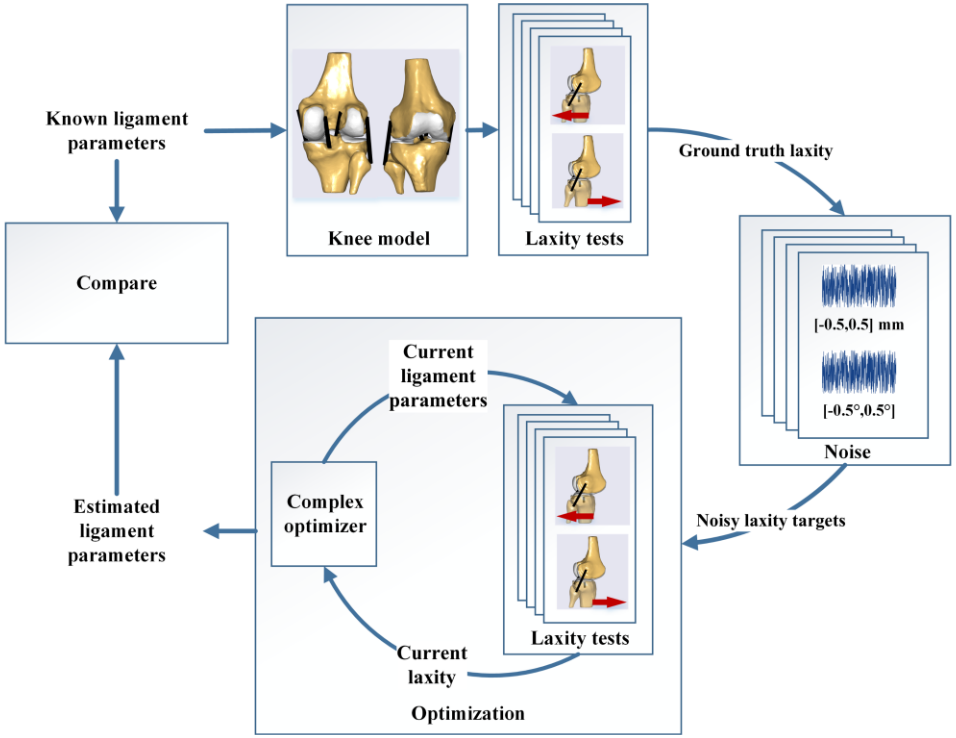
The webcast will begin shortly…

A methodology to evaluate the effects of kinematic measurement uncertainties on knee ligament properties estimated from laxity measurements

April 7th , 2021



ANYBODY TECHNOLOGY

Outline

- General introduction to the AnyBody Modeling System
- Presentation by Michael Skipper Andersen
  - *A methodology to evaluate the effects of kinematic measurement uncertainties on knee ligament properties estimated from laxity measurements*
- Question and answer session

Presenter:

Associate Professor Michael Skipper Andersen, PhD

Department of Materials and Production

Aalborg University, Denmark

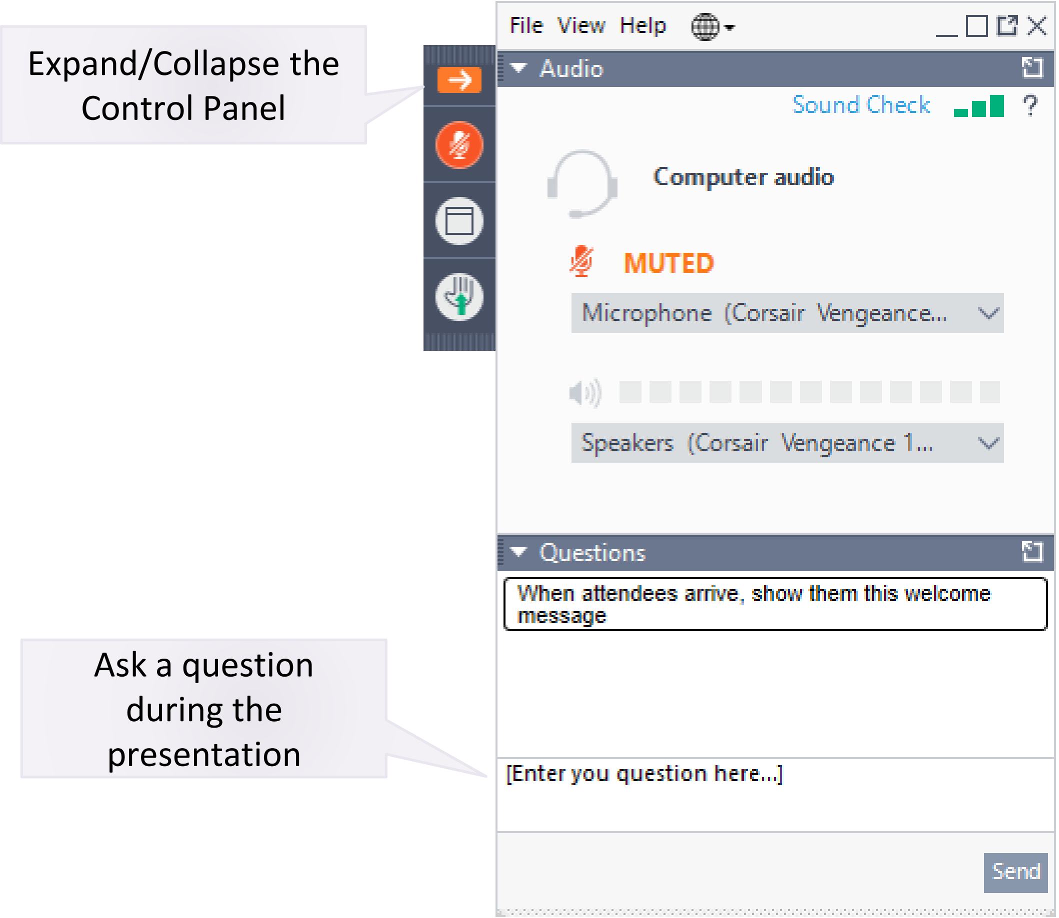
Host(s):
Bjørn Keller Engelund and Kristoffer Iversen
R&D Engineer
AnyBody Technology

Control Panel

The Control Panel appears on the right side of your screen.

Submit questions and comments via the Questions panel.

> *Questions will be addressed at the end of the presentation. If your question is not addressed, we will do so by email.*



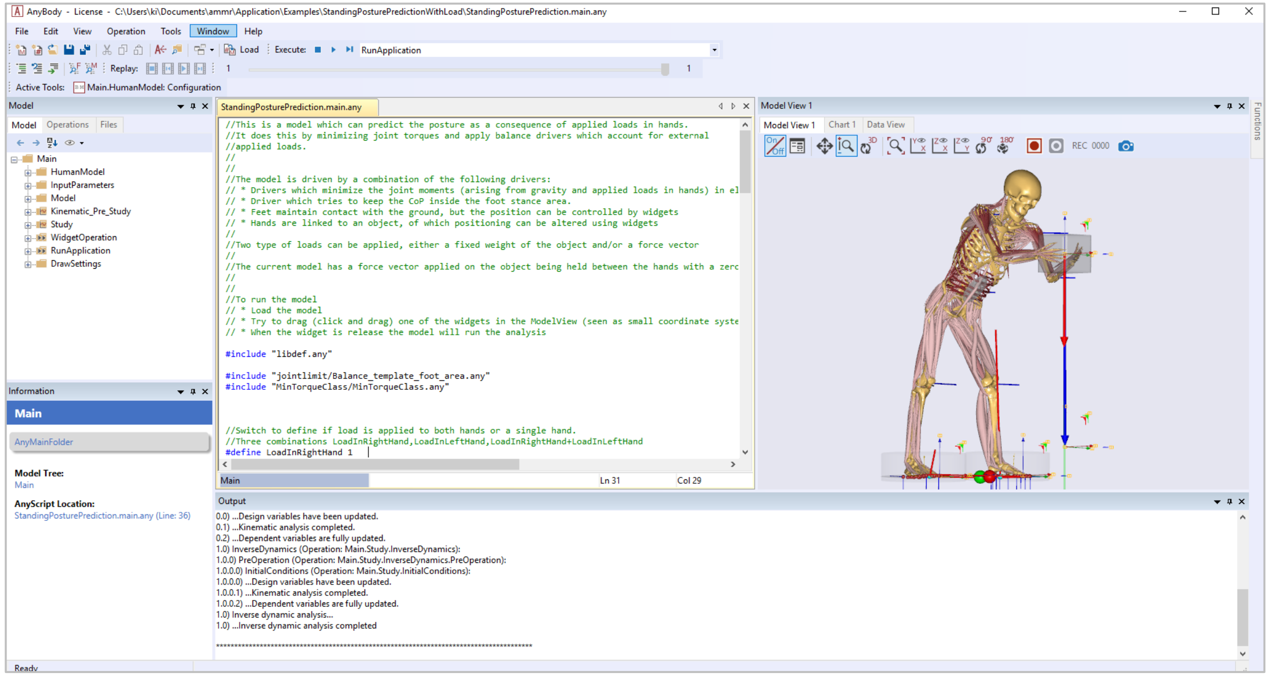
Musculoskeletal Simulation

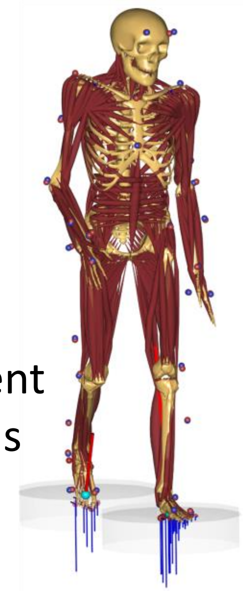
Motion Data
Kinematics and Forces

ANYBODY
Modeling System

Body Loads

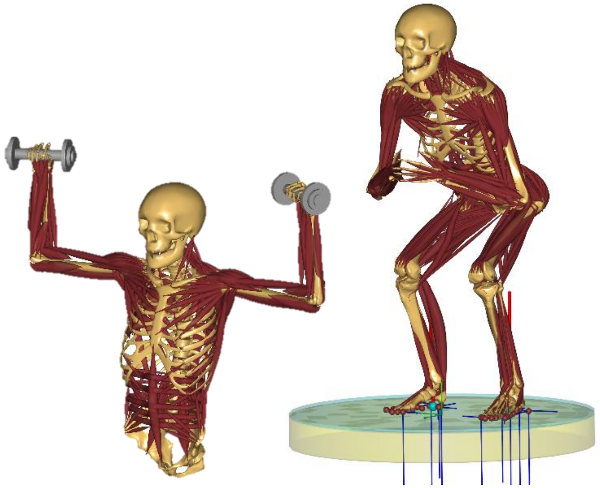
- Joint moments
- Muscle forces
- Joint reaction forces





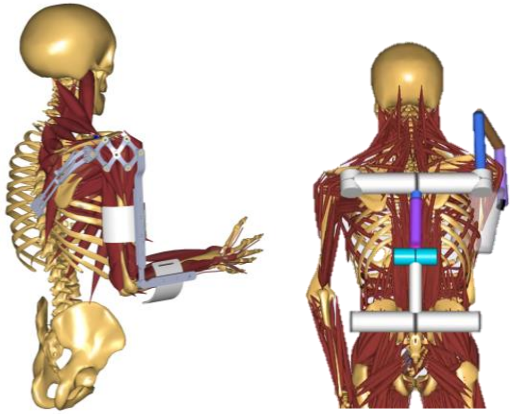
Movement Analysis

Product optimization design

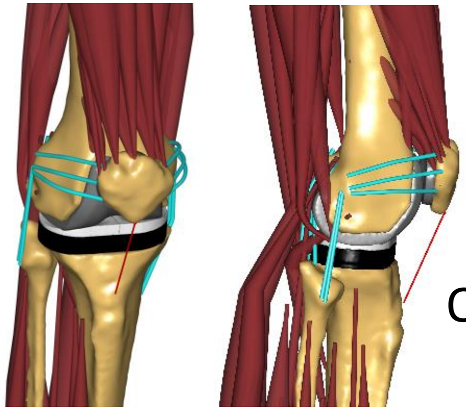


Sports

ANYBODY
Modeling System

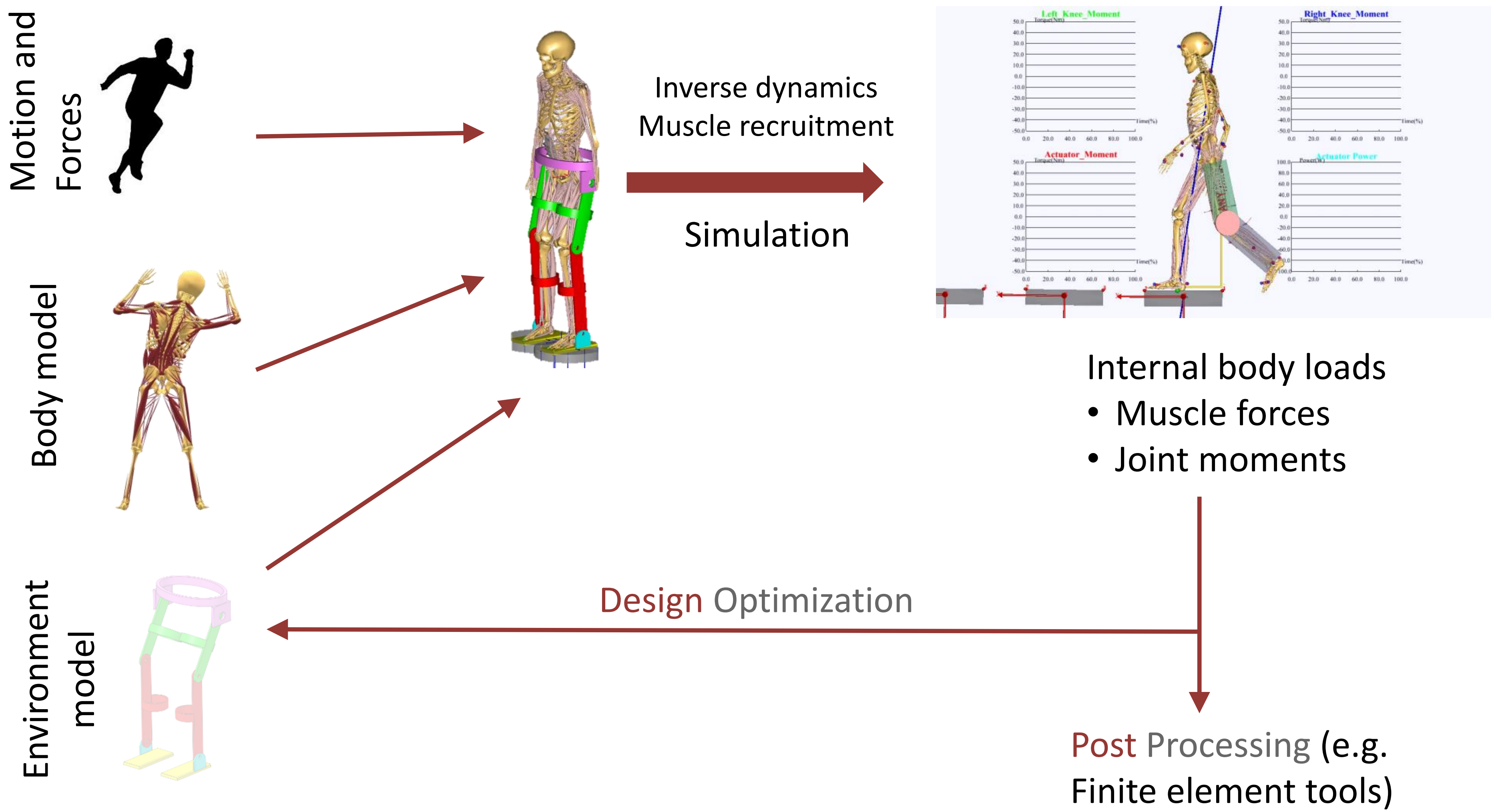


Assistive Devices



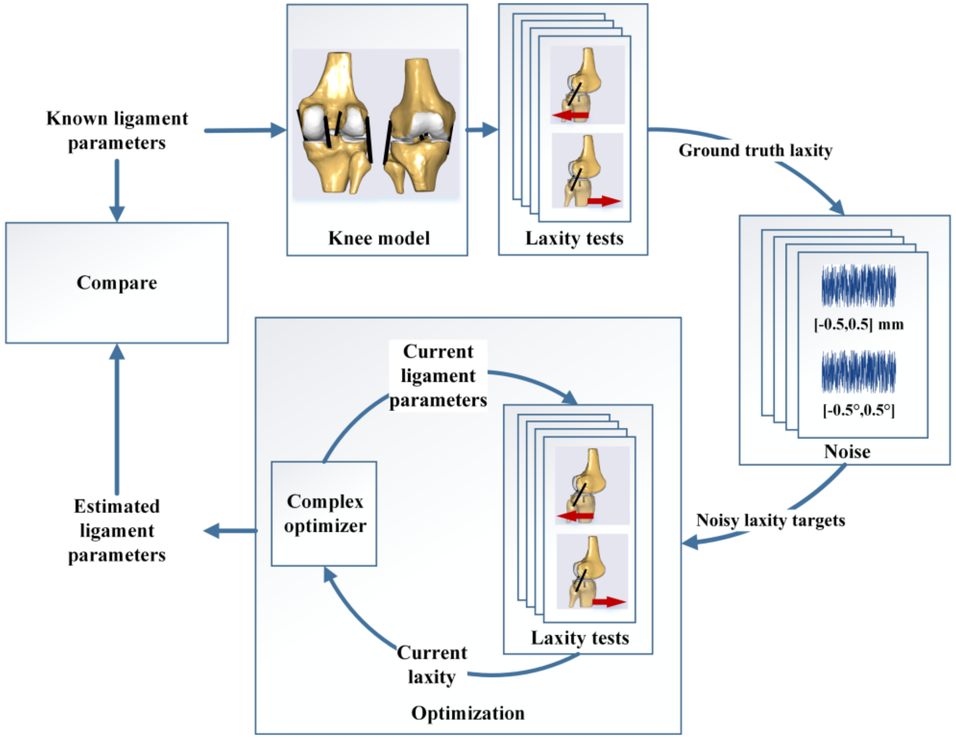
Orthopedics and rehab

AnyBody Modelling System



A methodology to evaluate the effects of kinematic measurement uncertainties on knee ligament properties estimated from laxity measurements

Presented by Associate Professor Michael Skipper Andersen, PhD



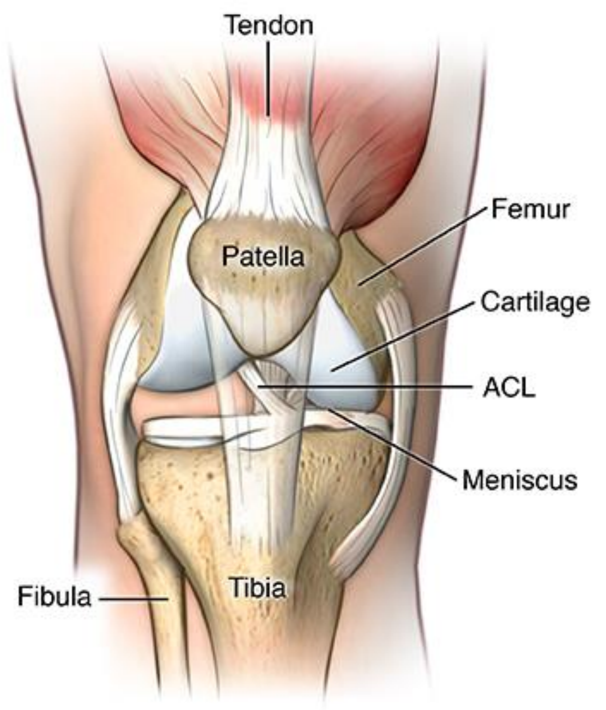
A methodology to evaluate the effects of kinematic measurement uncertainties on knee ligament properties estimated from laxity measurements

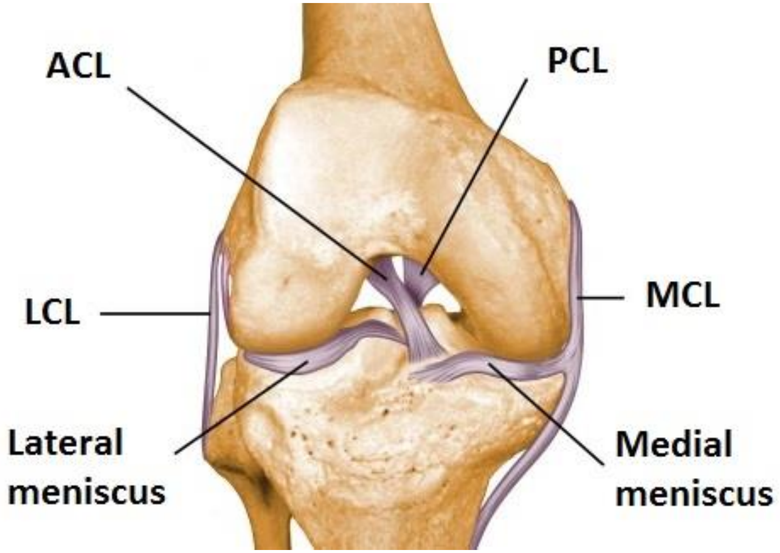
Associate Professor Michael Skipper Andersen

AALBORG UNIVERSITY
DENMARK

Introduction

- Ligaments plays an important role in maintaining knee joint stability and functionality
- Ligament parameters display high intersubjective variability
- Currently, there is no way to asses ligaments parameters directly non-invasively





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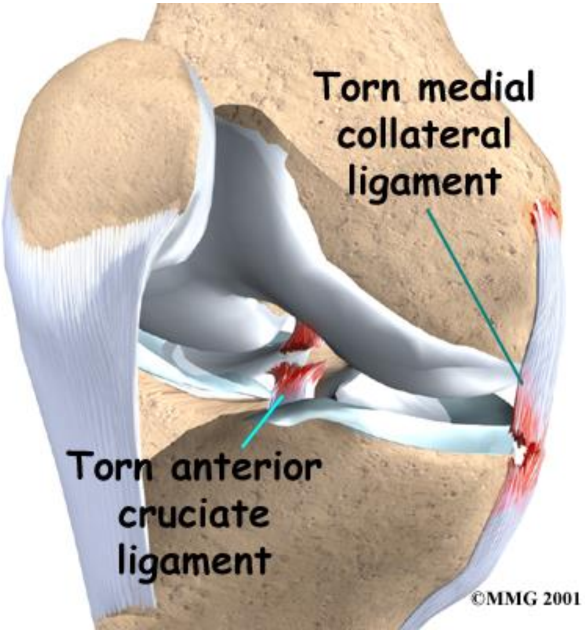
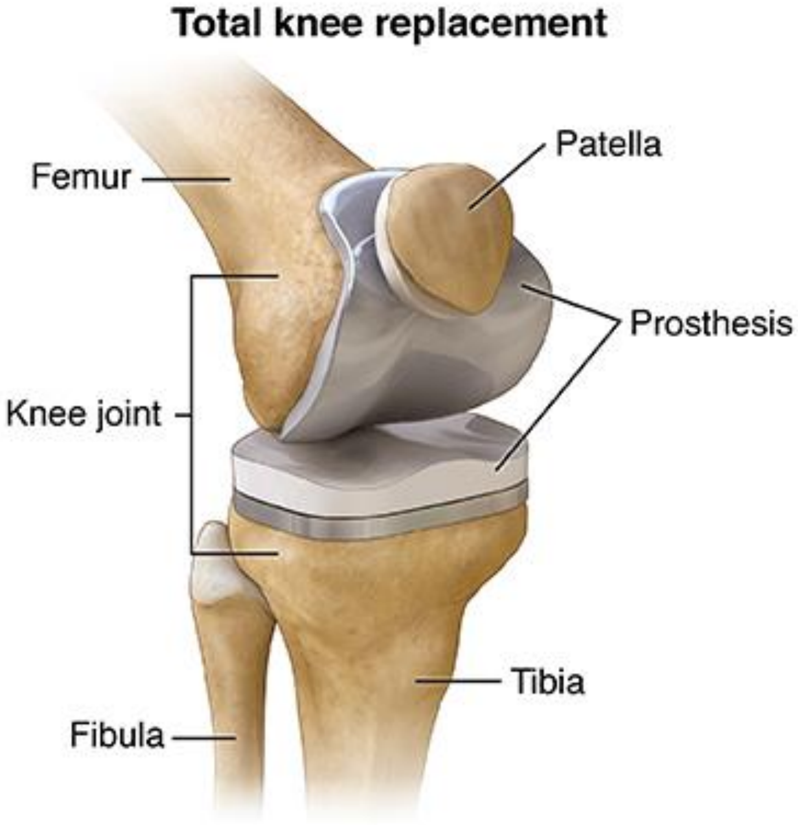
Joint instability

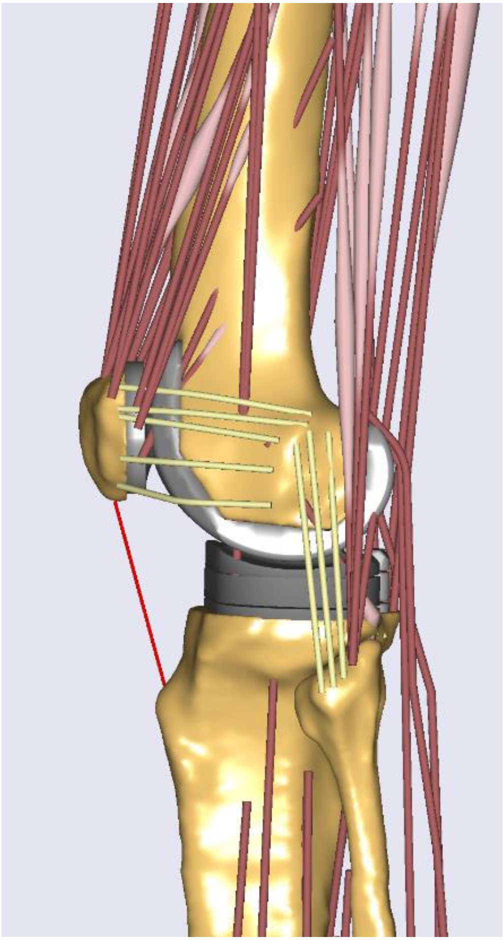




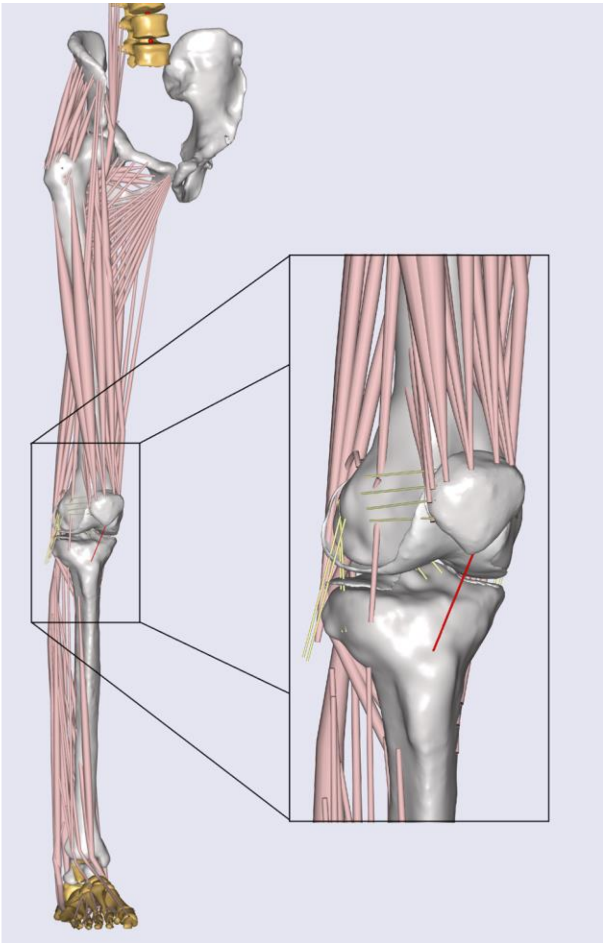
Computational knee models

Non-invasive estimates of:

- Knee kinematics
- Muscle loads
- Joint loads
- Ligament loads

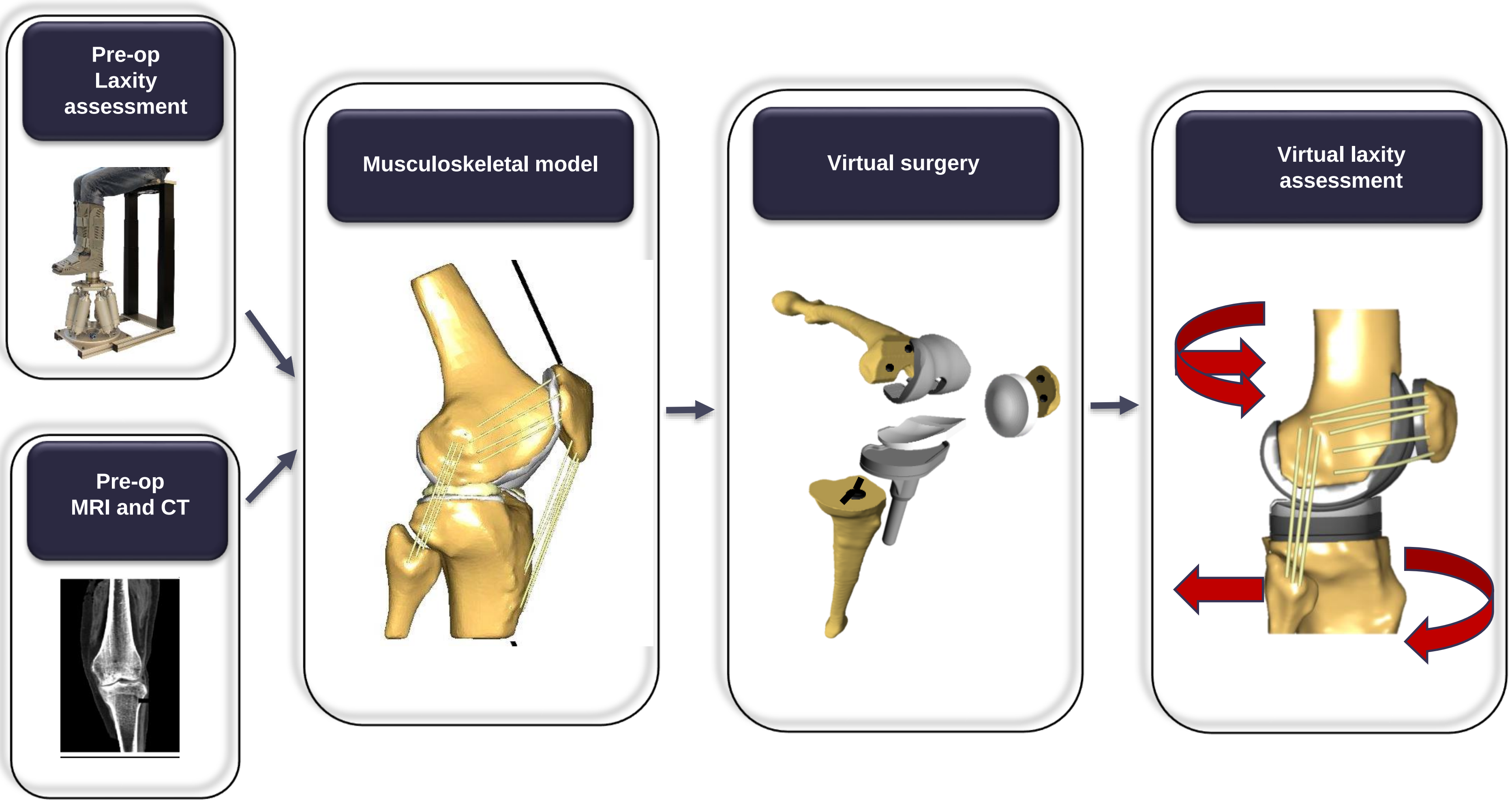


Marra et al. 2015. *J Biomech Eng*, 137(2): 020904

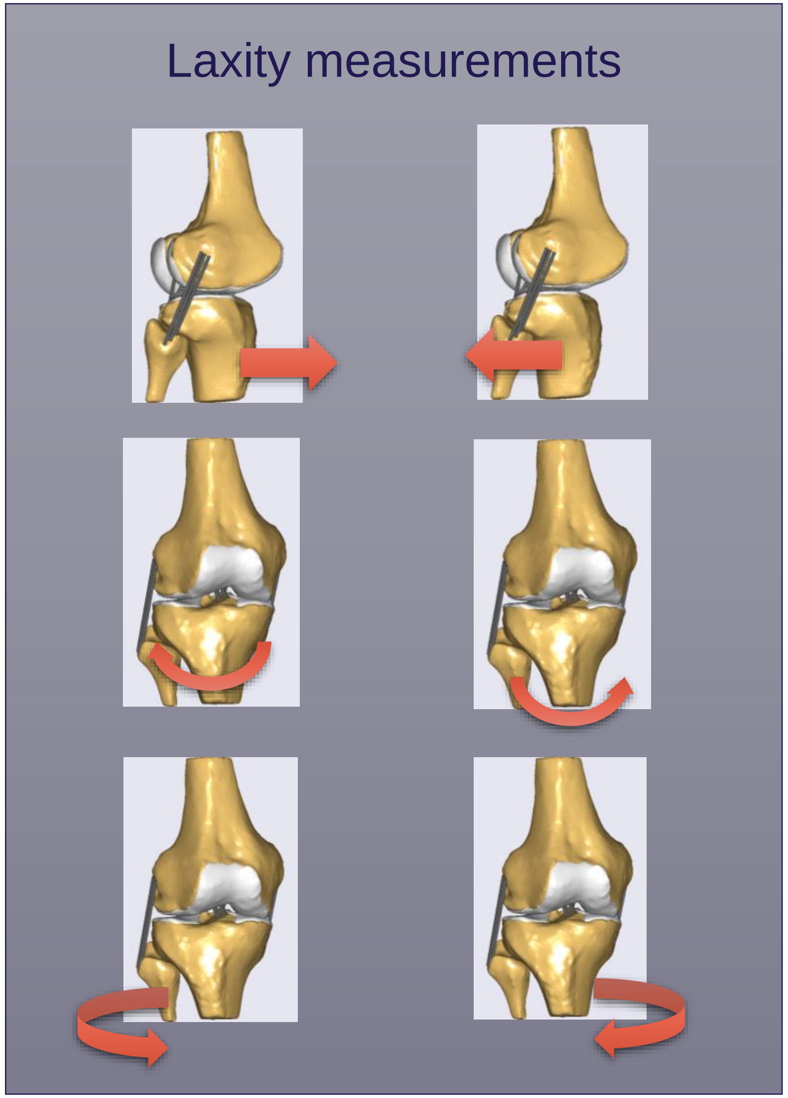


Dejtiar et al. 2020. *J Biomech Eng*, 142(6): 061001

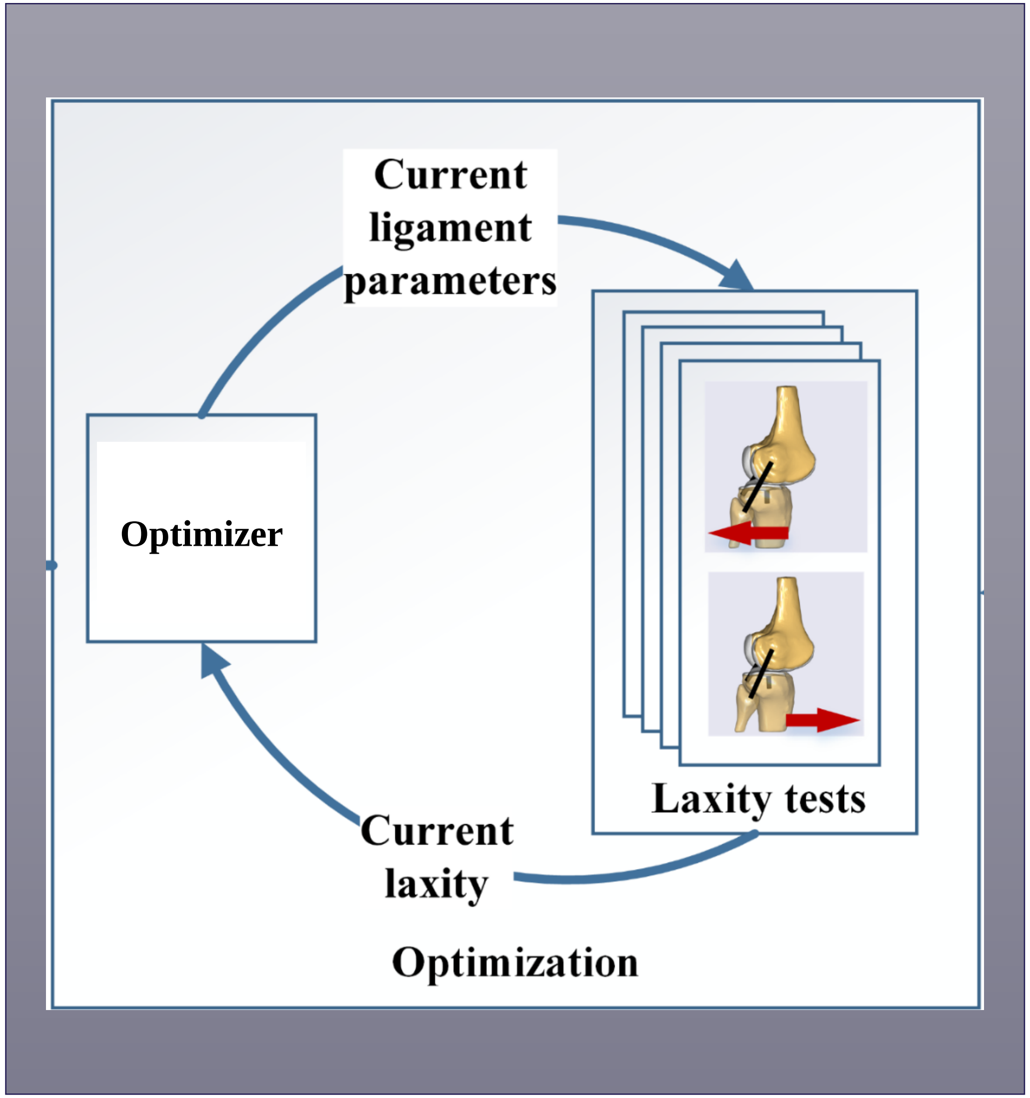
Pre-operative planning



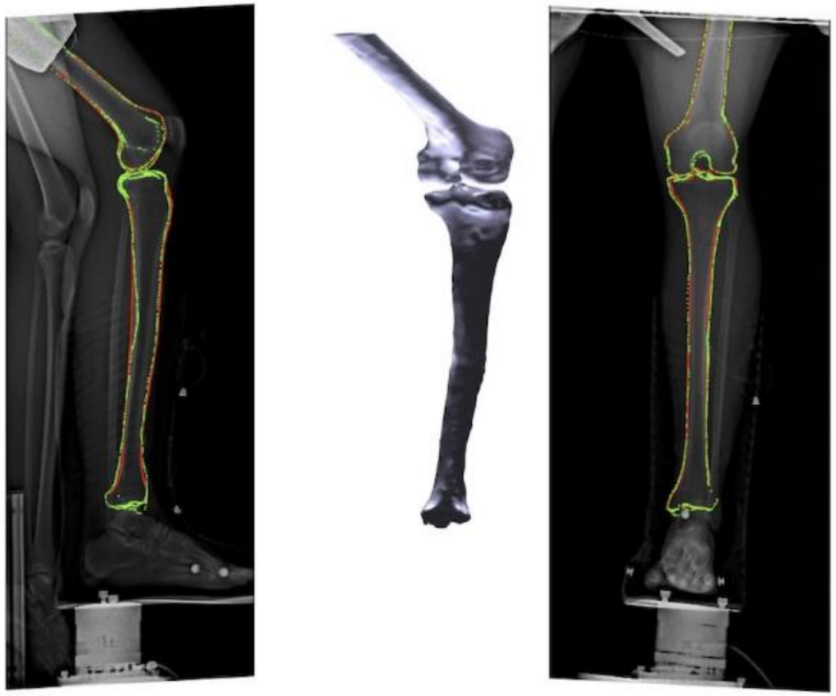
Identification of ligament properties from laxity tests

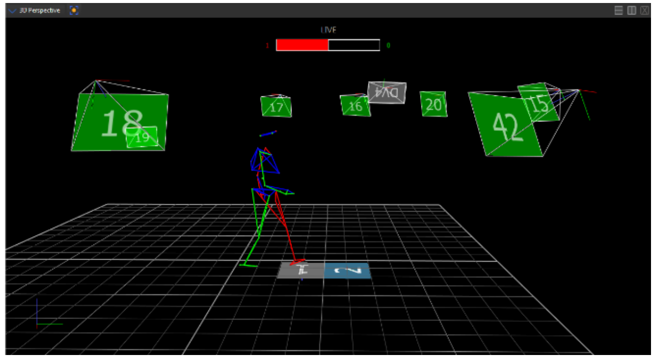


Knee kinematics
Loads



Kinematic noise





Pedersen et al. 2019 (EOS x-rays): Errors of ~2 mm and ~1 deg

Stentz-Olesen et al. 2017 (RSA): Errors of ~1 mm and ~1 deg

Merriaux et al. 2017. (Vicon): Errors of 0.35 mm for a single marker during slow dynamic movements

Research question

How sensitive are estimated ligament properties to kinematic measurement noise?

A Methodology to Evaluate the Effects of Kinematic Measurement Uncertainties on Knee Ligament Properties Estimated From Laxity Measurements

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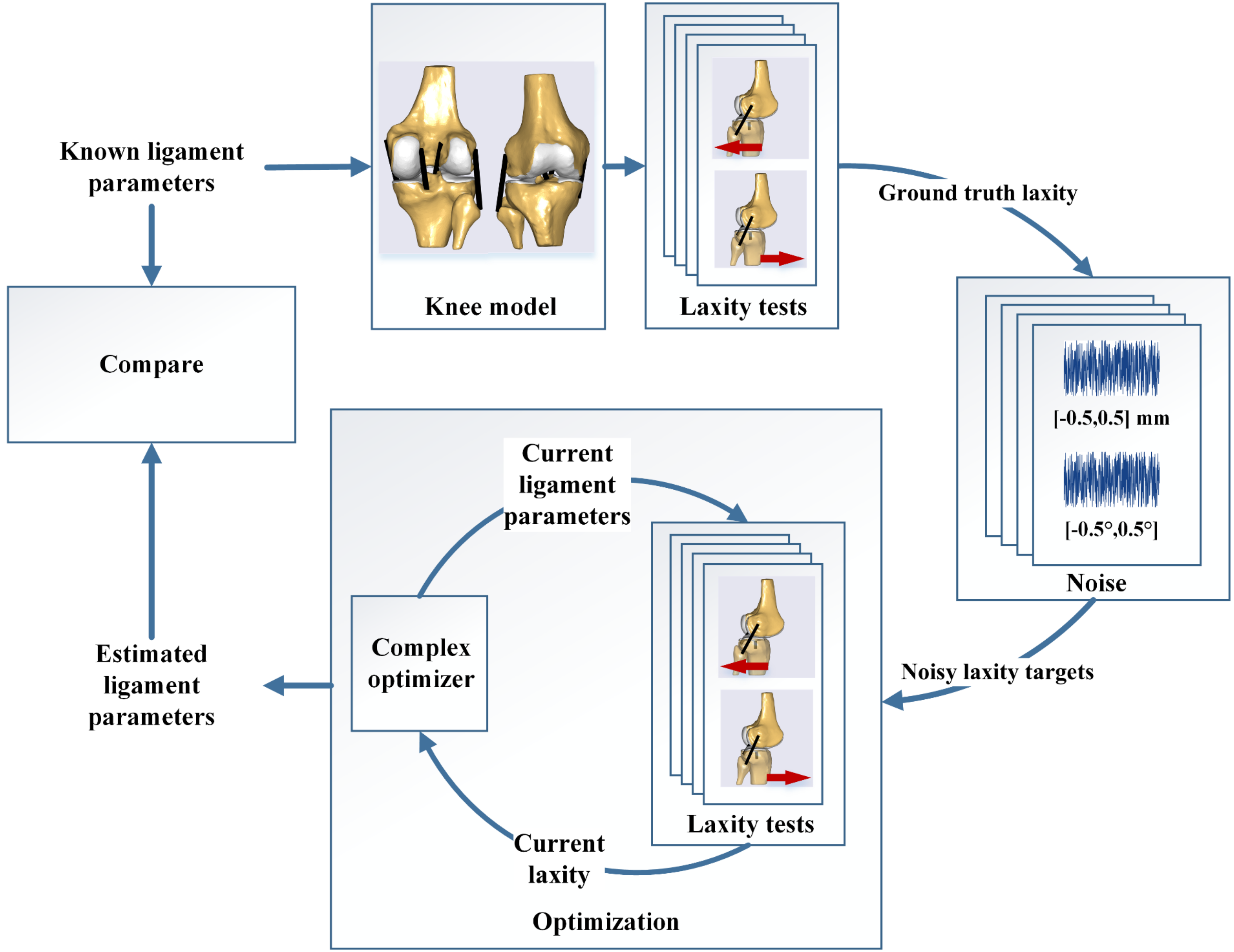
Ligaments are important joint stabilizers but assessing their mechanical properties remain challenging. We developed a methodology to investigate the effects of kinematic measurement uncertainty during laxity tests on optimization-based estimation of ligament properties. We applied this methodology to a subject-specific knee model with known ligament properties as inputs and compared the estimated to the known knee ligament properties under the influence of noise. Four different sets of laxity tests were simulated with an increasing number of load cases, capturing anterior/posterior, varus/valgus, and internal/external rotation loads at 0 deg and 30 deg of knee flexion. 20 samples of uniform random noise ([−0.5,0.5] mm and degrees) were added to each set and fed into an optimization routine that subsequently estimated the ligament properties based on the noise targets. We found a large range of estimated ligament properties (stiffness ranges of 5.97 kN, 7.64 kN, 8.72 kN, and 3.86 kN; reference strain ranges of 3.11%, 2.53%, 1.88%, and 1.58% for anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medical collateral ligament (MCL), and lateral collateral ligament (LCL), respectively) for three sets of laxity tests, including up to 22 load cases. A set of laxity tests with 60 load cases kept the stiffness and reference strain ranges below 470 N per unit strain and 0.85%, respectively. These results illustrate that kinematic measurement noise have a large impact on estimated ligament properties and we recommend that future studies assess and report both the estimated ligament properties and the associated uncertainties due to kinematic measurement noise. [DOI: 10.1115/1.4050027]

Andersen et al. 2021. *J Biomech Eng*, 143(6): 061003

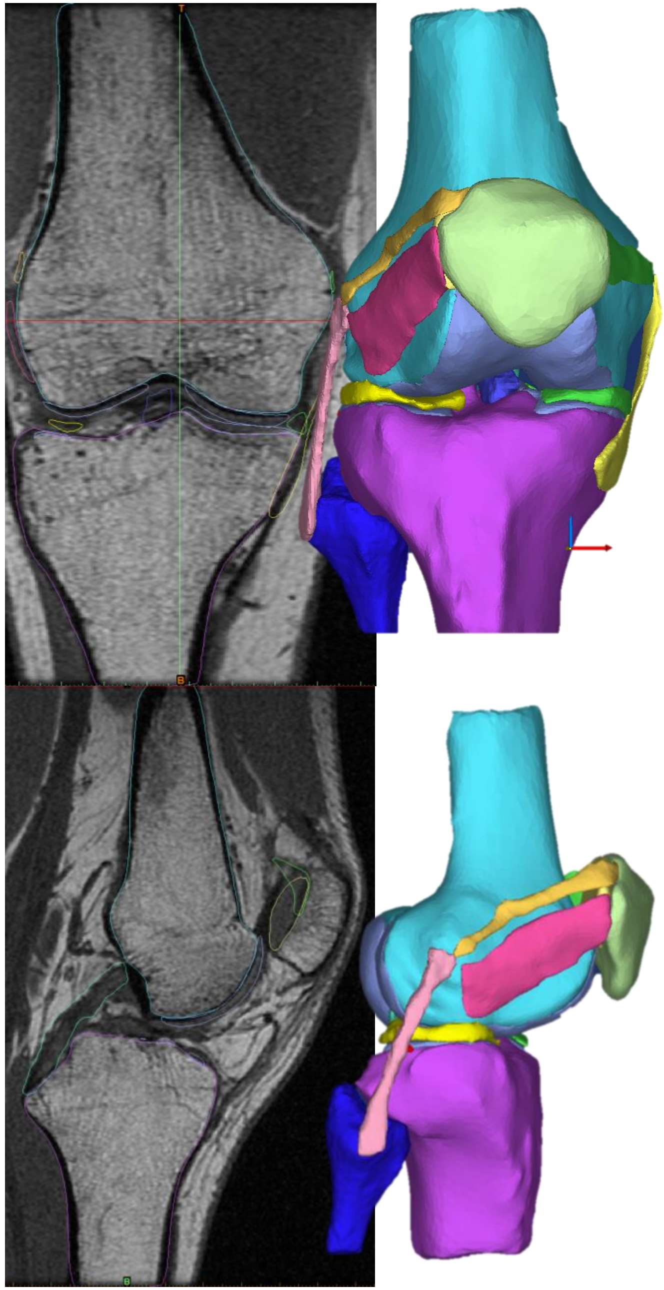
https://doi.org/10.1115/1.4050027


Known ligament parameters
Knee model
Laxity tests
Ground truth laxity
Compare
[-0.5,0.5] mm
[-0.5°,0.5°]
Noise
Current ligament parameters
Complex optimizer
Laxity tests
Noisy laxity targets
Estimated ligament parameters
Current laxity
Optimization

Data

- One female subject (27 year-old, 1.72 m, 61.2 kg)

- **MRIs:**
  - Detailed knee (OAI protocol)
  - Full lower limb scan (to identify hip and ankle centers)



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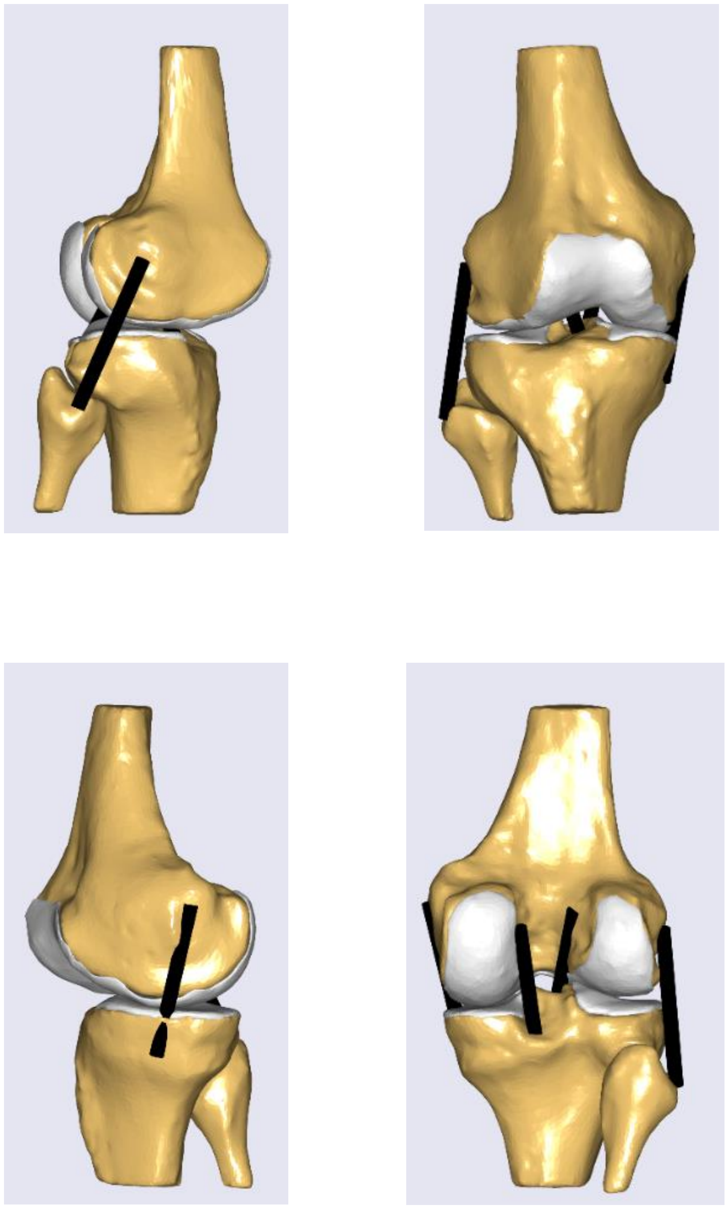
Knee Model

- Rigid femur and tibia
- Femur fixed to ground
- Knee angle driven + reaction moment
- Five Force-dependent kinematics degrees-of-freedom (DOFs)
- Single spring ligaments: ACL, PCL, MCL, LCL. Properties: Blankevoort et al., 1991. Nonlinear elastic model.
- Elastic foundation contact between femoral and tibial cartilage



Model created in the AnyBody Modeling System

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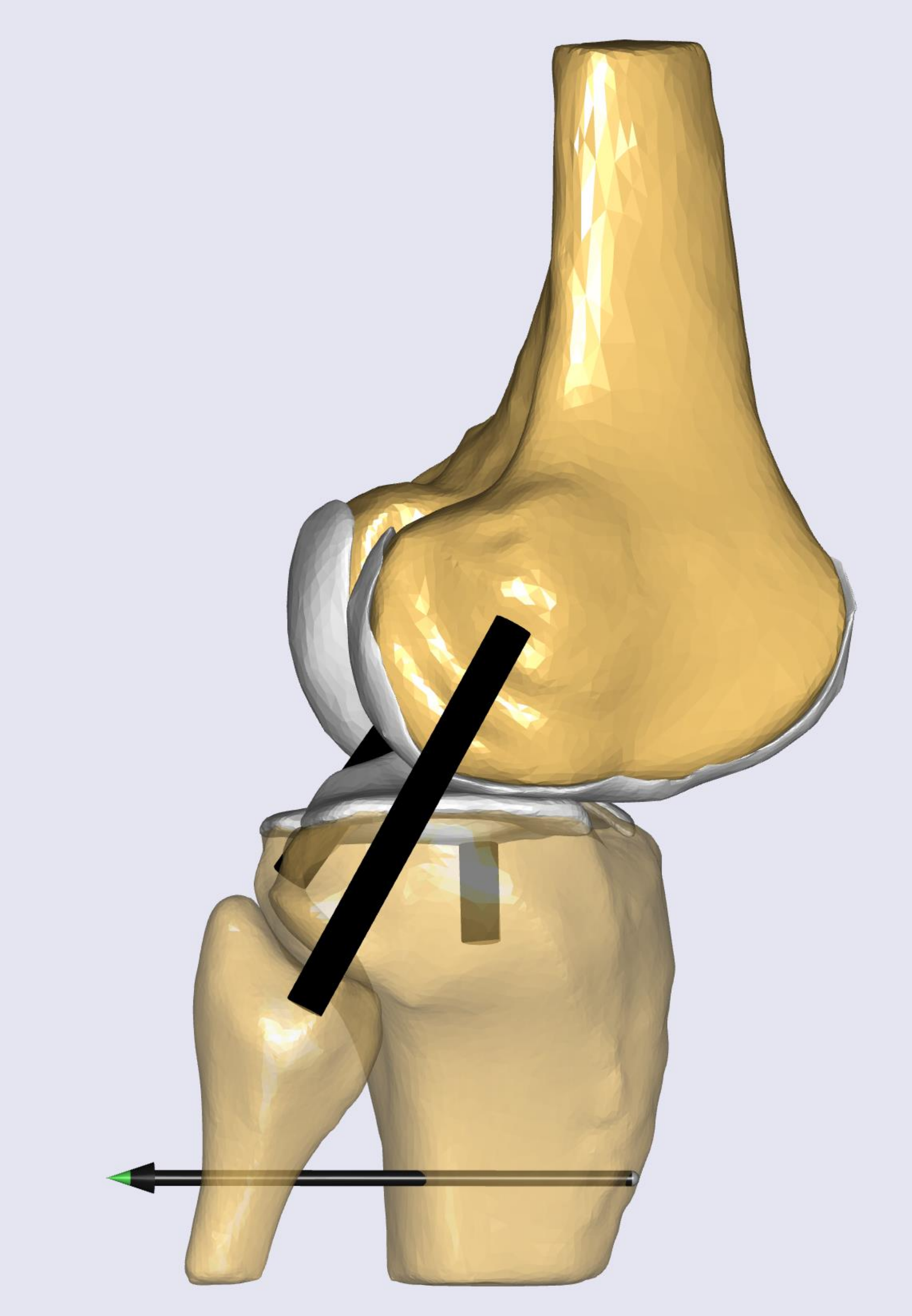

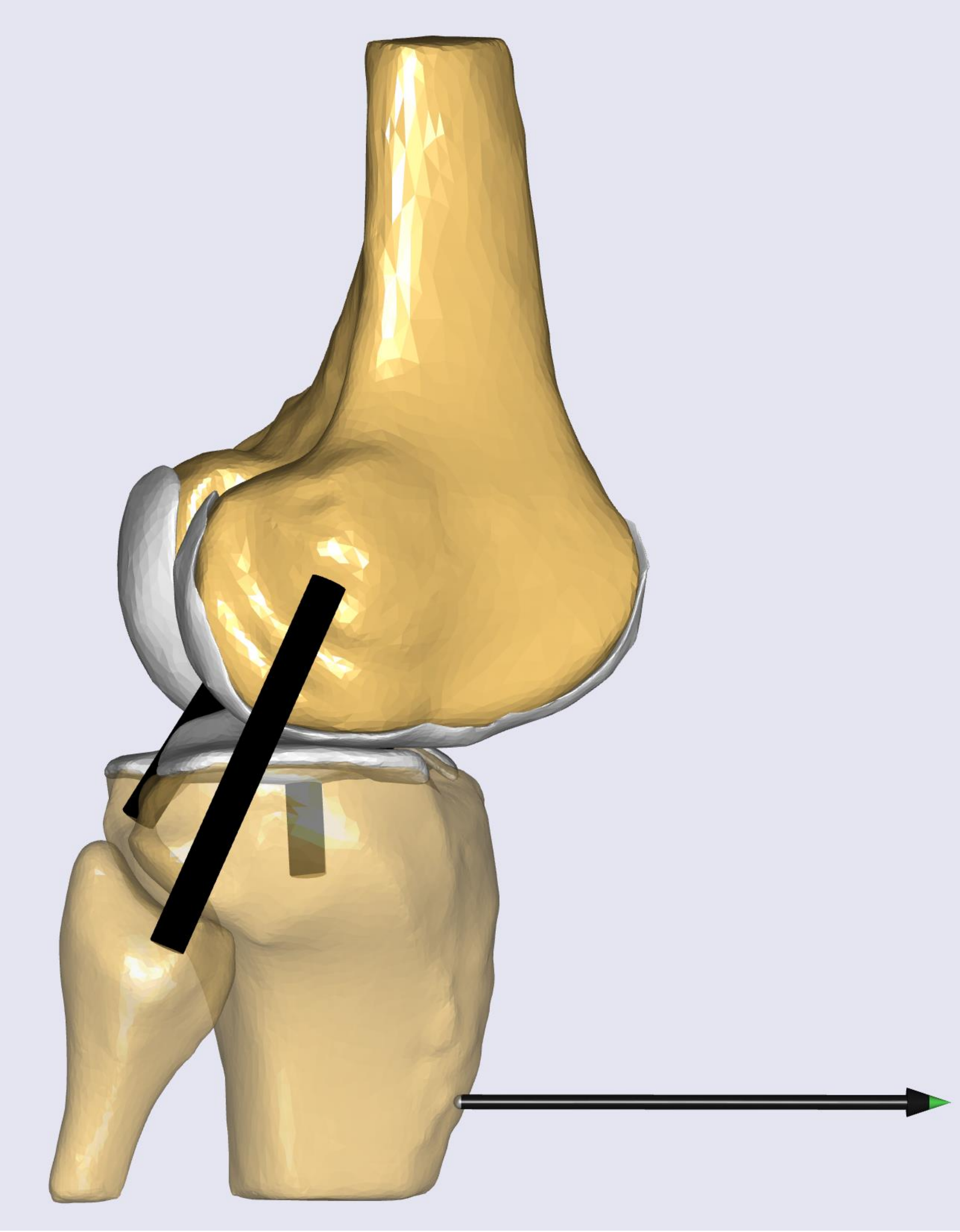

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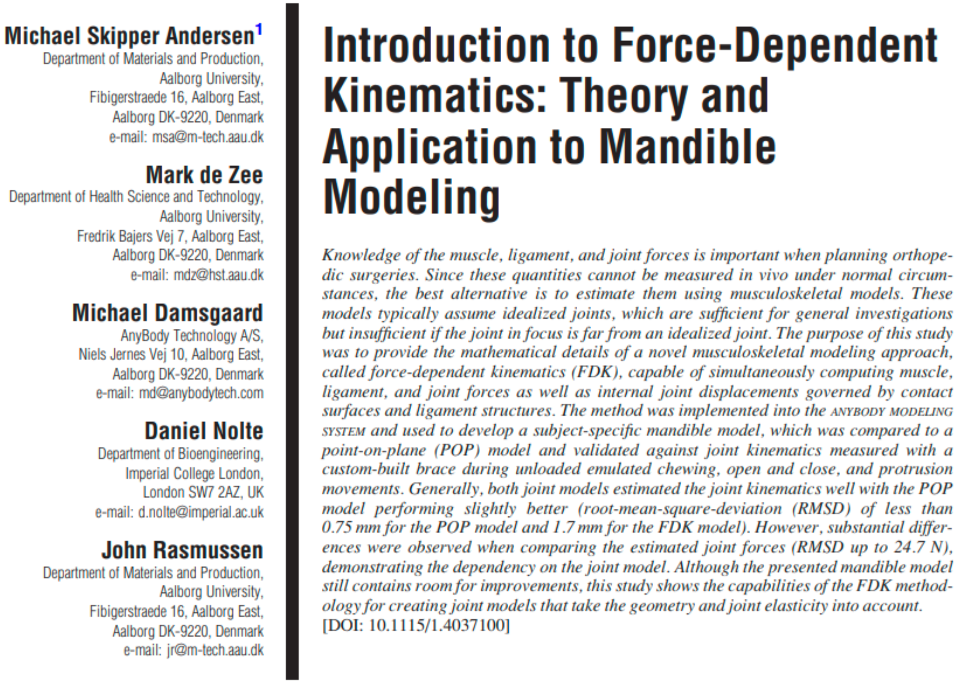
Force-dependent kinematics



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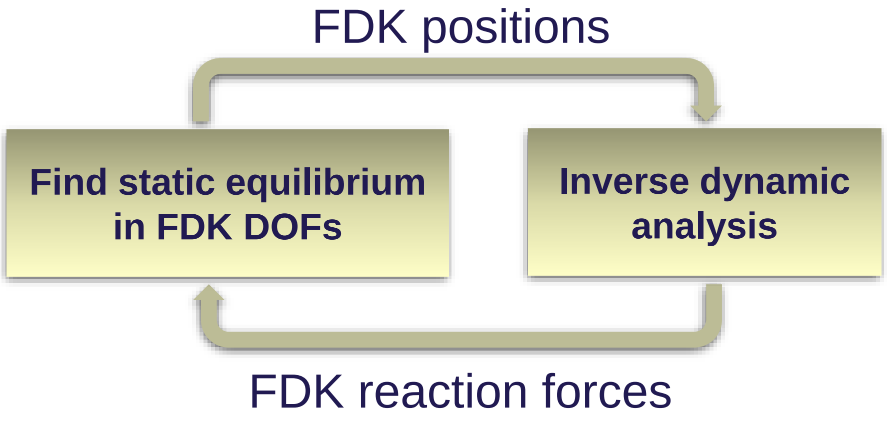
Introduction to Force-Dependent Kinematics: Theory and Application to Mandible Modeling

Knowledge of the muscle, ligament, and joint forces is important when planning orthopedic surgeries. Since these quantities cannot be measured in vivo under normal circumstances, the best alternative is to estimate them using musculoskeletal models. These models typically assume idealized joints, which are sufficient for general investigations but insufficient if the joint in focus is far from an idealized joint. The purpose of this study was to provide the mathematical details of a novel musculoskeletal modeling approach, called force-dependent kinematics (FDK), capable of simultaneously computing muscle, ligament, and joint forces as well as internal joint displacements governed by contact surfaces and ligament structures. The method was implemented into the ANYBODY MODELING SYSTEM and used to develop a subject-specific mandible model, which was compared to a point-on-plane (POP) model and validated against joint kinematics measured with a custom-built brace during unloaded emulated chewing, open and close, and protrusion movements. Generally, both joint models estimated the joint kinematics well with the POP model performing slightly better (root-mean-square-deviation (RMSD) of less than 0.75 mm for the POP model and 1.7 mm for the FDK model). However, substantial differences were observed when comparing the estimated joint forces (RMSD up to 24.7 N), demonstrating the dependency on the joint model. Although the presented mandible model still contains room for improvements, this study shows the capabilities of the FDK methodology for creating joint models that take the geometry and joint elasticity into account.

[DOI: 10.1115/1.4037100]

Andersen et al. 2017. *J Biomech Eng*, 139(9): 091001



- Simultaneously computes muscle, joint and ligament forces and internal joint kinematics.
- Uses *inverse dynamics* and *quasi-static force equilibrium* in selected DOFs.

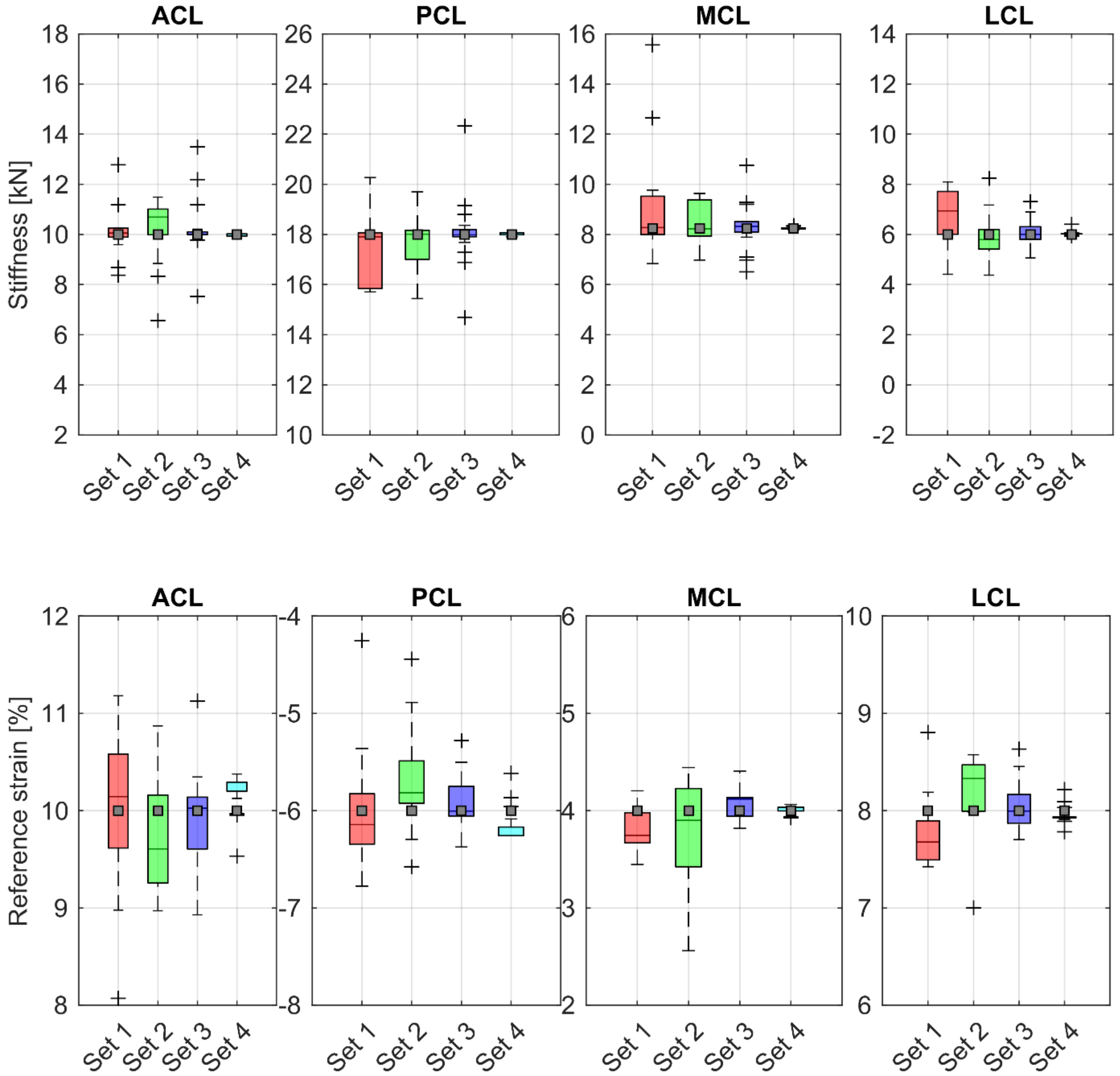
Laxity tests

Load direction	*Load magnitude*	*Knee flexion angle*
	Set 1	
No load	-	30°
Anterior	134.0 N	30°
Posterior	67.0 N	30°
Internal rotation	2.0 Nm	30°
External rotation	2.0 Nm	30°
Varus	10.0 Nm	0°
Valgus	10.0 Nm	0°
	Set 2	
No load	-	30°
Anterior	134.0, 80.4 N	30°
Posterior	67.0, 40.2 N	30°
Internal rotation	2.0, 1.2 Nm	30°
External rotation	2.0, 1.2 Nm	30°
Varus	10.0, 6.0 Nm	0°
Valgus	10.0, 6.0 Nm	0°

Laxity tests

Load direction	*Load magnitude*	*Knee flexion angle*
	Set 3	
No load	-	0°, 30°
Anterior	134.0, 80.4 N	0°, 30°
Posterior	67.0, 40.2 N	0°, 30°
Internal rotation	2.0, 1.2 Nm	0°, 30°
External rotation	2.0, 1.2 Nm	0°, 30°
Varus	10.0, 6.0 Nm	0°, 30°
Valgus	10.0, 6.0 Nm	0°, 30°
	Set 4	
No load	-	0°, 30°
Anterior	134, 107.2, 80.4, 53.6, 26.8 N	0°, 30°
Posterior	67, 53.6, 40.2, 26.8, 13.4 N	0°, 30°
Internal rotation	2.0, 1.6, 1.2, 0.8, 0.4 Nm	0°, 30°
External rotation	2.0, 1.6, 1.2, 0.8, 0.4 Nm	0°, 30°
Varus	10.0, 8.0, 6.0, 4.0, 2.0 Nm	0°, $30^{\circ *}$
Valgus	10.0, 8.0, 6.0, 4.0, 2.0 Nm	0°, 30°

Results



ACL
PCL
MCL
LCL
Stiffness [kN]
Reference strain [%]
Set 1
Set 2
Set 3
Set 4

Discussion

- Small measurement noise has a large effect on estimated ligament properties
- Only Set 4 (60 load cases) was able to mitigate the error effects

Limitations

- Only one subject
- Single spring ligaments
- Noise levels likely smaller than in reality
  - Pedersen et al. (EOS x-rays): Errors of ~2 mm and ~1 degrees
  - Stentz-Olesen et al. (RSA): Errors of ~1 mm and ~1 deg
  - Merriaux et al. (Vicon): Errors of 0.35 mm for a single marker during slow dynamic movements
- Likely understimated the ranges as only 20 samples were used per set

Conclusion and recommendation

- Sub-millimeter and sub-degree kinematic errors during laxity measurements can have a substantial effect on estimated ligament properties

- Besides reporting estimated properites, future studies should report the associated ligament property uncertainties due to measurement errors in their setups

Thank you!

Questions?

Associate Professor Michael Skipper Andersen

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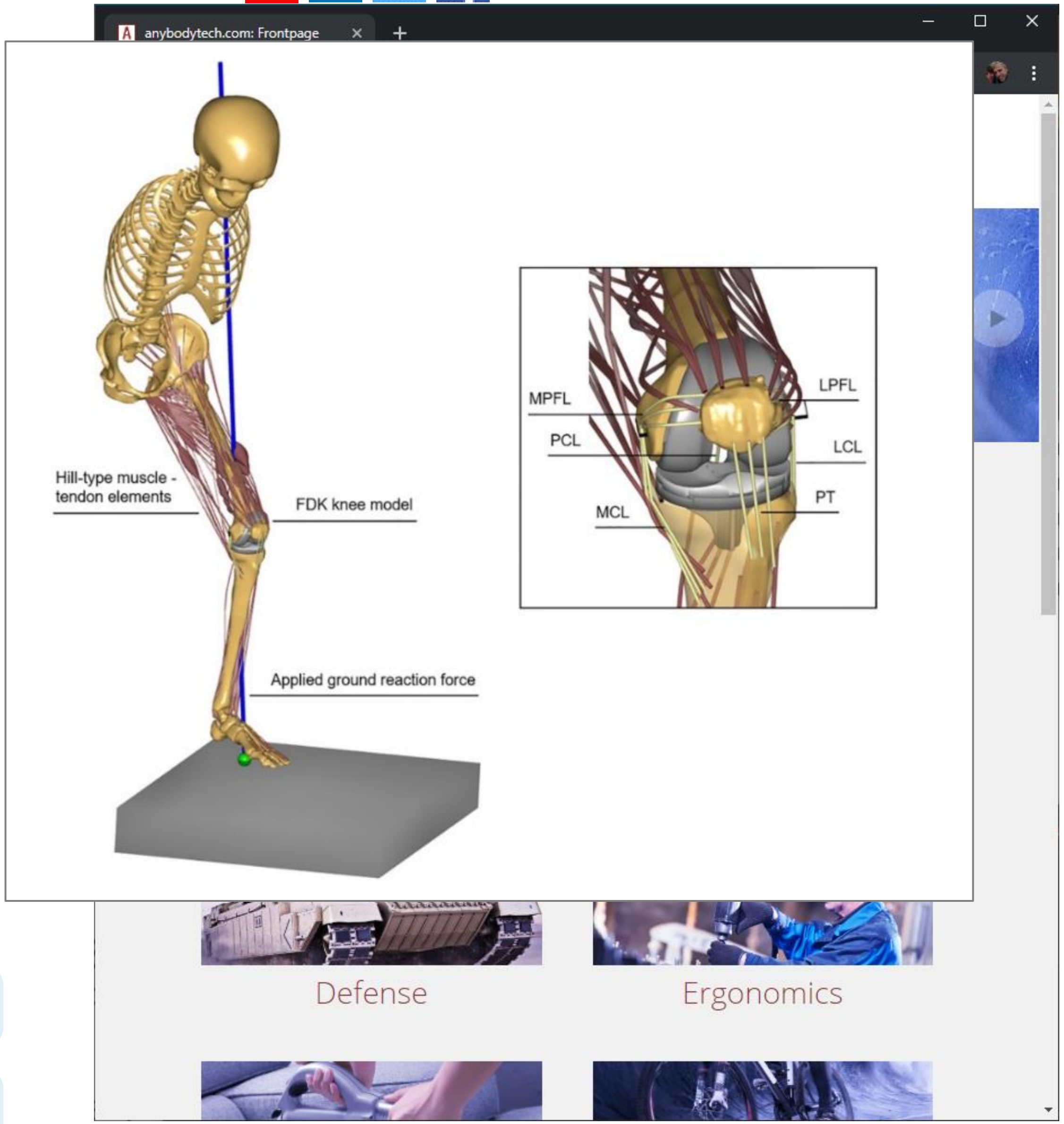
Events

- May 6th – webcast: A model-based methodology to quantify the sensitivity of muscle, ligament, and joint compressive forces to tibial insert thickness variations after total knee arthroplasty

- Aalborg University in Denmark is planning a new Advanced Musculoskeletal Modelling PhD course to be held 3-7th May 2021.



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Thank you for your attention - Time for questions