Analyzing non-conforming anatomical and prosthetic joints in the AnyBody Modeling System

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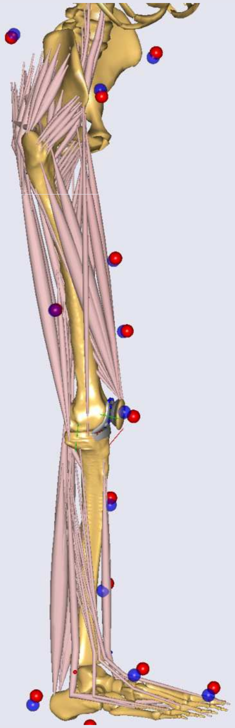

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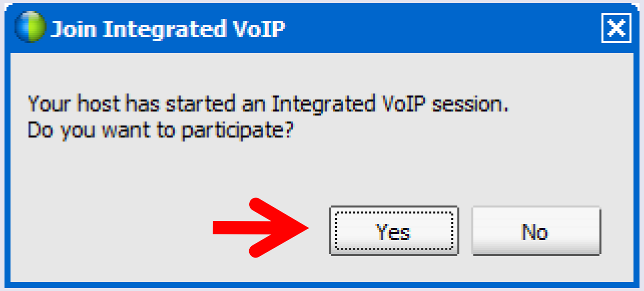

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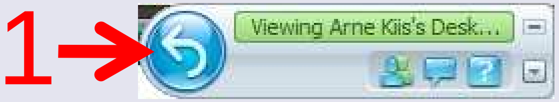

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Presenters

Michael Skipper Andersen
(Presenter)

Arne Kiis
(Host)

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About me

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Ph.D. in Mechanical Engineering at Aalborg University, 2009.

Q&A Panel

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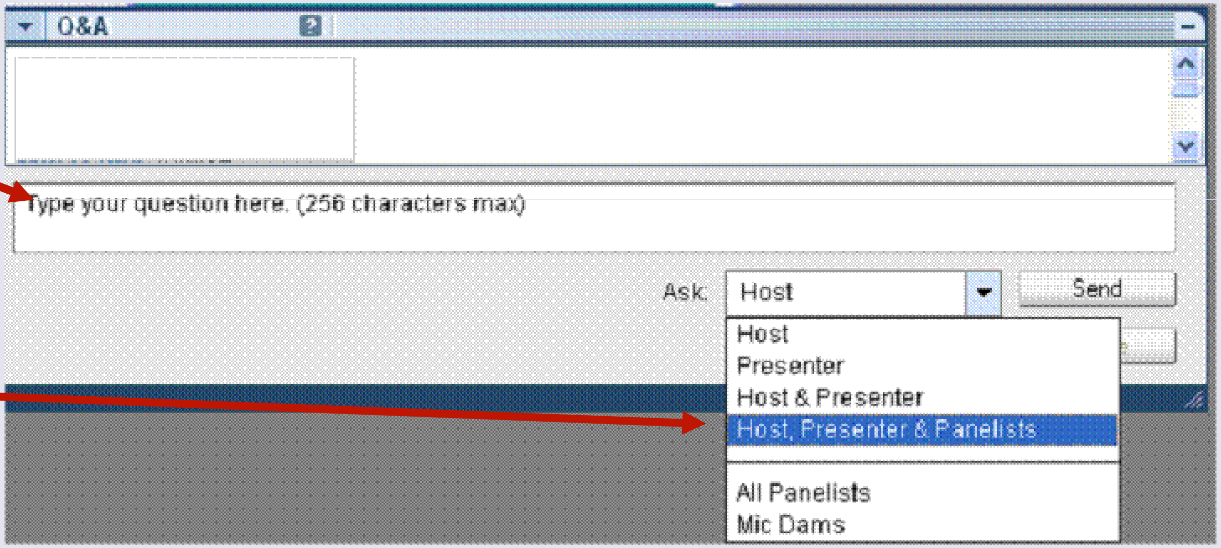


Type your question here. (256 characters max)

Ask: Host

Notice the answer displays next to the question in the Q&A box.
You may have to scroll up to see it.

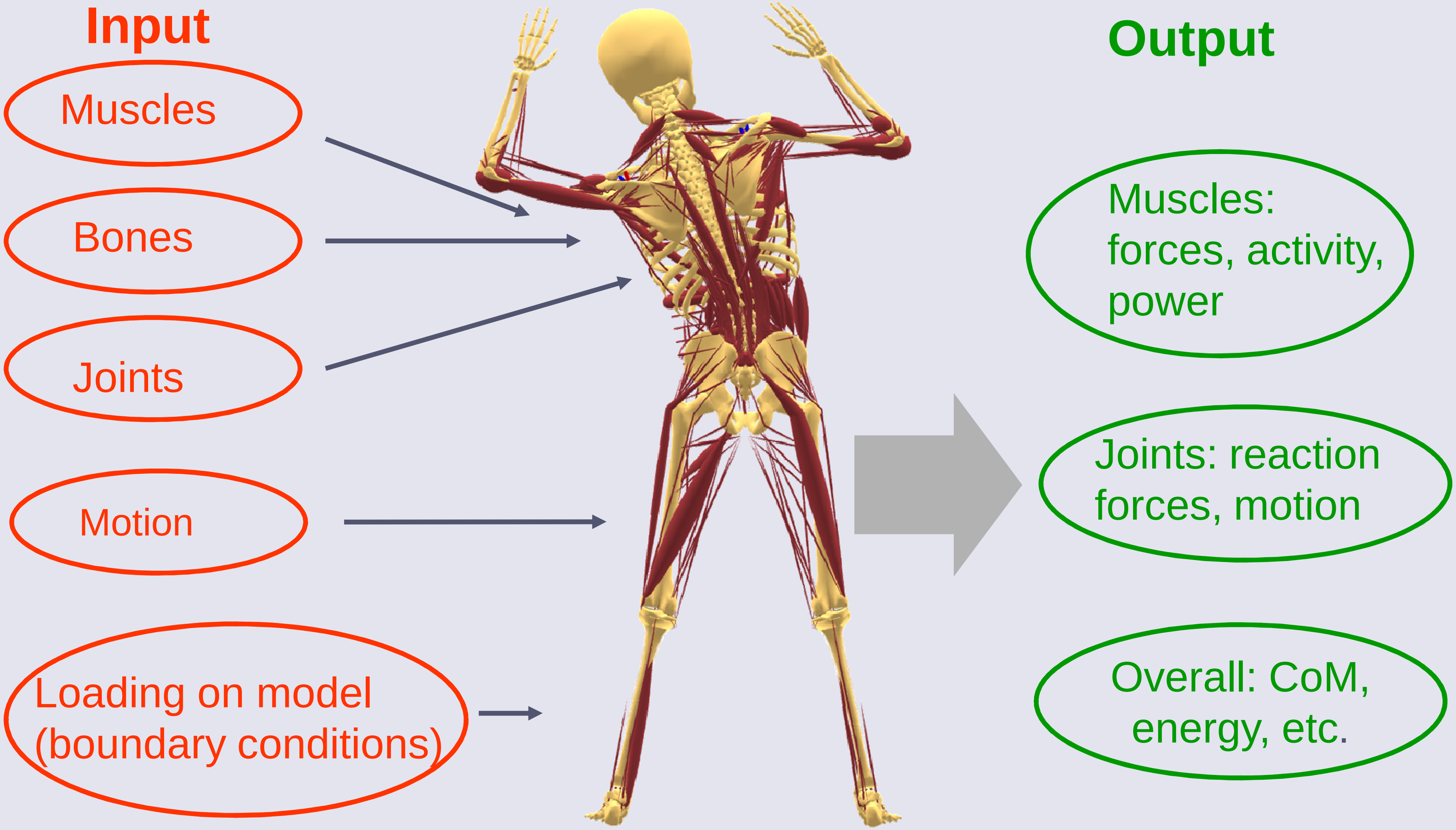
Agenda

- Brief introduction to inverse dynamic analysis.
- Force-dependent Kinematics.
  - Motivation.
  - The method.
  - Simple model demo in the AnyBody Modeling System.
- Preliminary Total Knee Replacement (TKR) model.
- Conclusion.
- Q & A.

Background

- Musculoskeletal modelling:
  - Model of the musculoskeletal system (bones, joints, ligaments and muscles).
  - Non-invasive estimation of joint reactions, ligament and muscle forces, which are difficult to measure.
  - Frequently accomplished through inverse dynamics.

Inverse Dynamics



Input

- Muscles
- Bones
- Joints
- Motion
- Loading on model (boundary conditions)

Output

- Muscles: forces, activity, power
- Joints: reaction forces, motion
- Overall: CoM, energy, etc.

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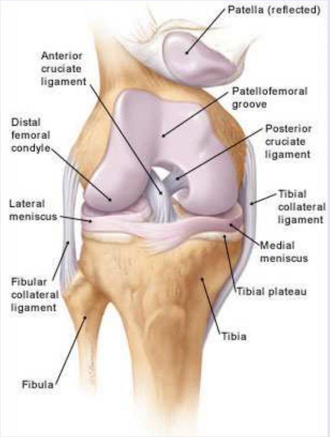
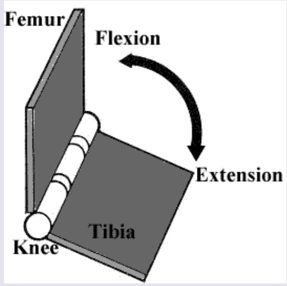
Joint modelling

Typical approach





- Idealized joint constraints, e.g revolute, spherical etc. or combinations.
- What are the problems?
  - Only few joints (e.g. the hip) are well approximated with idealized joint constraints.
  - Assumes infinitely strong reaction forces that can be recruited without a deformation.
  - Difficult, if not impossible, to directly include an implant model and obtain altered kinematics. This is due to the joint formulation via constraint equations.
  - Some parts are difficult to model with kinematic constraint equations, but easier with forces, e.g. contacts.

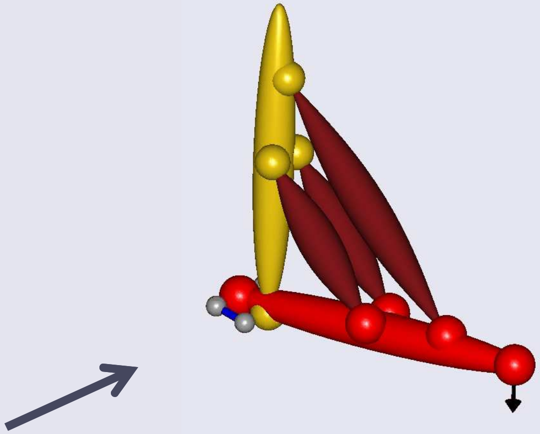
”Force-Dependent Kinematics” (FDK)

Idea: control the motion in some model DOFs by forces:

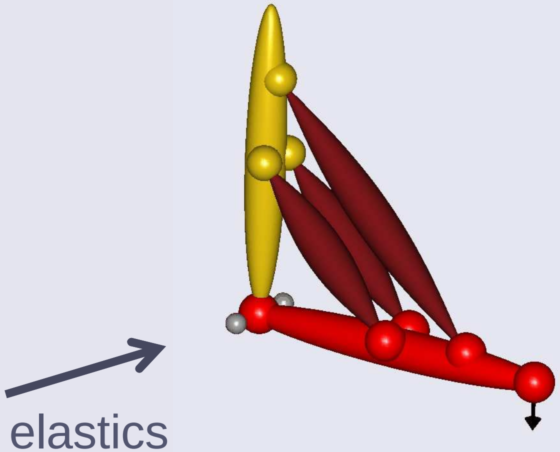
- Solve by assuming force equilibrium in certain DOF – i.e. a quasi-static analysis:
  - Somewhat average motion.
  - Assumes that vibrations are neglectable.
  - Not as time consuming as forward dynamics.

In the simple ”arm” model, the joint motions are where all the forces in the model balance. In other words, in the position, where no extra reaction forces are required.

The same problem could also be solved with forward dynamics.



“Weak” elastics



“Strong” elastics

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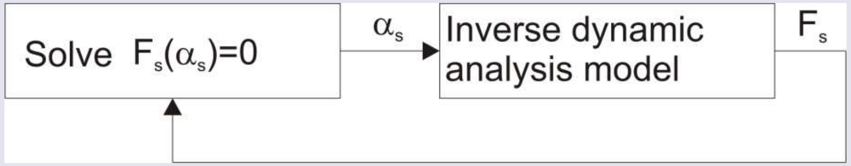
FDK

Solution method:

1. Introduce motion (α_s) and reaction forces (F_s) in the FDK directions.
2. For each time step, compute the position in the FDK directions, where no FDK reactions are required to balance the model.

   NB. During this step, the velocity and acceleration of α_s are assumed zero, i.e. we obtain a quasi-static solution.

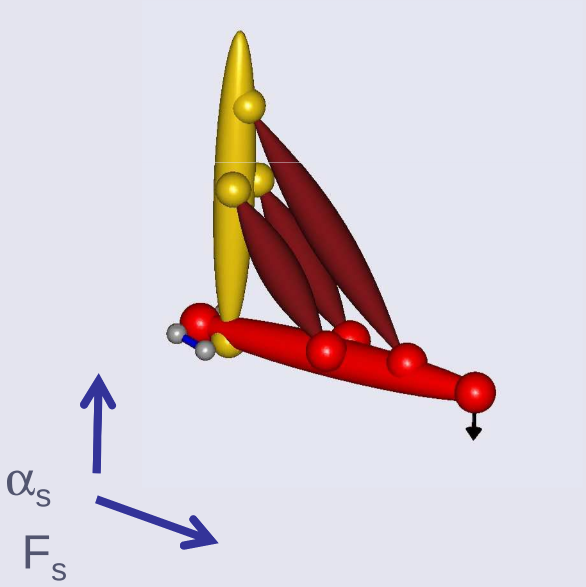


Solve $F_s(\alpha_s)=0$

α_s

Inverse dynamic analysis model

F_s



FDK

- Demo

Q&A Panel

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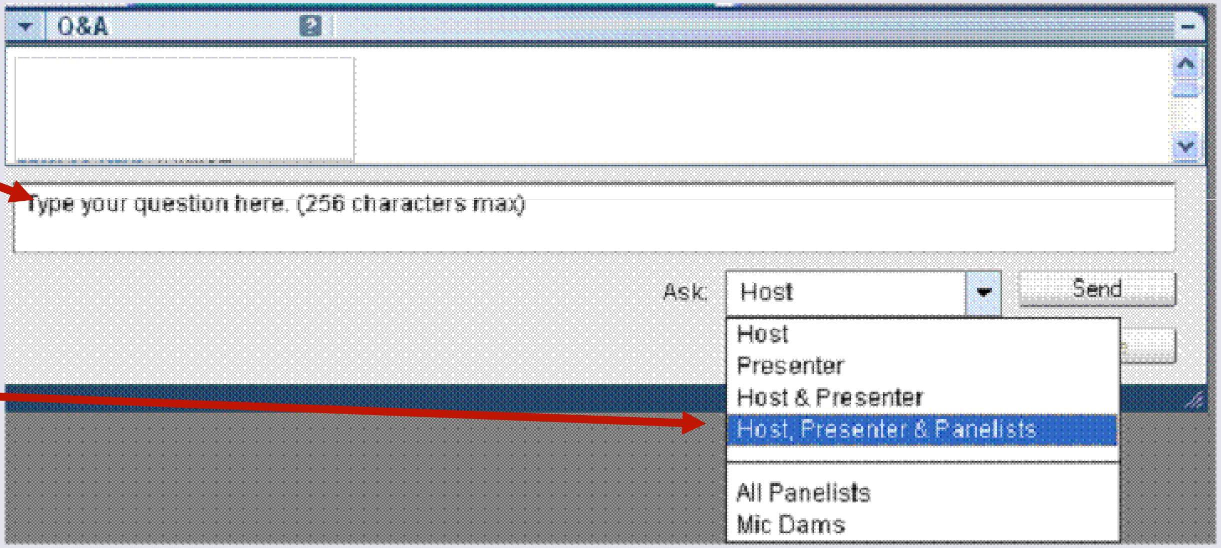

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Post-operative Total Knee Replacement (TKR) model

- The method has been used for modeling of TKR.
- The model is still work in progress.
- The data used comes from the Grand Challenge Competition to Predict In Vivo Knee Loads. The data set includes:
    - Marker trajectories.
    - Ground reaction forces.
    - CT scans of the prosthesis alone prior to the surgery as well as post-operative CT scans of the patient.
    - Electromyography of selected muscles.
    - Measured medial and lateral compressive forces in the knee from the instrumented prosthesis.

Grand Challenge Competition to Predict In Vivo Knee Loads

Project Overview

Description: Knowledge of muscle and joint contact forces during gait is necessary to characterize muscle coordination and function as well as joint and soft-tissue loading. Musculoskeletal modeling and simulation is required to estimate muscle and joint contact forces, since direct measurement is not feasible under normal conditions. This project provides the biomechanics community with a unique and comprehensive data set to validate muscle and contact force estimates in the knee. This data set includes motion capture, ground reaction, EMG, tibial contact force, and strength data collected from a subject implanted with an instrumented knee prosthesis.

Available Downloads and Their Potential Uses: The following raw and synchronized experimental data are available for download:
- Marker trajectories - plus description of marker set and static trials (200 Hz)
- Ground reaction forces - from 4 Bertec plates (1000 Hz)
- EMG signals - from 14 muscles in the implanted lower limb (1000 Hz)
- Tibial contact forces - measured from the instrumented prosthesis (200 Hz)

Downloads & Source Code

1. Data for Second Competition
2. Data for First Competition

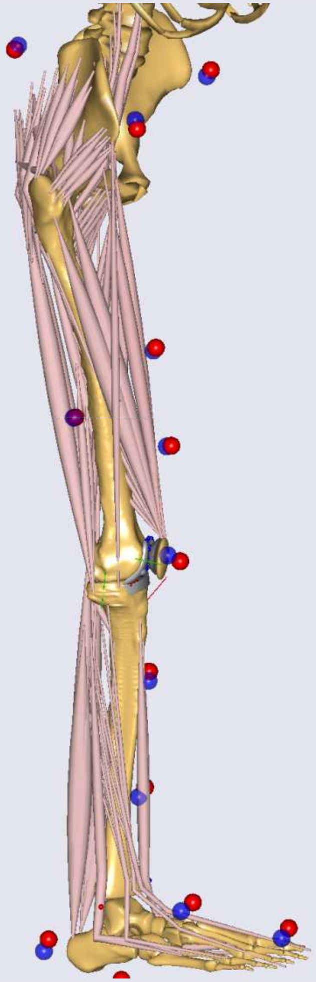
This projects does not store source code in Simtk's Subversion repository.

Driving Biological Problems

This project is part of

Modeling approach

- The model was constructed in the AnyBody Modeling System version 5.0 using the FDK approach.
- The lower extremity model based on the Klein Horsman data set was used.
- The revolute joint knee model was replaced with a more advanced model:
  - The prosthesis geometry was used to compute contact forces.
  - Nonlinear elastic ligaments.
  - Six FDK directions were introduced:
    - Five DOF in the tibiofemoral joint (all but flexion/extension).
    - One DOF in the patellofemoral joint.



Modeling workflow

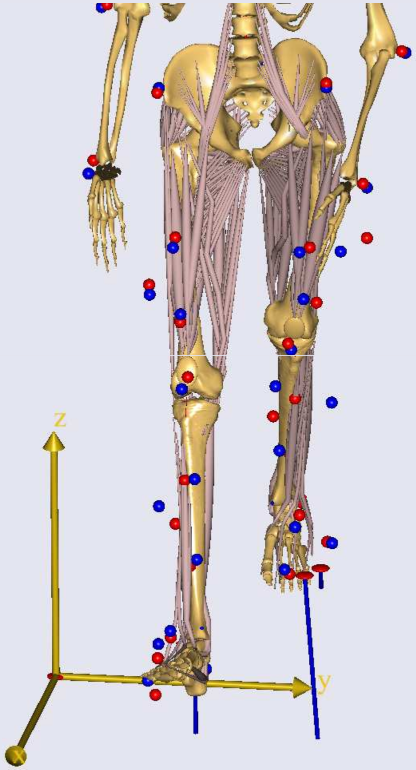
Scale the cadaver model

Optimize the model scaling and local marker coordinates to best fit the marker trajectories over the gait cycle.

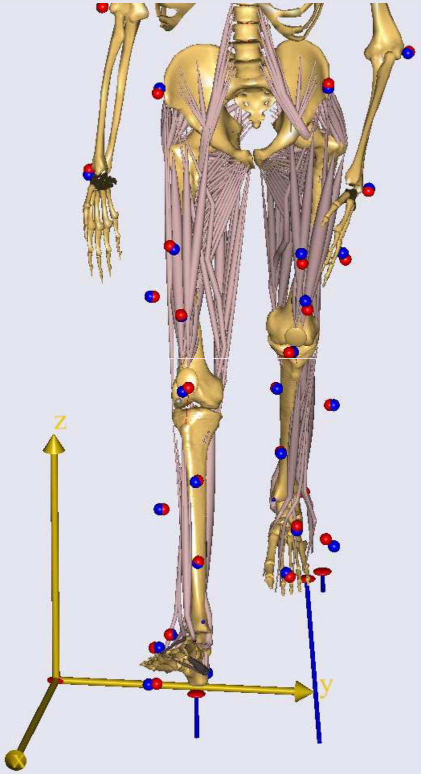
Design variables:

- Pelvis width
- Thigh lengths
- Shank lengths
- Foot lengths
- Trunk height
- Upper arm length
- Lower arm length
- All local marker coordinates not placed on bony landmarks.

Revolute joint knees were assumed during scaling. This joint assumption was removed after scaling.



Unscaled



Scaled

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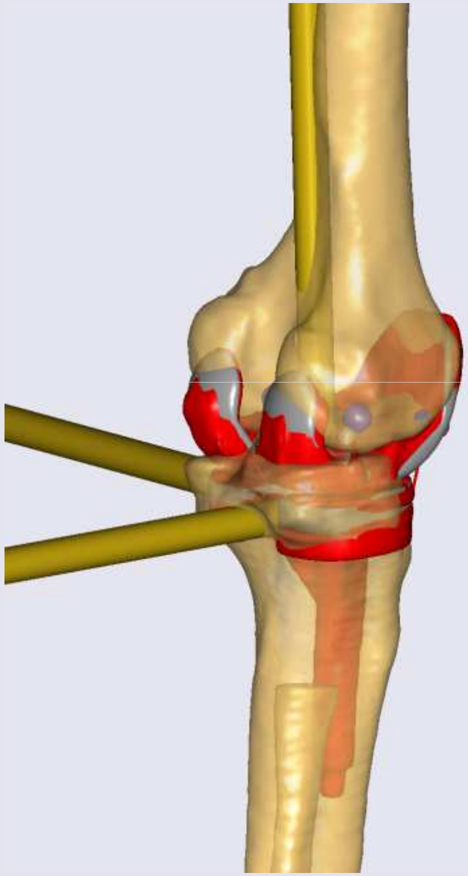
Modeling workflow

Register prosthesis geometry

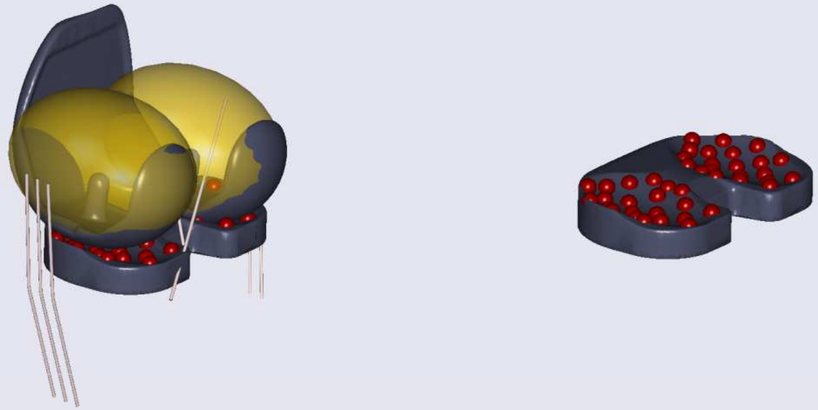
The alignment was accomplished using the scaled cadaver model, the centers of the epicondyles and CT scans of the prosthesis alone and post-operatively.



Modeling workflow

Contacts and passive structures

- Tibiofemoral joint modelled as:
  - Two ellipsoids in contact with a point cloud.
  - The collateral ligaments, PCL and Oblique Popliteal.
  - Medial/lateral linear spring to capture the edge of the implant.
  - Soft linear springs on all five DOF to ensure passive stiffness at all times.



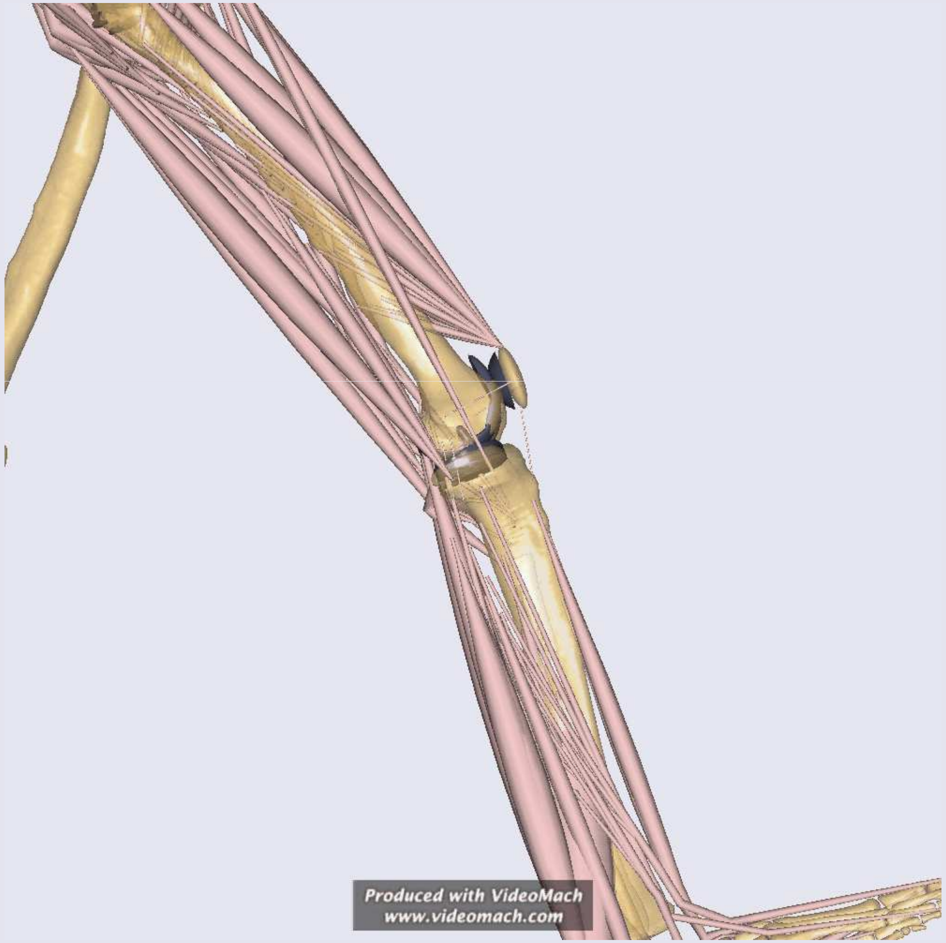
- Patellofemoral joint modelled as:
  - A sphere in contact with a point cloud.
  - A rigid model of the patella tendon.
  - Two artificial linear springs to pull patella into contact with the femoral part.

- Contact forces directly based on STL files is in progress.

Modeling workflow

Preliminary post-operative TKR model

The motion is observed from a camera attached to femur.



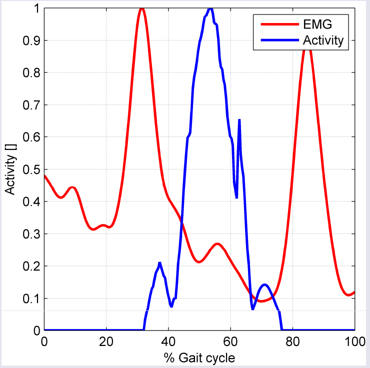
Generally the motion appears plausible.

Small jumps due to the rather rough surface representation.

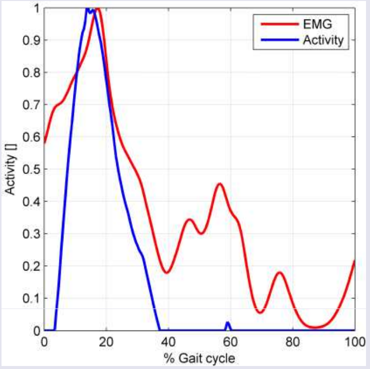
Results

EMG results:

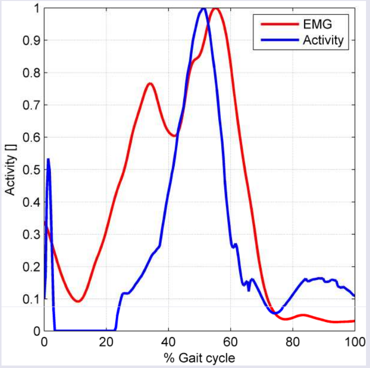
Rectus Femoris



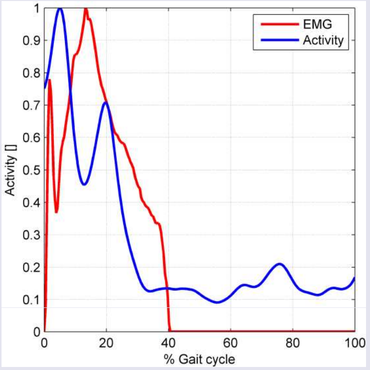
Vastus lateralis



Gastrocnemius



Gluteus Maximus

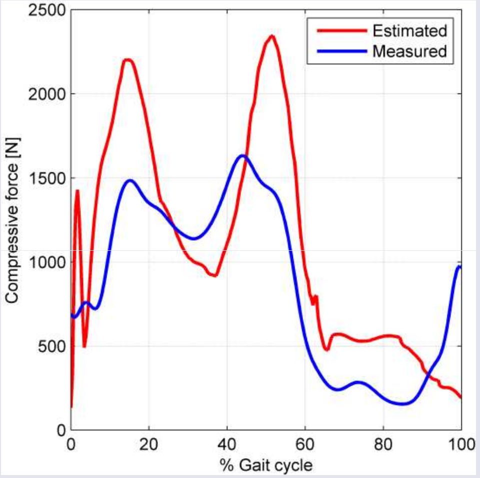


- Similar activation patterns are seen between the EMG and computed activities.
- The model is using Rectus Femoris at toe off, whereas the subject uses Vastii.

Results

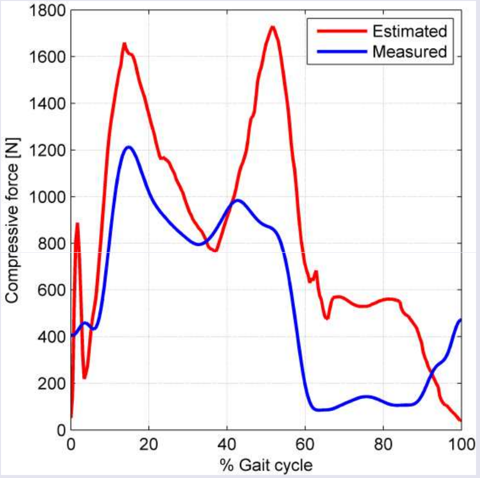
Compressive force results

Total compressive force



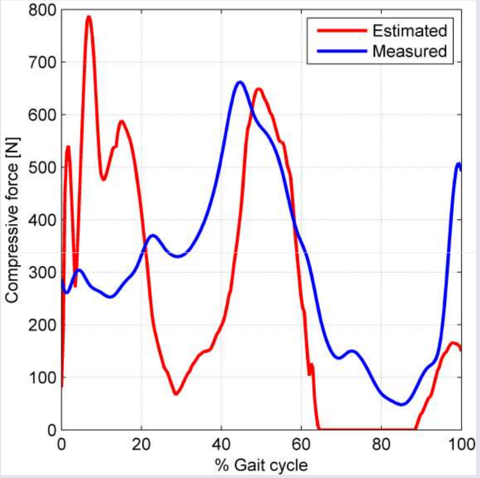
RMS error: 454 N

Medial force



RMS error: 400 N

Lateral force



RMS error: 203 N

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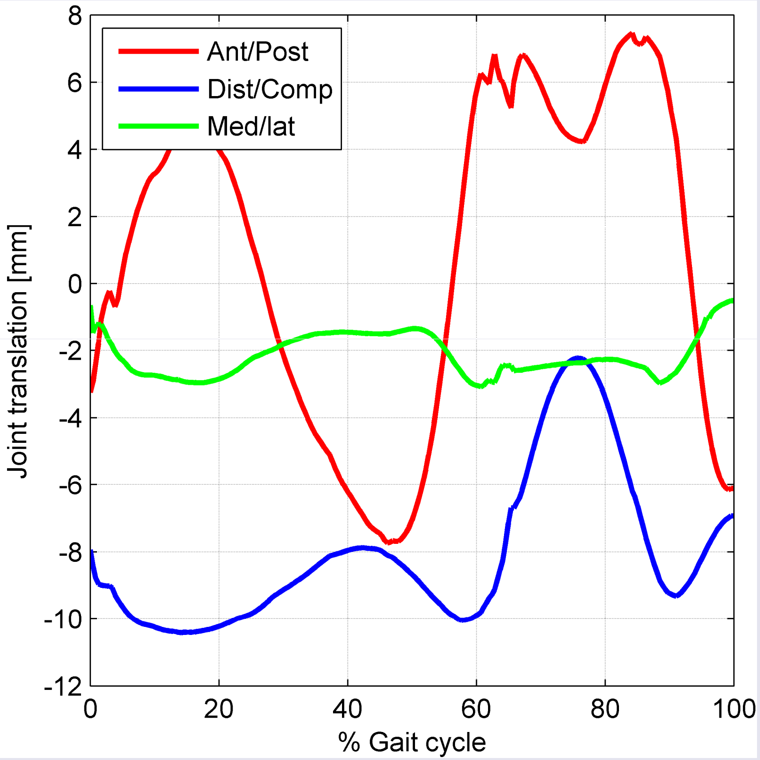
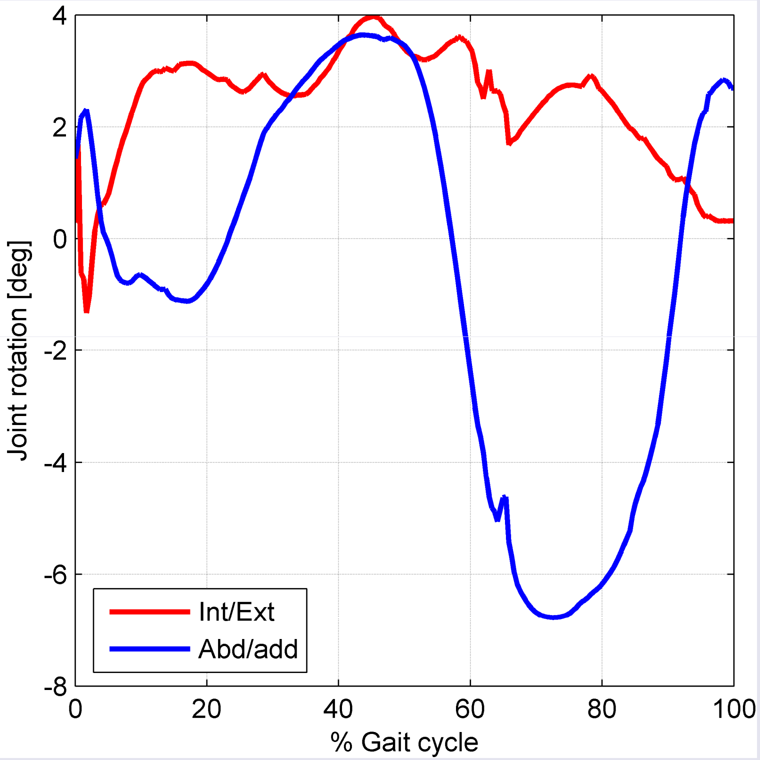
Results

Joint translations and rotations





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Conclusion

- **Method:**
  - The presented FDK method successfully computed both the joint translations, rotations as well as muscle and reaction forces.
  - Opens up new posibilities for detailed joint models in musculoskeletal models.
- **TKR Model results:**
  - Good agreement with EMG.
  - Trends of the compressive force is captured.
  - The peak compressive force is over-predicted.
  - The model shows plausible joint translations and rotations.
  - More work is still required to improve the force predictions.

Q&A Panel

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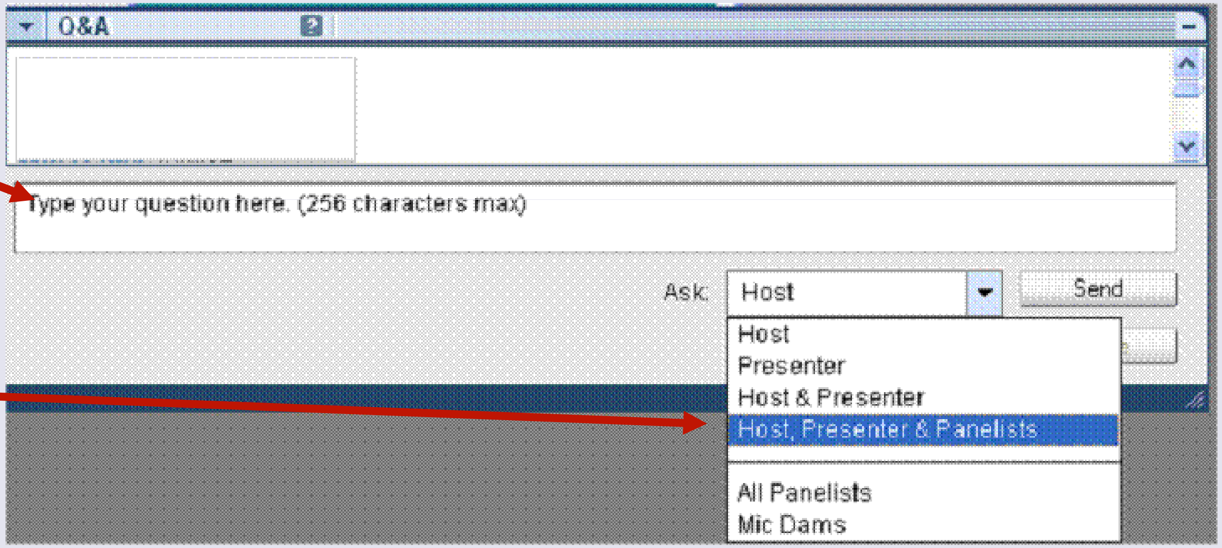

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