

models – meshes – geometries
images – mechanics data
usability issues – bugs - errors

your own data – models
customizations – derivative models



provide feedback on specifications
customize models for your needs

follow Open Knee(s) roadmap
analyze data – develop models
run simulations – document

VISIT **http://wiki.simtk.org/openknee**

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OPEN KNEE – GENERATION 1

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NIH/NIBIB R01EB009643
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Simbios

OPEN KNEE(S) – GENERATION 2

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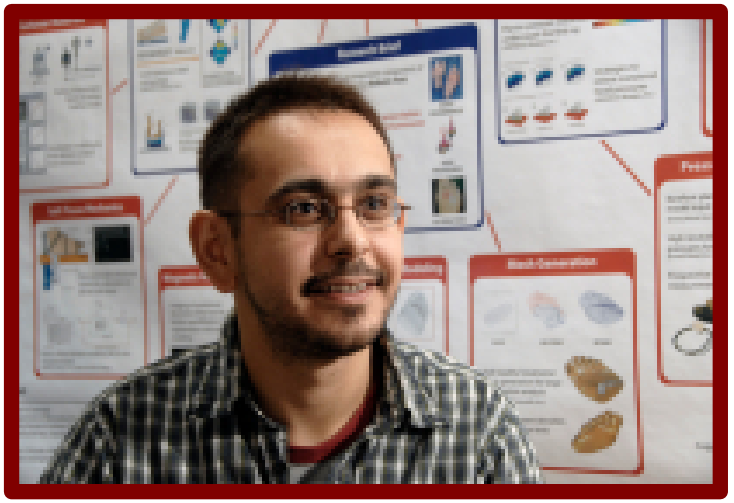

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LICENSING

TRADEMARKS & OWNERSHIPS