Open Knee: A Three-Dimensional Finite Element Representation of the Knee Joint

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PURPOSES OF KNEE MODELING

Joint and tissue functions

Pathological impacts

Injury mechanisms

Surgical interventions


MCL function

ACL impingement

Menisectomy
EXAMPLES OF KNEE MODELING

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.)

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

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

**Bones**
rigid body

**Cartilage**
nearly incompressible Neo-Hookean

**Menisci**
Fung orthotropic hyperelastic horn attachments as springs

**Ligaments**
transversely isotropic hyperelastic

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**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**
  - 100° passive (no load)
  - 100 N fixed flexion

**Line Graphs**
- **Knee Flexion**
  - Time (s) vs. Degree
  - Time (s) vs. Degree
- **Anterior Drawer Force**
  - Time (s) vs. Force
  - Time (s) vs. Force
DISSEMINATION

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

**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 Statistics (January 30, 2012)

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Project site</strong></td>
<td><a href="https://simtk.org/home/openknee">https://simtk.org/home/openknee</a></td>
</tr>
<tr>
<td><strong>Project launch date</strong></td>
<td>February 18, 2010</td>
</tr>
<tr>
<td><strong>Page hits</strong></td>
<td>19525 (past 180 days)</td>
</tr>
<tr>
<td><strong>Unique visitors</strong></td>
<td>902 (past 180 days)</td>
</tr>
</tbody>
</table>
| **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**    | 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 |

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Note: The table provides historical data as of January 30, 2012.

- A **tibiofemoral joint model** was developed with potential for problem specific **customization**.
- Simulation capacity was illustrated through simulations of passive flexion under compressive loading.
- Customization potential was illustrated by simulations of menisectomy.

- A transparent development platform was established.
- Dissemination pathway was constructed.
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.
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.
**Peer-Reviewed Articles**


**Thesis**


**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.


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

Project Steering
Advisory Board
Web-Based Collaboration

Experimentation
anatomical imaging
joint testing
tissue testing

Modeling & Simulations

Community Involvement
specifications review
community projects

Open Knee

Web-Based Computation
Simulation Software

XSEDE
Extreme Science and Engineering
Discovery Environment

FEBio
Finite Elements for Biomechanics
Open Knee

Modeling
Scott Sibole
Ahmet Erdemir
Craig Bennetts
Randy Heydon

Data
Bhushan Borotikar
Antonie J. van den Bogert

Simulation Software
Ben Ellis
Steve Maas
David Rawlins
Jeff Weiss

NIH/NIBIB R01EB009643 (model development)
NIH/NIGMS R01GM083925 (FEBio)
NIH/NIAMS R01AR049735 (data collection)

Simbios (project hosting)
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